TerraBrains verification manual

Every comparison TerraBrains holds between one of its results and a value from outside the engine that produced it — source, page, quantity, our value, the reference, the miss and the status — grouped by analysis type. Deviations are shown as deviations. Generated from the repository by `app/scripts/build-verification-manual.mjs`; nothing is typed in by hand.

313
FE kernel registry rows (updated 2026-11-12)

238
kernel rows within tolerance of an outside reference

26
kernel self-checks within tolerance (not outside evidence)

31
kernel deviations

4
kernel rows pending / blocked

6
kernel rows recorded, no published value

8
kernel rows superseded by newer rows

367
cited validation suites

4501 / 0
suite test blocks passing / failing

44/46
closed-form registry passes

How to read this manual

- **Status words are the registries' own.** *Pass* = within the tolerance the row states. *Deviation* / *Miss* = measured and outside that tolerance, or a difference the row records as known. *Pending* / *Blocked* / *Not run* = recorded, not yet runnable honestly. Three more appear on kernel rows: *Superseded* = an older stand-in or umbrella row, replaced by the newer row or rows named on it; not counted as a pass or as open; *Recorded, no published value* = we ran the case but the source publishes no number to compare with, so there is no verdict; *Explained difference* = a difference whose cause is established, with the evidence in the row, where the only value to compare with is the vendor's own output; still a difference. Kernel rows by status: 264 pass, 31 deviation, 6 recorded, no published value, 8 superseded, 4 pending.
- **Miss %** = (ours − reference) / reference × 100, signed, as recorded. "vs vendor" is against the vendor's published value (e.g. PLAXIS); "vs reference" against the closed form or printed value.
- **What a row is compared against.** 222 kernel rows against a published / analytical reference, 40 against a vendor-published value, 37 are self-checks (compared with something derived inside this project — not evidence of agreement with an outside source), 14 hold no value yet.
- **Validation suites.** The suites were run on 2026-11-12 at commit `8361e841c847` (engine tree `5feef79fb84d`), Node 22.18.0, darwin arm64 · Apple M2 Pro · 10 threads. No suite has been edited since that run. 83 suite prologues mention a difference they do not assert (a text heuristic); they carry ⚑.
- **Nothing here is "certified".** A pass is a verification: agreement within a measured tolerance on the case shown.

Contents

- Footings and bearing capacity — 17 kernel rows · 40 closed-form rows · 32 suites
- Settlement, stress distribution and consolidation — 23 kernel rows · 0 closed-form rows · 39 suites
- Slopes and embankments — factor of safety — 32 kernel rows · 0 closed-form rows · 16 suites
- Retaining walls, excavations and structural elements — 46 kernel rows · 3 closed-form rows · 35 suites
- Piles and deep foundations — 0 kernel rows · 0 closed-form rows · 30 suites
- Tunnels and underground works — 7 kernel rows · 0 closed-form rows · 9 suites
- Rock mechanics and rock slopes — 1 kernel rows · 1 closed-form rows · 9 suites
- Groundwater flow and seepage — 32 kernel rows · 0 closed-form rows · 19 suites
- Heat transfer, freezing and solute transport — 18 kernel rows · 0 closed-form rows · 1 suites
- Earthquake engineering, dynamics and liquefaction — 69 kernel rows · 0 closed-form rows · 32 suites
- Constitutive models and element tests — 48 kernel rows · 0 closed-form rows · 27 suites
- Finite-element meshing, solvers and procedures — 8 kernel rows · 0 closed-form rows · 17 suites
- Three-dimensional analysis — 12 kernel rows · 0 closed-form rows · 8 suites
- Pavements and airfields — 0 kernel rows · 2 closed-form rows · 62 suites
- Ground improvement — 0 kernel rows · 0 closed-form rows · 3 suites
- Site investigation, in-situ and laboratory tests — 0 kernel rows · 0 closed-form rows · 25 suites
- Reliability, back-analysis and design aids — 0 kernel rows · 0 closed-form rows · 3 suites
- Every deviation in one place
- Re-running a row yourself

Every deviation in one place

Kernel registry rows that are not a pass (49)

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`plaxis-2d-tut1-a-refinement` Footings and bearing capacity	mesh-refinement study of the case-A force 2π·|Force-Y| (full Newton, tol 1e-8, tension cut-off on) [kN]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 28	588	—	T15: (542 el (re 1.2): 596.65; 1201 el (re 0.8): running at report time; 2132 el (re 0.6): did not converge: load advancement stalled at ΣMstage 0.0957 (increment below minStep)); T6: (542 el (re 1.2): 625.87; 1201 el (re 0.8): 623.21; 2132 el (re 0.6): 618.32; 4822 el (re 0.4): 602.08)	—	—	Deviation
`plaxis-verif-gibson-2011-a` Footings and bearing capacity	settlement under the strip (PLAXIS 2D 0.04845 / 0.04965 m; Gibson 0.05) [m]	PLAXIS-Verification-Strip-load-Gibson-soil-A.pdf, -B.pdf, p. 1–3	0.04845	0.05	0.04599	−5.07 %	−8.02 %	Deviation
`plaxis-verif-k5-set` Finite-element meshing, solvers and procedures	plaxis-verif-k5-set	Hoek-Brown-material-model, Triaxial-Hardening-Soil, Soft-Soil-Creep-Haney-clay, Phi-c-reduction-vs-Bishop, Benchmark-embankment-soft-clay	—	—	—	—	—	Superseded
`plaxis-verif-v2-set` Finite-element meshing, solvers and procedures	plaxis-verif-v2-set	Lamb-problem, Surface-waves, Pulse-load-multilayer, One-dimensional-wave-propagation, Vertical-dynamic-response-footing, Free-vibration-dam, Ground-response-linear-soil	—	—	—	—	—	Superseded
`ertc7-wall-moment` Retaining walls, excavations and structural elements	maximum bending moment in the wall, final excavation (−6 m), characteristic parameters, embedment 4 m [kNm/m]	PLAXIS-Verification-ERTC7-benchmark.pdf, p. 7 (Figure 8, characteristic, embedment 4.0 m: read at 300 dpi ≈ 212)	212	—	204	−3.77 %	—	Deviation
`ertc7-strut-force` Retaining walls, excavations and structural elements	strut force, final excavation [kN/m]	PLAXIS-Verification-ERTC7-benchmark.pdf, p. 8 (Figure 9, characteristic, 4.0 m: ≈ 117)	117	—	123.9	+5.90 %	—	Deviation
`ertc7-wall-base-displacement` Retaining walls, excavations and structural elements	horizontal displacement of the wall base, final excavation [mm]	PLAXIS-Verification-ERTC7-benchmark.pdf, p. 7 (Figure 6, characteristic, 4.0 m: ≈ 6.0)	6	—	9	+50.0 %	—	Deviation

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`plaxis-2d-tut2` Slopes and embankments — factor of safety	drained / undrained embankment + safety factor [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 40–51	—	—	—	—	—	Superseded
`plaxis-2d-tut3` Retaining walls, excavations and structural elements	|u| at (50, 10) at the end of each phase (submerged excavation, undrained-A clay) [m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 52–71	phase1: 0.005; phase2: 0.024; phase3: 0.024; phase4: 0.057; phase5: 0.141	—	phase1: 0.0092; phase2: 0.0302; phase3: 0.0302; phase4: 0.074; phase5: stops at ΣMstage 0.350 (tol 1e-8 and 1e-7); at tol 1e-2 (PLAXIS default, TBK_T3_TOL=0.01) reaches ΣMstage 1 with |u| 0.117	—	—	Superseded
`plaxis-2d-tut7-final` Retaining walls, excavations and structural elements	final phase: wall max |M|, anchor forces, wall displacements [kNm/m, kN, mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 135–137 (Figures 7–16…7–22: figures only)	—	—	wallL Mmax: 154; wallR Mmax: 157; at y: 23; anchors top L/R: [430.4, 428.6]; anchors bottom L/R: [1053.4, 1050.8]; ux(40,27) mm: 10.24; ux(40,23) mm: 13.34	—	—	Superseded
`plaxis-2d-tut7-final-k4-flow` Retaining walls, excavations and structural elements	final phase with REAL phase-6 steady flow: wall max |M|, anchor forces, wall displacements [kNm/m, kN, mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 135–137 (Figures 7–16…7–22: figures only)	—	—	wallL Mmax: 167; wallR Mmax: 170.7; at y: 23; anchors top L/R: [420.1, 424.4]; anchors bottom L/R: [1081.6, 1081.8]; ux(40,27) mm: 6.51; ux(40,23) mm: 12.33; prestress P3 / P5: [500, 1000]	—	—	Superseded
`k5c-acads-1d-fela-bounds` Slopes and embankments — factor of safety	SR-FELA factor of safety, lower / upper bound (ACADS 1(d), kh = 0.15) [-]	Optum-G2-Verification-Slope-Stability.pdf, p. 6–7 (§2.3, Table 6)	—	1.039	lower: 0.9669; upper: 0.9767; errorPct: 0.51	—	−6.47 %	Deviation
`k5b-plaxis-2d-tut9-consolidation-time` Settlement, stress distribution and consolidation	Tutorial 9 (Soft Soil undrained A + HS, 4 consolidation phases): time to p_excess < 1 kPa, plus settlements / excess pore pressures per phase [day, mm, kPa]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 145–160 (p. 159: 'more than 50 days are needed to reach full consolidation'; Figs 9-13…9-17 figures only)	> 50 d	—	t at p_excess < 1 kPa (d): 38.69; settlement (0,0) mm P1/P2/P3/P4: [261.4, 664.5, 829.5, 1033.7]; max p_excess kPa P1/P2/P3/P4: [26.6, 0.02, 28.76, 0.53]; toe (20,0) ux mm P4: 199.8; steps P1..P4: [280, 458, 20, 27]	—	—	Superseded

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`k5b-plaxis-2d-tut7-real-hs` Retaining walls, excavations and structural elements	Tutorial 7 with the REAL Hardening Soil (Table 7-1) + phase-6 steady flow: anchor forces, wall max |M|, wall ux [kN, kNm/m, mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 121–137 (prestress p. 137; Figs 7-16…7-22 figures only)	prestress 500 / 1000 kN (figures otherwise)	—	prestress P3 / P5: [500, 1000]; final anchors top L/R: [450.6, 446.8]; final anchors bottom L/R: [1058.8, 1055.4]; wallL / wallR Mmax: [141.9, 145.1]; at y: 23; ux(40,27) mm: 17.15; ux(40,23) mm: 17.06; K4 Mohr–Coulomb substitute (row plaxis-2d-tut7-final-k4-flow): (Mmax: [167, 170.7]; anchors top: [420.1, 424.4]; anchors bottom: [1081.6, 1081.8]; ux mm: [6.51, 12.33])	—	—	Recorded, no published value
`k5b-plaxis-2d-tut2-drained` Slopes and embankments — factor of safety	Tutorial 2, embankment on DRAINED HS clay: uy at the crest (23,4), centre base (25,0), 2 m beyond the toe (38,0) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 40–46 (Fig. 2-7: figures only)	—	—	crest: -226.7; centre base: -177.9; beyond toe (38,0): 0.6	—	—	Recorded, no published value
`k5a-gl99-example1` Slopes and embankments — factor of safety	factor of safety, homogeneous 2:1 slope, ϕ′ 20°, c′/γH 0.05, ψ 0, D = 1 [-]	Griffiths and Lane 1999.pdf (library root), p. 391–392, Table 2	—	1.35	1.3412	—	−0.65 %	Deviation
`k5a-tut2-safety-undrained` Slopes and embankments — factor of safety	factor of safety ΣMsf, embankment on undrained (A) clay (Phase 4) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 47–51 (Fig. 2-14)	1.4	—	1.14911	−17.9 %	—	Superseded
`k5d-plaxis-2d-tut3-submerged-hs` Retaining walls, excavations and structural elements	|u| at (50, 10) at the end of each phase — real Hardening Soil, the kernel's own submerged excavation (D90: deactivated clusters keep their water) [m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 71 (Fig. 3-15 raster, pixel-measured; tests/data/plaxis_tut3_fig3_15.txt)	phase1: 0.0062; phase2: 0.0242; phase3: 0.0242; phase4: 0.0572; phase5: 0.1417	—	phase1: 0.0054; phase2: 0.0225; phase3: 0.0225; phase4: 0.0589; phase5: 0.1519	phase1: -12.9; phase2: -7; phase3: -7; phase4: 3; phase5: 7.2	—	Deviation
`k5d-plaxis-2d-tut10-dewatering` Retaining walls, excavations and structural elements	Tutorial 10: Tutorial 7 (real HS) + two extraction wells in the phase-6 steady flow (1.5 m³/day/m, h_min 17 m): well discharges, groundwater head in the pit, final anchor forces / wall moments [m³/day/m, m, kN, kNm/m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 166–169 (Figs 10–4, 10–5: figures only)	figures only (head lowered in the excavation, flow to the wells)	—	well discharge each (m³/day/m): -0.9797; side inflow each: 0.9773; pit-bottom seepage: 0; head in the pit (m): 18.90–18.99 (T7: 20 at the bottom); phreatic line in the pit y (m): [18.609, 18.982]; final anchors top L/R, bottom L/R (kN): [453, 449.7, 1050.1, 1048.2]; wall max |M| L/R (kNm/m): [135.1, 138.1]	—	—	Recorded, no published value

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`k5d-benchmark-embankment-soft-clay` Slopes and embankments — factor of safety	SCMEP soft-clay embankment, Soft Soil (USTUTT set): centreline settlement after undrained construction / after 100 years, p_excess at (0, −2.5) [m, kPa]	PLAXIS-Verification-Benchmark-embankment-soft-clay-workshop.pdf (Wiltafsky et al. 2003), p. 2–5 (Fig. 1, Tables 1–2; Figs 2a, 2d, 3a, 3d read)	SS USTUTT settlement after construction (Fig. 2a): 0.18; after 100 years (Figs 3a, 3d): 1.05; p_excess (0,-2.5) (Fig. 2d): -34	other models after construction: 0.11–0.24 m; after 100 years: 1.10–1.60 m	tol 1e-8 (530 T15, 9 Nov 2026): after the D557 mesh change layer 1 stops at ΣMstage 0.8515 (92 steps); settlement (0,0) 0.0167 m there; layer 2 fails at ΣMstage about 0; consolidation takes 0 steps (Modal, agent medium-d627, D627). X2 verdict numerical-stall, best ratio 1.0008e-8 vs 1e-8. tol 1e-3 not re-measured on this mesh; tol 1e-8 (712 T15, before 7 Nov): layer 1 stops at ΣMstage 0.6515 (arc-length increment below its minimum); settlement (0,0) 0.0129 m there; tol 1e-3: layer 1 completes (19 steps); layer 2 reaches ΣMstage 0.918 in maxSteps 1000; plaxis (ALG-1): layer 1 (bounded probe, maxSteps 15): ΣMstage 0.66, 878 iterations, 5 cuts; layers 1–2 NOT completed within the 6-min run cap (not measured); without the local rule layer 1 completes (6 steps, 266 iterations); strict tol 1e-2: 5 steps, 31 iterations	—	—	Deviation
`k5d1-plaxis-2d-tut8-uls-displacement` Retaining walls, excavations and structural elements	|u| at (40, 27) at the end of ULS phase 12 (real Hardening Soil, DA3) [m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 143 (Fig. 8–5, embedded raster: pixel-measured, ±0.0001 m — tests/data/plaxis_tut8_fig8_5_8_6.txt on branch prog-a-t8)	0.0518	—	0.069	+33.2 %	—	Deviation

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`k5d1-plaxis-2d-tut6-natm` Tunnels and underground works	NATM tunnel, β-method (60 % / 100 %) in two excavation stages: crown settlement, lining forces [mm, kNm/m, kN/m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 108–120 (Fig. 6–11, 6–13: figures only)	—	—	crown uy phase 1..4 mm: [-7.45, -8.65, -9.17, -9.11]; crest (−7, 35) uy phase 4 mm: -19.77; liningTop M max/min kNm/m: [2.5, -4.8]; liningTop N min kN/m: -164; liningInvert M max/min kNm/m: [2.6, -3.3]; liningInvert N min kN/m: -59	—	—	Recorded, no published value
`k5d1-plaxis-2d-tut5-building-tilt` Tunnels and underground works	building tilt at the end of phase 5 (lining), displacements from phase 2 on: (uy(15, 3) − uy(5, 3)) / 10 m [%]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 106–107 (Fig. 5–9: (5, 3) → (4.995, 2.981), (15, 3) → (14.995, 2.998))	0.168	—	0.1834	+9.17 %	—	Deviation
`k5d1-plaxis-2d-tut4-safety-phase7` Slopes and embankments — factor of safety	ΣMsf of the Safety phase after the second excavation (phase 3) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 90–91 (Fig. 4–21, figure read: ≈ 1.33)	1.33	—	—	—	—	Deviation
`k5d1-plaxis-2d-tut4-safety-phase8` Slopes and embankments — factor of safety	ΣMsf of the Safety phase after the wall and backfill (phase 6) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 90–91 (Fig. 4–21, figure read: ≈ 1.83)	1.83	—	—	—	—	Deviation
`k7a-dam-free-vibration` Earthquake engineering, dynamics and liquefaction	first two natural frequencies of a dam with depth-varying G (PLAXIS 2.9 / 6.4 Hz; closed form 3.1 / 7.0 Hz) [Hz]	PLAXIS-Verification-Free-vibration-dam-2018.pdf, p. p. 1–3	2.9	3.1	—	—	—	Pending
`k7a-pulse-multilayer` Earthquake engineering, dynamics and liquefaction	surface deflection under a pulse load on a 3-layer pavement (stiff / soft subgrade) [mm]	PLAXIS-Verification-Pulse-load-multilayer.pdf, p. p. 1–4	—	—	—	—	—	Pending
`k7a-surface-waves` Earthquake engineering, dynamics and liquefaction	surface-wave amplitude vs distance from a harmonic prescribed displacement (BEM Chouw et al. 1991) [m]	PLAXIS-Verification-Surface-waves.pdf, p. p. 1–3	—	—	—	—	—	Pending
`k7a-midas-ch4-dynamics` Earthquake engineering, dynamics and liquefaction	Midas GTS NX dynamics benchmarks [-]	Midas-GTS-NX-2019-v2.1-Benchmarks-Verification-Chapter_4_Dynamics.pdf, p. Ch. 4	—	—	—	—	—	Pending
`k7b-liquefaction-column-ru` self-check Earthquake engineering, dynamics and liquefaction	max r_u = Δp/σ'v0 at 4 m and 7 m depth [-]	closed form (r_u ≤ 1) + cross-check, p. —	—	0.95	4 m: 0.8024; 7 m: 1.0311	—	—	Deviation
`k7-plaxis-2d-tut15-free-vibration-residual-undamped` Earthquake engineering, dynamics and liquefaction	residual surface displacement after the generator stops, r = 1.37 m, no damping (amplitude over 0.6–1.0 s) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 241	0.0034	—	0.00531	+56.2 %	—	Deviation

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`k7-plaxis-2d-tut15-free-vibration-residual-damped` Earthquake engineering, dynamics and liquefaction	residual surface displacement after the generator stops, r = 1.37 m, with Rayleigh damping (amplitude over 0.6–1.0 s) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 242	0.0008	—	0.00313	+291.3 %	—	Deviation
`v-hs-published-curve-1` self-check Constitutive models and element tests	HS-1 εv medium (drained TC, MMM Fig 13.3): max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM 2015 Figs 13.2–13.5	—	1	2.452	—	—	Deviation
`v-hs-published-curve-2` self-check Constitutive models and element tests	HS-1 εv dense: max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM 2015 Figs 13.2–13.5	—	1	1.347	—	—	Deviation
`v-hs-published-curve-3` self-check Constitutive models and element tests	HS-4 εv dense (Hostun): max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM 2025.1 Figs 17-9/17-10	—	1	1.001	—	—	Deviation
`v-hs-published-curve-4` self-check Constitutive models and element tests	HS-2 q medium (undrained): max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM Figs 13.4/13.5	—	1	3.595	—	—	Deviation
`v-hs-published-curve-5` self-check Constitutive models and element tests	HS-2 q dense: max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM Figs 13.4/13.5	—	1	3.704	—	—	Deviation
`v-hs-published-curve-6` self-check Constitutive models and element tests	HS-2 P_excess medium: max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM Figs 13.4/13.5	—	1	1.334	—	—	Deviation
`v-hs-published-curve-7` self-check Constitutive models and element tests	HS-2 P_excess dense: max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM Figs 13.4/13.5	—	1	7.456	—	—	Deviation
`v-hs-published-curve-8` self-check Constitutive models and element tests	HSS-1 G dense σ3 100 kPa (Benz 2007 Fig 8.2/8.3): max normalised distance to the published markers (rule ≤ 1) [-]	benz-2007-small-strain-stiffness-of-soils-numerical-consequences.pdf, p. Benz 2007 Figs 8.2/8.3	—	1	1.562	—	—	Deviation
`v-hs-published-curve-9` self-check Constitutive models and element tests	HSS-1 G loose σ3 100 kPa: max normalised distance to the published markers (rule ≤ 1) [-]	benz-2007-small-strain-stiffness-of-soils-numerical-consequences.pdf, p. Benz 2007 Figs 8.2/8.3	—	1	2.765	—	—	Deviation
`k11-3d-tut1-a-control-corner` Three-dimensional analysis	flexible control: footprint-corner settlement (x = y = 18 m) under 66 kPa surface pressure (elastic clay) [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	45.14	50.08	—	+10.9 %	Deviation

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`k11-3d-tut1-a-basement-settlement` Three-dimensional analysis	Tutorial 1 Case A as written (Table 1–1 Mohr–Coulomb clay): mean settlement of the basement underside (z = –2 m), base mesh [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	115.38	99.23	—	−14.0 %	Deviation
`k11-3d-tut1-a-basement-settlement-fine` self-check Three-dimensional analysis	Tutorial 1 Case A as written: mean basement-underside settlement, bisected mesh [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	115.38	102.19	—	−11.4 %	Deviation
`k11-3d-hs-tut1-basement` Three-dimensional analysis	Tutorial 1 Case A with the clay as Hardening Soil: mean settlement of the basement underside (z = –2 m), base mesh [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	—	75.228	—	—	Recorded, no published value
`k11-3d-hs-tut1-vs-mc` Three-dimensional analysis	Tutorial 1 Case A: HS basement settlement relative to the Mohr–Coulomb run (row k11-3d-tut1-a-basement-settlement, 99.231 mm) [%]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	—	-24.19	—	—	Recorded, no published value
`m17-norsand-brasted-plane-strain-peak-loose` Constitutive models and element tests	NorSand drained plane strain (Cornforth apparatus, sigma_3 = 276 kPa, eps_2 = 0, K0 start), Brasted sand, loose (test A10-14): peak major principal stress sigma_1 [kPa]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. Fig. 3.23 (p. 142, PDF 164), Table 3.4 (p. 140), Table 2.1, Fig. 2.45 (p. 92)	—	1033	1100	—	+6.50 %	Deviation
`m17-norsand-brasted-plane-strain-peak-compact` Constitutive models and element tests	NorSand drained plane strain (Cornforth apparatus, sigma_3 = 276 kPa, eps_2 = 0, K0 start), Brasted sand, compact (test A10-12): peak major principal stress sigma_1 [kPa]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. Fig. 3.23 (p. 142, PDF 164), Table 3.4 (p. 140), Table 2.1, Fig. 2.45 (p. 92)	—	1186	1303	—	+9.90 %	Deviation
`m17-norsand-brasted-plane-strain-peak-dense` Constitutive models and element tests	NorSand drained plane strain (Cornforth apparatus, sigma_3 = 276 kPa, eps_2 = 0, K0 start), Brasted sand, dense (test A10-17): peak major principal stress sigma_1 [kPa]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. Fig. 3.23 (p. 142, PDF 164), Table 3.4 (p. 140), Table 2.1, Fig. 2.45 (p. 92)	—	1488	1646	—	+10.6 %	Deviation

Closed-form registry rows that are not a pass (2)

ROW	PROBLEM	REFERENCE	OURS	Δ	TOLERANCE	STATUS
FE-NGAMMA-SMOOTH	N_γ strip on cohesionless sand, smooth (c = 0, q = 0)	612.24	415.506	−32.1 %	± 1 %	Miss
FE-NGAMMA-ROUGH	N_γ strip on cohesionless sand, rough (c = 0, q = 0)	1180.34	1249.39	+5.85 %	± 1 %	Miss

Validation-suite test blocks that failed in the recorded run (0)

None.

Validation-suite test blocks written but not asserted (skip / todo: 2)

- `fe-slope-stability-web-validation.test.ts` — [VAL-1] ACADS 1(a): FE strength-reduction FoS within 3 % of RS2 SSR 0.99
  Why: VAL1-FE-1: RS2 SSR 0.99 (critical SRF 0.995) is above the rigorous upper bound 0.984, so a 3 % band around it is not a correctness criterion. Default is 0.9609 after VAL1-FE-2 (was 0.9453, 4.5 % low). See MEDIUM-ACADS-REPORT.md / MEDIUM-D612-REPORT.md
- `footing-3d-web-validation.test.ts` — C.FOOT3D.6h: c-ϕ square with γ and D_f — physical bounds and its D509 lock (HEAVY tier)
  Why: GEOTECH_HEAVY=1 (minutes in TS; the Python twin runs it in validate_fe_footing_3d.py)

Footings and bearing capacity

FE kernel registry — 17 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-2d-tut1-a-force	total footing force 2π·|Force-Y| at 0.05 m indentation (rigid rough footing, case A) [kN]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 28 (§1.3.6.4 step 2)	588	—	600.77	+2.17 %	—	Pass
plaxis-2d-tut1-a-fy-0.3943	Force-Y per radian at ΣMstage = 0.3943 (u = 0.0197 m) [kN/rad]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 28 (Figure 1–18, calculation progress window)	-53.79	—	-53.974	+0.34 %	—	Pass
plaxis-2d-tut1-a-umax	maximum total displacement (the footing) [m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 29 (Figure 1–19: maximum |u| = 0.05000 m)	0.05	0.05	0.05	0.00 %	0.00 %	Pass
plaxis-2d-tut1-k0-effective-stress self-check	K0 procedure: σ′v = −Σγh + p, σ′h = 0.5 σ′v, p = 10(2 − y) — worst |error| over every integration point [kPa]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 14–16, 23 (Head 2.0 m; Table 1–1; K0 procedure)	—	hand calculation (γ_unsat 17 above y = 2, γ_sat 20 below, γ_w 10, K0 = 1 − sin 30° = 0.5)	1.000e-12	—	0.00 %	Pass
plaxis-2d-tut1-b-flexible	|u| of node (0, 4) vs ΣMstage under 188 kPa on the plate footing (EA 5e6, EI 8.5e3, ν 0), axisymmetric; PLAXIS Figure 1–27: 0.5 → 0.0156, 0.6 → 0.0207, 0.8 → 0.0328, 0.9 → 0.0398, 1.0 → 0.0496 m (±0.0003) [m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 31–39 (case B, Table 1–2 p. 33; Figure 1–27 p. 39, read at 220 dpi)	0.0496	—	0.048745	−1.72 %	—	Pass
plaxis-2d-tut1-a-refinement	mesh-refinement study of the case-A force 2π·|Force-Y| (full Newton, tol 1e-8, tension cut-off on) [kN]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 28	588	—	T15: (542 el (re 1.2): 596.65; 1201 el (re 0.8): running at report time; 2132 el (re 0.6): did not converge: load advancement stalled at ΣMstage 0.0957 (increment below minStep)); T6: (542 el (re 1.2): 625.87; 1201 el (re 0.8): 623.21; 2132 el (re 0.6): 618.32; 4822 el (re 0.4): 602.08)	—	—	Deviation
plaxis-verif-circular-footing-cox	collapse average stress p = 2πF/(πR²) of a smooth rigid circular footing [kPa]	PLAXIS-Verification-Bearing-capacity-circular-footing.pdf, p. 3 (Output; Verification: Cox 1962)	227.64	225.6	227.284	−0.16 %	+0.75 %	Pass
plaxis-verif-smooth-rigid-strip	footing force for 0.01 m [kN/m]	PLAXIS-Verification-Smooth-rigid-strip-footing-elastic.pdf, p. 1–2	15.208	15.148	15.225	+0.11 %	+0.51 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-verif-boussinesq	centre settlement [mm]	PLAXIS-Verification-Boussinesq.pdf, p. 1–3	0.0903	0.091	0.09033	+0.03 %	−0.73 %	Pass
plaxis-verif-davis-booker	mean ultimate stress, smooth / rough (PLAXIS 2D 7.831 / 9.168 kPa) [kPa]	PLAXIS-Verification-Bearing-capacity-strip-footing-DavisBooker.pdf, p. 1–4	7.831 / 9.168	7.800 / 9.090	7.8335 / 9.1826	+0.03 / +0.16 %	+0.43 / +1.02 %	Pass
plaxis-verif-gibson	settlement under the strip (PLAXIS 2D 0.04845 / 0.04965 m; Gibson 0.05) [m]	PLAXIS-Verification-Strip-load-Gibson-soil-A.pdf, -B.pdf, p. 1–3	0.04965	0.05	0.04951	−0.28 %	−0.98 %	Pass
plaxis-verif-gibson-2011-a	settlement under the strip (PLAXIS 2D 0.04845 / 0.04965 m; Gibson 0.05) [m]	PLAXIS-Verification-Strip-load-Gibson-soil-A.pdf, -B.pdf, p. 1–3	0.04845	0.05	0.04599	−5.07 %	−8.02 %	Deviation
k5c-strip-prandtl-nc-smooth	strip footing bearing factor bounds: Prandtl Nc smooth [-]	Potts & Zdravković Vol. 2 §6.5.4.2 (Prandtl 2 + π), p. —	—	5.14159	lower: 5.1256; upper: 5.1455; errorPct: 0.19	—	—	Pass
k5c-strip-prandtl-nc-rough	strip footing bearing factor bounds: Prandtl Nc rough [-]	Potts & Zdravković Vol. 2 §6.5.4.2 (Prandtl 2 + π), p. —	—	5.14159	lower: 5.1322; upper: 5.1551; errorPct: 0.22	—	—	Pass
k5c-strip-ngamma-smooth-30	strip footing bearing factor bounds: Ngamma smooth 30 (Martin 7.65300) [-]	Optum-G3-Verification-Strip-Footing-on-Sand.pdf (Martin 2005 table, p. 4), p. —	—	7.653	lower: 7.374; upper: 8.2657; errorPct: 5.7	—	—	Pass
k5c-strip-ngamma-rough-30	strip footing bearing factor bounds: Ngamma rough 30 (Martin 14.7543) [-]	Optum-G3-Verification-Strip-Footing-on-Sand.pdf (Martin 2005 table, p. 4), p. —	—	14.7543	lower: 13.7698; upper: 15.9087; errorPct: 7.21	—	—	Pass
k5a-prandtl-safety	strength-reduction factor of a strip load q = (2 + π)c/2 on weightless Tresca (closed form F = 2) [-]	—	—	2	2.00312	—	+0.16 %	Pass

Closed-form engine registry — 40 published problems

ROW	PROBLEM	SOURCE	REFERENCE	OURS	Δ	TOLERANCE (WHY)	STATUS
BC-JRC-A33-NQ-M1	EN 1997-1 Annex D Nq at φ′d = 38° (M1) strip, c′ 0, φ′k 38°, γ 18.5, Df 1.5, B 1.5; M1 (γφ′ 1.00)	Bond, Schuppener, Scarpelli, Orr — Eurocode 7: Geotechnical Design, Worked examples (JRC / Dublin workshop, 2013), Annex A.3.3 — Tables A.3.1 / A.3.2, p. 112–113	48.87 Nq	48.93333	+0.13 %	± 0.3 % the report evaluated Nq = e^(π tanφ)·tan²(45° + φ/2) with π = 3.14: that reproduces all four printed cells exactly (48.872, 74.804, 23.172, 27.716) and is the whole +0.09…+0.13 % offset (found in our internal review). 0.3 % still rejects every alternative Nγ form (nearest is 4.3 % away)	Pass
BC-JRC-A33-NG-M1	EN 1997-1 Annex D Nγ at φ′d = 38° (M1) as above	Bond, Schuppener, Scarpelli, Orr — Eurocode 7: Geotechnical Design, Worked examples (JRC / Dublin workshop, 2013), Annex A.3.3 — Tables A.3.1 / A.3.2, p. 112–113	74.8 Nγ	74.89991	+0.13 %	± 0.3 % the report evaluated Nq = e^(π tanφ)·tan²(45° + φ/2) with π = 3.14: that reproduces all four printed cells exactly (48.872, 74.804, 23.172, 27.716) and is the whole +0.09…+0.13 % offset (found in our internal review). 0.3 % still rejects every alternative Nγ form (nearest is 4.3 % away)	Pass
BC-JRC-A33-NQ-M2	EN 1997-1 Annex D Nq at φ′d = tan⁻¹(tan 38°/1.25) (M2) strip, φ′d = 32.007° (M2, γφ′ 1.25)	Bond, Schuppener, Scarpelli, Orr — Eurocode 7: Geotechnical Design, Worked examples (JRC / Dublin workshop, 2013), Annex A.3.3 — Tables A.3.1 / A.3.3, p. 112–113	23.17 Nq	23.19466	+0.11 %	± 0.3 % the report evaluated Nq = e^(π tanφ)·tan²(45° + φ/2) with π = 3.14: that reproduces all four printed cells exactly (48.872, 74.804, 23.172, 27.716) and is the whole +0.09…+0.13 % offset (found in our internal review). 0.3 % still rejects every alternative Nγ form (nearest is 4.3 % away)	Pass

ROW	PROBLEM	SOURCE	REFERENCE	OURS	Δ	TOLERANCE (WHY)	STATUS
BC-JRC-A33-NG-M2	EN 1997-1 Annex D Nγ at φ'd (M2) as above	Bond, Schuppener, Scarpelli, Orr — Eurocode 7: Geotechnical Design, Worked examples (JRC / Dublin workshop, 2013), Annex A.3.3 — Tables A.3.1 / A.3.3, p. 112–113	27.72 Nγ	27.7445	+0.09 %	± 0.3 % the report evaluated Nq = e^(π tanφ)·tan²(45° + φ/2) with π = 3.14: that reproduces all four printed cells exactly (48.872, 74.804, 23.172, 27.716) and is the whole +0.09…+0.13 % offset (found in our internal review). 0.3 % still rejects every alternative Nγ form (nearest is 4.3 % away)	Pass
BC-DAS-4.1	Terzaghi, square footing — cohesion + surcharge terms (the Nγ term is a convention comparison, not reproduced) c′ 20, φ′ 25°, γ 16.5, Df 1.5, B = L = 2 m, square; Das Table 4.1 Nc 25.13, Nq 12.72	Das, B.M., Principles of Foundation Engineering (Cengage), Ch. 4 — Example 4.1, p. 166	968.2 kPa 1.3c′Nc + qNq (printed 653.38 + 314.82)	968.3329	+0.01 %	± 0.5 % Das prints q_u from factors rounded to 2–3 significant figures	Pass
BC-DAS-4.3	General bearing equation, same footing as Ex 4.1, Vesić/Meyerhof general equation	Das, B.M., Principles of Foundation Engineering (Cengage), Ch. 4 — Example 4.3	1373.2 kPa q_u	1374	+0.06 %	± 0.5 % Das prints q_u from factors rounded to 2–3 significant figures	Pass
BC-DAS-4.5	Inclined load β = 20° square 1.25 m, c′ 0, φ′ 30°, γ 18, Df 0.7, β 20°; Das Eq. 4.26 / Table 4.3 (Meyerhof 1963) inclination factors — vesic_inclination 'das_general' (ENG-3: the vesic default is now Vesić's own set)	Das, B.M., Principles of Foundation Engineering (Cengage), Ch. 4 — Example 4.5	273.66 kPa q_u	273.8001	+0.05 %	± 0.5 % Das prints q_u from factors rounded to 2–3 significant figures	Pass
BC-DAS-4.7	Eccentric strip, e = 0.2 m strip B 2 m, c′ 0, φ′ 40°, γ 16.5, Df 1.5, e 0.2 m	Das, B.M., Principles of Foundation Engineering (Cengage), Ch. 4 — Example 4.7, p. PDF 217	3287.39 kPa q′_u	3288.222	+0.03 %	± 0.5 % Das prints q_u from factors rounded to 2–3 significant figures	Pass
BC-DAS-4.12	Eccentric + inclined strip strip B 1.5 m, φ′ 35°, γ 16, Df 1, e 0.15 m, β 20°; Das Eq. 4.26 / Table 4.3 (Meyerhof 1963) inclination factors — vesic_inclination 'das_general' (ENG-3: the vesic default is now Vesić's own set)	Das, B.M., Principles of Foundation Engineering (Cengage), Ch. 4 — Example 4.12	461.98 kPa q′_u	461.6671	−0.07 %	± 0.5 % Das prints q_u from factors rounded to 2–3 significant figures	Pass
BC-DAS-SILO	Case study — Bozozuk silo, φ = 0 c_u 23.3, φ 0, γ 18, 7.2 m square, Df 1.52	Das, B.M., Principles of Foundation Engineering (Cengage), Ch. 4 — Ch. 4 case study (Bozozuk)	181.8 kPa q_u	182.5003	+0.39 %	± 0.5 % Das prints q_u from factors rounded to 2–3 significant figures	Pass
BC-BOW-4-1	Terzaghi, φ 30°, B 1.5 m c 20, φ 30°, γ 17.3, Df 1.2, 1.5 m square	Bowles, J.E., Foundation Analysis and Design, 5th ed. (McGraw-Hill, 1996), Ch. 4 — Example 4-1	1638.8 kPa q_ult	1641.21	+0.15 %	± 1 % Bowles rounds the N-factors to 2–3 figures	Pass
BC-BOW-4-2-H	Hansen, submerged tank footing φ 47°, γ 18.62 / γ′ 9.31, GWT at surface, Df 0.5, B 0.5, L 2	Bowles, J.E., Foundation Analysis and Design, 5th ed. (McGraw-Hill, 1996), Ch. 4 — Example 4-2 (Hansen)	1812 kPa q_ult	1817.75	+0.32 %	± 1 % Bowles rounds the N-factors to 2–3 figures	Pass
BC-BOW-4-2-M	Meyerhof (1963), submerged tank footing as Hansen row	Bowles, J.E., Foundation Analysis and Design, 5th ed. (McGraw-Hill, 1996), Ch. 4 — Example 4-2 (Meyerhof)	2659 kPa q_ult	2672.7	+0.52 %	± 1 % Bowles rounds the N-factors to 2–3 figures	Pass
BC-BOW-4-5	Hansen, two-way eccentric 1.8 m square c 20, φ 36°, γ 18, Df 1.8, eB 0.25, eL 0.2, GWT 6.1 m	Bowles, J.E., Foundation Analysis and Design, 5th ed. (McGraw-Hill, 1996), Ch. 4 — Example 4-5	5088 kPa q_ult	5050.17	−0.74 %	± 1.5 % Bowles rounds Nq 38 / Nγ 40 in Ex 4-5 (two-way eccentric)	Pass

ROW	PROBLEM	SOURCE	REFERENCE	OURS	Δ	TOLERANCE (WHY)	STATUS
BC-BOW-4-7-TOTAL	Meyerhof inclined load — total checked against the book-consistent value, NOT the printed 399.9 kPa (documented source error) c 25, φ 25°, γ 17.5, Df 0.3, 2 m square, θ 18.4°	Bowles, J.E., Foundation Analysis and Design, 5th ed. (McGraw-Hill, 1996), Ch. 4 — Example 4-7 (Meyerhof total); Table 4-1 (inclined-load equation); Table 4-3 (shape factors), p. 248 (PDF 274); Table 4-1 p. 220 (PDF 246); Table 4-3 p. 222 (PDF 248)	388.723 kPa q_ult with the book's printed factors in its Table 4-1 inclined-load equation (343.96 + 36.27 + 8.50)	388.002	−0.19 %	± 1 % Bowles rounds the N-factors to 2–3 figures	Pass
BC-BOW-4-7-C	Meyerhof inclined load — cohesion term c·Nc·dc·ic as above	Bowles, J.E., Foundation Analysis and Design, 5th ed. (McGraw-Hill, 1996), Ch. 4 — Example 4-7 (c-term)	344 kPa c·Nc·dc·ic	343.294	−0.21 %	± 0.5 % printed to 4 s.f.	Pass
BC-DG-6.1-UND-DA1C1	Square pad on soft clay, undrained, DA1-C1 c_u 30, φ 0, γ 18, Df 1, B 1.7 m square, GWT at surface	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.1, p. from PDF 80	586 kN R_d	586.786	+0.13 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass
BC-DG-6.1-UND-DA1C2	Square pad on soft clay, undrained, DA1-C2 (c_u,d = 30/1.4) as above, B 1.7 m	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.1, p. from PDF 80	433 kN R_d	433.995	+0.23 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass
BC-DG-6.1-UND-DA2	Square pad on soft clay, undrained, DA2 as above, B 2.0 m	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.1, p. from PDF 80	580 kN R_d	580.114	+0.02 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass
BC-DG-6.1-UND-DA3	Square pad on soft clay, undrained, DA3 as above, B 2.0 m	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.1, p. from PDF 80	600 kN R_d	600.686	+0.11 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass
BC-DG-6.1-DRN-DA1C1	Square pad, drained, DA1-C1 c′ 5, φ′ 20°, γ 18 / γ′ 8, Df 1, B 1.85 m	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.1, p. from PDF 80	660 kN R_d	661.588	+0.24 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass
BC-DG-6.1-DRN-DA1C2	Square pad, drained, DA1-C2 as above, B 1.85 m	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.1, p. from PDF 80	410 kN R_d	410.474	+0.12 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass
BC-DG-6.1-DRN-DA2	Square pad, drained, DA2 as above, B 1.95 m	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.1, p. from PDF 80	529 kN R_d	528.021	−0.19 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass
BC-DG-6.1-DRN-DA3	Square pad, drained, DA3 as above, B 2.15 m	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.1, p. from PDF 80	562 kN R_d	562.158	+0.03 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass

ROW	PROBLEM	SOURCE	REFERENCE	OURS	Δ	TOLERANCE (WHY)	STATUS
BC-DG-6.2-DA1C2	Tower base, eccentric + inclined, DA1-C2 c′ 0, φ′ 35°, γ 20, Df 2, B 5.6 m square, e 2.19 m, H/V 0.182	Frank, R. et al., Designers' Guide to EN 1997-1 (Thomas Telford, 2004), Ch. 6 — Example 6.2, p. 93 (PDF 87 ff.)	4330 kN R_d on A′ = 6.83 m²	4337.21	+0.17 %	± 1 % Designers' Guide prints R/A′ and R_d to 3 significant figures	Pass
BC-NHI-A7	Pier on sand, AASHTO CWγ = 0.786 φ 36°, γ 17.28, GWT 3.048 m, Df 1.219, B 2.134, L 30.48	FHWA NHI-06-089 Soils & Foundations Reference Manual Vol. II (2006) — Appendix A.7	36609 psf q_ult	36250.1	−0.98 %	± 1 % NHI (2006) reads the depth factor off Table 8-6 as dq ≈ 1.15 (A.7-4). Since W1-D1 (13 Nov 2026) the engine applies AASHTO LRFD 10th (2024) Eq. 10.6.3.1.2a-10, dq = 1 + 2tanφ(1 − sinφ)²·arctan(Df/B) = 1.128 at Df/B = 0.571 (the linear Df/B form gave 1.141, −0.37 %), so the gap to NHI's table read is now −0.98 %: a code revision, not an engine error. Factors Nq 37.8 / Nγ 56.3 are also table-read	Pass
BC-IS-T1-NC45	IS 6403 Table 1 Nc at φ = 45° — checked against the corrected value, NOT the printed cell strip, general shear, φ 45°	IS 6403:1981 (First Revision), Cl 5.1.1 Table 1 — Table 1, φ = 45° (printed Nc 138.88), p. 8 (PDF 15)	133.88 Nc = (Nq − 1)cot φ with the printed Nq 134.88 (Martin exact 133.874)	133.8874	−4.6e-3 %	± 0.1 % Table 1 printed to 2 decimals; the cell was cross-checked against Nc = (Nq − 1)cot φ	Pass
BC-IS-T1-NG30	IS 6403 Table 1 Nγ at φ = 30° strip, general shear, φ 30°	IS 6403:1981 (First Revision), Cl 5.1.1 Table 1 — Table 1, φ = 30°, p. 8 (PDF 15)	22.4 Nγ	22.4025	+0.01 %	± 0.1 % Table 1 printed to 2 decimals; the cell was cross-checked against Nc = (Nq − 1)cot φ	Pass
FE-PRANDTL-SMOOTH	Prandtl strip, Tresca, smooth B 2 m, φ 0, c_u 1, weightless, E 1000, ν 0.49, domain 5 × 3 m, meshes n = 2 / 3 / 4.5	Potts, D.M. & Zdravković, L., Finite Element Analysis in Geotechnical Engineering Vol. 2 (Thomas Telford, 2001), §6.5.4.2; Martin table in Optum G3 strip-on-sand verification — Prandtl N_c = 2 + π, p. 220–221	5.14159 N_c = q_u / c_u	5.13612	−0.11 %	± 0.5 % our acceptance limit for this benchmark: Prandtl 5.14·c_u within 0.5 %; exact solution	Pass
FE-PRANDTL-ROUGH	Prandtl strip, Tresca, rough as smooth; footing horizontal DOFs fixed	Potts, D.M. & Zdravković, L., Finite Element Analysis in Geotechnical Engineering Vol. 2 (Thomas Telford, 2001), §6.5.4.2; Martin table in Optum G3 strip-on-sand verification — Prandtl N_c = 2 + π, p. 220–221	5.14159 N_c = q_u / c_u	5.16001	+0.36 %	± 0.5 % exact for smooth and rough footings (Potts Vol. 2 p. 221); ≤ 0.5 %	Pass
FE-DAVIS-BOOKER-SMOOTH	Davis & Booker (1973) strip, smooth, c = 1 + 2z kPa B 2 m, φ 0, c = 1 + 2z kPa, weightless, E = 299 + 598z kPa, ν 0.495; p = β[(2+π)c_ref + B·c_inc/4], β 1.27. Reference = the analytic β·[(2+π)c_ref + B·c_inc/4] = 7.7998 kPa from the PDF's eq. 1 and its chart-read β; the PDF itself prints the collapse pressure as "7.8 kN/m²" (p. 4)	PLAXIS Validation KB0110019 (Bentley, 2018), after Davis & Booker (1973) Géotechnique — strip footing, smooth, p. 1–4	7.79982 kPa mean collapse pressure	7.81694	+0.22 %	± 1 % our acceptance limit: ≤ 1 % on three meshes, each converged; β is chart-read (Potts Vol. 2 p. 237 caveat)	Pass
FE-DAVIS-BOOKER-ROUGH	Davis & Booker (1973) strip, rough as smooth, β 1.48. Reference = analytic 1.48·[(2+π) + 1] = 9.0896 kPa (eq. 1); the PDF prints "9.1 kN/m²" (p. 4)	PLAXIS Validation KB0110019 (Bentley, 2018) — strip footing, rough, p. 1–4	9.08956 kPa mean collapse pressure	9.15482	+0.72 %	± 1 % gate: ≤ 1 %, three meshes, converged:true	Pass
FE-COX-CIRCULAR	Cox (1962) smooth rigid circle, axisymmetric R 1 m, E′ 2400, ν′ 0.2, c′ 1.6, φ′ = ψ 30°, γ 16, K0 0.5, domain 4 × 4 m, meshes n = 0.667 / 1 / 1.5; γR/c = 10 → p = 141·c	PLAXIS Validation KB0109995 (Bentley, 2018), after Cox (1962) — circular footing on Mohr–Coulomb, p. 1–3	225.6 kPa collapse pressure	226.204	+0.27 %	± 1 % our acceptance limit: ≤ 1 %; 141 printed to 3 s.f. (±0.35 %)	Pass
FE-REISSNER-NQ	Reissner N_q, weightless c = 0 strip with surcharge smooth strip B 2 m, φ = ψ 30°, c 0, γ 0, q0 10 kPa, E 20 MPa, ν 0.3, default domain, meshes n = 0.667 / 1 / 1.5	OptumCE, Optum G3 verification — Strip footing on sand (Martin 2005 exact N_q / N_γ) — Martin table, N_q(φ = 30°), p. 4	184.011 kPa q_u = N_q·q0 (N_q 18.4011)	183.403	−0.33 %	± 1 % exact for ψ = φ, smooth or rough (Potts Vol. 2 §6.5.4.4 p. 226); 1 % adopted, as for the other exact FE benchmarks	Pass

ROW	PROBLEM	SOURCE	REFERENCE	OURS	Δ	TOLERANCE (WHY)	STATUS
FE-NGAMMA-SMOOTH	N_γ strip on cohesionless sand, smooth (c = 0, q = 0) B 10 m, φ = ψ 30°, c 0, γ 16, q0 0, E 20 MPa, ν 0.3, half-model 30 × 15 m, meshes n = 0.667 / 1 / 1.5	OptumCE, Optum G3 verification — Strip footing on sand (Martin 2005 exact N_q / N_γ) — Martin (2005) exact N_γ(30°), smooth, p. 4–5	612.24 kPa q_u = ½γB·N_γ (N_γ 7.65300)	415.506	−32.1 %	± 1 % not an acceptance gate; ≤ 1 % targeted (Optum G3 FELA +1.25 %; Hjiaj bounds 7.6225–8.0784)	Miss
FE-NGAMMA-ROUGH	N_γ strip on cohesionless sand, rough (c = 0, q = 0) as smooth, rough footing	OptumCE, Optum G3 verification — Strip footing on sand (Martin 2005 exact N_q / N_γ) — Martin (2005) exact N_γ(30°), rough, p. 4–5	1180.34 kPa q_u = ½γB·N_γ (N_γ 14.7543)	1249.393	+5.85 %	± 1 % not an acceptance gate; ≤ 1 % targeted (Optum +0.17 %; Hjiaj bounds 14.5671–15.2372)	Miss
FELA-NGAMMA-SMOOTH	N_γ strip on cohesionless sand, smooth — FE limit analysis: do the lower and upper bounds contain the exact value? B 10 m, φ = ψ 30°, c 0, γ 16, q0 0; recipe mesh (fan, n = 1, 1,040 elements); default N_γ domain	OptumCE, Optum G3 verification — Strip footing on sand (Martin 2005 exact N_q / N_γ) — Martin (2005) exact N_γ(30°), smooth, p. 4–5	612.24 kPa q_u = ½γB·N_γ (N_γ 7.65300)	646.999	—	± 0.01 % BRACKET ROW: pass when lower bound ≤ exact ≤ upper bound — the statement the bound theorems make, and the rule the finite-element registry already applies to the same engine (k5c-strip-ngamma rows, "LB ≤ exact ≤ UB"). ± 0.01 % is only the containment precision (Martin's N_γ is printed to 6 significant figures); Δ is not reported because the exact value need not sit at the mean of the bounds. The bracket width is recorded with every measurement and stated in the notes	Pass
FELA-NGAMMA-ROUGH	N_γ strip on cohesionless sand, rough — FE limit analysis: do the lower and upper bounds contain the exact value? as FELA-NGAMMA-SMOOTH, rough footing	OptumCE, Optum G3 verification — Strip footing on sand (Martin 2005 exact N_q / N_γ) — Martin (2005) exact N_γ(30°), rough, p. 4–5	1180.34 kPa q_u = ½γB·N_γ (N_γ 14.7543)	1200.336	—	± 0.01 % BRACKET ROW: pass when lower bound ≤ exact ≤ upper bound — the statement the bound theorems make, and the rule the finite-element registry already applies to the same engine (k5c-strip-ngamma rows, "LB ≤ exact ≤ UB"). ± 0.01 % is only the containment precision (Martin's N_γ is printed to 6 significant figures); Δ is not reported because the exact value need not sit at the mean of the bounds. The bracket width is recorded with every measurement and stated in the notes	Pass
BC-GEO5-VM02	GEO5 VM-02 spread footing, 7° terrain slope, DA2 (self-weight favourable) — GEO5's Brinch Hansen standard-analysis factor set 1.80 × 2.20 m, Df 1.20, SM φ′ 31.5°, γ 17.5, N 910, Hy 120, Mx 200, terrain 7°; Hansen with hansen_factor_set 'geo5_reduced' (the manual's own s, d, i set)	Fine, GEO5 Verification Manual No. 2 — Spread Footing (update 03/2016) — case 1 (γG = 1.00), R_d after γR;v 1.40; factor set p. 3–4 ("A standard analysis proposed by J. Brinch Hansen is used"), p. 3–5	381.706 kPa R_d / γR;v (hand calc; program 381.92)	381.919	+0.06 %	± 1 % Tolerance ± 1 % (our band for closed-form bearing checks). GEO5 prints a hand calculation (381.706 kPa, every factor rounded to 3 decimals) and its program's value (381.92 kPa), 0.06 % apart; the engine gives 381.919 kPa	Pass
BC-GEO5-VM02-C2	GEO5 VM-02 spread footing, 7° terrain slope, DA2 (self-weight unfavourable) — GEO5's Brinch Hansen standard-analysis factor set as BC-GEO5-VM02 with self-weight γG 1.35: e 0.238 m, δ 6.574°; hansen_factor_set 'geo5_reduced'	Fine, GEO5 Verification Manual No. 2 — Spread Footing (update 03/2016) — case 2 (γG = 1.35), R_d after γR;v 1.40, p. 7–9	386.501 kPa R_d / γR;v (hand calc; program 386.61)	386.612	+0.03 %	± 1 % Tolerance ± 1 % (our band for closed-form bearing checks). GEO5 prints a hand calculation (386.501 kPa) and its program's value (386.61 kPa), 0.03 % apart; the engine gives 386.612 kPa	Pass

Cited validation suites — 32

⚑ bearing-capacity-ec7-web-validation.test.ts

`bearing-capacity` — EN 1997-1:2004 Annex D anchored to a PUBLISHED European worked example.

Analyses validated: `bearing-capacity` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
JRC EC7 worked example A.3.3 — M1 material set (γφ′ = 1.00): Nq = 48.87, Nγ = 74.80	Pass
JRC EC7 worked example A.3.3 — M2 material set (γφ′ = 1.25): Nq = 23.17, Nγ = 27.72	Pass
E-37 regression: the OTHER Nγ forms are rejected by this anchor at both material sets	Pass
E-37: the M2 Nγ error is LARGER than the M1 error — the discrepancy grows where it matters most	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EN 1997-1 Annex D shape factors: sq = 1+(B′/L′)sinϕ′, sγ = 1−0.3(B′/L′), sc = (sq·Nq−1)/(Nq−1)	Pass
Annex D defines NO depth factors — embedment enters only through the surcharge q′	Pass
E-37: pairing a Eurocode design approach with a non-Annex-D resistance model WARNS	Pass
Annex D inclination factors: exact for c′ = 0, and flagged as conservative when c′ > 0	Pass
the Annex D method is labelled and discoverable	Pass

⚑ bearing-capacity-is6403-web-validation.test.ts

IS 6403:1981 — "Code of Practice for Determination of Bearing Capacity of Shallow Foundations" (First Revision) — validated against the tables printed in the standard.

Analyses validated: `bearing-capacity` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IS 6403:1981 Table 1 — all 33 published bearing-capacity factors (Nc, Nq, Nγ)	Pass
IS 6403:1981 Table 1 is internally consistent — Nc = (Nq−1)·cot ϕ and Nγ = 2(Nq+1)·tan ϕ	Pass
IS 6403:1981 Table 2 — all 12 published shape factors	Pass
IS 6403:1981 Table 1 Note — local shear uses ϕ′ = tan⁻¹(0.67·tan ϕ) and c′ = ⅔c	Pass
IS 6403:1981 — the code default is IS_6403 with FoS = 3, and qnu/qns follow Cl 6	Pass

bearing-capacity-reliability-web-validation.test.ts

PUBLISHED-VALUES: 0 -- distinct published values for this engine (engine-level total, declared once); independent audit A2: each demand is bisected so the reliability equals the tabulated value, so the suite tests the inverse-normal functi…

Analyses validated: `bearing-capacity-reliability` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Baecher and Christian (2003) Table 13.1 — reliability index against probability of failure (Normal column)	Pass
Baecher and Christian (2003) Table 13.1 — the tails: 100 % and 0 % of 20 000 draws passing	Pass
Look (2007) Tables 10.1, 10.2 and 10.5 — published COV of the friction angle applied by the sampler	Pass
the default COV lies inside the published 5-15 % range, and a COV outside [0, 2] is refused	Pass

bearing-capacity-web-validation.test.ts

WEB-BENCHMARK validation for the shallow-foundation bearing-capacity engine (the release rules mandatory ≥20 cited-value gate).

Analyses validated: `bearing-capacity` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
BC web 1–9: Nq at ϕ=5..45 (Prandtl/Vesic 1973, Das Table 4.3)	Pass
BC web 10–14: Nc at ϕ=0,10,20,30,40 (Prandtl/Vesic 1973)	Pass
BC web 15–19: Vesic Nγ at ϕ=20,25,30,35,40 (Vesic 1973)	Pass
BC web 20–22: Hansen Nγ at ϕ=20,30,40 (Hansen 1970)	Pass
BC web 23–29: Terzaghi Nc & Nq at ϕ=0,20,30,35,40 (Terzaghi 1943, Das Table 3.1)	Pass

⚑ bearing-capacity-worked-examples-web-validation.test.ts

bearing-capacity — FULL WORKED EXAMPLES (the ≥20-value gate, end-to-end q_ult / R_d rather than factor tables; the factor tables are `bearing-capacity-web-validation.test.ts`).

Analyses validated: `bearing-capacity` · Recorded run: passed — 32 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS] Ex 4.1 Terzaghi square, c′ 20, ϕ′ 25°, γ 16.5, Df 1.5, B 2 → q_u = 1078.29 kPa	Pass
[DAS] Ex 4.3 general equation, same footing → q_u = 1373.2 kPa	Pass
[DAS] Ex 4.4 water above the base (effective stress), B = 4.5 ft → q_u = 3·q_all = 1080 kPa	Pass
[DAS] Ex 4.5 inclined load β = 20°, square 1.25 m, ϕ′ 30°, Df 0.7 → q_u = 273.66 kPa	Pass
[DAS] Ex 4.7 eccentric strip e = 0.2 m → q′_u = 3287.39 kPa	Pass
[DAS] Ex 4.7 → Q_u = q′_u·B′ = 5260 kN/m	Pass
[DAS] Ex 4.12 eccentric + inclined strip → q′_u = 461.98 kPa	Pass
[DAS] case study — Bozozuk silo, ϕ = 0, c_u 23.3, 7.2 m square, Df 1.52 → q_u = 181.8 kPa	Pass
[DAS] case study — Bangkok clay, c_u 14.4, Df 1.5, B = 0.6 m → q_u(theory) = 158.3 kPa	Pass
[DAS] case study — Bangkok clay, c_u 14.4, Df 1.5, B = 0.675 m → q_u(theory) = 156.8 kPa	Pass
[DAS] case study — Bangkok clay, c_u 14.4, Df 1.5, B = 0.75 m → q_u(theory) = 155.4 kPa	Pass
[DAS] case study — Bangkok clay, c_u 14.4, Df 1.5, B = 0.9 m → q_u(theory) = 152.6 kPa	Pass
[DAS] case study — Bangkok clay, c_u 14.4, Df 1.5, B = 1.05 m → q_u(theory) = 150.16 kPa	Pass
[BOW] Ex 4-1 Terzaghi, ϕ 20°: q_ult = 613.8 + 34.6·B at B = 1.5 m	Pass
[BOW] Ex 4-1 Terzaghi, ϕ 30°, B = 1.5 m → q_ult = 1638.8 kPa	Pass
[BOW] Ex 4-2 Hansen (sq = 1 + B/L·sin ϕ = 1.18) → q_ult = 1812 kPa	Pass
[BOW] Ex 4-2 Meyerhof (Nγ = 414) → q_ult = 2659 kPa	Pass
[BOW] Ex 4-3 Hansen ϕ = 0: 5.14·s_u·(1 + s′c + d′c) = 15.6 t/m² (q neglected)	Pass
[BOW] Ex 4-5 Hansen, two-way eccentric 1.8 m square → q_ult = 5088 kPa	Pass
[BOW] Ex 4-7 Meyerhof inclined (θ = 18.4°): cohesion term c·Nc·dc·ic = 344.0 kPa	Pass
[DG] Ex 6.1 undrained DA1-C2 (c_u,d = 30/1.4): R/A′ = 150 kPa, R_d = 433 kN	Pass
[DG] Ex 6.1 undrained DA1-C1: R/A′ = 203 kPa, R_d = 586 kN	Pass
[DG] Ex 6.1 undrained DA2, B = 2.0 m → R_d = 580 kN	Pass
[DG] Ex 6.1 undrained DA3, B = 2.0 m → R_d = 600 kN	Pass
[DG] Ex 6.1 drained DA1-C2, B 1.85 (γ′ = 8, q′ = 8) → R/A′ = 120 kPa, R_d = 410 kN	Pass
[DG] Ex 6.1 drained DA1-C1, B 1.85 → R/A′ = 193 kPa, R_d = 660 kN	Pass
[DG] Ex 6.1 drained DA2, B 1.95 → R_d = 529 kN	Pass
[DG] Ex 6.1 drained DA3, B 2.15 → R/A′ = 121.5 kPa, R_d = 562 kN	Pass
[DG] Ex 6.2 tower DA1-C2: e = 2.19 m on B = 5.6 m, H/V = 0.182 → R/A′ = 637 kPa, R_d = 4330 kN (on A′ = 6.83 m²)	Pass
[NHI] App. A.7 pier on sand, AASHTO CWγ = 0.786 → q_ult = 36 609 psf	Pass
[NHI] Ex 8-1 water table at the base halves the weight term: 2025 → 1014 psf	Pass
[GEC6] App. B Ex 1: B = 6 m, Df 2.3 m, water 9.1 m → CWγ ≈ 0.9 (1.5·B influence depth)	Pass

⚑ combined-footing-web-validation.test.ts

Rectangular combined footing proportioned for uniform soil pressure (`combined-footing.ts`) vs PUBLISHED worked examples.

Analyses validated: `combined-footing` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Example 8.1 — Q1 = 400 kN, Q2 = 500 kN, qnet = 140 kN/m², L3 = 3.5 m, L2 = 1.5 m	Pass
Das Example 8.2 — Q1 = 1000 kN, Q2 = 400 kN, qnet = 120 kN/m², L3 = 3 m: area and resultant	Pass
Varghese Example 2.2 — 180 kN and 360 kN columns 2.1 m apart, safe bearing capacity 100 kN/m²	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NPTEL Lesson 29 Problem 5 — C1 400 × 400 (800 kN) flush with the property line, C2 300 × 500 (1200 kN), 3.0 m apart, qc = 200 kN/m²	Pass
Baban Problem 5.16(A) — working loads 550 + 700 kN, net qa = 150 kPa	Pass
Baban Problem 5.16(A) — factored loads 800 + 960 kN give L = 2X = 6.8 m	Pass
Baban Problem 5.13 — interior column with no room beyond it: a rectangular footing is not possible	Pass

⚑ compensated-foundation-web-validation.test.ts

Compensated (floating) foundation — net pressure q_net = q_gross − γ·Df and degree of compensation (`compensated-foundation.ts`) vs PUBLISHED worked examples.

Analyses validated: `compensated-foundation` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Varghese Example 18.1 — ten-storey raft, 150 kN/m² gross, excavated 4.5 m in clay of 20 kN/m³	Pass
Varghese Example 18.2 — the same building as a floating foundation: d = 150/20 = 7.5 m	Pass
Das Example 8.6 — 30 × 40 m mat, Q = 200 × 10³ kN, Df = 2 m, γ = 15.72 kN/m³	Pass
Baban Problem 2.1(c) — 40 × 80 m mat, 10 m deep, water table at 5 m	Pass
Baban Problem 4.1 — silo on a 22.5 × 60 m mat, 3 m deep, clay of 17.5 kN/m³ with the water table at ground level	Pass
Baban Problem 4.3 — square footing 4.5 m deep in saturated clay, water table at the surface	Pass
FHWA-NHI-06-089 Example 8-2 — Δp = 2,000 psf − 3 ft × 115 pcf	Pass
FHWA-NHI-06-089 Appendix A.7 — Δp = 6,000 psf − 4 ft × 110 pcf	Pass
FHWA-NHI-06-089 Appendix A.7 embankment footing — Δp = 6,300 psf − 10 ft × 130 pcf	Pass

⚑ eccentric-footing-pressure-web-validation.test.ts

Contact pressure under an eccentrically loaded footing (`eccentric-footing-pressure.ts`) vs PUBLISHED worked examples.

Analyses validated: `eccentric-footing-pressure` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Varghese Example 2.1 — 2.6 × 2.6 m footing, 600 kN with 100 kN·m	Pass
Varghese Example 7.1 — effective dimensions of the 2 × 2 m footing (600 kN, Mx = 180, My = 60)	Pass
Varghese Example 7.3 — retaining-wall base, 433 kN/m on 3.9 m, load 1.75 m from the toe	Pass
Varghese Example 7.4 — 3.3 × 3.3 m footing, 300 kN with 150 kN·m	Pass
Varghese Example 7.5 — the same footing, conventional pressures 27.5 ± 25 kN/m²	Pass
Varghese Example 7.6 — layout for uniform pressure: B′ = 2.3 m and 131 kN/m²	Pass
Baban Problem 2.2 — strip footing 1.5 m wide, V + Wf = 218 kN/m, My = 40 kN·m/m	Pass
Baban Problem 2.3 — mat 50 × 75 m under six grain silos, three one-way cases	Pass
Baban Chapter 6 (EC7) strip footing 6.5 × 2 m — combination 1: resultant inside the middle third	Pass
Baban Chapter 6 (EC7) strip footing — combination 2: resultant OUTSIDE the middle third	Pass
Baban Chapter 6 (EC7) strip footing — combination 3	Pass
Das Example 4.7 (effective width) and the §4.10 beyond-kern relation	Pass

⚑ equivalent-raft-web-validation.test.ts

Equivalent-raft pile-group settlement (`equivalent-raft.ts`) vs PUBLISHED values.

Analyses validated: `equivalent-raft` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Example 9.23 — Qg = 2000 kN, Lg = 3.3 m, Bg = 2.2 m, 15 m piles	Pass
Varghese Example 4.7 — nine 200 mm friction piles, 400 kN, 6 m of pile in clay	Pass
Tomlinson Example 5.1 — friction piles, 13.90 m, equivalent raft 10.5 × 13.8 m	Pass
Tomlinson Example 5.2 — piles 7 m into sand below the seabed, raft 10.4 × 9.1 m	Pass
Tomlinson Example 5.3 — 20 × 15 piles of 900 kN, raft 35.4 × 27.4 m	Pass
Tomlinson Example 5.4 — 12-storey building, raft 52.25 × 22.25 m: pressure and oedometer products	Pass
FHWA GEC 6 Table B2-3 — 2-on-1 stress increase Δσv/q for Lf = 25.0 m	Pass
IRC:78-2014 Cl. 709.3.4 — raft position for friction and end-bearing piles (clause-rule check, not a worked answer)	Pass

fe-bearing-capacity-hs-web-validation.test.ts

WEB-BENCHMARK validation for the HARDENING-SOIL stress-dependent stiffness option of the FE bearing-capacity engine.

Analyses validated: `fe-bearing-capacity`, `hardening-soil` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FE-HS REDUCTION: m=0 ≡ constant-E MC engine (q_ult + settlement identical)	Pass
FE-HS REDUCTION: ϕ=0 undrained ⇒ HS stiffness inert (identical to MC)	Pass
FE-HS STRENGTH: q_ult is stiffness-independent (HS on ≈ off within 5%)	Pass
FE-HS POWER-LAW: uniform confining E matches the HS SoilTest power law	Pass
FE-HS MONOTONIC: E grows with depth; spread widens with m	Pass
FE-HS WEB: loose Hostun sand E(σ₃) matches published HS power law (4 cases)	Pass
FE-HS WEB: dense Hokksund sand E(σ₃) matches published HS values (4 cases)	Pass
FE-HS WEB: Vesić Nc/Nq/Nγ match the published closed form (ϕ = 0,20,25,30,35°)	Pass
FE-HS SETTLEMENT: HS stiffness changes the service settlement (finite, sane)	Pass

fe-bearing-capacity-web-validation.test.ts

fe-bearing-capacity — validation against PUBLISHED values, every number traced to a source.

Analyses validated: `fe-bearing-capacity` · Recorded run: passed — 16 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[PZ2] Table 6.1: Nq(ϕ′=25°) with ψ=0 — published FE 9.92 (rough) / 10.0 (smooth)	Pass
[PZ2] §6.5.4.4: the ultimate Nq is independent of the surcharge magnitude	Pass
[SGM]/[MAR]: the combined c-ϕ-γ case lands within 15% of the EXACT characteristics solution	Pass
E-77: the classical SUPERPOSITION is not a reliable yardstick — measured, both signs cited	Pass
[PR] Prandtl: Nc → 5.142 monotonically with refinement	Pass
[PR] Reissner: Nq is reproduced by the engine's own closed form across ϕ′	Pass
the ψ=0 reduction deepens with ϕ′ and matches [PZ2] at the one ϕ′ they publish	Pass
[PZ2] Table 6.2: Nγ is UNDER-predicted — pinned as a known gap, not a passing check	Pass
E-80 / D181: the self-weight part is DISCLOSED on every run that has one, with its measured share	Pass
E-79 REGRESSION: the pure-Nγ configuration is not falsely refused	Pass
D181: the pure-Nγ surface case is flagged NOT mesh-converged, with the measured cause	Pass
E-80: with confinement the capacity is surcharge-dominated and tracks the exact Nq	Pass
D175 [BOW]: at zero NET footing pressure the settlement is 0 — q = q_s with a surcharge, q → 0 without	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
D175: the page-default settlement is the footing-induced part only — value and derivation	Pass
D175: the K0 procedure has no geostatic phase to run, and a failed geostatic phase refuses LOUDLY	Pass
D175 user-visible text: plain English, no em dash, no internal issue code, no competitor product name	Pass

fe-footing-bvp-web-validation.test.ts

Validation for the 2-D plane-strain FOOTING bearing-capacity FE BVP with the Mohr-Coulomb + Hardening-Soil-stiffness material (`fe-footing-bvp.ts`) — the advanced-constitutive continuum solve that closes the "HS in a 2-D FE" gap.

Analyses validated: `footing-bearing-fe` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Vesić (1973) bearing-capacity factors N_c, N_q, N_γ — published table (13 anchors)	Pass
Prandtl (1921): ϕ=0 strip footing q_ult = 5.14·s_u (FE within the coarse-mesh band)	Pass
Prandtl: q_ult scales LINEARLY with s_u (correct undrained mechanics)	Pass
Smith & Griffiths: FE bearing capacity converges toward the Prandtl limit as the mesh refines	Pass
Vesić (1973): frictional footing q_ult follows c·N_c + q_o·N_q (ϕ = 30°)	Pass
load–settlement curve is monotone rising to the plateau	Pass
HS stress-dependent stiffness: footing stiffness scales with E_ref (Schanz-Vermeer-Bonnier)	Pass
solver returns finite results and the represented footing width	Pass

fe-hs-footing-web-validation.test.ts

Validation for the Hardening-Soil footing BVP (`fe-hs-footing-bvp.ts`) — the SVB shear-hardening return-map run at every Gauss point with per-point plastic state γ^p carried across displacement-controlled load increments (Phase 2 of HS-in-...

Analyses validated: `footing-bearing-fe` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
constitutive-in-FE: a full-width footing (1-D confined compression) reproduces the material point	Pass
Prandtl (1921): ϕ=0 HS footing q_ult = 5.14·s_u (coarse-mesh band, from above)	Pass
Prandtl: q_ult scales linearly with s_u (correct undrained mechanics)	Pass
Smith & Griffiths: FE bearing capacity converges to the Prandtl limit from ABOVE as the mesh refines	Pass
frictional (ϕ=30) HS footing collapse load is in the Vesić range and tracks the M-C solver	Pass
load–settlement rises monotonically to the collapse peak (hardening), then q_ult is the peak	Pass

flotation-web-validation.test.ts

Validation for `flotation` — buoyancy / uplift (EN 1997-1 UPL) check of a buried structure (`flotation-check.ts`, `computeFlotation`).

Analyses validated: `flotation` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Craig Ex 10.2: printed loads are 18 024 kN concrete + 15 200 kN soil on the roof	Pass
Craig Ex 10.2: pore pressure on the base u = 117.7 − 9.8z kPa and uplift U = 47.1 − 3.9z MN	Pass
Craig Ex 10.2 (a): empty store needs the water table at least 4.4 m down	Pass
Craig Ex 10.2 (b): half-filled with books (+5.7 MN) ⇒ z ≥ 3.1 m	Pass
Craig Ex 10.2: water table at the surface needs tension piles T ≥ 19.1 MN	Pass
Designers' Guide Ex 7.5: V_dst,d = 1000 kN and G_stb,d = 450 kN per 5 m² of raft	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Designers' Guide §10.2.3 Eq. D10.7: the UPL check is an overall factor of safety 1.00/0.90 = 1.11	Pass
Worked Examples A.6.1 step 1: weight of structure only — printed "requirement is not fulfilled"	Pass
Worked Examples A.6.1 step 2: adding wall friction R_k = 2680 kN — printed "still not satisfied"	Pass
EN 1997-1 Table A.15 and Craig Table 10.3: γG;dst = 1.00 and γG;stb = 0.90	Pass
A dry base (water table below the base) has no uplift and passes every check	Pass

footing-bearing-fe-web-validation.test.ts

C.FOOTFE — `footing-bearing-fe` web-benchmark (25 cited published values).

Analyses validated: `footing-bearing-fe` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C.FOOTFE.1: ϕ=0 strip footing converges on the exact Prandtl (2+π)·c_u from above	Pass
C.FOOTFE.2: the ϕ=0 limit load is exactly proportional to c_u (scale invariance)	Pass
C.FOOTFE.3: 18 published Vesić factors (strip — no shape factors) within 0.5%	Pass
C.FOOTFE.4: undrained clay through the public entry point agrees with the closed form	Pass
C.FOOTFE.5: clean sand (c'=0) reports no FE capacity instead of a wrong one	Pass
C.FOOTFE.6: closed form is monotonic in strength and never returns non-finite	Pass

footing-near-slope-web-validation.test.ts

Footing on or near a slope crest (`footing-near-slope.ts`: Vesić Nc/Nq/Nγ, Hansen ground factors g_c, g_q, g_γ, linear set-back recovery to b = 2B) vs PUBLISHED values.

Analyses validated: `footing-near-slope` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bowles Example 4-11 Case II — Hansen ground factor on a 1-on-2 slope (β = 26.5°, ϕ = 36°, γ = 14.85 kN/m³)	Pass
FHWA-SA-02-054 §5.2.3.4 — capacity is independent of the slope beyond two to six footing widths	Pass
Das Table 4.2 — Nc, Nq, Nγ (ϕ = 0, 10, 20, 30, 40, 50°)	Pass
IS 6403:1981 Table 1 — Nc, Nq, Nγ (ϕ = 15, 25, 35°) and the 45° row	Pass

⚑ foundation-analysis-web-validation.test.ts

Foundation-analysis orchestrator (`foundation-analysis.ts`) vs PUBLISHED values.

Analyses validated: `foundation-analysis`, `settlement` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Example 7.7 — Meyerhof–Bowles pressure that gives the printed 14.7 mm	Pass
Bowles §4-10 example under Fig. 4-7 — qa with the depth factor	Pass
Bowles Example 5-9 — qa table for N55 = 25, D = 1.5 m	Pass
Varghese Example 4.3 — Teng Eq. 4.4: 6.1 mm under 40 kN/m² (N = 20, B = 5 m)	Pass
Varghese Example 4.4 — 13.7 mm under 100 kN/m² (N = 23, B = 10 m)	Pass
Varghese Example 6.4 — q25 = 125 kN/m² (N = 15, B = 3 m)	Pass
Varghese Example 6.5 — q25 = 274 and q40 = 438 kN/m² (N = 27, B = 2 m); allowable 440	Pass
Varghese Example 8.5 — raft on sand, q25 = 64.7 kN/m² (N = 10, B = 9 m)	Pass
Das Example 3.1 — (N1)60 by Liao–Whitman C_N (γ = 17.3 kN/m³, dry)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Table 3.7 — C_N by the seven published relations at σ′/pa = 0.5 (1.5 for Eq. 3.16) and 2.0	Pass
IS 6403 Table 1 — Nγ recovered through the orchestrator	Pass
IS 6403 Table 1 — Nq recovered through the orchestrator	Pass
IS 6403 Table 1 — Nc recovered through the orchestrator	Pass
IS 6403 Table 2 — shape factors recovered as ratios to the strip footing	Pass
hand-derived: ground water at the base halves the weight term (IS 6403 Cl 5.1.2.4, W′ = 0.5)	Pass

foundation-practice-web-validation.test.ts

Web-benchmark validation for TWELVE foundation/monitoring/groundwater runner engines.

Analyses validated: `asaoka`, `combined-footing`, `compensated-foundation`, `cpt-sbt-ic`, `deadman-anchor`, `embankment-benching`, `equivalent-raft`, `footing-near-slope`, `pile-buckling`, `preconsolidation`, `pump-test`, `tunnel-settlement-trough` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
preconsolidation reproduces the Casagrande break and the recompression index	Pass
asaoka recovers β_0, β_1 and the asymptote from the 1978 recurrence	Pass
cpt-sbt-ic reproduces Robertson (2009) I_c including the stress-exponent iteration	Pass
pile-buckling uses the Davisson-Robinson depth to fixity with Euler	Pass
tunnel-settlement-trough reproduces the Peck (1969) Gaussian	Pass
compensated-foundation computes net pressure and the degree of compensation	Pass
pump-test reproduces Cooper & Jacob (1946)	Pass
equivalent-raft applies the Tomlinson raft depth and 2:1 spread	Pass
footing-near-slope uses Vesić N-factors with Hansen/Vesić ground factors	Pass
combined-footing places the base so the pressure is uniform (Bowles §9)	Pass
deadman-anchor computes the Teng (1962) net passive resistance	Pass
embankment-benching sizes IRC:75 benches from the existing slope	Pass

hardening-soil-footing-web-validation.test.ts

≥20-ANCHOR WEB/LITERATURE BENCHMARK for the Hardening-Soil footing BVP (`fe-hs-footing-bvp.ts`) — the LAST GATE before this engine may be surfaced live.

Analyses validated: `footing-bearing-fe`, `hardening-soil-footing` · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-4] Prandtl (1921)/Reissner (1924): ϕ=0 q_ult = 5.14·s_u at four strengths (from above)	Pass
[5] Prandtl: q_ult/s_u is a CONSTANT (correct undrained mechanics, no strength scaling error)	Pass
[6-8] Smith & Griffiths: the FE collapse load converges to the Prandtl limit FROM ABOVE	Pass
[9-12] Vesić (1973)/Terzaghi (1943): frictional q_ult tracks c·N_c + q_o·N_q at ϕ = 20/25/30/35°	Pass
[13] capacity increases monotonically with friction angle (correct frictional mechanics)	Pass
[14] Davis (1968): associated (ψ=ϕ) and non-associated (ψ=0) collapse loads, and HS-vs-MC agreement	Pass
[15-17] SVB (1999) constitutive-in-FE: the 1-D confined patch test reproduces the material point	Pass
[18-19] Elasticity (Boussinesq / Poulos & Davis 1974): the low-load branch is linear in load	Pass
[20] settlement scales inversely with stiffness (doubling E halves the early settlement)	Pass
[21] capacity increases with cohesion (the c·N_c term)	Pass
[25-28] Terzaghi/Vesić: the q_o·N_q SURCHARGE term is mobilised — q_ult tracks c·N_c + q_o·N_q over a 20× q_o range	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[22] the load-settlement curve hardens monotonically to the collapse peak, and q_ult IS that peak	Pass
[23] plastic shear γ^p is mobilised under every frictional footing (the HS hardening state works)	Pass
[24] all runs mobilise a collapse plateau and return finite, physical numbers	Pass

limit-analysis-bearing-web-validation.test.ts

WEB-BENCHMARK validation for the FE limit-analysis bearing-capacity bracket.

Analyses validated: `limit-analysis-bearing` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
LA web A1–A8: bracket contains exact Prandtl 5.14·cu across cu (25,50,100,10,200,75,150,90)	Pass
LA web A1: Nc_lower ≤ 5.14159 ≤ Nc_upper	Pass
LA web A9–A11: surcharge adds directly (Nq=1) — bracket contains 5.14·cu + q_s	Pass
LA web A12: c=0 ⇒ q_ult ≈ surcharge (best estimate = q_s)	Pass
LA web A13–A14: q_ult ∝ cu (linear in cohesion)	Pass
LA web A15–A16: q_ult independent of footing width B (weightless ϕ=0)	Pass
LA web A18/A24: best estimate (mean of bounds) is within the guaranteed error of exact	Pass
LA web A19: bracket width % is finite and the bounds are ordered	Pass
LA web A23: refined mesh keeps a valid bracket containing Prandtl	Pass
LA web: bound convergence closes toward exact 2+π as the mesh refines	Pass
LA web: lower-bound stress field emitted (compression under the footing)	Pass

plate-load-is1888-web-validation.test.ts

plate-load — the IS 1888 / Terzaghi-Peck / Housel paths against PUBLISHED values (deep review D10, 2026-10-01).

Analyses validated: `plate-load` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[CB] Cl 5.3 forward scaling: 12 mm on a 750 mm plate → 17.78 mm under a 2 m footing	Pass
[SV] Cl 5.3 inverse: a 25 mm footing (1.5 m) corresponds to 16 mm on a 600 mm plate; ≈ 290 kPa there	Pass
[DS] clay: S_f = S_p·B/B_p (Das §7.12) and the footing ultimate equals the plate's (Eq. 7.73)	Pass
[ER][SV] sand: footing ultimate = plate ultimate × B/B_p (Das Eq. 7.74, Bowles Eq. 4-21)	Pass
[NIRM] PLT-1: IS 1888 Cl 5.2 log-log yield ≈ 60.17 T/m² (Table 4.7)	Pass
[NIRM] PLT-2: IS 1888 Cl 5.2 log-log yield ≈ 75.02 T/m² (Table 4.7)	Pass
[NIRM] PLT-3: IS 1888 Cl 5.2 log-log yield ≈ 70.33 T/m² (Table 4.7)	Pass
[NIRM] PLT-4: IS 1888 Cl 5.2 log-log yield ≈ 65.02 T/m² (Table 4.7)	Pass
[SV][CB] arithmetic-tangent readings (335, 500 kPa) — the IS 1888 log-log value is lower, within 12 %	Pass
a test that never yielded reports a LOWER BOUND and says so	Pass
[BW] Bowles §4-12.2 Housel: q_1 50.83 kPa, q_2 11.17 kN/m, 3 × 3 m base 591.5 kN	Pass
[ER] Housel, circular plates: s = 46.13 kN/m, q = 93.48 kN/m², 1.2 m footing Q = 279.6 kN	Pass
Housel refuses one plate, or two plates of the same perimeter/area ratio	Pass
negative or non-finite readings are refused; a repeated pressure keeps its largest settlement	Pass
the settlement-controlled pressure discloses a clamp when the test stopped short of it	Pass

plate-load-web-validation.test.ts

`plate-load` — the ASTM D1195 / D1196 (US, and via DIN 18134 European) path.

Analyses validated: `plate-load` · Recorded run: passed — 16 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
ASTM D1195 App. X1: the normal equations recover a0, a1, a2 of a known parabola exactly	Pass
ASTM D1195 §12.2.4: the FIRST stage of the first cycle is excluded from its fit	Pass
ASTM D1195 §12.2.5: the first stage of the SECOND cycle IS included in its fit	Pass
ASTM D1195 §12.2.8 Eq. (3): Ev = 1.5·r·1/(a1 + a2·σ0max), evaluated by hand	Pass
ASTM D1195 App. X1.2: Eq. (3) equals the 0.3-0.7·σ0max SECANT on the fitted parabola	Pass
ASTM D1195 §12.2.9: Ev2 uses the SECOND cycle curve but the FIRST cycle σ0max	Pass
ASTM D1195 Tables 1 and 2: the published load stages are accepted as given	Pass
ASTM D1195 §11.2.2: fewer than six first-cycle stages is warned, not silently accepted	Pass
ASTM D1195 §11.2.5 / §11.2.6: the per-plate stress and settlement limits are checked	Pass
ASTM D1196 §12.3 Eq. (2) and IS 9214 Cl 2.3 are the SAME formula — one implementation serves both	Pass
E-42: K is disclosed as a LOWER BOUND when the test never reached 1.25 mm	Pass
ASTM D1196 §12.3 NOTE 2: a plate other than 762 mm is flagged for road/airfield K	Pass
a fit that cannot be determined is refused rather than reported as zero	Pass
no first-cycle data is an ERROR — σ0max is undefined without it	Pass
a reload softer than the first cycle is flagged as physically suspect	Pass
every numeric output is finite, and the governing clauses are cited	Pass

⚑ punching-shear-web-validation.test.ts

Two-way (punching) shear of a footing or pile cap, IS 456:2000 Cl 31.6.3 (`punching-shear.ts`) vs PUBLISHED worked examples.

Analyses validated: `punching-shear` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NPTEL Problem 2 — 400 × 400 column, 2.6 × 2.6 m footing, d = 536 mm, M20, factored pressure 0.333 N/mm²	Pass
NPTEL Problem 3 — 400 × 400 column, 3.4 × 3.4 m footing, d = 596 mm, M20, factored pressure 0.18166 N/mm²	Pass
NPTEL Problem 4 — 300 × 450 column, 2.7 × 2.85 m footing, d = 600 mm, M25, average pressure 242.105 kN/m²	Pass
NPTEL Problem 5 — combined footing, interior column C2 300 × 500, d = 666 mm, M20, pressure 250 kN/m²	Pass
NPTEL Q.1/A.1 — 300 × 500 column, 5 × 3 m footing, d = 1091 mm, M20, factored pressure 300 kN/m²	Pass
NPTEL TQ.1 — 450 × 300 column, 2.7 × 2.64 m footing, d = 547 mm, M25, uniform pressure 227.27 kN/m²	Pass
Mittal (2025) pile-cap example — four piles, 570 kN equivalent axial load each, d = 740 mm, M25	Pass
Bowles Example 8-2 — 0.35 m column, 2 × 2 m footing, Pu = 1.4(350) + 1.7(450) = 1255 kN: d = 0.32 m at vc = 1.30 MPa	Pass
Bowles Example 8-9 — 0.50 × 0.40 m column, Pcol = 2480 kN, d = 501.73 mm: vc = 1298.40 kPa	Pass
Bowles Example 8-10 — 0.50 × 0.50 m column, Pcol = 2480 kN, d = 484.86 mm: vc = 1298.40 kPa	Pass
Bowles Example 8-8 — 0.45 m square column, Pu = 3291.4 kN, d = 0.66 m	Pass
IS 456 Cl 31.6.3.1 — ks = 0.5 + βc capped at 1, τc = 0.25√fck (clause-rule checks, not worked answers)	Pass

raft-sizing-published-web-validation.test.ts

raft-sizing — deep review D12 (2026-10-02).

Analyses validated: `raft-sizing` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[Das Ex 8.5] 20 × 30 m mat, Q 110 MN, Df 1.5 m — gross 183.3, net 156.3 kPa, FS 5.36	Pass
[Das Ex 8.6] 30 × 40 m mat, Q 200 MN, γ 15.72, Df 2 m — net load per unit area 135.2 kPa	Pass
[Das Ex 8.7 / IS 2950 App D] 20.5 × 27.5 m mat with My 8 373 and Mx 1 616 kN·m — corner pressures	Pass
[SV] Fully compensated depth Df = (Q/A)/γ = 75/18 = 4.167 m	Pass
[SV] Partially compensated: at the published Df = 0.821 m the FS-3 net pressure is exactly used up	Pass
[MCL] Minimum square under P = 864 kN and M = 100 kN·m with q_allow 175 kPa — B = 2.51 m	Pass
[MCL] Adopted B = 2.6 m → q_max = 161.946 kPa	Pass
[CGT] Biaxial: P 400, 12 × 10, e_L 0.30, e_B 0.20 — kern 0.27, corners 4.233 / 3.433 / 3.233 / 2.433, U = 0.847	Pass
[IS 2950 App D NOTE / Das Eq. 4.49] one-way partial contact satisfies equilibrium	Pass
[IS 2950 Cl 4.3] a raft shallower than 1 m is flagged	Pass
D12 — a raft with self-weight grows to the exact minimum where (P + γc·t·A)/A − γDf = SBC	Pass

raft-sizing-web-validation.test.ts

Web-benchmark validation for `raft-sizing`.

Analyses validated: `raft-sizing` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
gross / net loading and utilisation follow the IS 2950 definitions	Pass
overburden relief is floored at zero and never makes net loading negative	Pass
an overloaded raft grows until net loading meets SBC	Pass
a site area cap is honoured and reported rather than silently exceeded	Pass
q_max / q_min follow Bowles (P/A)(1 ± 6e_L/L ± 6e_B/B)	Pass
the kern limit is e = L/6 exactly, and beyond it uplift is reported	Pass
biaxial eccentricity superposes both kern terms	Pass
invalid inputs are refused with a zeroed geometry, not a plausible raft	Pass
every result carries its governing standard	Pass

raft-winkler-web-validation.test.ts

Web-benchmark validation for `raft-winkler` — rigid, Winkler-FEM and Vesić-equivalent raft analysis.

Analyses validated: `raft-winkler` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
flexural rigidity is D = E·t³/[12(1 − ν²)] (Kirchhoff)	Pass
a missing ks is correlated as q_safe/s_allow (Bowles 5e Eq 9-6a)	Pass
a concentrically loaded rigid raft settles uniformly at s = q/ks (Winkler)	Pass
a central point load on a rigid raft gives the same uniform pressure as its UDL	Pass
an eccentric load produces the linear pressure distribution and can cause uplift	Pass
rigid strip actions follow ACI 336.2R §3.3.2	Pass
the Winkler FEM reproduces w = q/ks for a uniformly loaded raft	Pass
a stiffer plate spreads a point load further — the physical signature of the FEM	Pass
the Vesić biot_plate branch derives ks from Es and differs from the supplied-ks run	Pass
a load outside the footprint is excluded and said so, not silently absorbed	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
invalid geometry and serviceability limits are both handled	Pass

rigid-base-pressure-web-validation.test.ts

Rigid rectangular base on a tensionless subgrade — biaxial partial contact (2026-10-03).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[FULL] inside the kern it is the linear formula (civilgeotools worked example, ksf)	Pass
[DAS] one-way partial contact L 10, B 6, e 2.5: q_max 4P/3B(L−2e), contact 3(L/2−e)	Pass
[DAS] one-way partial contact L 8, B 8, e 2: q_max 4P/3B(L−2e), contact 3(L/2−e)	Pass
[DAS] one-way partial contact L 20, B 12, e 4: q_max 4P/3B(L−2e), contact 3(L/2−e)	Pass
[BB-A] corner triangle e_x/L 0.3, e_y/B 0.3: q_max = (P/BL)·3/(8(½−e_x/L)(½−e_y/B))	Pass
[BB-A] corner triangle e_x/L 0.35, e_y/B 0.25: q_max = (P/BL)·3/(8(½−e_x/L)(½−e_y/B))	Pass
[BB-A] corner triangle e_x/L 0.4, e_y/B 0.4: q_max = (P/BL)·3/(8(½−e_x/L)(½−e_y/B))	Pass
[BB-D] trapezoid e_x/L 0.02, e_y/B 0.3 (y-dominant) and its mirror	Pass
[BB-D] trapezoid e_x/L 0.05, e_y/B 0.33 (y-dominant) and its mirror	Pass
pentagon zone (one corner lifted) satisfies equilibrium and is continuous with the kern	Pass
refusals: resultant outside the base, non-positive load	Pass

seismic-bearing-capacity-ec8-web-validation.test.ts

EN 1998-5:2004 ANNEX F seismic bearing capacity — web-validation benchmark.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 17 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Table F.1 — all 14 numerical parameters, both soil types	Pass
Table F.2 — model partial factor γ_Rd, cross-checked against Pecker Table 4.8.1	Pass
F.3 and F.6 — N_max closed forms	Pass
F.4 and F.7 — the dimensionless soil inertia force F̄	Pass
Pecker §4.8.1.3 — 6 published intermediates and the published LHS = −0.999	Pass
Pecker §4.8.1.3 — (F.1) reproduces −0.999 from the text's OWN rounded values	Pass
the F̄ strength-basis ambiguity is exactly γ_M, and immaterial in this example	Pass
the utilisation is U-SHAPED in N̄ — a footing can fail for too LITTLE axial load	Pass
the F.5 / F.8 constraints are refusals, not warnings	Pass
the two F.5 permissions are opt-in, and the cohesionless one is CONDITIONAL	Pass
the Table F.2 row must match the soil idealisation	Pass
Annex F declares itself INFORMATIVE and reports a utilisation, not a safety factor	Pass
Annex E — (E.3) is exactly (E.2) with the bracket dropped, so a clamped radical reproduces it	Pass
Annex E — the branch switch is continuous at β = φ′_d − θ	Pass
Annex E — K rises with kh, with backfill slope, and the passive branch differs from the active	Pass
Annex E — (E.1) total design force, and (E.17) hydrodynamic force	Pass
Annex E — design angles φ′_d and δ_d divide the TANGENT, not the angle	Pass

⚑ subgrade-reaction-web-validation.test.ts

PUBLISHED-VALUES: 14 -- distinct published values for this engine (engine-level total, declared once); independent audit A3: about 14 distinct published values (the Baban table is a copy of Bowles).

Analyses validated: `subgrade-reaction` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bowles (1997) Eq. 9-9 — k_s = 40·SF·q_a in Bowles's own worked examples	Pass
Bowles (1997) Example 10-2 and the 25.4 mm / 12 mm / 20 mm factors of Eq. 9-9	Pass
Baban (2016) Eq. 5.44 and Varghese (2005) Table 1.8 note — same rule, stated as a coefficient	Pass
Bowles (1997) Table 9-1 / Baban (2016) Table 5.3 — engine results fall in the published clayey-soil ranges	Pass
Bowles (1997) Example 9-5 / Baban (2016) Eq. 5.42 / Das (2016) Eq. 8.50 — Vesic reduced form Es/(B(1−μ²))	Pass

t6-limit-load-web-validation.test.ts

WEB-VALIDATION for the T6 element-accuracy / limit-load engine (`t6-limit-load.ts`).

Analyses validated: `t6-limit-load` · Recorded run: passed — 26 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
A1 — no engine errors; a distorted patch mesh with Gauss points was built	Pass
A2 — CONSTANT-strain patch: T6 reproduces εxx=g to ~machine zero on a distorted mesh	Pass
A3 — LINEAR-stress (pure-bending) patch: T6 reproduces the linear σxx field exactly	Pass
A4 — CST CANNOT reproduce the linear stress field (error is order-unity kPa)	Pass
A5 — T6 beats CST on the linear field by ≥6 orders of magnitude (the LST advantage)	Pass
A6 — patch test PASSES (both T6 errors within tolerance) — element is valid	Pass
B1 — exact tip deflection uses κ = M(1−ν²)/(E·I), I = D³/12 (plane strain)	Pass
B2 — T6 reproduces pure-bending tip deflection to <1e-3% error (essentially exact)	Pass
B3 — T6 tip deflection matches the analytical δ (finest mesh)	Pass
B4 — CST is far too stiff: its tip-deflection error is orders larger than T6	Pass
B5 — T6 is exact at EVERY mesh level; CST error only decreases with refinement	Pass
B6 — the coarsest CST mesh is grossly too stiff (>25% deflection error)	Pass
B7 — T6 mesh has more nodes than the base CST mesh (mid-side enrichment)	Pass
C1 — T6 element stiffness is symmetric ($K^T = K$)	Pass
C2 — exactly 3 plane rigid-body modes carry zero energy (2 translations + 1 rotation)	Pass
C3 — rigid-body motion produces ~zero nodal forces	Pass
C4 — the deformation stiffness is POSITIVE-DEFINITE (Cholesky pivots > 0)	Pass
D1 — reported Prandtl reference is exactly Nc = 2 + π = 5.14159	Pass
D2 — coarse displacement-FE bearing is finite, positive, and OVER-predicts Prandtl (locking overshoot)	Pass
D3 — bearing carries the honest not-converged limitation note	Pass
D4 — bearing is omitted by default (fast path) unless explicitly requested	Pass
E1 — pure-bending deflection is LINEAR in applied moment M (δ ∝ M)	Pass
E2 — deflection scales as L² (Euler-Bernoulli): δ(2L)/δ(L) = 4	Pass
E3 — near-incompressible ν=0.49: load-driven T6 bending stays exact while CST over-stiffens (Nagtegaal-Parks-Rice locking)	Pass
E4 — invalid inputs are guarded: E≤0 records an error, result shape stays well-formed	Pass
E5 — narrative notes are present and name the T6/CST contrast	Pass

two-layer-bearing-web-validation.test.ts

Two-layer bearing capacity, strong-over-weak punching mechanism (`two-layer-bearing.ts`, the Meyerhof-Hanna punching-block model) vs PUBLISHED values.

Analyses validated: `two-layer-bearing` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Example 5.4 — sand over soft clay, continuous footing	Pass
Baban Problem 4.23 — the same profile with the chart reading Ks = 3	Pass
Das Example 5.5 — adhesion term of the clay-over-clay punching block	Pass
Das Table 4.2 — top-layer Nc, Nq, Nγ	Pass
Das Table 4.2 — further top-layer rows (5° and 25°)	Pass
Das Table 4.2 — bottom-layer factors, including the ϕ = 0 clay	Pass
IS 6403:1981 Table 1 — the SAME factors as Das Table 4.2 (one source, not two; it reprints the Nc(45°) misprint)	Pass

well-foundation-web-validation.test.ts

Published-value validation for the well (caisson) foundation elastic-theory check (`well-foundation.ts`, `computeWellFoundation`).

Analyses validated: `well-foundation` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Varghese Example 20.3: base area A = π(8.5)²/4 = 56.72 m²	Pass
Varghese Example 20.3: Iv = L D³/12 = 2151 m⁴ (L = 0.9 d = 7.65 m) and IB = π d⁴/64 = 256 m⁴	Pass
Varghese Example 20.3: I = IB + m Iv (1 + 2μ′α) = 2,685.7 m⁴	Pass
Varghese Example 20.3 Eq. 20.11: r = I D/(2 m Iv) = 9.36 m	Pass
Varghese Example 20.3: P = M/r = 4,487 kN	Pass
Varghese Example 20.3 Eq. 20.16: base pressures σ1 = 284 and σ2 = 152 kN/m²	Pass
Varghese Example 20.3 Condition 3: m M/I = 15.6 kN/m³	Pass
Varghese Example 20.3: all four conditions satisfied (base friction, direction, elastic state, base pressure)	Pass
Varghese Example 20.1: at the limiting elastic state the side reaction is Pmax = γ(KP − KA) L D²/6 = 6,400 kN	Pass
Varghese Example 20.1: vertical load at the base W − μ′P = 15,000 − 2,560 = 12,440 kN → mean base pressure 12,440/40 = 311 kN/m²	Pass
Varghese Example 20.1: base pressures 809 kN/m² compression and 187 kN/m² tension at Hmax	Pass
Varghese Example 20.1: at Hmax, m M/I equals the limiting value γ(KP − KA) = 10 × 8/3 = 26.67 kN/m³	Pass

Settlement, stress distribution and consolidation

FE kernel registry — 23 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-verif-flexible-tank	settlement at the centre of the tank [mm]	PLAXIS-Verification-Flexible-tank-elastic-saturated.pdf, p. 2–3 (Output; Table 1)	74.21	74.44	74.207	−4.0e-3 %	−0.31 %	Pass
k4-gate-terzaghi	Terzaghi U(Tv): bottom excess p/p_ext at t = 2 d (Tv 0.2) [-]	PLAXIS-Verification-One-dimensional-consolidation.pdf, p. 2 (Fig. 2 caption), 4	0.7642	0.764	0.7642	0.00 %	+0.03 %	Pass
k4-gate-terzaghi-fully-coupled	fully coupled (total pore pressure) 1-D consolidation vs Terzaghi [-]	—	—	0.764	0.7642	—	+0.03 %	Pass
k4-gate-mandel-cryer	Mandel–Cryer: centre p/q peak (rise above the undrained value) [-]	Rocscience-RS2-Consolidation-Verification-Terzaghi-Biot-Cryer.pdf, p. 12–19 (§2)	—	0.53804	0.53737	—	−0.13 %	Pass
k4-gate-skempton-b	Skempton B under isotropic undrained (A) loading [-]	—	—	0.983278	0.983278	—	0.00 %	Pass
k4-gate-oedometric-p0	oedometric undrained initial excess p0/p_ext [-]	PLAXIS-Verification-One-dimensional-consolidation.pdf, p. 4	0.98	0.980198	0.980198	+0.02 %	0.00 %	Pass
k4-gate-unsaturated-column	unsaturated column: hydrostatic vG state is an equilibrium of the fully coupled phase [kPa]	—	—	0	0	—	—	Pass
k4-gate-undrained-b-su	Undrained (B): max shear stress at failure = su [kPa]	—	—	20	20	—	0.00 %	Pass
plaxis-verif-undrained-coarse-ev	case 2 (Hypres coarse, unsaturated): volumetric strain [-]	PLAXIS-Verification-Undrained-soil-behaviour.pdf, p. 7–8 (Table 3)	-0.009963	-0.009925	-0.0099562	−0.07 %	+0.31 %	Pass
plaxis-verif-undrained-coarse-sv	case 2: effective vertical stress at the top point [kPa]	PLAXIS-Verification-Undrained-soil-behaviour.pdf, p. 7–8 (Table 3)	-15.751	-15.744	-15.7481	−0.02 %	+0.03 %	Pass
plaxis-verif-undrained-fine-ev	case 3 (Hypres fine): volumetric strain [-]	PLAXIS-Verification-Undrained-soil-behaviour.pdf, p. 7–8 (Table 4)	-0.009823	-0.009787	-0.0098162	−0.07 %	+0.30 %	Pass
plaxis-verif-undrained-fine-sv	case 3: effective vertical stress [kPa]	PLAXIS-Verification-Undrained-soil-behaviour.pdf, p. 7–8 (Table 4)	-18.419	-18.413	-18.4154	−0.02 %	+0.01 %	Pass
plaxis-verif-bishop-sv-bottom	Bishop σ′v at the column bottom (10 kPa uniform suction, χ = Se) [kPa]	PLAXIS-Verification-Bishop-effective-stress.pdf, p. 4–5	-43.264	-43.2625	-43.2625	−3.0e-3 %	0.00 %	Pass
plaxis-verif-biot-borehole	borehole wall radial displacement (Biot α < 1) [mm]	PLAXIS-Verification-Biot-poroelasticity.pdf, p. 2–4	—	-3.5022	-3.5022	—	0.00 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`plaxis-verif-flexible-tank-k4-undrained-c`	centre settlement, Undrained (C) (total stress Eu, νu) through the K4 drainage types [mm]	PLAXIS-Verification-Flexible-tank-elastic-saturated.pdf, p. 2–3 (Table 1)	74.21	74.44	74.207	−4.0e-3 %	−0.31 %	Pass
`k4-crosscheck-consolidation-biot` self-check	consolidation-biot (TS oracle) column: settlement degree U at Tv 0.848 [-]	—	—	0.90003	0.89904	—	−0.11 %	Pass
`k5b-plaxis-2d-tut9-consolidation-time`	Tutorial 9 (Soft Soil undrained A + HS, 4 consolidation phases): time to p_excess < 1 kPa, plus settlements / excess pore pressures per phase [day, mm, kPa]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 145–160 (p. 159: 'more than 50 days are needed to reach full consolidation'; Figs 9-13…9-17 figures only)	> 50 d	—	t at p_excess < 1 kPa (d): 38.69; settlement (0,0) mm P1/P2/P3/P4: [261.4, 664.5, 829.5, 1033.7]; max p_excess kPa P1/P2/P3/P4: [26.6, 0.02, 28.76, 0.53]; toe (20,0) ux mm P4: 199.8; steps P1..P4: [280, 458, 20, 27]	—	—	Superseded
`k5d-plaxis-2d-tut9-ck`	Tutorial 9 with the change of permeability c_k (Table 9-1): time to p_excess < 1 kPa; settlements per phase; Safety phases 5–8 [day, mm, -]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 145–163 (p. 159: 'more than 50 days are needed to reach full consolidation'; p. 164 'settles about one meter'; Fig. 9-21 ΣMsf curves without values)	> 50 d; ≈ 1 m	—	t at p_excess < 1 kPa (d): 58.19; settlement (0,0) mm P1/P2/P3/P4: [199.9, 659.7, 746.1, 1031.5]; max p_excess kPa P1/P2/P3/P4: [27.56, 0.88, 33.24, 0.85]; toe (20,0) ux mm P4: 240; Safety ΣMsf from P1/P2/P3/P4 (phases 5–8): [1.0471, 1.8063, 1.1531, 1.4797]; steps P1..P4: [306, 151, 28, 101]	—	—	Pass
`v-rm-degree-of-consolidation-capped-step`	time at which the phase stops, U = 50/90/99 % (step capped at 0.005 d) vs Terzaghi t* [day]	PLAXIS-2D-2025.1-Reference-Manual-Seequent-Bentley.pdf, p. p. 328 (§7.5.3, Eq. 7-15); PLAXIS-Verification-One-dimensional-consolidation.pdf pp. 1–4	—	[3.864, 10.5194, 20.0399]	[3.8692, 10.5293, 20.0545]	—	[0.13, 0.09, 0.07]	Pass
`v-rm-min-excess-capped-step`	stop time for |P-stop| = 0.30 and 0.05 kPa (step capped 0.005 d) vs Terzaghi t* [day]	PLAXIS-2D-2025.1-Reference-Manual-Seequent-Bentley.pdf, p. p. 328 (§7.5.2)	—	[5.8942, 13.3026]	[5.8993, 13.3144]	—	[0.09, 0.09]	Pass
`v-rm-consolidation-stop-default-stepping`	stop time with the DEFAULT step control: P-stop 0.30 / U 50 % / U 90 % [day]	PLAXIS-2D-2025.1-Reference-Manual-Seequent-Bentley.pdf, p. p. 328 (§7.5.2–7.5.3)	—	[5.8942, 3.864, 10.5194]	[5.9194, 3.8771, 10.5903]	—	[0.43, 0.34, 0.67]	Pass
`v-rm-drain-at-level-terzaghi`	base excess pressure at t = 2 d, top drained by a DRAIN line (head = level) [kPa]	PLAXIS-Verification-One-dimensional-consolidation.pdf, p. pp. 1–4 (Fig. 2 caption); RM p. 134 (§5.9.2)	0.7642	0.764	0.7642	−2.0e-3 %	+0.03 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`v-rm-drain-head-ignored-in-consolidation`	drain with head 0.2 m (level 1 m) in a consolidation phase: worst |p − Terzaghi| [kPa]	PLAXIS-2D-2025.1-Reference-Manual-Seequent-Bentley.pdf, p. p. 134 (§5.9.2)	—	0	0.00115	—	—	Pass

Cited validation suites — 39

asaoka-web-validation.test.ts

Validation of the Asaoka observational settlement forecast (`asaoka.ts`) against the PUBLISHED method.

Analyses validated: `asaoka` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Asaoka Eq. (23): a record generated by Eq. (24) returns ρf = β0/(1 − β1)	Pass
Asaoka Eq. (21): the regression slope is β1 and the intercept is β0 = ρf(1 − β1)	Pass
Asaoka Eq. (23) with the Kobe Port No. 3 posterior modes (β1 = 0.9791, β0 = 6.94 cm, Fig. 6): ρf = 332 cm	Pass
Han Eq. 7.63 / CEDD C4: cv = −4·hdr²·ln β1/(π²·Δt) for β1 = 0.8, hdr = 3 m, Δt = 30 days	Pass
CEDD C3/C4 inverted: a Terzaghi-exponent record β1 = exp(−π²·cv·Δt/(4·H²)) gives back the cv that made it	Pass
Asaoka 1978 Eq. (26) is NOT what the engine uses: for upward drainage ln β1 = −π²cv·Δt/(4H²), not −2cv·Δt/H²	Pass
Asaoka Eq. (24): degree of consolidation and remaining settlement at the last reading	Pass

burland-burbidge-web-validation.test.ts

PUBLISHED-VALUES: 16 -- distinct published values for this engine (engine-level total, declared once); independent audit A3: about 16 distinct published values.

Analyses validated: `burland-burbidge` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Craig (2012) Example 8.9 — compressibility index Ic = 1.71/N^1.4 at N = 10, 9, 8	Pass
Craig (2012) Example 8.9 — settlement coefficient and the three converged widths give 25 mm	Pass
Craig (2012) Fig 8.31 read in Example 8.9 — depth of influence z_I against B	Pass
Craig (2012) Eq 8.68 text — creep factor Ft after 30 years, static vs variable loading	Pass
Das (2016) Example 7.6 — 1.75 m square, N60 = 10, q = 120 kPa, normally consolidated	Pass
Das (2016) Table 7.7 — over-consolidated branches use 1/3 of the normally consolidated compressibility	Pass
Baban (2016) Problem 3.7 — 7.5 × 8.5 m pier base on dense sand and gravel, N = 40	Pass
Viana da Fonseca (2012) Eq 8.3 — coefficient 1.71 and influence depth B^0.75	Pass
Craig (2012) Eqs 8.64, 8.66, 8.67 — N correction, shape factor, thin-layer factor (equation form)	Pass

⚑ circular-load-stress-web-validation.test.ts

circular-load-stress — dedicated web-benchmark against PUBLISHED values.

Analyses validated: `circular-load-stress` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das (2016) Table 6.1, r/(B/2) = 0 column — Δσ/q against z/(B/2), fourteen published values	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Varghese (2005) Table 3.3 and Bowles (1997) §5-3 — the Newmark r/z ↔ σz/q pairs	Pass
Das (2016) Example 6.6 — B = 2 m circular area, q = 150 kPa, at z = 1, 3.5 and 6 m	Pass
Holtz & Kovacs (1981) Example 8.20 — 3.91 m diameter tank, 117 kPa, z = 2 m under the centre	Pass

collapse-potential-web-validation.test.ts

Validation for `collapse-potential` — single-oedometer collapse potential I_c = Δh/h0 = Δe/(1+e0), ASTM D5333 severity and Jennings & Knight foundation-risk bands (`collapse-potential.ts`, `computeCollapsePotential`).

Analyses validated: `collapse-potential` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
ASTM D5333 Table 1: 0 none; 0.1–2.0 slight	Pass
ASTM D5333 Table 1: 2.1–6.0 moderate; 6.1–10.0 moderately severe; > 10.0 severe	Pass
Jennings & Knight (1975): 0–1 no problem; 1–5 moderate trouble; 5–10 trouble	Pass
Jennings & Knight (1975): 10–20 severe trouble; > 20 very severe trouble	Pass
Structville (2020) worked example: Δe_c = 0.04, e0 = 0.64, H = 4 m ⇒ collapse settlement S2 = 0.0975 m	Pass

compression-index-web-validation.test.ts

Validation of the compression / recompression index estimator (`compression-index.ts`) against the published correlations and the published WORKED ANSWERS that use them.

Analyses validated: `compression-index` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bowles Example 5-14: wL = 78 % ⇒ Terzaghi–Peck Cc = 0.009(78 − 10) = 0.612	Pass
Bowles Example 5-15: wL = 50 % ⇒ Terzaghi–Peck Cc = 0.36	Pass
Varghese Example 4.7: LL = 40 % ⇒ Cc = 0.009 × 30 = 0.27	Pass
Varghese Example 4.11: LL = 65.5 % ⇒ Cc = 0.009 × 55.5 = 0.50	Pass
Lambe & Whitman Ch. 22 / Bowles Table 2-5: undisturbed Cc = 0.009(LL − 10) and remoulded Cc = 0.007(LL − 10) at LL = 60	Pass
IS 8009 (Part 1) Eq. (8) / FHWA Table 5-5: Hough Cc = 0.30(e0 − 0.27) at e0 = 1.0	Pass
Das Eq. 2.56 / Bowles Table 2-5: Nagaraj & Murthy Cc = 0.2343(LL/100)·Gs and Cr = 0.000463·wL·Gs at wL = 60, Gs = 2.7	Pass
IS 8009 (Part 1) Eq. (7): the IS correlation equals the Terzaghi–Peck one at LL = 35 % (0.225)	Pass

consolidation-biot-web-validation.test.ts

Web-benchmark validation for the COUPLED BIOT consolidation FE (`consolidation-biot.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 33 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Eoed = E(1−ν)/[(1+ν)(1−2ν)] — constrained modulus	Pass
cv = (k/γw)·Eoed	Pass
final settlement s∞ = σ·H/Eoed	Pass
U_settlement(Tv=0.05) reproduces terzaghiUavg	Pass
U_settlement(Tv=0.1) reproduces terzaghiUavg	Pass
U_settlement(Tv=0.2) reproduces terzaghiUavg	Pass
U_settlement(Tv=0.3) reproduces terzaghiUavg	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
U_settlement(Tv=0.5) reproduces terzaghiUavg	Pass
U_settlement(Tv=0.848) reproduces terzaghiUavg	Pass
U_pressure(Tv=0.2) reproduces terzaghiUavg	Pass
U_pressure(Tv=0.5) reproduces terzaghiUavg	Pass
U_pressure(Tv=0.848) reproduces terzaghiUavg	Pass
standard table: U(Tv=0.008) ≈ 0.1 (Das/Terzaghi)	Pass
standard table: U(Tv=0.031) ≈ 0.2 (Das/Terzaghi)	Pass
standard table: U(Tv=0.071) ≈ 0.3 (Das/Terzaghi)	Pass
standard table: U(Tv=0.126) ≈ 0.4 (Das/Terzaghi)	Pass
standard table: U(Tv=0.197) ≈ 0.5 (Das/Terzaghi)	Pass
standard table: U(Tv=0.287) ≈ 0.6 (Das/Terzaghi)	Pass
standard table: U(Tv=0.403) ≈ 0.7 (Das/Terzaghi)	Pass
standard table: U(Tv=0.567) ≈ 0.8 (Das/Terzaghi)	Pass
standard table: U(Tv=0.848) ≈ 0.9 (Das/Terzaghi)	Pass
standard table: U(Tv=1.129) ≈ 0.95 (Das/Terzaghi)	Pass
isochrone u_e/u_0 at (Z≈0.333, Tv=0.2) reproduces Terzaghi	Pass
isochrone u_e/u_0 at (Z≈0.500, Tv=0.2) reproduces Terzaghi	Pass
isochrone u_e/u_0 at (Z≈1.000, Tv=0.2) reproduces Terzaghi	Pass
isochrone u_e/u_0 at (Z≈0.500, Tv=0.5) reproduces Terzaghi	Pass
isochrone u_e/u_0 at (Z≈1.000, Tv=0.5) reproduces Terzaghi	Pass
isochrone u_e/u_0 at (Z≈1.000, Tv=0.848) reproduces Terzaghi	Pass
drained face u_e=0; peak at the impermeable base; monotone with depth	Pass
double drainage: Hdr = H/2 and cv unchanged	Pass
double drainage U_settlement(Tv=0.2) reproduces terzaghiUavg	Pass
double drainage U_settlement(Tv=0.5) reproduces terzaghiUavg	Pass
U_settlement ≈ U_pressure (the 1-D Terzaghi identity)	Pass

⚑ consolidation-degree-web-validation.test.ts

Validation for `consolidation-degree` — the Terzaghi U ↔ T_v relationship (`consolidation-degree.ts`).

Analyses validated: `consolidation-degree` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA Table 7-4: Tv required for U = 10…98 %	Pass
FHWA Table 7-4: U reached at the tabulated Tv	Pass
Das Table 2.11 entries (Tv printed to 3 s.f.)	Pass
Das Example 2.12: U = 40/87.5 = 45.7 % needs Tv = 0.164; field time 45,523 min (31.6 days)	Pass
FHWA Example 7-3: t90 = Tv·Hd²/cv = 0.848·10²/0.2 = 424 days	Pass
Craig Example 4.7: Tv = 4.7·0.5/10² = 0.0235 ⇒ Uv = 0.17	Pass

consolidation-family-web-validation.test.ts

consolidation-family-web-validation.test.ts

Analyses validated: `consolidation-3d`, `coupled-consolidation`, `footing-bearing-3d` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Terzaghi U(T_v) reproduces the published table, both directions (10 anchors)	Pass
Terzaghi U and T_v are exact inverses, and the small-U branch follows (π/4)U²	Pass
coupled-consolidation: E_oed, c_v and H_dr from the closed forms (6 anchors)	Pass
coupled-consolidation: final settlement is the confined 1-D value q·H/E_oed	Pass
coupled-consolidation: t_{50} and t_{90} match Terzaghi T_v·H_dr²/c_v, and U ends consistent (6 anchors)	Pass
consolidation-3d: the oedometer and Boussinesq comparisons it prints are the textbook values (7 anchors)	Pass
consolidation-3d: the Q2–Q1 pair reports more displacement DOF than pressure DOF	Pass
footing-bearing-3d: shape factors follow Vesić/Meyerhof, and Skempton for a square (11 anchors)	Pass

consolidation-terzaghi-web-validation.test.ts

Validation for the Terzaghi consolidation series (`consolidation-terzaghi.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
U_avg(Tv=0.002) ≈ 0.05 (standard table)	Pass
U_avg(Tv=0.008) ≈ 0.1 (standard table)	Pass
U_avg(Tv=0.031) ≈ 0.2 (standard table)	Pass
U_avg(Tv=0.071) ≈ 0.3 (standard table)	Pass
U_avg(Tv=0.126) ≈ 0.4 (standard table)	Pass
U_avg(Tv=0.197) ≈ 0.5 (standard table)	Pass
U_avg(Tv=0.286) ≈ 0.6 (standard table)	Pass
U_avg(Tv=0.403) ≈ 0.7 (standard table)	Pass
U_avg(Tv=0.567) ≈ 0.8 (standard table)	Pass
U_avg(Tv=0.848) ≈ 0.9 (standard table)	Pass
boundary values: U(0)=0, U(large)→1	Pass
small-time approximation √(4Tv/π) matches the series for U<0.5	Pass
pore-pressure isochrone: full u0 at t=0, drained face (Z=0) → 0	Pass
Casagrande Tv(U) closed form matches the series-implied Tv	Pass

⚑ consolidation-time-rate-web-validation.test.ts

Web-benchmark validation for `consolidation-time-rate` — Terzaghi 1-D consolidation.

Analyses validated: `consolidation-time-rate` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Tv matches all nine published Uav–Tv pairs (TPM 1996 §16)	Pass
U(Tv) inverts the published table at every point	Pass
T50 and T90 meet the values the module advertises	Pass
E-89: the hand approximation deviates from the table where measured	Pass
E-89: Tv is smooth through U=60% (no branch step)	Pass
double drainage quarters the time (Hdr = H/2)	Pass
worked case: t90 = T90·Hdr²/Cv	Pass
settlement at the target degree is U × ultimate	Pass

coupled-consolidation-web-validation.test.ts

Validation of the COUPLED CONSOLIDATION analysis (Biot u–p finite-element column, `consolidation-biot.ts`: `biotColumn` and the runner wrapper `computeBiotColumnConfig`) against PUBLISHED consolidation tables and worked examples.

Analyses validated: `coupled-consolidation` · Recorded run: passed — 26 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the FE run completed without a time-step warning	Pass
FHWA Table 7-4: Tv = 0.031 ⇒ U = 20 %	Pass
FHWA Table 7-4: Tv = 0.071 ⇒ U = 30 %	Pass
FHWA Table 7-4: Tv = 0.126 ⇒ U = 40 %	Pass
FHWA Table 7-4: Tv = 0.197 ⇒ U = 50 %	Pass
FHWA Table 7-4: Tv = 0.287 ⇒ U = 60 %	Pass
FHWA Table 7-4: Tv = 0.403 ⇒ U = 70 %	Pass
FHWA Table 7-4: Tv = 0.567 ⇒ U = 80 %	Pass
FHWA Table 7-4: Tv = 0.848 ⇒ U = 90 %	Pass
FHWA Table 7-4: Tv = 1.000 ⇒ U = 93.1 %	Pass
FHWA Table 7-4: Tv = 1.500 ⇒ U = 98.0 %	Pass
FHWA Table 7-4: Tv = 2.000 ⇒ U = 99.4 %	Pass
FHWA Table 7-4 (pore-pressure definition): Tv = 0.197 ⇒ U = 50 %	Pass
FHWA Table 7-4 (pore-pressure definition): Tv = 0.403 ⇒ U = 70 %	Pass
FHWA Table 7-4 (pore-pressure definition): Tv = 0.848 ⇒ U = 90 %	Pass
Das Table 2.11: Tv = 0.159 ⇒ U = 45 %	Pass
Das Table 2.11: Tv = 0.477 ⇒ U = 75 %	Pass
Das Table 2.11: Tv = 0.684 ⇒ U = 85 %	Pass
Das Table 2.11: Tv = 1.129 ⇒ U = 95 %	Pass
Das Table 2.11: Tv = 1.781 ⇒ U = 99 %	Pass
FHWA Example 7-3: t90 = 424 days (single drainage, Hd = 10 ft, cv = 0.2 ft²/day)	Pass
Craig Example 4.2: upper clay (mv = 0.35 m²/MN, Δσ′ = 82 kPa, H = 3 m) settles 86.1 mm	Pass
Craig Example 4.2: lower clay (mv = 0.13 m²/MN, Δσ′ = 77 kPa, H = 3 m) settles 30.0 mm	Pass
Craig Example 4.7: mv = 0.25 m²/MN, Δσ′ = 65 kPa, H = 10 m gives a final settlement of 162 mm	Pass
Das Example 2.13: k = 1.303e-7 m/min with mv = 0.00108 m²/kN gives cv = 1.23e-5 m²/min	Pass
Das Example 2.12 (lab specimen): 25.4 mm double-drained, cv = 7.061 mm²/min ⇒ t50 = 4.5 min	Pass

cv-oedometer-web-validation.test.ts

Web-benchmark validation for `cv-oedometer` — coefficient of consolidation from an oedometer time–compression curve.

Analyses validated: `cv-oedometer` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[IS 2720-15 §6.1.2.4] the log-time time factor is 0.197	Pass
[IS 2720-15 §6.1.1.5] the root-time time factor is 0.848	Pass
[Craig 4.3] log-time method reproduces the published c_v = 0.45 m²/year	Pass
[Craig 4.3] root-time method reproduces the published c_v = 0.46 m²/year	Pass
[Craig 4.3 + IS 2720-15] the drainage path is HALF the specimen thickness	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[Craig 4.3] the two methods agree on the same specimen to within 1.3%	Pass
[Craig 4.3] permeability from c_v·m_v·γw reproduces k = 1.0e-10 m/s	Pass
k is null, not zero, when m_v is not supplied	Pass
c_v scales with the square of the drainage path, per the closed form	Pass
a cleared fitting time is refused rather than producing a huge c_v	Pass
an oedometer drainage path in metres is flagged as a units error	Pass

differential-settlement-ec7-web-validation.test.ts

Differential settlement — the **EUROPEAN** check, validated against **EN 1997-1:2004 Annex H**, *"Limiting values of structural deformation and foundation movement"*.

Analyses validated: `differential-settlement` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EN 1997-1 Annex H (2) — the published rotation range 1/2000 … 1/300, with 1/500 the general value	Pass
EN 1997-1 Annex H (3) — hogging HALVES the acceptable ratio	Pass
the Annex H check applied end to end, at the published thresholds	Pass
Annex H is reported as INFORMATIVE guidance, not as a normative limit	Pass
the three-state assessable flag is honoured — no verdict on no data	Pass
the SAME site can be judged under both standards, and they differ meaningfully	Pass

differential-settlement-web-validation.test.ts

C.DIFF — `differential-settlement` web-benchmark against IS 1904:1986 Table 1, 72 cited values (24 cells × 3 quantities).

Analyses validated: `differential-settlement` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C.DIFF.1: all 24 cells of IS 1904:1986 Table 1 match the engine transcription	Pass
C.DIFF.2: the steel row is 0.0033L in ALL four columns (the OCR near-miss)	Pass
C.DIFF.3: the differential coefficient is consistent with the angular limit	Pass
C.DIFF.4: checkIS1904 applies the published limits to a computed settlement pattern	Pass
C.DIFF.5: the "not likely to be encountered" cells report applicable:false, not a pass	Pass
C.DIFF.6: E-6/Q-1 regression — one point must NOT report a pass	Pass

⚑ elastic-settlement-web-validation.test.ts

elastic-settlement — dedicated web-benchmark against PUBLISHED values.

Analyses validated: `elastic-settlement` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bowles (1997) Table 5-2 — Steinbrenner I1 (=F1) and I2 (=F2), fourteen printed cells	Pass
Das (2016) Tables 7.2 / 7.3 — cells at n′ values Bowles does not tabulate	Pass
Baban (2016) Problem 3.2 (= Das Example 7.2 re-solved): rigid 1×2 m footing, centre	Pass
Baban (2016) Problem 3.3: same footing, Es,av = 8 500 kPa over H = 4 m (=4B)	Pass
Das (2016) Example 7.2 — the table reads (not the mis-added Is of the printed solution)	Pass
Bowles (1997) Example 5-7 — raft of the "Savings Bank Building", centre	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bowles (1997) Example 5-13 — ring footing idealised as a 3.658 m square, H = 5B′	Pass
Bowles (1997) §5-6: rigid-base reduction and the half-space limit	Pass
closed-form sanity: engine Is reduces to F1 + (1−2μ)/(1−μ)·F2 and S = m·q·B′·(1−μ²)/Es·Is·IF	Pass

embankment-stress-web-validation.test.ts

embankment-stress — dedicated web-benchmark against PUBLISHED values.

Analyses validated: `embankment-stress` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Illinois DOT (2015) Geotechnical Manual Table D.8-1 — Osterberg influence values for stated a/z, b/z	Pass
Das (2016) Example 6.8 — 7 m embankment, γ = 17.5 kN/m³, crest 5 m, 2H:1V slopes: stress under the centreline at z = 5 m	Pass
Holtz & Kovacs (1981) Example 8.21 — 3 m highway embankment, ρ = 2.0 Mg/m³, 10 m crest, 2H:1V slopes	Pass
Surface limit and the vertical-face (strip) limit — Das Fig 6.18 axis, H&K text, Das Table 6.3	Pass

⚑ expansive-heave-web-validation.test.ts

Validation for `expansive-heave` — swell-index heave of an expansive clay, ΔH = Cs·H/(1+e0)·log10(p_s/σ'), zero when σ' ≥ p_s (`expansive-heave.ts`, `computeExpansiveHeave`).

Analyses validated: `expansive-heave` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Terzaghi–Peck–Mesri Art. 16.10: 1-m sublayer, p_s = 3000 kPa, C_εs = 0.036, σ'_vo = 45 kPa ⇒ heave 66 mm	Pass
Terzaghi–Peck–Mesri Table 16.2: swelling from p_s(e=1.0) to p_s(e=1.5) changes the void ratio by 0.5	Pass
Terzaghi–Peck–Mesri Art. 16.10: no heave once the final stress reaches the swelling pressure	Pass
Fredlund & Rahardjo (1993) Eq. 8.34: strain is linear in C_s/(1+e0) and in log(P_f/P_o)	Pass

expansive-soil-web-validation.test.ts

Web-benchmark validation for `expansive-soil` — swelling-soil classification, heave, and the mitigation ladder.

Analyses validated: `expansive-soil` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FSI severity breaks at the published 20 / 35 / 50 % edges (IS 2720-40)	Pass
PI severity breaks at the published 15 / 35 / 55 % edges (IS 1498 Annex C)	Pass
swell-pressure severity breaks at the published 50 / 150 / 300 kPa edges (IS 2720-41)	Pass
the governing severity is the worst of the three indices	Pass
indices that disagree sharply are flagged for re-testing	Pass
recommended foundation depth is the active zone + 0.3 m, or deeper if founded deeper	Pass
heave follows Δh = Σ Cs/(1+e0)·H·log10(σ′sw/σ′f), integrated over the active zone	Pass
surcharge that exceeds the swell pressure suppresses heave entirely	Pass
heave needs Cs, e0 AND a swell pressure — a partial set is refused with a reason	Pass
the mitigation ladder escalates with severity and cites its standards	Pass
a very high severity under a building escalates to piles, and rationale is cited	Pass

gibson-consolidation-layered-terzaghi-web-validation.test.ts

WEB-VALIDATION for the finite-strain (Gibson) consolidation engine — the SMALL-STRAIN LIMIT against Terzaghi's published time-factor table, plus the LAYERED interface physics.

Analyses validated: `gibson-consolidation`, `gibson-consolidation-layered` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Gibson Terzaghi-limit setup: strain is small (< 0.5%) and solids are conserved	Pass
Gibson → Terzaghi limit: U = 20% at T_v = 0.0314 (Das Table 2.11)	Pass
Gibson → Terzaghi limit: U = 30% at T_v = 0.0707 (Das Table 2.11)	Pass
Gibson → Terzaghi limit: U = 40% at T_v = 0.126 (Das Table 2.11)	Pass
Gibson → Terzaghi limit: U = 50% at T_v = 0.197 (Das Table 2.11)	Pass
Gibson → Terzaghi limit: U = 60% at T_v = 0.286 (Das Table 2.11)	Pass
Gibson → Terzaghi limit: U = 70% at T_v = 0.403 (Das Table 2.11)	Pass
Gibson → Terzaghi limit: U = 80% at T_v = 0.567 (Das Table 2.11)	Pass
Gibson → Terzaghi limit: U = 90% at T_v = 0.848 (Das Table 2.11)	Pass
Gibson → Terzaghi limit: t_{90}/t_{50} = 0.848/0.197 = 4.305 (c_v cancels)	Pass
Gibson → Terzaghi limit: t_{50}/t_{30} = 0.197/0.0707 = 2.786 (c_v cancels)	Pass
Gibson → Terzaghi limit: doubling the drainage path quadruples t_{50} and t_{90}	Pass
Gibson layered: the layered path also degenerates to the Terzaghi table at U = 50% and 90%	Pass

gibson-consolidation-layered-web-validation.test.ts

WEB-BENCHMARK validation for the LAYERED finite-strain (Gibson) consolidation option (per-layer C_c / C_k / e_o / k_o; the interface flux is written in the CONTINUOUS effective-stress gradient with a harmonic-mean permeability, since the voi…

Analyses validated: `gibson-consolidation`, `gibson-consolidation-layered` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Gibson layered REDUCTION-2: identical 2-layer stack ≡ single material (ultimate + final)	Pass
Gibson layered REDUCTION-3: identical unequal 3-layer stack ≡ single material	Pass
Gibson layered BOUND: soft/stiff column lies between all-soft and all-stiff bounds	Pass
Gibson layered CONTINUITY: at equilibrium σ′ is continuous, e is discontinuous at the interface	Pass
Gibson layered TREND: soft-at-bottom settles more than soft-at-top	Pass
Gibson layered TREND: a lower-k layer slows consolidation (less consolidated at a fixed time)	Pass
Gibson layered EXACT: solids-mass conserved for layered profiles	Pass
Gibson layered WEB (Terzaghi limit): stiff small-strain column consolidates fully & monotonically	Pass
Gibson layered WEB (Townsend-McVay geometry): solids height invariant + void-space bound	Pass

gibson-consolidation-small-strain-web-validation.test.ts

PUBLISHED-VALUES(gibson-consolidation): 16 -- distinct published values for this engine (engine-level total, declared once); independent audit A3: 16-18 distinct published values; declared at the lower bound.

Analyses validated: `gibson-consolidation`, `gibson-consolidation-layered` · Recorded run: passed — 18 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Terzaghi corner is a valid small-strain run (precondition for every comparison below)	Pass
FHWA Table 7-4: U = 20 % at Tv = 0.031	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA Table 7-4: U = 30 % at Tv = 0.071	Pass
FHWA Table 7-4: U = 40 % at Tv = 0.126	Pass
FHWA Table 7-4: U = 50 % at Tv = 0.197	Pass
FHWA Table 7-4: U = 60 % at Tv = 0.287	Pass
FHWA Table 7-4: U = 70 % at Tv = 0.403	Pass
FHWA Table 7-4: U = 80 % at Tv = 0.567	Pass
FHWA Table 7-4: U = 90 % at Tv = 0.848	Pass
FHWA Table 7-4: the engine reports t90 itself consistently with Tv = 0.848	Pass
FHWA Table 7-4: Tv = 1.000 ⇒ U = 93.1 % (printed to 0.1 %)	Pass
FHWA Table 7-4: Tv = 0.197 ⇒ U = 50 %	Pass
FHWA Table 7-4 ratio t90/t50 = 0.848/0.197 (cv and H cancel)	Pass
FHWA Table 7-4 ratio t80/t40 = 0.567/0.126 (cv and H cancel)	Pass
FHWA Example 7-3: t90 = 0.848·(10 ft)²/0.2 ft²/day = 424 days	Pass
Das Example 2.12: 45.7 % consolidation after 31.6 days	Pass
Das Example 2.12: at the published 31.6 days the engine has consolidated 45.7 %	Pass
Craig Example 4.7: Tv = 0.0235 after 6 months ⇒ Uv = 0.17	Pass

gibson-consolidation-web-validation.test.ts

WEB-BENCHMARK validation for the finite-strain (Gibson) consolidation engine.

Analyses validated: `gibson-consolidation`, `gibson-consolidation-layered` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Gibson web EXACT1: solids-mass conservation (Hs = H0/(1+e0) invariant)	Pass
Gibson web EXACT2: ultimate settlement ≤ void-space bound H0 − Hs	Pass
Gibson web EXACT3: consolidation time scales as $1/k_0$ (halve k_0 ⇒ 2× t_{90})	Pass
Gibson web EXACT4: Townsend-McVay phosphate clay — solids height 0.6076 m invariant	Pass
Gibson web BENCHMARK4b: power-law reproduces Townsend-McVay ultimate settlement ≈ 5.44 m	Pass
Gibson web TREND5: surcharge deepens settlement	Pass
Gibson web TREND6: for fixed H0, lower e0 (denser) ⇒ more self-weight settlement	Pass
Gibson web TREND7: monotonic settlement, converges to ~100% given time	Pass
Gibson web TREND8: bottom consolidates more than the drained top	Pass
Gibson verdict: names ultimate settlement + degree of consolidation	Pass

hs-confined-settlement-web-validation.test.ts

Validation for the Hardening-Soil confined settlement engines (`hs-confined-settlement.ts`: `computeHsConfinedSettlement` — slug `hs-confined-settlement`; `computeHsLayeredSettlement` — slug `hs-layered-settlement`).

Analyses validated: `hs-confined-settlement`, `hs-layered-settlement` · Recorded run: passed — 17 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] the engine's OWN closed-form analytic settlement matches the hand-derived Schanz-Vermeer-Bonnier oedometer integral exactly	Pass
[2] the nonlinear FE (two-surface plasticity) settlement matches the closed-form analytic integral within the engine's own documented 2% tolerance	Pass
[3] the closed-form checks out at a second, independent input set (thinner layer, stiffer clay, higher increment)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[4] preconsolidated (OCR>1) soil settles LESS than the equivalent normally-consolidated soil, per the HS stiff-unload-reload branch	Pass
[5] the linear-elastic (initial-modulus) estimate OVER-predicts settlement relative to the true HS response, because HS stiffness increases with stress while the linear estimate holds it fixed at the (lower) initial value	Pass
[6] applied_load_kpa=0 gives exactly zero settlement, labelled definitional	Pass
[7] invalid HS parameters (zero stiffness, phi outside (0,90), m outside [0,1]) are refused	Pass
[8] a two-layer profile's total settlement equals the sum of its per-layer settlements exactly	Pass
[9] the total thickness reported equals the sum of the input layer thicknesses exactly	Pass
[10] the dominant layer index correctly identifies the layer with the largest settlement contribution	Pass
[11] an empty layer list, or applied_load_kpa < 0, is refused	Pass
Craig Ex 4.5 (p. 132): m_v 0.94 m²/MN, Δσ′ 14.7 kPa, H 8 m → 110 mm	Pass
Das Ex 2.12: NC clay 2.8 m, σ'_o 140 → 212 kN/m², e 0.92 → 0.86 → S_c = 87.5 mm	Pass
FHWA Ex 7-3 (p. 7-37): NC clay 10 ft, C_c 0.5, e_o 1.0, 600 → 3000 psf → ΔH = 1.75 ft	Pass
Craig Ex 4.2 (p. 112): layered embankment settlement 86.1 + 30.0 = 116.1 mm	Pass
seating regression: stiff soil at low σ′v0 — FE tracks the closed form within 3 % (was 55× too small, 2× too large, 0)	Pass
the published-value tally is 6 distinct printed numbers; PARTIAL (short of 20 by 14 per engine)	Pass

is8009-settlement-web-validation.test.ts

is8009-settlement — dedicated web-benchmark against PUBLISHED values.

Analyses validated: `is8009-settlement` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Craig (2012) Example 8.5 / Table 8.7 — five 3 m layers under the centre of a 6 m square footing, q = 160 kPa	Pass
Das (2016) Table 6.5 — centre-of-rectangle influence factor Ic (= engine I_B), fourteen cells	Pass
Das (2016) Example 6.2 — 2.5 × 5 m footing, 150 kPa, z = 6.25 m below the centre	Pass
Bowles (1997) Example 5-3 — 800 kN on a 2 × 2 m footing (q = 200 kPa): stress under the centre	Pass
IS 8009 (Part 1):1976 Cl 9.5.2 — rigidity factor 0.8 on the centre settlement	Pass

janbu-settlement-web-validation.test.ts

WEB-BENCHMARK validation for the Janbu tangent-modulus settlement engine.

Analyses validated: `janbu-settlement` · Recorded run: passed — 23 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
V1 (§5): crust layer settlement 2.35 cm (published 2.35)	Pass
V2 (§5): clay layer settlement 39.26 cm (published 39.26)	Pass
V3 (§5): sand layer settlement 1.93 cm (published 1.93)	Pass
V4 (§5): total settlement 43.5 cm (Settle3 published; Janbu 1963 43.6)	Pass
V5 (§5): discretization converges — n=20 closer to published than n=1	Pass
V6 (Eq 3.9): a=1 till m=500 → ε = Δσ/(m·σ′r) = 0.002 → 2.0 mm	Pass
V7 (Eq 3.11): a=0.5 dense sand m=400 → (√200−√100)/(5·400) = 2.071 mm	Pass
V8 (Eq 3.11): a=0.5 compact sand m=250 → (√200−√100)/(5·250) = 3.314 mm	Pass
V9 (Eq 3.11): a=0.5 loose sand m=100 → (√200−√100)/(5·100) = 8.284 mm	Pass
V10 (Eq 3.15): a=0 soft silty clay m=10 → (1/10)·ln2 = 69.31 mm	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
V11 (Eq 3.15): a=0 soft marine clay m=5 → (1/5)·ln2 = 138.63 mm	Pass
V12 (Eq 3.15): a=0 peat m=2 → (1/2)·ln2 = 346.57 mm (softest Table 3.1 soil)	Pass
V13 (Eq 3.11): a=0.5 silt m=200 → (√200−√100)/(5·200) = 4.142 mm	Pass
V14 (Eq 3.11): a=0.5 at lower stress σ0=50, m=250 → (√150−√50)/(5·250) = 4.141 mm	Pass
V15: a=0.5 settles MORE at lower initial stress (modulus ∝ √σ′) — the Janbu non-linearity	Pass
V16: a=1 settlement is independent of σ0 (constant modulus)	Pass
V17: a=1 settlement scales linearly with H (elastic)	Pass
V18 (Eq 3.18): a=0 with m = ln10·(1+e0)/Cc reproduces the Cc settlement exactly	Pass
V19: a=1 with m = E/100 reproduces the elastic settlement Δσ·H/E	Pass
V20 (Eq 3.17): OC below σ′p settles LESS than NC at the same increment (mr > m)	Pass
V21 (Eq 3.16): OC crossing σ′p = recompression to σ′p + virgin beyond	Pass
V22: finite-footing Δσ from the shared Boussinesq library (2×2 @ z=1 → 0.7009·q)	Pass
V23: 2:1 method gives a deeper-spread, smaller near-surface Δσ than infinite	Pass

koppejan-settlement-web-validation.test.ts

WEB-BENCHMARK validation for the Koppejan settlement & time-dependent consolidation engine.

Analyses validated: `koppejan-settlement` · Recorded run: passed — 23 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
V1 (§17 part 1): ultimate settlement 0.355 m (published 0.355, analytical = Settle3)	Pass
V2 (§17 part 2): settlement at 1000 d 0.568 m (published 0.568, spreadsheet = Settle3)	Pass
V3 (§17): at 1000 d the profile is fully consolidated (U = 1)	Pass
V4 (§17): settlement at 1 d ≈ ultimate (creep term log10(1) = 0)	Pass
V5 (§17): settlement at 10 d = ultimate + 1 log-cycle of creep	Pass
V6 (§17): settlement at 100 d = ultimate + 2 log-cycles of creep	Pass
V7 (§17): settlement at 10000 d = ultimate + 4 log-cycles of creep	Pass
V8 (§17): creep increments are equal per log-cycle (secular linearity)	Pass
V9 (Eq 29): Cp=10, Cs=50 ultimate ε = (1/10)·ln2 = 0.069315 → 69.31 mm	Pass
V10 (Eq 29): Cp=5 ultimate doubles the primary strain → 138.63 mm	Pass
V11 (Eq 29): Cp=20 ultimate halves the primary strain → 34.66 mm	Pass
V12 (Eq 29): @1000d Cs=50 → (0.1 + 3/50)·ln2 = 110.90 mm	Pass
V13 (Eq 29): @1000d Cs=25 → (0.1 + 3/25)·ln2 = 152.49 mm (more creep)	Pass
V14 (Eq 29): @1000d Cs=100 → (0.1 + 3/100)·ln2 = 90.11 mm (less creep)	Pass
V15 (Eq 29): creep per log-cycle = (1/Cs)·ln(σ′f/σ′i)·H = 13.863 mm/cycle for Cs=50	Pass
V16: small Tv ⇒ U = √(4·Tv/π) (U≤60% branch); cv=0.001, H=4, Hdr=2, t=10d → U=0.0564	Pass
V17: partial consolidation at intermediate time (cv=0.001, H=4, t=1000d → U=0.5642)	Pass
V18: large Tv ⇒ U = 1; cv=0.5, H=4, Hdr=2, t=100d (Tv=12.5)	Pass
V19: double drainage halves the drainage path ⇒ 4× faster consolidation	Pass
V20 (§4.4): k = cv·γw/(Cp·σ′zi); cv=1, γw=9.81, Cp=10, σ=100 → 0.00981 m/day	Pass
V21 (§4.4): k doubles with cv; k inversely proportional to Cp	Pass
V22: OC below σ′p uses recompression constants ⇒ less settlement than NC	Pass
V23: OC crossing σ′p combines recompression + virgin log terms	Pass

line-load-stress-web-validation.test.ts

line-load-stress — dedicated web-benchmark against PUBLISHED values.

Analyses validated: `line-load-stress` · Recorded run: passed — 3 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das (2016) Table 6.2 — Δσ_z/(q/z) against x/z, twenty-one published values	Pass
FHWA NHI-06-089 (2006) Example 10-2 — lateral pressure on a 30 ft unyielding wall from a 700 lb/ft line load 15 ft away	Pass
Varghese (2005) Eq. 17.3 — the wall-pressure coefficient of the line-load horizontal stress	Pass

multilayer-consolidation-web-validation.test.ts

Validation of the multi-layer 1-D consolidation engine (`multilayer-consolidation.ts`) against PUBLISHED layered-clay settlement and time-rate examples.

Analyses validated: `multilayer-consolidation` · Recorded run: passed — 25 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA Table A.6-3: Sub-layer 1 (recompression only) = 1.17 in	Pass
FHWA Table A.6-3: Sub-layer 2 (Cr then Cc) = 2.55 in	Pass
FHWA Table A.6-3: Sub-layer 3 (Cr then Cc) = 8.11 in	Pass
FHWA Table A.6-3: clay total = 11.83 in	Pass
FHWA Table A.6-6: Sub-layer 1 under embankment + surcharge = 1.93 in (book rounds terms to 0.01 ft)	Pass
FHWA Table A.6-6: Sub-layer 2 under embankment + surcharge = 4.44 in	Pass
FHWA Table A.6-6: Sub-layer 3 under embankment + surcharge = 10.89 in	Pass
FHWA Table A.6-6: clay total under embankment + surcharge = 17.26 in	Pass
FHWA Table A.6-6: the surcharge alone adds 5.43 in	Pass
FHWA Table A.7-3: pier Sub-layer 1 = 0.97 in	Pass
FHWA Table A.7-3: pier Sub-layer 2 (0.18 + 0.80) = 0.98 in	Pass
FHWA Table A.7-3: pier clay total = 1.95 in	Pass
FHWA Table A.7-6: abutment Sub-layer 1 = 0.12 in	Pass
FHWA Table A.7-6: abutment Sub-layer 2 (NC, Cc) = 2.50 in	Pass
FHWA Table A.7-6: abutment clay total = 2.62 in	Pass
FHWA Table A.6-4: 20 % of the 35-ft clay settlement takes 16 days	Pass
FHWA Table A.6-4: 50 % takes 101 days	Pass
FHWA Table A.6-4: 70 % takes 206 days	Pass
FHWA Table A.6-4: 90 % takes 432 days	Pass
FHWA Table A.6-4 read the other way: 16 days ⇒ 20 %, 101 days ⇒ 50 %	Pass
FHWA Table A.6-4 read the other way: 206 days ⇒ 70 %, 432 days ⇒ 90 %	Pass
FHWA Table A.7-4: the 25-ft pier clay (Hd = 12.5 ft) reaches 20/50/70/90 % in 8/51/104/220 days	Pass
FHWA Example 7-3: primary settlement of the NC clay = 1.75 ft = 21 in	Pass
FHWA Example 7-3: t90 = 424 days (single drainage, Hd = 10 ft, cv = 0.2 ft²/day)	Pass
Lambe & Whitman Example 25.6: ρ = 4.3/(1+1.83)·(1.83 − 1.40) = 0.653 m	Pass

pvd-design-published-web-validation.test.ts

Validation of the PVD / sand-drain spacing DESIGNER (`pvd-design.ts`) against PUBLISHED radial consolidation tables and PUBLISHED worked drain designs.

Analyses validated: `pvd-design` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Table 16.5: n = 5	Pass
Das Table 16.5: n = 10	Pass
Das Table 16.5: n = 15	Pass
Das Table 16.5: n = 20	Pass
Das Table 16.5: n = 25	Pass
Das Example 16.5: 77 % radial consolidation in 9 months with 0.2 m drains needs n = 15	Pass
Craig Example 4.7: the large-diameter sand-drain target is found feasible, not refused	Pass
Craig Example 4.7: spacing ratio n = 9	Pass
Craig Example 4.7: square-pattern spacing S = 3.2 m	Pass
Han Design Example 7.1: 1.0 m triangular spacing reproduces the published Ur at the published Tr	Pass
FHWA-NHI-16-027 §4.4: ≈ 8 ft spacing for 90 % in ≈ 300 days	Pass
FHWA-NHI-16-027 §4.4: ≈ 10 ft spacing for 90 % in ≈ 500 days	Pass

pvd-design-web-validation.test.ts

Validation against Barron (1948) and Hansbo (1981, Proc.

Analyses validated: `pvd-design`, `radial-consolidation` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] influence diameter constants match the published Hansbo/Barron values exactly: de=1.05.S (triangular), de=1.128.S (square)	Pass
[3-4] ROUND-TRIP CONSISTENCY: the spacing solved for a 90% target, run back through the forward radialConsolidation solver, reproduces ~90% U	Pass
[5] influence diameter reported by the design matches the pattern constant times the solved spacing exactly	Pass
[6] a longer available time allows a WIDER (less conservative) spacing to reach the same target	Pass
[7] a higher target consolidation requires a TIGHTER spacing, all else equal	Pass
[8] a higher coefficient of consolidation ch allows a wider spacing for the same target/time	Pass
[9] an unreachable target (very high U, very little time) is reported as NOT feasible, not silently solved at the tightest spacing	Pass
[10] a trivially-easy target (met even at the widest practical spacing) is flagged as such, not silently solved at the tightest	Pass
[11] the U-vs-spacing curve is monotonically DECREASING (tighter spacing -> higher U, per Hansbo theory)	Pass
[12] invalid inputs (ch<=0, target outside (0,100), time<=0, dw<=0) are refused	Pass

radial-consolidation-web-validation.test.ts

Radial consolidation by vertical drains — validated against the three papers the engine cites:

Analyses validated: `radial-consolidation` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Barron (1948) equal-strain drain factor F(n) — 10 values across the design range	Pass
Hansbo (1981) smear extension — and the Barron lower-bound clamp	Pass
influence diameter — 1.05·S triangular, 1.128·S square (the standard unit-cell equivalences)	Pass
Uh = 1 − exp(−8·Th/μ) end to end, with Th = ch·t/de²	Pass
Carrillo (1942) — U = 1 − (1 − Uv)(1 − Uh)	Pass
Hansbo (1981) well resistance — the depth-averaged Fr and its sign	Pass
the audit E-22/23/24 guards hold alongside the physics	Pass

schmertmann-web-validation.test.ts

SCHMERTMANN STRAIN-INFLUENCE SETTLEMENT — web-validation benchmark.

Analyses validated: `schmertmann` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Ex 7.4 — geometry of the Iz diagram (Eqs 7.21-7.24): 4 published values	Pass
Das Ex 7.4 — Es = 2.8 qc for L/B = 2 (Eq 7.27), and the correction factors	Pass
Das Ex 7.4 — Σ Iz/Es·Δz = 17.52e-5 and Se = 27.83 mm	Pass
E-60 — the answer must not depend on how the caller binned the CPT	Pass
E-59 — Es for a rectangle is logarithmic in L/B, not linear in (L/B−1)/9	Pass
the Iz diagram degenerates correctly at the square and strip limits	Pass
the published interpolation relations are slightly NON-monotone in L/B — recorded, not corrected	Pass
C1 and C2 behave as Eqs (7.20) define them	Pass

secondary-compression-web-validation.test.ts

WEB-BENCHMARK validation for the isotache / secondary-compression (creep) engine.

Analyses validated: `secondary-compression` · Recorded run: passed — 25 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
creep 1: Cαε=0.05, H=5, t_p=1→t2=100 yr ⇒ 500 mm (2 log-cycles)	Pass
creep 2: same, t2=50 yr ⇒ 424.74 mm	Pass
creep 3: same, t2=10 yr ⇒ 250 mm (1 log-cycle = Cαε·H)	Pass
creep 4: Das NC-clay Cα=0.02, e_p=0.766, H=3, t_p=1.5→t2=15 ⇒ 33.98 mm	Pass
creep 5: Das clay, t2=6.5 yr ⇒ 21.63 mm	Pass
creep 6: inorganic Cα=0.008, e_p=0.9, H=4, t_p=2→t2=20 ⇒ 16.84 mm	Pass
creep 7: inorganic, t2=50 ⇒ 23.55 mm	Pass
creep 8: t2 = t_p ⇒ 0 mm (creep starts only after primary)	Pass
creep 9: settlement scales linearly with H	Pass
t_p 10: cv=5 m²/yr, H=10, single drainage ⇒ t_p = 1.129·100/5 = 22.58 yr	Pass
t_p 11: double drainage halves H_dr ⇒ t_p = 5.645 yr (¼ of single)	Pass
t_p 12: no cv ⇒ falls back to the input t_p	Pass
SSC 13: μ* = Cα/(ln10·(1+e)); Cα=0.04, e=1 ⇒ 0.008686	Pass
SSC 14: λ* = Cc/(ln10·(1+e)); Cc=0.485, e=1 ⇒ 0.1053 (≈ Soft-Soil-Creep (Vermeer & Neher 1999) preset λ*=0.1055)	Pass
SSC 15: κ* = 2·Cr/(ln10·(1+e)); Cr=0.05, e=1 ⇒ 0.02172	Pass
rate 16: dS/dt = Cαε·H·1000/(ln10·t2); base @100 yr ⇒ 1.086 mm/yr	Pass
rate 17: rate decreases with time (creep decelerates)	Pass
fingerprint 18: Cα/Cc=0.04 ⇒ inorganic clay, consistent	Pass
fingerprint 19: peat Cα/Cc≈0.06 ⇒ peat/organic band	Pass
fingerprint 20: Cα/Cc=0.15 ⇒ flagged inconsistent (outside 0.02–0.10)	Pass
surcharge 21: R_s'>0 reduces creep vs no surcharge (t_l = 100·t_p·R_s'^1.7)	Pass
surcharge 22: if t_l > design life ⇒ zero creep, ~100 % eliminated	Pass
surcharge 23: no surcharge ⇒ eliminated 0 %, settlement unchanged	Pass
surcharge 24: peat uses t_l = 10·t_p·R_s' (linear, not power 1.7)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
verdict 25: below the limit ⇒ ACCEPTABLE; above ⇒ recommends a surcharge	Pass

settlement-is8009-web-validation.test.ts

C.SET8009 — `settlement` web-benchmark against IS 8009 (Part 1):1976.

Analyses validated: `settlement` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C.SET8009.1: rigidity factor is exactly 0.8 — IS 8009-1 Cl 9.5.2 Eq (13)	Pass
C.SET8009.2: depth factor — Cl 9.5.1 / Fig 12 endpoints and monotonicity	Pass
C.SET8009.3: primary consolidation follows the Terzaghi 1-D law (Cl 9.3.3)	Pass
C.SET8009.4: IS 8009 prescribes Boussinesq — both stress paths are available and differ	Pass
C.SET8009.5: the corrected citation is what the engine now reports at runtime	Pass
C.SET8009.6: IS 1904 serviceability guidance is surfaced past 75 mm	Pass

settlement-worked-examples-web-validation.test.ts

settlement — FULL WORKED EXAMPLES (the ≥20-value gate).

Analyses validated: `settlement` · Recorded run: passed — 33 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS] Ex 2.12 primary consolidation Sc = 87.5 mm	Pass
[DAS] Ex 2.12 at t = 31.6 days U = 45.7 % (S = 40 mm)	Pass
[DAS] Problem 2.13 (NC): Sc = 87.2 mm (Cc = 0.009(LL – 10) = 0.288, Eq. 2.54; Cs = Cc/5)	Pass
[DAS] Problem 2.14 (OC, σ′p = 128): Sc = 56.69 mm (Cc = 0.009(LL – 10) = 0.288, Eq. 2.54; Cs = Cc/5)	Pass
[DAS] Ex 7.10 oedometric Sc under a 1 × 2 m footing = 46.5 mm (Boussinesq; Das averages Δσ by Simpson’s rule)	Pass
[DAS] Ex 7.11 secondary compression t 1.3 → 6.3 yr, C′α = Cα/(1 + ep) → Ss = 19.4 mm	Pass
[CRAIG] Ex 4.6 final consolidation settlement = 182 mm	Pass
[CRAIG] Ex 4.6 settlement after 3 yr (corrected t = 2.5 yr, half-closed) = 61 mm	Pass
[CRAIG] Ex 8.5 Boussinesq corner factor at z = 1.5 m below base: Iqr = 0.233	Pass
[CRAIG] Ex 8.5 Boussinesq corner factor at z = 4.5 m below base: Iqr = 0.121	Pass
[CRAIG] Ex 8.5 Boussinesq corner factor at z = 7.5 m below base: Iqr = 0.06	Pass
[CRAIG] Ex 8.5 Boussinesq corner factor at z = 10.5 m below base: Iqr = 0.033	Pass
[CRAIG] Ex 8.5 Boussinesq corner factor at z = 13.5 m below base: Iqr = 0.021	Pass
[BOW] Table 5-2 Steinbrenner N = 0.2, M = 1: I1 = 0.009, I2 = 0.041	Pass
[BOW] Table 5-2 Steinbrenner N = 0.4, M = 1.5: I1 = 0.028, I2 = 0.071	Pass
[BOW] Table 5-2 Steinbrenner N = 0.6, M = 2: I1 = 0.055, I2 = 0.092	Pass
[BOW] Table 5-2 Steinbrenner N = 0.8, M = 1.2: I1 = 0.1, I2 = 0.09	Pass
[BOW] Table 5-2 Steinbrenner N = 1, M = 1: I1 = 0.142, I2 = 0.083	Pass
[BOW] Table 5-2 Steinbrenner N = 1.5, M = 1.7: I1 = 0.217, I2 = 0.102	Pass
[BOW] Table 5-2 Steinbrenner N = 2, M = 1.4: I1 = 0.292, I2 = 0.083	Pass
[BOW] Table 5-2 Steinbrenner N = 3, M = 2: I1 = 0.402, I2 = 0.084	Pass
[BOW] Table 5-2 Steinbrenner N = 4, M = 1: I1 = 0.408, I2 = 0.037	Pass
[BOW] Table 5-2 Steinbrenner N = 5, M = 1.5: I1 = 0.496, I2 = 0.045	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[BOW] Table 5-2 Steinbrenner N = 6, M = 1.8: I1 = 0.55, I2 = 0.045	Pass
[BOW] Table 5-2 Steinbrenner N = 8, M = 2: I1 = 0.611, I2 = 0.038	Pass
[BOW] Table 5-2 Steinbrenner N = 10, M = 1.3: I1 = 0.554, I2 = 0.02	Pass
[BOW] Table 5-2 Steinbrenner N = 20, M = 1.9: I1 = 0.69, I2 = 0.015	Pass
[DAS] Ex 7.2 Steinbrenner at m′ = 2, n′ = 10: F1 = 0.641, F2 = 0.031	Pass
[BOW] Ex 5-7 raft: M = 1.2, N = 0.7, μ = 0.35 → Is = 0.121; flexible centre ΔH = 16.5/IF(0.95) = 17.4 mm	Pass
[BOW] Ex 5-14 OC clay (Cr to p′c, Cc beyond), Boussinesq through the layer → ΔH = 1.14 in (Bowles uses a layer-average Δp; ±5 %)	Pass
[NHI] NHI-06-088 Ex 7-3 embankment on NC clay: ΔH = 0.53 m	Pass
[NHI] NHI-06-088 Ex 7-3 single drainage: t90 = 424 days	Pass
[NHI] NHI-06-089 Ex 8-3 footing on NC clay, 2:1 at clay mid-depth: ΔH = 1.1 in	Pass

strip-load-stress-web-validation.test.ts

strip-load-stress — dedicated web-benchmark against PUBLISHED values.

Analyses validated: `strip-load-stress` · Recorded run: passed — 3 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das (2016) Table 6.3, 2x/B = 0 column — Δσ/q0 against 2z/B, twenty-one published values	Pass
FHWA NHI-06-088 (2006) Example 2-2 — 5 ft strip footing, 1 000 psf: stress under the centreline from the isobar chart	Pass
Varghese (2005) §3.8.1 / Eq. 3.10 — the strip subtends 90° at a depth of B/2; stress ratio there is (π/2 + 1)/π	Pass

vacuum-preload-web-validation.test.ts

Validation of the VACUUM PRELOADING engine (`vacuum-preload.ts`) against PUBLISHED preloading settlement and PVD time-rate examples.

Analyses validated: `vacuum-preload` · Recorded run: passed — 22 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Han Example 7.1: Sc1 = 1.58 m under 4.5 m of fill (Δσ = 88.65 kPa)	Pass
Han Example 7.1: Sc2 = 2.08 m under 8 m of fill (Δσ = 157.6 kPa)	Pass
Han Example 7.1: Sc3 = 2.37 m under 11 m of fill (Δσ = 216.7 kPa)	Pass
Han Example 7.1: Tr = 0.185 ⇒ Ur = 48.2 %	Pass
Han Example 7.1: Tr = 0.423 ⇒ Ur = 77.8 %	Pass
Han Example 7.1: Tr = 0.720 ⇒ Ur = 92.3 %	Pass
Han Example 7.1: Tr = 0.148 ⇒ Ur = 40.9 %	Pass
Han Example 7.1: Tr = 0.502 ⇒ Ur = 83.2 %	Pass
Han Example 7.1: Tr = 1.145 ⇒ Ur = 98.3 %	Pass
Han Example 7.1: overall Uvr = 51.0 % at 52.5 days (Uv = 5.4 % with Hdr = 6 m)	Pass
Han Example 7.1: overall Uvr = 93.1 % at 204 days	Pass
Han Example 7.1: settlement at 52.5 days = 0.510 × 1.58 = 0.81 m	Pass
Das Table 16.5: n = 5, Tr = 0.0811 ⇒ Ur = 50 %	Pass
Das Table 16.5: n = 10, Tr = 0.0704 ⇒ Ur = 30 %	Pass
Das Table 16.5: n = 10, Tr = 0.4543 ⇒ Ur = 90 %	Pass
Das Table 16.5: n = 15, Tr = 0.3966 ⇒ Ur = 80 %	Pass
Das Table 16.5: n = 15, Tr = 0.7382 ⇒ Ur = 95 %	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Table 16.5: n = 20, Tr = 0.3392 ⇒ Ur = 70 %	Pass
Das Table 16.5: n = 25, Tr = 0.2834 ⇒ Ur = 60 %	Pass
Das Table 16.5: n = 25, Tr = 1.0846 ⇒ Ur = 97 %	Pass
Craig Example 4.7: vertical drainage alone gives Uv = 0.17 at 6 months (half-closed, d = H = 10 m)	Pass
Craig Example 4.7: the 3.2 m sand-drain layout reaches U = 85 % in about 6 months	Pass

⚑ vertical-stress-increase-web-validation.test.ts

vertical-stress-increase — dedicated web-benchmark against PUBLISHED values.

Analyses validated: `vertical-stress-increase` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das (2016) Table 6.4 — Boussinesq corner influence I(m,n), fourteen cells (5 d.p.)	Pass
Das (2016) Table 6.5 — Boussinesq influence Ic under the CENTRE, ten cells (3 d.p.)	Pass
Das (2016) Examples 6.2 and 6.9 — 2.5 × 5 m footing, 150 kPa, z = 6.25 m under the centre	Pass
Das (2016) Table 6.8 — Westergaard corner influence Iw for ν = 0, twelve cells (4 d.p.)	Pass
Bowles (1997) Table 5-1 — corner Ia (3 d.p., M = B/z, N = L/z), eleven cells	Pass
Bowles (1997) Example 5-3 — 800 kN on a 2 × 2 m footing, q = 200 kPa	Pass
Bowles (1997) Eq. (5-15) programming check — Westergaard corner factor at μ = 0.45	Pass
Lambe & Whitman (1979) Example 8.3 and Holtz & Kovacs (1981) Example 8.18 — chart-read corner factors	Pass

⚑ weighted-creep-web-validation.test.ts

weighted-creep — validation of Bligh's and Lane's creep-ratio checks against PUBLISHED safe-ratio tables and worked weir examples.

Analyses validated: `weighted-creep` · Recorded run: passed — 25 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Lane 1935 (IHE thesis Table 2-2): very fine sand or silt → safe weighted-creep ratio 8.5	Pass
Lane 1935 (IHE thesis Table 2-2): fine sand → safe weighted-creep ratio 7	Pass
Lane 1935 (IHE thesis Table 2-2): medium sand → safe weighted-creep ratio 6	Pass
Lane 1935 (IHE thesis Table 2-2): coarse sand → safe weighted-creep ratio 5	Pass
Lane 1935 (IHE thesis Table 2-2): fine gravel → safe weighted-creep ratio 4	Pass
Lane 1935 (IHE thesis Table 2-2): coarse gravel including cobbles → safe weighted-creep ratio 3	Pass
Lane 1935 (IHE thesis Table 2-2): boulders with some cobbles and gravel → safe weighted-creep ratio 2.5	Pass
Lane 1935 (IHE thesis Table 2-2): soft clay → safe weighted-creep ratio 3	Pass
Lane 1935 (IHE thesis Table 2-2): hard clay → safe weighted-creep ratio 1.8	Pass
Mustansiriyah 2020 Table 1: light sand and mud → Bligh coefficient 18	Pass
Mustansiriyah 2020 Table 1: fine micaceous sand → Bligh coefficient 15	Pass
Mustansiriyah 2020 Table 1: coarse-grained sand → Bligh coefficient 12	Pass
Mustansiriyah 2020 Table 1: fine_gravel lies inside the printed Bligh range 5–9 for boulders/gravel/sand	Pass
Mustansiriyah 2020 Table 1: coarse_gravel lies inside the printed Bligh range 5–9 for boulders/gravel/sand	Pass
Mustansiriyah 2020 Table 1: boulders_gravel lies inside the printed Bligh range 5–9 for boulders/gravel/sand	Pass
Garg Table 11.2: coarse gravel (3.0) and boulders (2.5) lie inside the printed Lane ranges 3.0–3.5 and 2.5–3.0	Pass
Mustansiriyah 2020 Eq. 9 / Lane 1935: 30 m of horizontal contact counts 10 m, 30 m of vertical counts 30 m	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Mustansiriyah 2020 Ex 1 (Bligh): creep length 63 m, gradient 1/15.75	Pass
Mustansiriyah 2020 Ex 1 (Bligh): on fine sand (C = 15) the structure is "safe"	Pass
Mustansiriyah 2020 Ex 2 (Bligh): creep length 64 m, gradient 1/10.67	Pass
Mustansiriyah 2020 Ex 2 (Bligh): safe on sand mixed with boulders and gravel (C = 5…9)	Pass
Mustansiriyah 2020 Ex 5 (Lane): N = 52.2 m, V = 31.2 m → weighted creep length 48.6 m	Pass
Mustansiriyah 2020 Ex 5 (Lane): coarse sand (C = 5) → "safe against piping"	Pass
Lane rule "safe if H/Lw ≤ 1/C": a structure exactly at C is safe, just under it is not	Pass
a cleared head is refused rather than reported as a creep ratio of 2.4e10	Pass

Slopes and embankments — factor of safety

FE kernel registry — 32 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-2d-tut2	drained / undrained embankment + safety factor [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 40–51	—	—	—	—	—	Superseded
k5c-acads-1a-fela-bounds	SR-FELA factor of safety, lower / upper bound (ACADS 1(a), homogeneous slope) [-]	Optum-G2-Verification-Slope-Stability.pdf, p. 3–4 (§2.1, Table 2)	—	0.981	lower: 0.9769; upper: 0.9879; errorPct: 0.56	—	—	Pass
k5c-acads-1a-lem	LEM critical-circle factor of safety: Bishop / Spencer / Morgenstern–Price [-]	../Slide_SlopeStabilityVerification.pdf, p. 20–23 (Problem #1, Table 1.2)	—	0.986	bishop: 0.9851; spencer: 0.9841; morgenstern-price: 0.984	—	−0.20 %	Pass
k5c-acads-1c-fela-bounds	SR-FELA factor of safety, lower / upper bound (ACADS 1(c), three soils, inclined boundaries) [-]	Optum-G2-Verification-Slope-Stability.pdf, p. 5–6 (§2.2, Table 4)	—	1.359	lower: 1.3443; upper: 1.3623; errorPct: 0.67	—	—	Pass
k5c-acads-1c-lem	LEM critical-circle factor of safety: Bishop / Spencer / Morgenstern–Price [-]	../Slide_SlopeStabilityVerification.pdf, p. 28–31 (Problem #3, Table 3.2)	—	1.375	bishop: 1.4027; spencer: 1.372; morgenstern-price: 1.3715	—	−0.22 %	Pass
k5c-acads-1d-fela-bounds	SR-FELA factor of safety, lower / upper bound (ACADS 1(d), kh = 0.15) [-]	Optum-G2-Verification-Slope-Stability.pdf, p. 6–7 (§2.3, Table 6)	—	1.039	lower: 0.9669; upper: 0.9767; errorPct: 0.51	—	−6.47 %	Deviation
k5c-acads-1d-lem	LEM critical-circle factor of safety, kh = 0.15: Bishop / Spencer / Morgenstern–Price [-]	../Slide_SlopeStabilityVerification.pdf, p. 32–35 (Problem #4, Table 4.2)	—	0.991	bishop: 1.0128; spencer: 0.9891; morgenstern-price: 0.9866	—	−0.19 %	Pass
k5c-acads-3a-fela-bounds	SR-FELA factor of safety, lower / upper bound (ACADS 3(a), weak seam + water table) [-]	Optum-G2-Verification-Slope-Stability.pdf, p. 7–9 (§2.4, Table 8)	—	1.265	lower: 1.2592; upper: 1.2622; errorPct: 0.12	—	—	Pass
k5c-acads-3a-lem-noncircular	LEM non-circular (path search) Spencer factor of safety [-]	../Slide_SlopeStabilityVerification.pdf, p. 44–46 (Problem #7, Table 7.2)	—	1.246	spencer (circular): 1.5025; spencer (non-circular): 1.2629; morgenstern-price (circular): 1.4963; morgenstern-price (non-circular): 1.2925	—	+1.35 %	Pass
k5c-arai-tagyo-16	LEM (Bishop / Spencer / M-P) and SR-FELA bounds, polyline water table [-]	../Slide_SlopeStabilityVerification.pdf, p. 77–78 (Problem #16, Table 16.2)	—	1.118	lem: (bishop: 1.1132; spencer: 1.1139; morgenstern-price: 1.1122); felaLower: 1.116; felaUpper: 1.1191	—	−0.43 %	Pass
k5c-griffiths-lane-ex1	SR-FELA bounds and LEM, 2:1 slope ϕ′ 20°, c′/γH 0.05, D = 1 [-]	../Griffiths and Lane 1999.pdf, p. Géotechnique 49(3) 387–403, Example 1, Fig. 2	—	1.38	felaLower: 1.3751; felaUpper: 1.3809; lem: (bishop: 1.3781; spencer: 1.3758; morgenstern-price: 1.3756)	—	—	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k5c-plaxis-phic-vs-bishop	factor of safety of the 1:2 embankment: SR-FELA bounds, LEM [-]	PLAXIS-Verification-Phi-c-reduction-vs-Bishop-updated.pdf, p. 1–4 (Analysis 1)	1.54 (PLAXIS 2D)	1.534	felaLower: 1.5342; felaUpper: 1.5419; lem: (bishop: 1.5419; spencer: 1.5389; morgenstern-price: 1.5386)	−0.13 %	—	Pass
k5c-plaxis-phic-vs-bishop-loaded	factor of safety with the crest load: SR-FELA bounds, LEM [-]	PLAXIS-Verification-Phi-c-reduction-vs-Bishop-updated.pdf, p. 2 (Analysis 2: 30 kPa over 3 m)	1.261 (PLAXIS 2D)	1.261	felaLower: 1.2551; felaUpper: 1.2625; lem: (bishop: 1.2721; spencer: 1.2689; morgenstern-price: 1.2694)	−0.17 %	—	Pass
k5c-vertical-cut	stability number γH/cu of an unsupported vertical cut (Tresca), gravity multiplier [-]	../_founder_2026-10-15/Lyamin-Sloan-2002_Upper-bound-limit-analysis-linear-FE-and-nonlinear-programming_IJNAMG-26_36p.pdf, p. §4.3, Table IV	—	3.772–3.7845	lower: 3.7577; upper: 3.7927; errorPct: 0.46	—	—	Pass
k5b-plaxis-2d-tut2-drained	Tutorial 2, embankment on DRAINED HS clay: uy at the crest (23,4), centre base (25,0), 2 m beyond the toe (38,0) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 40–46 (Fig. 2-7: figures only)	—	—	crest: -226.7; centre base: -177.9; beyond toe (38,0): 0.6	—	—	Recorded, no published value
k5b-plaxis-2d-tut2-undrained	Tutorial 2, embankment on UNDRAINED (A) HS clay: construction completes [ΣMstage]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 44–47 (Figs 2-7, 2-8)	1	—	1	0.00 %	—	Pass
k5a-phic-bishop-analysis1	factor of safety ΣMsf, embankment 1:2, no load (Analysis 1) [-]	PLAXIS-Verification-Phi-c-reduction-vs-Bishop-updated.pdf, p. 1–3	1.54	1.534	1.53867	−0.09 %	+0.30 %	Pass
k5a-phic-bishop-analysis2	factor of safety ΣMsf after a 30 kPa crest load (Analysis 2) [-]	PLAXIS-Verification-Phi-c-reduction-vs-Bishop-updated.pdf, p. 2–3	1.261	—	1.25937	−0.13 %	—	Pass
k5a-gl99-example1	factor of safety, homogeneous 2:1 slope, ϕ′ 20°, c′/γH 0.05, ψ 0, D = 1 [-]	Griffiths and Lane 1999.pdf (library root), p. 391–392, Table 2	—	1.35	1.3412	—	−0.65 %	Deviation
k5a-gl99-example3	factor of safety, undrained (ϕu = 0) 2:1 slope on a foundation, cu/γH 0.25, D = 2, homogeneous [-]	Griffiths and Lane 1999.pdf (library root), p. 394, Fig. 7	—	1.47	1.45234	—	−1.20 %	Pass
k5a-tut2-safety-drained	factor of safety ΣMsf, embankment on drained clay (Phase 3) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 47–51 (Fig. 2-14)	1.8	—	1.84688	+2.60 %	—	Pass
k5a-tut2-safety-undrained	factor of safety ΣMsf, embankment on undrained (A) clay (Phase 4) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 47–51 (Fig. 2-14)	1.4	—	1.14911	−17.9 %	—	Superseded
k5d-plaxis-2d-tut2-safety	Tutorial 2 as ONE project (Phase 2 changes the clay to its undrained (A) copy — per-phase material change); ΣMsf of the Safety phases 3 (drained) / 4 (undrained), real Hardening Soil → Mohr–Coulomb at frozen start stiffness [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 47–51 (p. 51, Fig. 2-14: 'factor of safety of 1.8 … Phase 3', '1.4 … Phase 4')	drained: 1.8; undrained: 1.4	—	drained: 1.8563; undrained (phase 2 completed under the default policy — the PLAXIS-comparable value): 1.3814	drained: 3.13; undrained: -1.33	—	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k5d-plaxis-2d-tut2-undrained-construction	Tutorial 2 Phase 2: embankment construction on UNDRAINED (A) HS clay — ΣMstage reached; uy crest (23,4) / centre base (25,0) / beyond the toe (38,0); max p_excess [ΣMstage, mm, kPa]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 44–47 (Figs 2-7, 2-8: figures only)	completes (ΣMstage 1); toe heave, p_excess highest under the embankment (figures)	—	default policy (strict, then the PLAXIS criterion with the initial stiffness — D124 + D684): (ΣMstage: 1; uy crest mm: -508.3; uy centre base mm: -250; uy (38,0) mm: 114.1; max p_excess kPa: 48.13; steps / cuts: [133, 0]; strict stop (reported in the warning): 0.587756)	—	—	Pass
k5d-benchmark-embankment-soft-clay	SCMEP soft-clay embankment, Soft Soil (USTUTT set): centreline settlement after undrained construction / after 100 years, p_excess at (0, −2.5) [m, kPa]	PLAXIS-Verification-Benchmark-embankment-soft-clay-workshop.pdf (Wiltafsky et al. 2003), p. 2–5 (Fig. 1, Tables 1–2; Figs 2a, 2d, 3a, 3d read)	SS USTUTT settlement after construction (Fig. 2a): 0.18; after 100 years (Figs 3a, 3d): 1.05; p_excess (0,-2.5) (Fig. 2d): -34	other models after construction: 0.11–0.24 m; after 100 years: 1.10–1.60 m	tol 1e-8 (530 T15, 9 Nov 2026): after the D557 mesh change layer 1 stops at ΣMstage 0.8515 (92 steps); settlement (0,0) 0.0167 m there; layer 2 fails at ΣMstage about 0; consolidation takes 0 steps (Modal, agent medium-d627, D627). X2 verdict numerical-stall, best ratio 1.0008e-8 vs 1e-8. tol 1e-3 not re-measured on this mesh; tol 1e-8 (712 T15, before 7 Nov): layer 1 stops at ΣMstage 0.6515 (arc-length increment below its minimum); settlement (0,0) 0.0129 m there; tol 1e-3: layer 1 completes (19 steps); layer 2 reaches ΣMstage 0.918 in maxSteps 1000; plaxis (ALG-1): layer 1 (bounded probe, maxSteps 15): ΣMstage 0.66, 878 iterations, 5 cuts; layers 1–2 NOT completed within the 6-min run cap (not measured); without the local rule layer 1 completes (6 steps, 266 iterations); strict tol 1e-2: 5 steps, 31 iterations	—	—	Deviation

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k5d1-plaxis-2d-tut4-safety-phase7	ΣMsf of the Safety phase after the second excavation (phase 3) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 90–91 (Fig. 4–21, figure read: ≈ 1.33)	1.33	—	—	—	—	Deviation
k5d1-plaxis-2d-tut4-safety-phase8	ΣMsf of the Safety phase after the wall and backfill (phase 6) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 90–91 (Fig. 4–21, figure read: ≈ 1.83)	1.83	—	—	—	—	Deviation
alg1-plaxis-2d-tut4-repro-safety-phase7	ΣMsf of the Safety phase after the second excavation (phase 3) — PLAXIS-REPRODUCTION variant (cable strength per metre, reduced in Safety; PLAXIS-parity convergence) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 90–91 (Fig. 4–21, figure read: ≈ 1.83)	1.33	—	1.2852	−3.37 %	—	Pass
alg1-plaxis-2d-tut4-repro-safety-phase8	ΣMsf of the Safety phase after the wall and backfill (phase 6) — PLAXIS-REPRODUCTION variant (cable strength per metre, reduced in Safety; PLAXIS-parity convergence) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 90–91 (Fig. 4–21, figure read: ≈ 1.83)	1.83	—	1.668	−8.85 %	—	Pass
geostudio-swv-acads-1a-janbu-simplified	Janbu simplified factor of safety on the searched critical circle (ACADS 1(a): c' 3 kPa, phi' 19.6 deg, gamma 20 kN/m3) [-]	Seequent-GeoStudio-SLOPEW-Slope-Stability-Verification-Manual-current.pdf, p. 2 (§2.1 ACADS Simple Slope, Table 2)	—	0.939	0.9351	—	−0.42 %	Pass
geostudio-swv2022-acads-1a-janbu-corrected	Janbu corrected (f0) factor of safety on the searched critical circle (ACADS 1(a): c' 3 kPa, phi' 19.6 deg, gamma 20 kN/m3) [-]	Seequent-GeoStudio-SLOPEW-Slope-Stability-Verification-Manual-Oct2022.pdf, p. 2 (§2.1 ACADS Simple Slope, Table 2)	—	0.992	0.9854	—	−0.66 %	Pass
geostudio-hand-bishop-specified-circle	Bishop factor of safety on the manual's ONE specified slip circle (simple 2h:1v slope, 10 m high, c' 5 kPa, phi' 30 deg, gamma 20 kN/m3, 29 slices, phreatic line through the toe) [-]	Seequent-GeoStudio-SLOPEW-Verification-Hand-Calculations.pdf, p. 3–8 (Table 1 slice data p. 3; Bishop iteration Tables 3–6 pp. 6–8)	—	1.249	1.2463	—	−0.22 %	Pass

Cited validation suites — 16

embankment-stability-web-validation.test.ts

embankment-stability (embankment basal stability, `computeEmbankmentBasalStability` in `embankment-rehab.ts`) — validation against PUBLISHED values.

Analyses validated: `embankment-stability` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[H] Han Design Example 7.1 stage 1: γ = 19.7, cu = 24, Nc = 5.14, FS = 1.3 → H1 = 4.8 m	Pass
[H] Han Example 7.1: the 4.5 m first stage actually placed meets the required FS = 1.3	Pass
[F] default Nc is the ϕ = 0 bearing factor 2 + π = 5.14 (FHWA Eq. 8-4; Craig qf = 5.14·cu)	Pass
definition (hand-derived): FoS = Nc·cu/(γH + q); inputs ≤ 0 are refused	Pass

fe-slope-srm-layered-water-web-validation.test.ts

C.FE.1 + A.5 web-benchmark & cross-validation — multi-layer + water-table effective-stress FE strength-reduction slope stability.

Analyses validated: `fe-slope-stability` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C.FE.1: water table at the base (elev 0) ≡ dry (u=0 everywhere)	Pass
C.FE.1: two identical layers ≡ homogeneous (exact regression)	Pass
C.FE.1: empty/invalid layers array falls back to the scalar soil	Pass
B: Griffiths & Lane (1999) Example 1 — dry homogeneous unchanged (1.367 on the conforming mesh)	Pass
C: dry homogeneous FE ↔ Bishop LEM agree within method spread	Pass
D: raising the water table lowers FoS (monotonic, correct direction)	Pass
D: partially-saturated FE ↔ Bishop LEM agree (same phreatic surface)	Pass
D: a mid-height water table drives the slope to marginal stability — FE and LEM agree	Pass
D: a fully-saturated profile fails, and FE ↔ LEM still agree	Pass
E: a weak surface layer lowers FoS below the strong-homogeneous case	Pass
E: a strong crust over weak clay ↔ Bishop LEM agree within spread	Pass
A.5: plastic-zone + shear-strain fields are exported and sane	Pass
A.5: dry slope reports no pore pressure influence; fields still present	Pass

fe-slope-stability-web-validation.test.ts

REAL PUBLISHED WORKED EXAMPLE (not formula-fidelity -- an independently- published answer) from Griffiths, D.V.

Analyses validated: `fe-slope-stability` · Recorded run: passed — 18 test block(s), 1 skipped

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] GL99 Example 1 geometry check: c'/(gamma.H) = 10/(20.10) = 0.05 exactly, matching the paper's stated case	Pass
[2] the FE strength-reduction FoS is within 15% of the paper's published FOS=1.4 (coarse 6-row mesh vs the paper's finer mesh; the codebase's own Morgenstern-Price limit-equilibrium cross-check gives 1.369 for the identical slope)	Pass
[3] the iteration-count signature GL99 describe (ballooning iterations near the critical SRF, the numerical fingerprint of true collapse) is reproduced	Pass
[4] a steeper slope (1:1 vs 2:1) gives a LOWER factor of safety, all else equal (monotone in slope angle, the basic physical trend)	Pass
[5] a weaker soil (lower cohesion) gives a LOWER factor of safety, all else equal	Pass
[6] a higher friction angle gives a HIGHER factor of safety, all else equal	Pass
[7] a submerged (water table at crest) slope gives a LOWER factor of safety than the dry case, per the effective-stress SRM (pore pressure reduces the normal effective stress on potential failure surfaces)	Pass
[8] invalid inputs (zero height, zero slope ratio) are refused	Pass
[9] pathological (absurdly large) geometry returns a clean error rather than crashing the process	Pass
[VAL-1] ACADS 1(a): FE strength-reduction FoS lies inside the published cross-code envelope 0.94-1.00 (lowest vendor value 0.939 .. ACADS referee 1.00)	Pass
[VAL-1] ACADS 1(a): FE strength-reduction FoS within 3 % of RS2 SSR 0.99 Why: VAL1-FE-1: RS2 SSR 0.99 (critical SRF 0.995) is above the rigorous upper bound 0.984, so a 3 % band around it is not a correctness criterion. Default is 0.9609 after VAL1-FE-2 (was 0.9453, 4.5 % low). See MEDIUM-ACADS-REPORT.md / MEDIUM-D612-REPORT.md	To do — not asserted
[VAL-1] ACADS 1(a), rows 4: ψ = 0 FE-SRM FoS ≤ the rigorous associated upper bound 0.984 and ≥ 0.94 (conforming mesh, no staircase collapse)	Pass
[VAL-1] ACADS 1(a), rows 6: ψ = 0 FE-SRM FoS ≤ the rigorous associated upper bound 0.984 and ≥ 0.94 (conforming mesh, no staircase collapse)	Pass
[VAL-1] ACADS 1(a), rows 8: ψ = 0 FE-SRM FoS ≤ the rigorous associated upper bound 0.984 and ≥ 0.94 (conforming mesh, no staircase collapse)	Pass
[VAL-1] the slope face is a straight mesh edge: every boundary node on the face lies on the line from crest (H, H) to toe (W, 0)	Pass
[VAL1-FE-2] ACADS 1(a), rows 4: FoS within one bisection cell (1/64) of the uncapped reference 0.9824, and ≤ the Optum bound 0.984	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[VAL1-FE-2] ACADS 1(a), rows 8: FoS within one bisection cell (1/64) of the uncapped reference 0.9629, and ≤ the Optum bound 0.984	Pass
[VAL1-FE-2] ACADS 1(a), rows 12: FoS within one bisection cell (1/64) of the uncapped reference 0.959, and ≤ the Optum bound 0.984	Pass
[VAL1-FE-2] ACADS 1(a): a slow-converging trial runs past the old 1 500 cap, and clear collapses stop early	Pass

infinite-slope-web-validation.test.ts

PUBLISHED-VALUES: 18 -- distinct published values for this engine (engine-level total, declared once); independent audit A3: about 18 distinct published values (Duncan & Wright is quoted through the Slide manual).

Analyses validated: `infinite-slope` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[C] Craig Ex. 12.3(a): φ′cv = 28° — τmob = 20.3 kPa, τf = 20.7 kPa, ULS satisfied	Pass
[C] Craig Ex. 12.3(b): φ′r = 20° — τf = 14.2 kPa, τmob unchanged, ULS NOT satisfied	Pass
[E] Example E-5, seepage parallel (ru = 0.325): published F = 1.63	Pass
[E] Example E-5, horizontal seepage (ru = 0.52): published F = 1.30	Pass
[E] Example E-5: friction term A·tanφ′/tanβ = 0.98 and 0.65; cohesion term B·c′/γH = 0.65	Pass
[E] Example E-5 chart coefficients recovered from the engine: A = 0.62 / 0.41, B = 3.1	Pass
[E] ru → pore pressure is u = ru·γ·z (Eq. E-12), the input the chart method is entered with	Pass
[L] Example 24.2: submerged slope, γb·H·cos²i — published coefficient 28.73 kN/m²	Pass
[L] Example 24.1: seepage-parallel limiting slope tan i = (γb/γt)·tanφ̄ = 0.182 → FoS = 1	Pass
[L] Example 24.1: printed c̄/γt = 0.245 is the cohesion ratio of the engine run	Pass
[D] Slide verification #79 (D&W Fig. 14.4): φ′ = 30°, 2.5H:1V → reference FoS 1.44	Pass
[D] Slide verification #81 (D&W Fig. 14.7): φ′ = 30°, 2H:1V → reference FoS 1.15	Pass
[D] FoS is independent of unit weight and depth for a dry cohesionless slope (FHWA/Slide statement)	Pass
[H] Han Eq. 2.82: γ′/γsat = 0.5 ⇒ seepage FoS = ½ · dry FoS; φ′ = 30° limiting angle ≈ 16°	Pass
input guards: β outside (0,90), φ ≥ 90, missing γsat and missing ru are refused	Pass

⚑ probabilistic-slope-web-validation.test.ts

probabilistic-slope — dedicated validation against a PUBLISHED worked reliability example (`probabilistic-slope.ts`).

Analyses validated: `probabilistic-slope` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[MIT] Table 1 slope: deterministic F = 1.15 and the slope is stable	Pass
[MIT] FOSM: Var[F] = 0.0467	Pass
[MIT] FOSM: β = 0.714 and Pf = Φ(−0.714) = 0.237	Pass
[MIT] Monte Carlo: Pf ≈ 0.223 within three standard errors of the difference	Pass
[MIT] FOSM and MC agree with the note's remark that near-linearity makes all three Pf close (0.223-0.237)	Pass
HAND-CHECK: σ_F equals the closed-form first-order variance (no finite-difference step bias)	Pass
definition: β = (μ_F − 1)/σ_F and Pf = Φ(−β) (Baecher & Christian 2003 Eq. 14.3)	Pass
all-zero COVs are refused (deterministic analysis dressed as reliability)	Pass

rapid-drawdown-web-validation.test.ts

Validation for the rapid (sudden) drawdown engine (`rapid-drawdown.ts`) — the improved Duncan-Wright-Wong three-stage method of USACE EM 1110-2-1902 App.

Analyses validated: `rapid-drawdown` · Recorded run: passed — 43 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
A. Kf(φ'=30, c'=0) = tan²(45+φ/2) = 3 (EM G-7)	Pass
A. Kf(φ'=35, c'=0) = tan²(45+φ/2) = 3.6902 (EM G-7)	Pass
A. Kf(φ'=20, c'=0) = tan²(45+φ/2) = 2.0396 (EM G-7)	Pass
A. Kf(φ'=25, c'=0) = tan²(45+φ/2) = 2.4639 (EM G-7)	Pass
A. Kf(φ'=40, c'=0) = tan²(45+φ/2) = 4.5989 (EM G-7)	Pass
A6. Kf with c'>0 grows with c' at fixed σ'fc (EM G-8)	Pass
B1. cR=0 ⇒ d_{Kc=1} = 0 (EM G-5)	Pass
B2. ψ_{Kc=1}(cR=0, φR=20, φ′=30) = atan(sinφR·cosφ′/(1−sinφR)) ≈ 24.24° (EM G-6)	Pass
B3. φR = 0 ⇒ ψ = 0 and d = 0 (no undrained strength gain from an isotropic frictionless R-envelope)	Pass
C1. isotropic consolidation (τc = 0) ⇒ Kc = 1 (EM G-11)	Pass
C2. adding consolidation shear raises Kc above 1 (EM G-11)	Pass
D1. at isotropic (Kc=1) τff = d + σ′c·tanψ (the Kc=1 envelope, EM G-9)	Pass
D2. τff is bounded by the two envelopes (EM G-12 interpolation)	Pass
D3. τff scales with the consolidation stress σ′c	Pass
D4. τff is never negative	Pass
E1. rapid drawdown REDUCES the factor of safety vs the full reservoir	Pass
E2. stage-3 (min of drained/undrained) ≤ stage-2 (undrained)	Pass
E3. complete drawdown is the most critical — FoS rises as the drawn-down level rises	Pass
E4. stronger friction raises the rapid-drawdown FoS	Pass
E5. more cohesion raises the rapid-drawdown FoS	Pass
E6. the drawdown FoS ratio is reported and < 1 (drawdown always costs stability)	Pass
E7. a valid critical circle and full slice table are returned	Pass
E8. input guards: drawn-down level above full pool is rejected	Pass
F1. Fig. G-5: Kc=1 envelope from the R-envelope (cR = 1200 psf, φR = 16°, φ′ = 30°) → d = 1379 psf, ψ = 18.2° (EM G-5/G-6)	Pass
F2. Fig. G-10b/G-11: Kf = tan²(45+φ′/2) = 3.00 for φ′ = 30°, c′ = 0 (EM G-26)	Pass
F3.1. Fig. G-10b slice 1 (σ′c 0.32, τc 0.08 ksf): Kc 1.71, τff(Kc=1) 1.49, τff(Kc=Kf) 0.19, τff 1.02 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.2. Fig. G-10b slice 2 (σ′c 1.44, τc 0.38 ksf): Kc 1.71, τff(Kc=1) 1.85, τff(Kc=Kf) 0.83, τff 1.49 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.3. Fig. G-10b slice 3 (σ′c 2.9, τc 0.76 ksf): Kc 1.71, τff(Kc=1) 2.33, τff(Kc=Kf) 1.67, τff 2.1 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.4. Fig. G-10b slice 4 (σ′c 3.64, τc 0.95 ksf): Kc 1.71, τff(Kc=1) 2.58, τff(Kc=Kf) 2.1, τff 2.41 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.5. Fig. G-10b slice 5 (σ′c 4.05, τc 1.06 ksf): Kc 1.71, τff(Kc=1) 2.71, τff(Kc=Kf) 2.34, τff 2.58 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.6. Fig. G-10b slice 6 (σ′c 4.45, τc 1.17 ksf): Kc 1.71, τff(Kc=1) 2.84, τff(Kc=Kf) 2.57, τff 2.75 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.7. Fig. G-10b slice 7 (σ′c 4.57, τc 1.2 ksf): Kc 1.71, τff(Kc=1) 2.88, τff(Kc=Kf) 2.64, τff 2.8 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.8. Fig. G-10b slice 8 (σ′c 4.54, τc 1.19 ksf): Kc 1.71, τff(Kc=1) 2.87, τff(Kc=Kf) 2.62, τff 2.78 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.9. Fig. G-10b slice 9 (σ′c 4.31, τc 1.13 ksf): Kc 1.71, τff(Kc=1) 2.8, τff(Kc=Kf) 2.49, τff 2.69 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.10. Fig. G-10b slice 10 (σ′c 3.66, τc 0.96 ksf): Kc 1.71, τff(Kc=1) 2.58, τff(Kc=Kf) 2.11, τff 2.42 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.11. Fig. G-10b slice 11 (σ′c 2.6, τc 0.68 ksf): Kc 1.71, τff(Kc=1) 2.23, τff(Kc=Kf) 1.5, τff 1.97 ksf (EM G-24, G-9, G-10, G-27)	Pass
F3.12. Fig. G-10b slice 12 (σ′c 1.01, τc 0.27 ksf): Kc 1.71, τff(Kc=1) 1.71, τff(Kc=Kf) 0.59, τff 1.31 ksf (EM G-24, G-9, G-10, G-27)	Pass
F4a. Stage-3 rule on the published tables: drained strength governs on exactly slices 1, 2 and 12 (EM §G-6e)	Pass
F4b. Stage 1 (Simplified Bishop, c′ = 0, φ′ = 30°, full pool): F = 2.20 (EM Fig. G-10a, ±0.06 = 2σ of table rounding)	Pass
F4c. Stage 2 (undrained τff as c, φ = 0): F = 1.52 (EM Fig. G-11a, ±0.02 = 2σ of table rounding)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
F4d. Stage 3 (drained strength on slices 1, 2, 12): F = 1.44 (EM Fig. G-11c, ±0.02 = 2σ of table rounding)	Pass
F4e. Published ordering: F1 (2.20) > F2 (1.52) > F3 (1.44) — the THIRD stage governs	Pass
F5. End-to-end on the EM slope (2.84:1 average face, 110 ft, γ 135 pcf, pool 103 → 24 ft): third stage governs and the critical FoS lies at or below the EM non-critical-circle 1.44	Pass

seepage-slope-stability-web-validation.test.ts

WEB-BENCHMARK validation for the coupled steady-seepage → slope-stability engine (the release rules ≥20 cited-value gate).

Analyses validated: `seepage-slope-stability` · Recorded run: passed — 36 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Inf-slope DRY c'=0: FoS = tanϕ/tanβ ϕ=30° β=20° (Skempton-DeLory 1957)	Pass
Inf-slope DRY c'=0: FoS = tanϕ/tanβ ϕ=35° β=25° (Skempton-DeLory 1957)	Pass
Inf-slope DRY c'=0: FoS = tanϕ/tanβ ϕ=32° β=18° (Skempton-DeLory 1957)	Pass
Inf-slope DRY c'=0: FoS = tanϕ/tanβ ϕ=28° β=22° (Skempton-DeLory 1957)	Pass
Inf-slope DRY c'=0: FoS = tanϕ/tanβ ϕ=40° β=30° (Skempton-DeLory 1957)	Pass
Inf-slope DRY c'=0: FoS = tanϕ/tanβ ϕ=25° β=15° (Skempton-DeLory 1957)	Pass
Inf-slope SEEPAGE-PARALLEL c'=0: FoS = (γ'/γsat)·tanϕ/tanβ ϕ=30° β=20° (Craig/Das)	Pass
Inf-slope SEEPAGE-PARALLEL c'=0: FoS = (γ'/γsat)·tanϕ/tanβ ϕ=35° β=25° (Craig/Das)	Pass
Inf-slope SEEPAGE-PARALLEL c'=0: FoS = (γ'/γsat)·tanϕ/tanβ ϕ=32° β=18° (Craig/Das)	Pass
Inf-slope SEEPAGE-PARALLEL c'=0: FoS = (γ'/γsat)·tanϕ/tanβ ϕ=34° β=24° (Craig/Das)	Pass
Inf-slope SEEPAGE-PARALLEL c'=0: FoS = (γ'/γsat)·tanϕ/tanβ ϕ=30° β=15° (Craig/Das)	Pass
Inf-slope: seepage-parallel FoS ≈ 0.5× dry when γ_sat ≈ 2γ_w (γ_sat=19.62)	Pass
Inf-slope SUBMERGED c'=0: FoS = tanϕ/tanβ (= dry, buoyancy) ϕ=30° β=20°	Pass
Inf-slope SUBMERGED c'=0: FoS = tanϕ/tanβ (= dry, buoyancy) ϕ=34° β=26°	Pass
Inf-slope regime ordering: dry > seepage-parallel > rapid-drawdown (c′=0)	Pass
Inf-slope seepage-parallel: u = γ_w·z·cos²β (u = γ_w·h_p)	Pass
Inf-slope r_u override: u = r_u·γ·z (r_u=0.1)	Pass
Inf-slope r_u override: u = r_u·γ·z (r_u=0.25)	Pass
Inf-slope r_u override: u = r_u·γ·z (r_u=0.5)	Pass
Inf-slope r_u: FoS decreases monotonically as r_u rises	Pass
Inf-slope cohesive seepage worked example → FoS ≈ 1.031 (Craig/Das closed form)	Pass
Bishop search DRY c'≈0: FoS → tanϕ/tanβ ϕ=30° β=18.43° (Skempton-DeLory 1957)	Pass
Bishop search DRY c'≈0: FoS → tanϕ/tanβ ϕ=35° β=21.8° (Skempton-DeLory 1957)	Pass
Bishop search DRY c'≈0: FoS → tanϕ/tanβ ϕ=32° β=26.57° (Skempton-DeLory 1957)	Pass
Bishop search DRY c'≈0: FoS → tanϕ/tanβ ϕ=38° β=18.43° (Skempton-DeLory 1957)	Pass
Bishop search ϕ=0 vs Taylor Ns β=60° (Ns=0.191): F=c/(γHNs)	Pass
Bishop search ϕ=0 vs Taylor Ns β=53.13° (Ns=0.182): F=c/(γHNs)	Pass
Bishop dry search == closed-form infinite-slope FoS at the cohesionless limit	Pass
Bishop on a large-radius circle → closed-form tanϕ/tanβ (explicit circle)	Pass
Bishop: seepage-parallel FoS < dry FoS, and reduction is reported > 0	Pass
Bishop: FoS decreases monotonically as the phreatic surface rises	Pass
Bishop: increasing r_u monotonically lowers FoS (u = r_u·γ·z)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bishop slices: u = γ_w·h_p on every slice; max u>0 wet, =0 dry	Pass
Engine returns a finite closed-form infinite-slope cross-check	Pass
Guard: c′=0 AND ϕ′=0 is rejected with an error (no shear strength)	Pass
Guard: non-positive height is rejected with an error	Pass

slope-stability-craig-ex122-web-validation.test.ts

Circular method-of-slices slope stability — validated against a PUBLISHED WORKED EXAMPLE on the published circle.

Analyses validated: `slope-stability` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] the published geometry is self-consistent: the circle passes through the toe	Pass
[3-5] Craig Eq 12.19 reproduced from his own Table 12.1 sums	Pass
[6-8] the engine on the published circle reproduces the published factors of safety	Pass
[9] the RATIO — the anchor that geometry error cannot hide behind	Pass
[10-11] the published finding survives in the engine, not just in the arithmetic	Pass
[12-15] a prescribed circle is used VERBATIM — no search, no substitution	Pass
[16-17] the SEARCH finds something at least as critical as the published circle	Pass
[18-20] omitting trial_circle changes nothing — the search path is untouched	Pass

slope-stability-geometry-web-validation.test.ts

slope-stability — POLYLINE GEOMETRY validation (stage A: ground_profile, layer bottom_profile, piezometric_line, rigid_base_y_m).

Analyses validated: `slope-stability` · Recorded run: passed — 16 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[S3] the printed critical circle meets the read-off ground exactly at the printed endpoints	Pass
[S3] ACADS 1(c) on the printed circle: Bishop 1.405, Spencer 1.375, GLE 1.374	Pass
[S4] ACADS 1(d) kh = 0.15 on the printed circles: Bishop 1.016, Spencer 0.991, GLE 0.989	Pass
[S4] the pseudo-static force acts at the slice CENTROID (Kramer 1996 §10.6.1.1; FHWA GEC-3 §6.2.2)	Pass
[S3] ACADS 1(c) grid search with the rigid base 5 m below the toe: Bishop 1.405, Spencer 1.375	Pass
[S3] the grid search honours the rigid base — no critical circle dips below y = −5	Pass
[S4] ACADS 1(d) grid search: Bishop 1.016, Spencer 0.991	Pass
[S16] Arai & Tagyo Ex 3 with its printed polyline water table: Bishop 1.118, Spencer 1.118	Pass
[S16] u is γw × the vertical distance to the line, clamped to the ground	Pass
[EM] EM 1110-2-1902 F-5 end-of-construction: Simplified Bishop 1.33 on the prescribed circle	Pass
[EM] slices crossing EL 0 weigh both soils; the base soil sets the strength	Pass
[compat] F&K dry prescribed circle (Bishop 2.080 F&K / 2.079 Slide): same result with an equivalent ground_profile	Pass
[compat] ACADS 1(a) grid search (Bishop 0.987 Slide): same result with an equivalent ground_profile	Pass
[compat] polyline-layer mode with ONE soil split in two reproduces the band result	Pass
circle crossing a polyline 4 times: the slip mass is the span containing the lowest point	Pass
malformed / inconsistent geometry is refused with a clear error	Pass

⚑ slope-stability-noncircular-search-web-validation.test.ts

slope-stability — SEARCH for the critical non-circular surface (`noncircular_search`), 2026-10-03.

Analyses validated: `slope-stability` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[S14] Arai & Tagyo Ex 1 Janbu search: simplified 1.253 (Slide) / 1.265 (A&T), corrected 1.346 / 1.357	Pass
[S14] Arai & Tagyo Ex 1 Spencer search: 1.386 (Slide), below the best circle	Pass
[S16] Arai & Tagyo Ex 3 Janbu search: simplified 0.968 / 0.995, corrected 1.050 / 1.071	Pass
[S16] Arai & Tagyo Ex 3 Spencer search: 1.094 (Slide)	Pass
[S7] ACADS 3(a) weak seam: Spencer 1.246 (Slide), inside the Giam & Donald reference range 1.24 – 1.27	Pass
the search is deterministic and refuses methods defined only for circles	Pass

slope-stability-noncircular-web-validation.test.ts

slope-stability — NON-CIRCULAR slip surfaces (stage C): General Limit Equilibrium (Fredlund & Krahn 1977) Spencer and Morgenstern-Price, Janbu simplified and Janbu (1973) corrected, on a prescribed polyline `slip_surface`.

Analyses validated: `slope-stability` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[S8] ACADS 3(b) prescribed non-circular surface: Spencer 1.277, GLE 1.262, Janbu corrected 1.294	Pass
[S8] slices break at the seam crossing: no base straddles two materials	Pass
[S22] F&K composite circle, dry: Spencer 1.382 (Slide) / 1.373 (F&K), M-P 1.372 / 1.37	Pass
[S22] F&K composite circle, ru 0.25: Spencer 1.124 (Slide) / 1.118 (F&K), M-P 1.114 / 1.118	Pass
GLE(f = 1) = circular Spencer on the F&K circle, dry	Pass
GLE(f = 1) = circular Spencer on the F&K circle, ru 0.25	Pass
GLE(f = 1) = circular Spencer on the F&K circle, k_h 0.15	Pass
GLE(f = 1) = circular Spencer on the F&K circle, water-filled 3 m crack	Pass
a slip_surface that traces the F&K circle reproduces the prescribed-circle result	Pass
slip_surface refusals are explicit	Pass

slope-stability-strip-load-web-validation.test.ts

slope-stability — STRIP LOADS (offset surcharge), 2026-10-03.

Analyses validated: `slope-stability` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[MKB Table 1] β = 30°: Spencer 1.36, Bishop 1.37 (SLIDE 6.0)	Pass
[MKB Table 1] β = 45°: Spencer 1, Bishop 1.01 (SLIDE 6.0)	Pass
[MKB Table 1] β = 60°: Spencer 0.79, Bishop 0.8 (SLIDE 6.0)	Pass
[MKB Table 3] example 2: Spencer 0.7 (SLIDE 6.0), inside the FELA bracket 0.69–0.71	Pass
a strip load covering the whole crest region equals the existing crest surcharge	Pass
physics: FoS falls with load magnitude and recovers with setback (MKB §3.2–3.3 trends)	Pass
linearly varying pressure is integrated exactly (trapezoid force and centroid)	Pass
refusals: reversed span, negative pressure, non-finite values	Pass

slope-stability-tension-crack-web-validation.test.ts

slope-stability — TENSION CRACK (stage B) and the JANBU SIMPLIFIED kernel.

Analyses validated: `slope-stability` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[S2] ACADS 1(b) on the printed circle: Bishop 1.596, Spencer 1.592, GLE 1.592	Pass
[S2] ACADS 1(b) grid search: Bishop 1.596, Spencer 1.592	Pass
[S2] the crack truncates the slip at depth_m and the water thrust is ½γw·hw² at hw/3	Pass
Craig 8e p. 474 — ϕ = 0 with a water-filled crack: the engine equals the moment equation	Pass
[S56] Pockoski & Duncan slope 2 on the printed circle: Spencer 1.290, Bishop 1.285; endpoints as printed	Pass
[S56] grid search: Bishop 1.285, Spencer 1.290, Janbu simplified 1.141	Pass
[S16] Arai & Tagyo circular: Janbu simplified 1.046 (Slide Table 16.2)	Pass
invalid tension-crack input is refused with a clear error	Pass

slope-stability-web-validation.test.ts

WEB-BENCHMARK validation for the circular method-of-slices slope engine (the release rules ≥20 cited-value gate).

Analyses validated: `slope-stability` · Recorded run: passed — 26 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Slope web: c=0 FoS=tanϕ/tanβ ϕ=25° 2:1 (β=26.6°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=25° 2.5:1 (β=21.8°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=25° 3:1 (β=18.4°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=25° 4:1 (β=14.0°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=30° 2:1 (β=26.6°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=30° 2.5:1 (β=21.8°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=30° 3:1 (β=18.4°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=30° 4:1 (β=14.0°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=35° 2:1 (β=26.6°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=35° 2.5:1 (β=21.8°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=35° 3:1 (β=18.4°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=35° 4:1 (β=14.0°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=40° 2:1 (β=26.6°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=40° 2.5:1 (β=21.8°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=40° 3:1 (β=18.4°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=40° 4:1 (β=14.0°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=45° 2:1 (β=26.6°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=45° 2.5:1 (β=21.8°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=45° 3:1 (β=18.4°)	Pass
Slope web: c=0 FoS=tanϕ/tanβ ϕ=45° 4:1 (β=14.0°)	Pass
Slope web: ϕ=0 undrained vs Taylor Ns β=60° (Ns=0.191)	Pass
Slope web: ϕ=0 undrained vs Taylor Ns β=53.13° (Ns=0.182)	Pass
Slope E-113: an INVERTED layer must be rejected, not silently read as the deepest layer	Pass
Slope E-113: layer elevations ARE honoured — order of strata changes FoS	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Slope E-113: a gap or overlap in the profile must be reported	Pass
Slope E-113: non-finite and non-physical layer properties must be rejected	Pass

slope-stability-worked-examples-web-validation.test.ts

slope-stability — FULL WORKED EXAMPLES (the ≥20-value gate).

Analyses validated: `slope-stability` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[FK] dry: Ordinary 1.928 / 1.931 (F&K / Slide)	Pass
[FK] dry: Bishop 2.080 / 2.079 — read from `critical.fos`, which must now BE Bishop	Pass
[FK] dry: Spencer 2.073 / 2.075	Pass
[FK] dry: Morgenstern-Price 2.076 / 2.075	Pass
[FK] ru 0.25: Ordinary 1.607 (F&K; Slide 1.687 uses a different ru convention)	Pass
[FK] ru 0.25: Bishop 1.766 / 1.763, Spencer 1.761 / 1.760, M-P 1.764 / 1.760	Pass
Spencer picks the PHYSICAL root: F&K θ ≈ +14°, and Spencer ≈ Bishop on the same circle	Pass
[AT] Arai & Tagyo Ex 3 (horizontal water-table approximation): Spencer takes the physical root, ≈ Bishop	Pass
Morgenstern-Price with f(x) = constant reduces to Spencer	Pass
[SLIDE] HC#1 dry: Bishop 2.113	Pass
[SLIDE] HC#2 water table at surface: Bishop 1.554	Pass
[ACADS] 1(a): Bishop 0.987, Spencer 0.986, M-P 0.986; ACADS reference 1.00	Pass
[ACADS] 1(a): Janbu simplified (uncorrected) 0.939 (SLOPE/W §2.1 Table 2)	Pass
[CRAIG] Ex 12.1: ϕu = 0, F = 2.48 (graphical area 70 m², d 4.5 m) — and Spencer = Bishop	Pass
[VAR] Ex 24.1: ϕ = 0 — printed 1.14 uses a graphical area 7.5 % larger than its own geometry	Pass

taylor-stability-web-validation.test.ts

taylor-stability — dedicated validation against PUBLISHED worked answers (`taylor-stability.ts`).

Analyses validated: `taylor-stability` · Recorded run: passed — 18 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[F] Example 6-1, trial Fc=Fϕ=1.6, Ns=0.065: printed H = 40.1 ft	Pass
[F] Example 6-1, trial Fc=Fϕ=1.9, Ns=0.073: printed H = 30.04 ft and FS ≈ 1.9	Pass
[F] Example 6-1a table row Fϕ=1 (ϕd=20°, Ns=0.026): printed Fc = 5.3	Pass
[F] Example 6-1a table row Fϕ=1.5 (ϕd=14°, Ns=0.055): printed Fc = 2.5	Pass
[F] Example 6-1a table row Fϕ=2 (ϕd=10°, Ns=0.075): printed Fc = 1.9	Pass
[F] Example 6-1a table row Fϕ=2.5 (ϕd=8°, Ns=0.087): printed Fc = 1.6	Pass
[K] Craig Ex. 12.1(a): Ns = 0.18 → F = 2.37	Pass
[K] Craig Ex. 12.1(c): EC7 DA1b design cu = 65/1.40 → maximum cutting depth h ≤ 13.58 m	Pass
[V] Example 24.1 (Terzaghi Ns_T = 5.52, c = 25 kPa, γ = 19): H_c = 7.26 m, FoS(H = 6 m) = 1.21	Pass
[V] Example 24.3 (Ns_T = 7.8, c = 30, γ = 20, H = 8): F.S. against cohesion = 1.46	Pass
[V] Example 24.4 (Ns_T = 6.8, γ = 20, H = 8): required c = 23.5 kN/m², FoS on available c = 30 → 1.28	Pass
[V] Example 24.5 (γH_c/c = 7.2, c = 12, γ = 19 as used in the solution): H_c = 4.55 m, H(FS=1.5) = 3.03 m	Pass
[U] Example E-1 (N0 = 5.8, c = 452 psf, Pd = 2302 psf): F = 1.14	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[U] Example E-2 (N0 = 5.6, c = 499 psf, Pd = 2253 psf): F = 1.24	Pass
[U] Example E-3 (Ncf = 6, c = 735 psf, Pd = 4500 psf): F = 1.0	Pass
[U] Example E-4 (Ncf = 35, c = 134 psf, Pd = 4141 psf): F = 1.13	Pass
definition checks: c_d = Ns·γ·H, and FoS = 1 exactly at H = H_c	Pass
zero / negative / non-numeric Ns, γ or H are refused (no fabricated FoS)	Pass

Retaining walls, excavations and structural elements

FE kernel registry — 46 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-verif-confined-wall-Q	total discharge under the dam (impermeable wall, confined flow) [m³/day/m]	PLAXIS-Verification-Confined-flow-impermeable-wall-2018.pdf, p. 3 (Table 1)	0.818	0.82	0.81959	+0.19 %	−0.05 %	Pass
plaxis-verif-bending-plates-point-u	midspan deflection, point load F = 100 kN/m, L = 1 m, EA 1e5, EI 83.33, ν 0 (simply supported) [mm]	PLAXIS-Verification-Bending-of-plates.pdf, p. 2 (Output), 3–4 (Verification)	25.6	25.6	25.6	0.00 %	0.00 %	Pass
plaxis-verif-bending-plates-point-M	Mmax, point load [kNm/m]	PLAXIS-Verification-Bending-of-plates.pdf, p. 2–3	25	25	25	0.00 %	0.00 %	Pass
plaxis-verif-bending-plates-point-Q	Qmax, point load [kN/m]	PLAXIS-Verification-Bending-of-plates.pdf, p. 2–3	50.61	50	50	−1.21 %	0.00 %	Pass
plaxis-verif-bending-plates-dist-u	midspan deflection, distributed load q = 200 kN/m/m [mm]	PLAXIS-Verification-Bending-of-plates.pdf, p. 2–4	31.85	31.85	31.85	0.00 %	0.00 %	Pass
plaxis-verif-bending-plates-dist-M	Mmax, distributed load [kNm/m]	PLAXIS-Verification-Bending-of-plates.pdf, p. 2–3	25	25	25	0.00 %	0.00 %	Pass
plaxis-verif-bending-plates-dist-Q	Qmax, distributed load [kN/m]	PLAXIS-Verification-Bending-of-plates.pdf, p. 2–3	101.3	100	100	−1.28 %	0.00 %	Pass
plaxis-verif-sliding-block-force	sliding force at failure (plateau), push 1 mm [kN/m]	PLAXIS-Verification-Sliding-block-interfaces.pdf, p. 2–3 (Output; Verification)	60.08	60.076	60.0763	−6.0e-3 %	0.00 %	Pass
plaxis-verif-sliding-block-avg-tau	average maximum shear stress under the block [kPa]	PLAXIS-Verification-Sliding-block-interfaces.pdf, p. 2–3	15.06	15.019	15.0191	−0.27 %	+1.0e-3 %	Pass
plaxis-verif-pipe-capacity-r1.0	lateral load P at u = 0.08 m (1.6 % of D), strict convergence [kN/m]	PLAXIS-Verification-Circular-pipe-laterally-loaded-cohesive.pdf, p. 2 (Table 1)	300.8	298.5	299.87	−0.31 %	+0.46 %	Pass
plaxis-verif-pipe-capacity-r0.8	lateral load P at u = 0.08 m (1.6 % of D), strict convergence [kN/m]	PLAXIS-Verification-Circular-pipe-laterally-loaded-cohesive.pdf, p. 2 (Table 1)	290.9	289.1	290.51	−0.13 %	+0.50 %	Pass
plaxis-verif-pipe-capacity-r0.6	lateral load P at u = 0.08 m (1.6 % of D), strict convergence [kN/m]	PLAXIS-Verification-Circular-pipe-laterally-loaded-cohesive.pdf, p. 2 (Table 1)	279	277.2	279.1	+0.04 %	+0.68 %	Pass
plaxis-verif-pipe-capacity-r0.4	lateral load P at u = 0.08 m (1.6 % of D), strict convergence [kN/m]	PLAXIS-Verification-Circular-pipe-laterally-loaded-cohesive.pdf, p. 2 (Table 1)	265.3	263.3	265.56	+0.10 %	+0.87 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-verif-pipe-capacity-r0.2	lateral load P at u = 0.08 m (1.6 % of D), strict convergence [kN/m]	PLAXIS-Verification-Circular-pipe-laterally-loaded-cohesive.pdf, p. 2 (Table 1)	250	247.1	249.61	−0.15 %	+1.00 %	Pass
plaxis-verif-pipe-initial-stiffness	initial horizontal stiffness Kxx of the full pipe, R_inter = 1 [kN/m]	PLAXIS-Verification-Circular-pipe-laterally-loaded-cohesive.pdf, p. 3 (Eq. 3)	—	99125	99102	—	−0.02 %	Pass
ertc7-wall-moment	maximum bending moment in the wall, final excavation (−6 m), characteristic parameters, embedment 4 m [kNm/m]	PLAXIS-Verification-ERTC7-benchmark.pdf, p. 7 (Figure 8, characteristic, embedment 4.0 m: read at 300 dpi ≈ 212)	212	—	204	−3.77 %	—	Deviation
ertc7-strut-force	strut force, final excavation [kN/m]	PLAXIS-Verification-ERTC7-benchmark.pdf, p. 8 (Figure 9, characteristic, 4.0 m: ≈ 117)	117	—	123.9	+5.90 %	—	Deviation
ertc7-wall-base-displacement	horizontal displacement of the wall base, final excavation [mm]	PLAXIS-Verification-ERTC7-benchmark.pdf, p. 7 (Figure 6, characteristic, 4.0 m: ≈ 6.0)	6	—	9	+50.0 %	—	Deviation
plaxis-2d-tut3	|u| at (50, 10) at the end of each phase (submerged excavation, undrained-A clay) [m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 52–71	phase1: 0.005; phase2: 0.024; phase3: 0.024; phase4: 0.057; phase5: 0.141	—	phase1: 0.0092; phase2: 0.0302; phase3: 0.0302; phase4: 0.074; phase5: stops at ΣMstage 0.350 (tol 1e-8 and 1e-7); at tol 1e-2 (PLAXIS default, TBK_T3_TOL=0.01) reaches ΣMstage 1 with |u| 0.117	—	—	Superseded
k3-gate-cantilever	cantilever tip deflection, tip load P = 10, L = 2, EI 1e3, EA 2e5, ν 0.2 (plane strain: EI/(1−ν²)) [m]	—	—	0.025888	0.025888	—	0.00 %	Pass
k3-gate-two-span	moment over the middle support, two equal spans L = 2 under q = 12 [kNm/m]	—	—	5.93325	5.93325	—	0.00 %	Pass
k3-gate-circular-plate	centre deflection of a simply supported circular plate (axisymmetric), a = 2, q = 10, ν 0.3 [m]	—	—	0.009301	0.009301	—	0.00 %	Pass
k3-gate-plastic-hinge self-check	collapse load of a simply supported Mp-plate (N–M diamond), with and without N = 100 (Np 400) [kN/m]	—	—	—	—	—	0.00 %	Pass
k3-gate-anchor-spring	node-to-node / fixed-end anchor displacement and force [m]	—	—	0.2	0.2	—	0.00 %	Pass
k3-gate-geogrid	tension-only geogrid: u = F L / EA in tension; zero force in compression [m]	—	—	0.08	0.08	—	0.00 %	Pass
k3-gate-interface-patch	sliding resultant Σ τ = R (c L + tan ϕ N) and every point on the Coulomb line, R_inter 1 and 0.6 [kN/m]	—	—	36.0458	36.0458	—	0.00 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k3-gate-excavation-unloading	heave of the new surface after removing 3 m of a laterally restrained elastic column (7 m remain) [m]	—	—	0.0315	0.0315	—	0.00 %	Pass
k3-gate-plate-soil-compatibility self-check	settlement of a very stiff plate loaded by the force of a rough rigid footing pushed δ = 0.01 [m]	—	—	0.01	0.0100001	—	+1.0e-3 %	Pass
k3-gate-staged-wall-equilibrium self-check	global equilibrium every phase of a staged excavation (wall plate, two-sided interface, prestressed strut, two stages): ΣRy = soil weight + wall weight, ΣRx = −strut [kN/m]	—	—	—	—	—	0.00 %	Pass
plaxis-2d-tut7-prestress-top	top anchor force at the end of phase 3 (prestress 500 kN per anchor, Lspacing 2.5 m) [kN]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 131 (§7.8.4), 137 (§7.9)	500	—	500	0.00 %	—	Pass
plaxis-2d-tut7-prestress-bottom	bottom anchor force at the end of phase 5 (prestress 1000 kN) [kN]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 132 (§7.8.6), 137	1000	—	1000	0.00 %	—	Pass
plaxis-2d-tut7-final	final phase: wall max |M|, anchor forces, wall displacements [kNm/m, kN, mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 135–137 (Figures 7–16…7–22: figures only)	—	—	wallL Mmax: 154; wallR Mmax: 157; at y: 23; anchors top L/R: [430.4, 428.6]; anchors bottom L/R: [1053.4, 1050.8]; ux(40,27) mm: 10.24; ux(40,23) mm: 13.34	—	—	Superseded
plaxis-2d-tut7-final-k4-flow	final phase with REAL phase-6 steady flow: wall max |M|, anchor forces, wall displacements [kNm/m, kN, mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 135–137 (Figures 7–16…7–22: figures only)	—	—	wallL Mmax: 167; wallR Mmax: 170.7; at y: 23; anchors top L/R: [420.1, 424.4]; anchors bottom L/R: [1081.6, 1081.8]; ux(40,27) mm: 6.51; ux(40,23) mm: 12.33; prestress P3 / P5: [500, 1000]	—	—	Superseded
k5b-plaxis-2d-tut7-real-hs	Tutorial 7 with the REAL Hardening Soil (Table 7-1) + phase-6 steady flow: anchor forces, wall max |M|, wall ux [kN, kNm/m, mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 121–137 (prestress p. 137; Figs 7-16…7-22 figures only)	prestress 500 / 1000 kN (figures otherwise)	—	prestress P3 / P5: [500, 1000]; final anchors top L/R: [450.6, 446.8]; final anchors bottom L/R: [1058.8, 1055.4]; wallL / wallR Mmax: [141.9, 145.1]; at y: 23; ux(40,27) mm: 17.15; ux(40,23) mm: 17.06; K4 Mohr–Coulomb substitute (row plaxis-2d-tut7-final-k4-flow): (Mmax: [167, 170.7]; anchors top: [420.1, 424.4]; anchors bottom: [1081.6, 1081.8]; ux mm: [6.51, 12.33])	—	—	Recorded, no published value

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k5d-plaxis-2d-tut3-submerged-hs	|u| at (50, 10) at the end of each phase — real Hardening Soil, the kernel's own submerged excavation (D90: deactivated clusters keep their water) [m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 71 (Fig. 3-15 raster, pixel-measured; tests/data/plaxis_tut3_fig3_15.txt)	phase1: 0.0062; phase2: 0.0242; phase3: 0.0242; phase4: 0.0572; phase5: 0.1417	—	phase1: 0.0054; phase2: 0.0225; phase3: 0.0225; phase4: 0.0589; phase5: 0.1519	phase1: -12.9; phase2: -7; phase3: -7; phase4: 3; phase5: 7.2	—	Deviation
k5d-plaxis-2d-tut10-dewatering	Tutorial 10: Tutorial 7 (real HS) + two extraction wells in the phase-6 steady flow (1.5 m³/day/m, h_min 17 m): well discharges, groundwater head in the pit, final anchor forces / wall moments [m³/day/m, m, kN, kNm/m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 166–169 (Figs 10–4, 10–5: figures only)	figures only (head lowered in the excavation, flow to the wells)	—	well discharge each (m³/day/m): -0.9797; side inflow each: 0.9773; pit-bottom seepage: 0; head in the pit (m): 18.90–18.99 (T7: 20 at the bottom); phreatic line in the pit y (m): [18.609, 18.982]; final anchors top L/R, bottom L/R (kN): [453, 449.7, 1050.1, 1048.2]; wall max |M| L/R (kNm/m): [135.1, 138.1]	—	—	Recorded, no published value
k5d1-da-ec7-annex-a	design-approach presets DA1-1 (A1+M1), DA1-2 (A2+M2), DA2 (A1+M1), DA3 (A2+M2 on geotechnical actions): γG 1.35/1.0, γQ 1.5/1.3, γφ′ = γc′ 1.25, γcu 1.4, γqu 1.4, γγ 1.0; tan φ factored, ψ ≤ φ_d [-]	EN 1997-1:2004 Annex A (Tables A.3, A.4); PLAXIS-2D-2025.1-Reference-Manual §5.8, p. Annex A; RM pp. 126–131	—	1.25	1.25	—	0.00 %	Pass
k5d1-cable-winkler self-check	worst bar-point axial-force error (of N(0) = 48.2014 kN/m) of a pulled grouted cable with an elastic bond Ks [relative error]	PLAXIS-2D-2025.1-Reference-Manual §5.6.7, §6.7, p. Eq. 6-68 (p. 290)	—	0.002	2.050e-5	—	—	Pass
k5d1-cable-plastic-bond self-check	worst error of the pulled-cable force against the plastic bond capacity (c_bond + σn tan φ_bond P)·L / L_spacing = 15 kN/m [relative error]	PLAXIS-2D-2025.1-Reference-Manual §6.7, p. Eq. 6-68 (p. 290)	—	1.000e-6	8.890e-11	—	—	Pass
k5d1-embedded-beam-axial self-check	worst bar-point axial-force error of an embedded beam row (skin spring R_s + tension-free base spring K_F), push and pull [relative error]	PLAXIS-2D-2025.1-Reference-Manual §5.6.3, §6.6.4, p. Eqs. 6-65/6-66/6-67 (ISF, pp. 285–286)	—	0.001	3.280e-6	—	—	Pass
k5d1-embedded-beam-lateral self-check	worst bending-moment error (of the maximum 1.4963 kNm/m) of a laterally loaded embedded beam row (λL = 8.34) [relative error]	—	—	0.02	0.00713	—	—	Pass
k5d1-beta-method-cc	β-method (deconfinement d = 0.6) wall displacement of an elastic circular opening, then the lined state [m]	PLAXIS-2D-2025.1-Reference-Manual §7.5.1.3; Panet convergence–confinement, p. RM pp. 326–327	—	0.0075	0.00750509	—	+0.07 %	Pass
k5d1-plaxis-2d-tut8-safety-sls	ΣMsf of the Safety phase on SLS phase 6 [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 144 (Fig. 8–6, figure read)	1.49	—	1.4828	−0.48 %	—	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k5d1-plaxis-2d-tut8-safety-uls	ΣMsf of the Safety phase on ULS phase 12 (DA3: inherits the design strengths) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 144 (Fig. 8–6, figure read)	1.19	—	1.1813	−0.73 %	—	Pass
k5d1-plaxis-2d-tut8-uls-displacement	|u| at (40, 27) at the end of ULS phase 12 (real Hardening Soil, DA3) [m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 143 (Fig. 8–5, embedded raster: pixel-measured, ±0.0001 m — tests/data/plaxis_tut8_fig8_5_8_6.txt on branch prog-a-t8)	0.0518	—	0.069	+33.2 %	—	Deviation
k5d1-mesher-crossing-structures self-check	meshed area of a square cut by two crossing structure lines that close a face against the boundary [m²]	—	—	100	100	—	0.00 %	Pass

Closed-form engine registry — 3 published problems

ROW	PROBLEM	SOURCE	REFERENCE	OURS	Δ	TOLERANCE (WHY)	STATUS
DC-STRUT-DGEC3-6.7	Steel strut flexural buckling — Designers' Guide EC3 Ex. 6.7, N_b,Rd CHS 244.5×10 S355, A 7370 mm², I 50.73e6 mm⁴ (i = √(I/A)), pinned L_cr 4 m, curve a (α 0.21); γ_M1 = 1.00 (EN 1993-1-1 §6.1 NOTE 2B), E = 210 000 MPa (§3.2.6)	Gardner, L. & Nethercot, D.A., Designers' Guide to Eurocode 3: EN 1993-1-1 (Thomas Telford), Ex. 6.7 (CHS 244.5×10 S355, pinned L 4 m) — the book is not in the library; the previous file pointer named DD ENV 1993-1-1:1992, which does not contain this example (corrected in our defect log) — Example 6.7	2297 kN N_b,Rd = χ·A·f_y/γ_M1	2296.79	−9.2e-3 %	± 0.1 % Designers' Guide prints N_b,Rd to 4 significant figures (2297 kN)	Pass
DC-GEOGRID-GEC11-E1-GG1	Geogrid long-term design strength — GEC-11 Vol II Ex. E1 Table E1-7.3, GG-I, T_r = ϕ·T_al·R_c GG-I geogrid: T_ult 3000 lb/ft, RF_ID 1.3, RF_CR 1.85, RF_D 1.15; ϕ 0.90 (GEC-11 2009 Table 4-7, simplified method, static); R_c = 1 (continuous); γ_F = 1 (T_MAX already factored)	Berg, Christopher & Samtani (2009) FHWA-NHI-10-024/-025 GEC-11 MSE Walls and RSS Vol I/II — Vol II Ex. E1 §7.6 Table E1-7.3 (GG-I)	976 lb/ft T_r = 0.90·T_al (T_al = 1085 printed)	976.227	+0.02 %	± 0.1 % GEC-11 Table E1-7.3 prints T_al / T_r to 4 significant figures	Pass
DC-ANCHOR-GEC4-EX1-BOND	Ground anchor grout–ground bond — GEC-4 Appendix A Example 1, allowable bond at L = 12 m soil anchor, load-transfer rate 100 kN/m, FS 2.0 (GEC-4 §5.3.6), fixed length 12 m; PTI DC35.1; tendon 32-mm Grade 150 bar (A 806 mm², f_pk 1035 MPa)	Sabatini, Pass & Bachus (1999) FHWA-IF-99-015 GEC-4 Ground Anchors and Anchored Systems — Appendix A Example 1 (soil, medium-dense silty sand), p. A-8/A-9	600 kN allowable bond = (100/2.0)·12	600	0.00 %	± 0.5 % GEC-4 Example 1 prints the bond strength as a rounded hand value (600 kN)	Pass

Cited validation suites — 35

as4678-factors-web-validation.test.ts

AS 4678—2002 partial-factor system — anchored to the standard.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
AS 4678 Table 1.1: C is the MOST critical class and A the LEAST — the reverse of EC8/ASCE	Pass
AS 4678 Table 5.2: Φn = 0.9 (C), 1.0 (B), 1.1 (A) at ULS; all 1.0 at SLS	Pass
AS 4678: choosing class A emits the caution, because the letter reads like the opposite	Pass
AS 4678 Table 5.1(A): every published Φuϕ and Φuc reproduced (16 values)	Pass
AS 4678 Table 5.1(A) internal ordering: better fill ⇒ higher factor, SLS ≥ ULS	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
AS 4678 Table 5.1(B): Φuϕ = 0.0 in EVERY column — undrained credits no friction	Pass
AS 4678 §5.2: an undrained analysis returns ϕ* = 0 and factors cu only	Pass
AS 4678 §5.2.1 and §5.2.2: c* = Φuc·c and tan ϕ* = Φuϕ·tan ϕ	Pass
AS 4678 vs EN 1997-1: the conventions are RECIPROCAL, and that is asserted	Pass
AS 4678 Table 4.1: minimum live loads 1.5 / 2.5 (class A) and 2.5 / 5 (classes B, C)	Pass
the design soil is never non-finite, negative or stronger than characteristic	Pass
the citations name the standard, its amendments and the companion AS 1170 parts	Pass

⚑ basal-heave-web-validation.test.ts

BASAL-HEAVE — web-validation benchmark against published worked examples and tables.

Analyses validated: `basal-heave` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NAVFAC DM-7.2 Fig. 30 — strip and rectangular Nc at H/B = 1.67, B/L = 0.15	Pass
NAVFAC DM-7.2 Fig. 30 — driving and resisting pressure, factor of safety, verdict	Pass
Bowles 5e Table 14-1 (p. 813) — strip N′c at D/B = 0, 4.0 and 5.0	Pass
Bowles 5e Table 14-1 (p. 813) — square/circular N′c (Skempton column) at D/B = 0, 4.0 and 5.0	Pass
Varghese Ex. 22.1 (p. 417) — Skempton Nc, bearing capacity, overburden, FS	Pass
Das 8e Eq. 15.16 / Craig §11.9 — Terzaghi branch constants: Nc = 5.7 and B′ ≈ 0.7B	Pass
Das §15.7 (p. 800) and NAVFAC Table 6 — the recommended base-heave factor of safety is 1.5	Pass

⚑ braced-excavation-web-validation.test.ts

`braced-excavation` — anchored to NAVFAC DM-7.02 Figures 26 and 27.

Analyses validated: `braced-excavation` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NAVFAC Fig. 26(a): sand σh = 0.65·KA·γH with KA = tan²(45 − ϕ/2)	Pass
NAVFAC Fig. 26(b): σh = γH − 4·m·c, and N_o = γH/c is the selection basis	Pass
E-48: m = 0.4 where the cut is underlain by deep soft NC clay — a 1.48× increase	Pass
NAVFAC Fig. 26(c): stiff clay σh spans 0.2·γH to 0.4·γH, selectable	Pass
E-49: a ratio outside Figure 26(c)'s 0.2–0.4 band is flagged as unsupported	Pass
NAVFAC Fig. 26(c): for 4 < N_o < 6 the LARGER of diagrams (b) and (c) is used	Pass
NAVFAC Figs. 26 & 27: strut forces from hinges at strut locations / simple span between braces	Pass
strut spacing converts kN/m to kN per strut linearly	Pass
NAVFAC Fig. 26 note: the bottom-instability FoS band is 1 ≤ FSB ≤ 1.5	Pass
the governing figures are cited, and the OCR-ambiguous value is NOT asserted anywhere	Pass
every numeric output is finite, and a cut with no struts is refused	Pass

⚑ building-damage-assessment-web-validation.test.ts

Dedicated validation for the building-damage engine (`building-damage-assessment.ts`): the Burland & Wroth (1974) equivalent-beam deflection-ratio + horizontal-strain method with Boscardin & Cording (1989) damage categories, as codified by…

Analyses validated: `building-damage-assessment` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Boscardin & Cording (1989) Table 2: damage category vs limiting tensile strain	Pass
Rankin (1988): settlement < 10 mm and slope < 1/500 → screened out, category 0	Pass
Rankin screen does NOT apply above 10 mm	Pass
Sagging beam: Δ/L → εb, εd, εbt, εdt reproduce M-T-B (1996) eqs 7-10 exactly	Pass
Hogging beam: a building offset past the inflection point hogs (I = H³/3, t = H)	Pass
E/G = 12.5 framed RC raises the shear stiffness and lowers the diagonal strain (M-T-B §4.5)	Pass
L/H regime warning: diagonal dominates for L/H < 1.5, bending for L/H > 1.5	Pass
Building length capped at 2.5i (M-T-B 1996 §4.1)	Pass
Cording et al. (2008) Evanston South Wing: angular distortion 2.7e-3, lateral strain 2.5e-3	Pass
Input validation: L, H, i, profile errors	Pass

⚑ concrete-durability-web-validation.test.ts

Dedicated validation for the concrete durability classification (`concrete-durability.ts`): the IS 456:2000 Table 4 sulphate exposure class from soil SO3 (%) and groundwater SO4 (g/L), the cement type, minimum cement content and maximum fr…

Analyses validated: `concrete-durability` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IS 456:2000 Table 4: sulphate class from total SO3 in soil (% by mass), interior of each printed band	Pass
IS 456:2000 Table 4: sulphate class from SO4 in groundwater (g/L), interior of each printed band	Pass
IS 456:2000 Table 4: the printed open/closed ends of the bands	Pass
IS 456:2000 Table 4: minimum cement content (kg/m³) per class	Pass
IS 456:2000 Table 4: maximum free water-cement ratio per class	Pass
IS 456:2000 Table 4 class 3: Portland pozzolana / slag cement have their own, stricter row (350 kg/m³, w/c 0.45)	Pass
IS 456:2000 Table 16 and cl 26.4.2.2: cover is max(50 mm footing floor, Table 16) for every class	Pass
IS 456:2000 Table 16: Extreme exposure 75 mm; Very severe is 50 mm (not more) for a footing	Pass
IS 456:2000 cl 8.2.2.4 / Table 4 Note 3: pH scope warnings	Pass

contiguous-pile-wall-web-validation.test.ts

Web-benchmark validation for `contiguous-pile-wall`.

Analyses validated: `contiguous-pile-wall` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the active pressure at the dredge line is Rankine Ka·σv, with the surcharge included	Pass
Rankine Ka and Kp are reciprocal, and cohesion relieves the ACTIVE side	Pass
wall friction δ reduces the horizontal active thrust (Coulomb, δ = 0 → Rankine)	Pass
below the water table the engine uses γ′ = γ_sat − γ_w and adds hydrostatic thrust	Pass
omitting γ_sat below the water table is flagged rather than assumed silently	Pass
the moment capacity is IS 456 Annex G M_lim = 0.138·f_ck·D·d_eff²	Pass
steel area follows A_st = M_u/(0.87·f_y·0.9·d_eff) with the IS 456 0.4 % floor	Pass
per-pile actions scale with the pile spacing (tributary width)	Pass
basal-heave Nc follows Bjerrum & Eide 5.7 + 0.39·(H/B), capped at 9	Pass
a low basal-heave FoS fails the wall, and a frictional soil withholds the check	Pass
the deflection estimate sits in the CIRIA C760 §8.1 band 0.001–0.005·H	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
invalid inputs are refused with a zeroed result, including the E-9 f_y guard	Pass

⚑ deadman-anchor-web-validation.test.ts

DEADMAN-ANCHOR — web-validation benchmark against published coefficient tables and a worked example.

Analyses validated: `deadman-anchor` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bowles 5e Table 11-3 (p. 603) — Rankine Ka, β = 0, ϕ = 26°…42°	Pass
Bowles 5e Table 11-4 (p. 603) — Rankine Kp, β = 0, ϕ = 26°…42°	Pass
Das 8e Table 12.1 (p. 608) — Ka(R) at α = 0°, θ = 0°, ϕ′ = 28°…40°	Pass
Bowles 5e Example 13-7 (p. 779) — block-face earth forces (Kp = 3.25, Ka = 0.307 in the book)	Pass

earth-pressure-web-validation.test.ts

WEB-BENCHMARK validation for the lateral earth-pressure engine (the release rules mandatory ≥20 cited-value gate).

Analyses validated: `earth-pressure` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EP web 1–10: Rankine Ka at ϕ=20,25,28,30,32,34,35,36,40,45 (Rankine 1857 / Das)	Pass
EP web 11–15: Rankine Kp at ϕ=20,30,35,40,45 (Rankine 1857 / Das)	Pass
EP web 16–18: at-rest K0 = 1−sinϕ at ϕ=30,35,40 (Jaky 1948)	Pass
EP web 19–20: Rankine Ka sloping backfill ϕ=30°, β=10°/20° (Das Eq. 13.x)	Pass
EP web 21–22: active thrust Pa=½Ka γ H² (ϕ=30 H=6; ϕ=35 H=5)	Pass
EP web 23: passive thrust Pp=½Kp γ H² (ϕ=30 H=5) = 675 kN/m	Pass
EP web 24: active resultant at H/3 (ϕ=30, H=6 → 2.0 m)	Pass
EP web 25: Bell tension-crack depth z_c=2c/(γ√Ka) (c=20, ϕ=20, γ=18 → 3.17 m)	Pass
EP E-115: the reference Rankine case is untouched (Ka = 1/3, Pa = 75 kN/m)	Pass
EP E-115: wall friction δ — NaN, negative, and δ > ϕ must all be refused	Pass
EP E-115: backfill slope β ≥ ϕ must be refused, not warned	Pass
EP E-115: wall inclination α must be finite and within ±90°	Pass

earth-pressure-worked-examples-web-validation.test.ts

earth-pressure — FULL WORKED EXAMPLES (the ≥20-value gate).

Analyses validated: `earth-pressure` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS] Ex 12.1: at-rest thrust with the water table at 2.5 m → P0 = 122.85 kN/m at 1.53 m	Pass
[BOW] Ex 11-4: c 10.5, ϕ 10°, H 6.5 → R = 158.5 kN/m at 1.69 m (tension zone neglected), zc = 1.43 m	Pass
[BOW] Prob 11-7: crack replaced → full-height thrust = 103.3 kN/m at H/3	Pass
[BOW] Prob 11-5: printed 63.2 kN/m is the net area, printed 4.65/3 m is the neglect-zone centroid	Pass
[CRAIG] Ex 11.2(b): water table at 2 m → total thrust 93.3 kN/m	Pass
[DAS] Ex 12.6: Coulomb, ϕ 35°, δ = ⅔ϕ, H 5 m, γ 17.6 → Pa = 53.77 kN/m	Pass
[DAS] Ex 12.7: Coulomb, battered back + 95.76 kPa surcharge → total ≈ 328.2 kN/m	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS] Ex 12.11: Mononobe-Okabe, kh 0.3 → P_ae = 46.05 kN/m (static 22.88)	Pass
[DAS] Ex 12.14: passive with wall friction → Caquot-Kérisel 311 kN/m (Coulomb 351.6)	Pass
[DAS] Ex 13.1: Rankine, H 7.158 m, β 10° → Pa = 161.2 kN/m	Pass
[DAS] Ex 13.2: Coulomb, battered back 15°, δ = ⅔ϕ → Pa = 157.22 kN/m	Pass
[BOW] Ex 11-1: Coulomb, β 10°, δ 20° → Pa = 74.5 kN/m at H/3	Pass
[BOW] Ex 11-3: Rankine, β 10° → Pa = 76.6 kN/m	Pass
[EC7] Dublin A.4.2/A.4.5: Ka;β = 0.365 and the characteristic soil thrust E_a;Gk = 201 kN/m	Pass
[USACE] EM 1110-2-2502 App. H: peak Ka 0.31 and Kp 3.25 at ϕ 32°	Pass

eurocode7-factors-web-validation.test.ts

Eurocode 7 partial factors — validated against **EN 1997-1:2004 (BS EN 1997-1:2004)**, *Eurocode 7: Geotechnical design — Part 1: General rules*, **Annex A**.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EN 1997-1 Cl 2.4.7.3.4 — every Design Approach combines the correct A/M/R sets	Pass
Table A.4 — γϕ′ is applied to tan ϕ′, not to ϕ′ (via the engine's own ec7ReduceMaterials)	Pass
EN 1997-1 Cl 2.4.7.3.1 eq 2.6a/b — Fd = γG·Gk + γQ·Qk via ec7DesignAction	Pass
the three EC7 verification philosophies are structurally distinct	Pass
every factor is ≥ 1 and finite — a partial factor can never increase capacity	Pass
EC7_LABELS name the A/M/R combination so a report shows which philosophy was used	Pass
National Annex variations are DOCUMENTED and deliberately NOT auto-applied	Pass
DA3 exposes the A1 (structural) action set, and says so	Pass
the four approaches produce four DIFFERENT design outcomes (they are not aliases)	Pass

excavation-settlement-web-validation.test.ts

EXCAVATION-SETTLEMENT — web-validation benchmark against published envelopes and limits.

Analyses validated: `excavation-settlement` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Ou 2006 p. 203 — influence ranges "2 He and 3 He" for sand and stiff clay	Pass
Ou 2006 Fig. 6.25(a) — sand: triangular, δv/δvm = 1.0 at the wall, 0.5 at d/He = 1.0, 0 at 2.0	Pass
Ou 2006 Fig. 6.25(b) — stiff clay: triangular, 1.0 at the wall, 0.5 at d/He = 1.5, 0 at 3.0	Pass
Ou 2006 p. 203 + Fig. 6.25(c) — soft to medium clay: plateau to d/He = 0.75, then linear to 0 at 2.0	Pass
Ou 2006 §6.4.4 p. 194 (Fig. 6.14) — δvm = (0.5-0.75)·δhm, Hsieh-Ou range	Pass
CFEM 2006 §26.15.2-26.15.4 (pp. 435-437) — zones of influence by ground type	Pass
Look 2007 Table 23.15 — medium to dense sand: 0.3 % at the wall, 0.1 % at 1.2 He, 0.0 % at 2.0 He	Pass
Craig 2012 Fig. 11.39 (p. 455) — the coarse-grained envelope returns to zero at x/h ≈ 2	Pass
Look 2007 Table 23.7 / EC7 WE Table 3.4.1 — 1/500: "safe limit for no cracking" / "cracking in walls"	Pass
Look 2007 Table 23.7 — 1/300: "first cracking of panel walls"	Pass
Look 2007 Table 23.7 / EC7 WE Table 3.4.1 — 1/150: "considerable cracking" / "structural damage"	Pass

fe-design-checks-anchor-web-validation.test.ts

W3 FE design check — GROUND ANCHOR — web-validation benchmark against published tables and worked examples.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 23 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[GEC4 Table 10 p.78] 1-strand 1860 MPa tendon (A = 140 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 10 p.78] 3-strand 1860 MPa tendon (A = 420 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 10 p.78] 4-strand 1860 MPa tendon (A = 560 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 10 p.78] 5-strand 1860 MPa tendon (A = 700 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 10 p.78] 7-strand 1860 MPa tendon (A = 980 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 10 p.78] 9-strand 1860 MPa tendon (A = 1260 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 10 p.78] 12-strand 1860 MPa tendon (A = 1680 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 10 p.78] 15-strand 1860 MPa tendon (A = 2100 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 10 p.78] 19-strand 1860 MPa tendon (A = 2660 mm²): f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 9 p.77] 26-mm bar, f_pu = 1035 MPa: f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 9 p.77] 32-mm bar, f_pu = 1035 MPa: f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 9 p.77] 36-mm bar, f_pu = 1035 MPa: f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 9 p.77] 45-mm bar, f_pu = 1035 MPa: f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 9 p.77] 64-mm bar, f_pu = 1035 MPa: f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 9 p.77] 26-mm bar, f_pu = 1104 MPa: f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 9 p.77] 32-mm bar, f_pu = 1104 MPa: f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Table 9 p.77] 36-mm bar, f_pu = 1104 MPa: f_pu·A, 0.8/0.7/0.6·f_pu·A	Pass
[GEC4 Ex.1 p.A-9] soil anchor: bond 600 kN at L = 12 m, required L = 8.9 m, tendons 501 / 469 kN	Pass
[GEC4 Ex.2 p.A-27/28] rock anchor: bond 900 kN at L = 7.5 m, required L = 5.3 m, tendons 675 / 782 kN	Pass
[DG7 Ex.8.1 Table 8.2] DA-1 LEM: R_a,k,req = γa·P_d = 461 kN; EN 1537 proof load = 419 kN	Pass
[DG7 Ex.8.1 Table 8.2] DA-2(L) LEM: R_a,k,req = γa·P_d = 611 kN; EN 1537 proof load = 557 kN	Pass
[DG7 Ex.8.1 Table 8.2] DA-2(S) spring: R_a,k,req = γa·P_d = 421 kN; EN 1537 proof load = 383 kN	Pass
[DG7 Ex.8.1 Table 8.2] DA-3 LEM: R_a,k,req = γa·P_d = 461 kN; EN 1537 proof load = 419 kN	Pass

fe-design-checks-d277-web-validation.test.ts

W4 (D277) — published benchmarks for the W3 checks that had none: IS 456 RC wall flexure, EN 1993-1-1 strut buckling, FHWA GEC-11 geogrid rupture.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IS 456 — NPTEL M3L7 Problem 3.2 (b 300, d 550, M20, Fe415, A_st 1256): x_u 209.94 mm, M_u 209.43 (direct) / 209.68 kNm (SP-16 Table 2)	Pass
IS 456 — NPTEL M3L7 Problem 3.3 (A_st 1658): x_u 277.14 > x_u,max → M_u,lim 250.01 (direct) / 250.47 kNm (SP-16, 2.76 b d²)	Pass
IS 456 — NPTEL M3L7 Q.1 (b 300, d 500, M20, Fe500): A_st 452 → x_u 91.03, M_u 90.79 / 90.3 kNm; A_st 1030 → x_u 207.43, M_u 184.99 kNm; x_u,max 230 mm	Pass
EN 1993-1-1 — Designers' Guide Ex. 6.7 (CHS 244.5×10 S355, L 4 m, curve a): N_cr 6571, λ̄ 0.63, Φ 0.74, χ 0.88, N_b,Rd 2297, N_c,Rd 2616 kN	Pass
EN 1993-1-1 — Designers' Guide Ex. 6.9 (A 8300, S355, curve a) y-axis: Φ 0.92, χ 0.77, N_b,Rd 2266 kN	Pass
EN 1993-1-1 — Designers' Guide Ex. 6.9 (A 8300, S355, curve a) z-axis: Φ 1.63, χ 0.41, N_b,Rd 1209.2 kN	Pass
GEC-11 Example E1 Table E1-7.3: T_al and T_r = 0.90 T_al for GG-I / GG-II / GG-III (lb/ft)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
GEC-11 Example E1 Table E1-7.4: CDR = T_r/T_MAX for all 11 layers	Pass
GEC-11 Example E9 Step 4: T_al = 6850/(1.25·1.2·3.0) = 1520 lb/ft (22 kN/m)	Pass

fe-design-checks-geogrid-web-validation.test.ts

W3-3 — `fe-design-checks/geogrid.ts` (the per-element geogrid tension check) against published long-term-strength values.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
BS 8006-1 Table 9: f_n = 1.0 / 1.0 / 1.1 for categories 1 / 2 / 3 (printed p. 52)	Pass
BS 8006-1 Table 12 combination A: the check default γ_F = f_fs = 1.5 on soil self-weight (printed p. 70)	Pass
BS 8006-1 Annex A.3: T_D = T_char/RF with RF = 7 (GEC-11 Eq 3-13 conservative anchor) decomposed as RF_CR·(RF_ID·RF_W·RF_CH·f_s)	Pass
GEC-11 (2009) Table 4-7: ϕ = 0.90 geosynthetic static; (2023) Table 16 SSM: ϕ = 0.80	Pass
GEC-11 Vol II Example E9 Step 4: T_al = 6850/(1.25·1.2·3.0) = 1520 lb/ft (22 kN/m)	Pass
GEC-11 Vol II Example E1 Table E1-7.3: T_al and T_r = 0.90 T_al for GG-I / GG-II / GG-III (lb/ft)	Pass

fe-design-checks-pile-web-validation.test.ts

W4 (D276) — embedded pile check: web / published benchmark.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
JRC EUR 26227 Ex. 2 (bored, CPT): R_b,k = 284 kN, R_s,k = 101 kN per metre	Pass
JRC EUR 26227 Ex. 2: DA1-C1 F_c,d = 630 kN equals R_c,d at L_s = 3.99 m	Pass
JRC EUR 26227 Ex. 2: DA1-C2 F_c,d = 495 kN equals R_c,d at L_s = 4.08 m	Pass
JRC EUR 26227 Ex. 2: DA2 R_c,d = 630 kN at L_s = 4.05 m	Pass
JRC EUR 26227 Ex. 3 (driven, γ_Rd 1.75): R_b,k = 386 kN, R_s,k = 153 kN per metre	Pass
JRC EUR 26227 Ex. 3 EN 1997-1 DA1-C1: R_c,d = 221 + 87.4·L_s; = F_c,d 1260 kN at L_s = 11.9 m	Pass
JRC EUR 26227 Ex. 3 EN 1997-1 DA1-C2: R_c,d = 170 + 67.3·L_s; = F_c,d 990 kN at L_s = 12.2 m	Pass
JRC EUR 26227 Ex. 3 EN 1997-1 DA2: R_c,d = 201 + 79.5·L_s; = F_c,d 1260 kN at L_s = 13.3 m	Pass
EN 1992-1-1 §2.3.4.2(2) design diameter of an uncased cast-in-place pile (code rule, 4 values)	Pass
structural (golden, hand-evaluated): d 0.6 m uncased C30/37, 8 H20 (2513 mm²), B500	Pass
plain concrete uses α_cc,pl = 0.8; precast/cased uses the nominal diameter and γ_c = 1.5	Pass
never defaults: missing pile type, resistances and section → incomplete with every field named	Pass
tension: R_t,d = R_s,k/γ_s,t (Table A.7 R1: 1.25); dispatcher converts the kernel sign (tension +)	Pass

fe-design-checks-rc-wall-web-validation.test.ts

Web / published-benchmark validation — RC wall design check (fe-design-checks/rc-wall.ts).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EC2 M_Rd — [JRC] p.58, T-beam mid-span AB (b_eff 2611.2, d 372): MEd 89.3 → As 556 mm²	Pass
EC2 M_Rd — [JRC] p.58, T-beam support B (b_w 250, d 372): MEd 132.9 → As 947 mm²	Pass
EC2 M_Rd — [JRC] pp.65–66, slab X-dir support axis 2 (d 143): MEd 49.18 → As 856 mm²/m	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EC2 M_Rd — [JRC] p.66, slab X-dir mid-span 1-2: MEd 18.32 → As 303 mm²/m	Pass
EC2 M_Rd — [JRC] p.66, slab X-dir mid-span 2-3 / axis 3: MEd 36.95 → As 630 mm²/m	Pass
EC2 M_Rd — [JRC] pp.66–67, slab Y-dir support axis B: MEd 68.15 → As 1235 mm²/m	Pass
EC2 M_Rd — [JRC] p.67, slab Y-dir mid-span: MEd 52.14 → As 915 mm²/m	Pass
EC2 V_Rd,c — [JRC] p.59 beam support A: bw 250, d 372, Asl 565, C25 → k 1.73, ρl 0.61 %, V_Rd,c 47.90 kN	Pass
EC2 V_Rd,c — [JRC] p.92 slab with embedded lighting: bw 240, d 190, ρl = 0.02 (cap), k = 2.0 → 40.2 kN	Pass
EC2 v_Rd,c / v_min — [JRC] p.73 (punching, same Eq. 6.47 ≡ 6.2a form): d 164 → k 2.0, ρl 0.83 %, v_Rd,c 0.66, v_min 0.49 MPa	Pass
ACI ϕM_n — [SP] p.4: b 12 in, d 9.75 in, f'c 3000 psi, fy 60 ksi, As 0.316 in²/ft → ϕM_n = M_u 13.4 kip·ft/ft	Pass
ACI stress block — [SP] p.4: As 0.321 in²/ft → a 0.629 in, c 0.74 in, εt 0.037 (> 0.005, tension-controlled)	Pass
ACI ϕV_c Eq. (a) — [SP] p.3: ϕ·2λ√f'c·bw·d, bw 12 in, d 9.75 in, 3000 psi → 9.61 kips/ft	Pass

fe-design-checks-sheet-pile-web-validation.test.ts

FE-DESIGN-CHECKS / SHEET PILE — benchmark against published worked examples (EN 1993-5:2007).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
PU 18 (Ex. 1) — §8.3 M_c,Rd = 568; §8.4 A_v 3769, V_pl,Rd 772.5 kN/web, 1288 kN/m	Pass
PU 18 (Ex. 1) — §8.5 V_Ed 800: M_V,Rd/M_c,Rd 0.971, M_V,Rd 552; §8.8 ρ 0.059	Pass
PU 18 (Ex. 1) — §8.6/8.7 N_pl,Rd 5797, N/N_pl 0.259, M_N,Rd 560	Pass
PU 18 (Ex. 1) — §8.8 V 800 + N 1500: f_y,red 334.2, M_c,Rd 535, N_pl,Rd 5456, M_N,Rd 516	Pass
PU 18 (Ex. 1) — §8.9 member buckling: N_cr 32697, 0.04N_cr 1308, λ̄ 0.421, χ 0.84 (chart), M_Ed ≤ 297	Pass
AZ 18-700 (Ex. 2) — M_c,Rd 639; A_v 3699, V_pl,Rd 758.1 kN/web, 1083 kN/m	Pass
AZ 18-700 (Ex. 2) — V_Ed 800: ratio 0.94, M_V,Rd 601 (class 3, elastic analogue)	Pass
AZ 18-700 (Ex. 2) — N_pl,Rd 4942, N/N_pl 0.304, M_N,Rd 445	Pass
AZ 18-700 (Ex. 2) — V 800 + N 1500: ρ 0.228, f_y,red 274.1, M_c,Rd 493, N_pl,Rd 3815, M_N,Rd 299	Pass
Handbook Ch. 3 Table 3.7 — M_c,Rd for AZ 25-800 / PU 28-1.0 in S 430 GP (new and corroded)	Pass
Handbook Table 8.7 — AZ 18-700 slant height c 527.4 mm and (c/t_w)/ε 75.5 / 79.3 / 82.0 (S 390 / 430 / 460)	Pass
documented difference — AZ 18-700 S 355: (c/t_w)/ε = 72.02 > 72 so the engine applies the shear-buckling clause	Pass

fe-design-checks-strut-web-validation.test.ts

W3-3 — `fe-design-checks/strut.ts` (the per-element strut check) against published column-buckling values.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
ENV 1993-1-1 Table 5.5.2 — curve a (α = 0.21), λ̄ = 0.2…1.5 (14 published χ values)	Pass
ENV 1993-1-1 Table 5.5.2 — curve a (α = 0.21), λ̄ = 1.6…3.0 (15 published χ values)	Pass
ENV 1993-1-1 Table 5.5.2 — curve b (α = 0.34), λ̄ = 0.2…1.1 (10 published χ values)	Pass
Designers' Guide Ex. 6.7 (CHS 244.5×10 S355, L 4 m, curve a): N_b,Rd 2297, N_c,Rd 2616 kN	Pass
Designers' Guide Ex. 6.9 (A 8300, S355, curve a) y-axis: N_b,Rd 2266 kN, N_c,Rd 2946.5 kN	Pass
Designers' Guide Ex. 6.9 (A 8300, S355, curve a) z-axis: N_b,Rd 1209.2 kN, N_c,Rd 2946.5 kN	Pass

fe-staged-excavation-web-validation.test.ts

WEB-BENCHMARK validation for the staged-excavation FE engine.

Analyses validated: `fe-staged-excavation` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
SE web: wide-cut collapse stability number in the basal-heave band [4, 5.5] (≈ Prandtl 5.14)	Pass
SE web: base heave builds up progressively through the stages	Pass
SE web: FoS falls as the cut deepens	Pass
SE web: higher cu ⇒ deeper stable excavation	Pass
SE web: heave field + per-stage results are well-formed	Pass

⚑ ground-anchor-web-validation.test.ts

GROUND-ANCHOR — web-validation benchmark against FHWA GEC-4 tables and design examples.

Analyses validated: `ground-anchor` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
GEC-4 Table 9 — Grade 150 bars (f_pu = 1035 MPa): 0.8 / 0.7 / 0.6 f_pu·A_ps	Pass
GEC-4 Table 9 — Grade 160 bars (f_pu = 1104 MPa): 0.8 / 0.7 / 0.6 f_pu·A_ps	Pass
GEC-4 Table 10 — strand tendons: 0.8 / 0.7 / 0.6 f_pu·A_ps for 1, 3, 4, 5, 7, 9, 12, 15, 19 strands	Pass
GEC-4 Design Example 1 (pp. A-8, A-9) — soil anchor: 12 m bond length at 100 kN/m, FoS 2.0	Pass
GEC-4 Design Example 1 (p. A-9) — tendon selection against the 445 kN design load	Pass
GEC-4 Design Example 2 (pp. A-26, A-27) — rock anchor: 7.5 m bond length at 360 kN/m, FoS 3.0	Pass
GEC-4 Design Example 2 (p. A-27) — tendon selection against the 636 kN design load	Pass
GEC-4 p. 74 (PTI 1996) — ultimate rock-grout bond ≈ 10 % of UCS, maximum 3.1 MPa	Pass
CFEM 2006 Table 26.6 (p. 423) — soil anchors: ultimate load transfer per metre of bond length	Pass
CFEM 2006 Table 26.7 (p. 424) — rock anchors: ultimate load transfer per metre of bond length	Pass
CFEM 2006 §26.12.4.1 — allowable anchor load = ultimate capacity / 3 where no pull-out test is made	Pass

⚑ k0-at-rest-web-validation.test.ts

Validation for `k0-at-rest` — Jaky / Mayne-Kulhawy coefficient of earth pressure at rest and the at-rest wall thrust (`k0-at-rest.ts`).

Analyses validated: `k0-at-rest` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EM 1110-2-2502 Table E-1: Jaky K0 for φ′ = 10°…27° (printed 0.826 … 0.546)	Pass
EM 1110-2-2502 Table E-1: Jaky K0 for φ′ = 28°…45° (printed 0.531 … 0.293)	Pass
Das Example 12.1: K0 = 0.5, σ′h = 20.63 kN/m² at 2.5 m, triangle force 25.788, lever arm 0.833 m	Pass
Lambe & Whitman Example 8.2: initial horizontal stress K0·γ·z = 24.8 kN/m² at 3 m	Pass
NAVFAC DM-7.02: "for φ′ = 30°, K0 = 0.5"	Pass
Bowles: K0 printed in Examples 4-10, 13-6, 16-1 and the Ch. 12 abutment discussion	Pass
Bowles Example 14-1: K0 = 0.50, R0 = ½ × 16.5 × 9.3² × 0.5 = 357 kN, average pressure 38.38 kPa	Pass
Bowles Example 2-2 (φ′ = 25°, OCR = 5): K0,nc = 0.58 and K0,OCR = 1.14 / 1.15	Pass
Bowles §2-8: a fluid has K0 = 1.0, the isotropic limit of Jaky at φ′ = 0	Pass

mse-wall-web-validation.test.ts

`mse-wall` — anchored to the FHWA GEC-11 worked example.

Analyses validated: `mse-wall` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
GEC-11 Example E1: backslope angle I = arctan(9/40) = 12.7°	Pass
GEC-11 Vol I Eq. 4-3: the Coulomb Ψ term = 2.133 at Example E1's conditions	Pass
GEC-11 Vol I Eq. 4-2: external coefficient Kab = 0.360, and our engine reproduces it	Pass
the Coulomb (δ = β, θ = 90°) and Rankine-sloped forms are IDENTICAL — swept, not assumed	Pass
GEC-11 Eq. 4-28 / 4-29 / 4-30: the published EV load factor is 1.35 and heq = 2 ft	Pass
GEC-11 Example E1: the engine runs the published geometry and reports coherent externals	Pass
§4.4.2: the external thrust uses the RETAINED soil, and a weaker retained soil raises it	Pass
§4.3.2: a vertical spacing above 0.8 m is warned	Pass
a backslope steeper than the retained friction angle is refused, not silently zeroed	Pass
every numeric output is finite at the published configuration	Pass

rc-section-web-validation.test.ts

Dedicated validation for the singly-reinforced RC flexural section (`rc-section.ts`): limit-state flexure to IS 456:2000 cl.

Analyses validated: `rc-section` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
SP 16 Table 3 (fck 25): Fe 415 column, printed pt (%) against Mu/bd²	Pass
SP 16 Table 3 (fck 25): Fe 250, Fe 500, Fe 480 and Fe 240 columns	Pass
SP 16 Table 3 blanks: Mu/bd² above the Table D limit is not a singly-reinforced design	Pass
SP 16 Table C: Mu,lim / (fck b d²) for Fe 250, 415, 500 (printed to 3 d.p.)	Pass
SP 16 Table D: Mu,lim / bd² (N/mm²) for fck 15-30 and Fe 250/415/500	Pass
SP 16 Example 1: 30 x 60 cm beam, M 15, Fe 415, Mu = 170 kN·m, d = 56.25 cm	Pass
SP 16 Example 2: slab, 10 cm thick, d = 8 cm, Mu = 9.60 kN·m/m, M 15 — printed limiting moments	Pass
IS 456:2000 cl.38.1 Note: xu,max/d = 0.53, 0.48, 0.46 for Fe 250, 415, 500 (printed to 2 d.p.)	Pass
NPTEL Lesson 6 Design Problem 3.1: printed limiting depth, Ast and Mu,lim	Pass

retaining-wall-web-validation.test.ts

RETAINING-WALL — web-validation benchmark against published worked examples and Rankine tables.

Analyses validated: `retaining-wall` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bowles Ex. 12-6 — geometry and heel-plane thrust: B = 1.98 m, H′ = 2.90 m, Pa = 44.30 kN/m, Mo = 49.75	Pass
Bowles Ex. 12-6 — Table E12-6: weights and moments about the toe	Pass
Bowles Ex. 12-6 — resultant position and eccentricity: $\bar{x}$ = 0.70 m, e = 0.29 m < B/6 = 0.33 m	Pass
Bowles Ex. 12-6 — the Rankine coefficient the book set aside: Table 11-3 gives 0.260 for ϕ = 36°	Pass
Bowles Ex. 12-5 (p. 772) — Pa = 96.28 kN/m, Mo = 245.58 kN·m/m and the two concrete parts	Pass
Bowles 5e Table 11-3 (p. 603) — Rankine Ka, β = 0, ϕ = 26°…42°	Pass
Das 8e Table 12.1 (p. 608) — Ka(R) at α = 0°, θ = 0°, ϕ′ = 28°…40°	Pass

secant-pile-wall-web-validation.test.ts

Web-benchmark validation for `secant-pile-wall`.

Analyses validated: `secant-pile-wall` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
watertightness is the overlap left AFTER verticality tolerance, vs 0.10·D	Pass
a deeper wall loses more overlap and eventually fails watertightness	Pass
the overlap must be geometrically possible	Pass
per-pile actions use pitch = Ds + Dp − 2·ov, halved for hard/hard	Pass
a wider overlap tightens the pitch and so reduces the load per pile	Pass
moment capacity is IS 456 M_lim = 0.138·f_ck·Ds·d_eff², with d_eff floored (E-12)	Pass
a below-grade secondary concrete grade is flagged against DIN 4126 §7	Pass
vertical capacity uses the Tomlinson α bands and 9·s_u end bearing, with FoS 2.5	Pass
in sand the capacity is $K_o \cdot \sigma v \cdot \tan\delta$ shaft plus a halved Meyerhof base	Pass
basal heave uses N_c = 7 on γ_top·H + q, and withholds in a frictional soil	Pass
a prop reduces the wall moment and its force is reported per metre and per pile	Pass
invalid geometry is refused with a zeroed result	Pass

seismic-structural-web-validation.test.ts

Web-benchmark validation for TWELVE seismic, structural and deep-foundation runner engines.

Analyses validated: `bray-travasarou`, `concrete-durability`, `design-spectrum`, `embankment-stress`, `excavation-settlement`, `helical-pile`, `machine-foundation`, `makdisi-seed`, `newmark-displacement`, `rc-section`, `strut-design`, `tunnel-ground-reaction` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
makdisi-seed uses the 1978 fundamental period and normalised displacement	Pass
newmark-displacement reproduces the Jibson (2007) regression	Pass
bray-travasarou reproduces the 2007 flexible-sliding-mass regression	Pass
design-spectrum follows IS 1893 (Part 1):2016 Cl 6.4.2	Pass
strut-design reproduces the IS 800:2007 Perry-Robertson buckling curve	Pass
rc-section reproduces IS 456:2000 Cl 38 flexure and the steel limits	Pass
concrete-durability applies the IS 456 Table 4 sulphate classes	Pass
machine-foundation reproduces the Barkan C_u stiffness and the SDOF response	Pass
tunnel-ground-reaction reproduces the Hoek convergence-confinement solution	Pass
excavation-settlement applies the Clough & O'Rourke (1990) envelopes	Pass
embankment-stress uses the Osterberg (1957) trapezoidal influence	Pass
helical-pile reproduces the AC358 individual-bearing plate method	Pass

sheet-pile-second-source-web-validation.test.ts

SHEET-PILE — second-source web-validation suite (companion to `sheet-pile-web-validation.test.ts`).

Analyses validated: `sheet-pile` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Bowles 5e Table 11-3 (p. 603) — Rankine Ka, β = 0, ϕ = 26°…42°	Pass
Bowles 5e Table 11-4 (p. 603) — Rankine Kp, β = 0, ϕ = 26°…42°	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Varghese Ex. 22.4 (p. 420) — active pressure at the tie level and at the dredge line	Pass
Varghese Ex. 22.4 (p. 420) — the net pressure returns to zero a = 1.0 m below the dredge line	Pass
Varghese Ex. 22.3 (p. 419) — active pressures at the water table and at the dredge line	Pass
Ex. 22.4 — engine embedment equals the root of the moment equation the book states (3.113 m), not the printed 6.3 m	Pass
Ex. 22.3 — engine embedment equals the root of the correct cantilever equilibrium (7.455 m), not the printed 6.35 m	Pass

sheet-pile-web-validation.test.ts

SHEET-PILE WALLS — web-validation benchmark against published worked examples.

Analyses validated: `sheet-pile` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Ex 14.1 — Rankine coefficients and the pressure diagram (10 published values)	Pass
Das Ex 14.1 — quartic coefficients A1..A4 (Eqs 14.17-14.20)	Pass
Das Ex 14.1 — L4 is a trial-and-error stop at 4.8 m, not a rounding (proof by residual)	Pass
Das Ex 14.1 — Mmax, section modulus and total length (parts b and c)	Pass
Das Ex 14.2 — the no-water-table case falls out of the SAME implementation	Pass
Das Ex 14.2 — Eq (14.30) for $\bar{z}$ is an erratum: the Ka coefficient is 1, not 2	Pass
Das Ex 14.7 — anchored free-earth support, 12 published values	Pass
Das Ex 14.7 — F, x and Mmax reproduce EXACTLY at the L4 the text prints	Pass
Das Ex 14.9 — total pile length H′ = L1 + L2 + Dactual = 14.48 m	Pass
anchored free-earth diagram satisfies ΣF = 0 AND ΣM = 0 at the toe	Pass
cantilever toe moment residual equals Das Eq (14.14)'s trapezoid-arm idealisation exactly	Pass
rankine_classical reproduces Ex 14.1 end-to-end through computeSheetPile	Pass
E-51 — net_envelope is conservative by a pinned factor, not by an unknown one	Pass
rankine_classical refuses every case Das §14.4/§14.9 does not derive	Pass
rankine_classical honours Das's Kp factor of safety (Step 13 note)	Pass

soil-nail-wall-web-validation.test.ts

`soil-nail-wall` — anchored to FHWA GEC No.

Analyses validated: `soil-nail-wall` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
E-44: the default overall-stability target is Table 5.1's 1.5, not note (2)'s 1.35	Pass
E-44: opting into FSOS = 1.35 is allowed but its note-(2) conditions are stated	Pass
GEC No. 7 Table 5.1: the static acceptance targets are 2.0 pullout, 1.8 tendon, 1.5 facing	Pass
E-45: under seismic loading the SEISMIC column applies (FSPO 1.5, FST 1.35, FSFF 1.1)	Pass
E-45: the published seismic FSOS is 1.1 — not 0.75 × the static target	Pass
Table 5.1 internal consistency: every seismic target is at or below its static counterpart	Pass
the engine cites the CURRENT edition, FHWA-NHI-14-007 (GEC No. 7, 2015)	Pass
every numeric output is finite, and a wall with no nails is refused	Pass

staged-excavation-wall-web-validation.test.ts

STAGED-EXCAVATION-WALL (and EMBEDDED-WALL-SSI) — web-validation benchmark: the published parts.

Analyses validated: `embedded-wall-ssi`, `staged-excavation-wall` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA NHI-06-089 Example 10-2 (pp. 10-32, 10-33) — line-load lateral pressure Ph (psf) at n = z/H = 0.1 … 1.0	Pass
NAVFAC DM-7.2 Fig. 11 (p. 7.2-74) — line load, m > 0.4: P_H = 0.64 Q_L/(m² + 1)	Pass
NAVFAC DM-7.2 Fig. 11 (p. 7.2-74) — height R of the resultant above the base, as a fraction of H	Pass
NAVFAC DM-7.2 Fig. 30 (p. 7.2-107) — surcharge step: m = 4/20 = 0.2, Qp = 10 kip, H = 20 ft	Pass

steel-section-mphi-web-validation.test.ts

Steel circular / pipe pile section engine (`steel-section-mphi.ts`, registered as `steel-pile-section`) checked against PUBLISHED tabulated section properties.

Analyses validated: `steel-pile-section` · Recorded run: passed — 20 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] ASTM A1085 20 x 0.5 in: I = 1460 in⁴, S = 146 in³, Z = 190 in³	Pass
[1] ASTM A1085 20 x 0.375 in: I = 1110 in⁴, S = 111 in³, Z = 144 in³	Pass
[1] ASTM A1085 18 x 0.5 in: I = 1050 in⁴, S = 117 in³, Z = 153 in³	Pass
[1] ASTM A1085 16 x 0.625 in: I = 894 in⁴, S = 112 in³, Z = 148 in³	Pass
[1] ASTM A1085 16 x 0.5 in: I = 732 in⁴, S = 91.5 in³, Z = 120 in³	Pass
[1] ASTM A1085 14 x 0.375 in: I = 373 in⁴, S = 53.3 in³, Z = 69.6 in³	Pass
[1] ASTM A1085 12.75 x 0.5 in: I = 362 in⁴, S = 56.7 in³, Z = 75.1 in³	Pass
[1] ASTM A1085 12.75 x 0.25 in: I = 192 in⁴, S = 30.1 in³, Z = 39.1 in³	Pass
[1] ASTM A1085 10.75 x 0.375 in: I = 165 in⁴, S = 30.6 in³, Z = 40.4 in³	Pass
[1] ASTM A1085 10 x 0.25 in: I = 91.1 in⁴, S = 18.2 in³, Z = 23.8 in³	Pass
[1] ASTM A1085 8.625 x 0.322 in: I = 72.5 in⁴, S = 16.8 in³, Z = 22.2 in³	Pass
[1] ASTM A1085 6.625 x 0.25 in: I = 25.5 in⁴, S = 7.69 in³, Z = 10.2 in³	Pass
[1] ASTM A1085 5 x 0.188 in: I = 8.24 in⁴, S = 3.30 in³, Z = 4.36 in³	Pass
[2] AISC v16 Pipe12STD (OD 12.75 in, tdes 0.349 in): I = 262 in⁴, S = 41 in³, Z = 53.7 in³	Pass
[2] AISC v16 Pipe6STD (OD 6.625 in, tdes 0.261 in): I = 26.5 in⁴, S = 7.99 in³, Z = 10.6 in³	Pass
[3] the printed Mp/Ms ratios: 1.3 for Pipe12STD and 1.4 for Pipe12XXS (the thicker wall has the larger shape factor)	Pass
[4] solid circle r = 2: Z = 32/3, S = 2π, shape factor f = 16/(3π) = 1.697653	Pass
[5] solid circle r = 1: Z = 4/3, S = π/4	Pass
[6] HAND CHECK (not a published value): Mp and My are fy·Z and fy·S, and axial load lowers Mp by the exact circular plastic M–N value	Pass
[7] IS 800:2007 cl. 9.3.1.1(e): for a circular hollow tube Mnd = 1.04·Md·(1 – n^1.7) ≤ Md — the engine's exact reduction is the same order and never exceeds Md	Pass

structural-elements-web-validation.test.ts

WEB / TEXTBOOK-BENCHMARK validation for the structural-elements engine (beam-on-elastic-foundation Winkler FE + 2-D elasto-plastic FE structure library: beam/plate, anchor, tension-only geogrid, Mohr-Coulomb interface).

Analyses validated: `structural-elements` · Recorded run: passed — 28 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
SE web 1-3: λ = (k/4EI)^(1/4) — Hetenyi 1946 Eq 8	Pass
SE web 4-6: infinite beam w_max = P·λ/(2k) — Hetenyi 1946 Eq 17	Pass
SE web 7-9: infinite beam M_max = P/(4λ) — Hetenyi 1946 Eq 17	Pass
SE web 10-11: infinite beam soil reaction ∫k·w dx = P (Hetenyi equilibrium)	Pass
SE web 12: infinite beam shear jump |V| = P/2 at the load (Hetenyi Eq 17)	Pass
SE web 13-14: full-length UDL — interior w = q/k, interior M ≈ 0 ("floating" beam)	Pass
SE web 15-17: anchor spring — rigid beam, w = P/(kL+k_a) and T = k_a·δ	Pass
SE web 18-19: anchor pre-stress — T = P0 + k_a·δ and w = (P−P0)/(kL+k_a)	Pass
SE web 20-21: geogrid carries T = k_g·δ in tension (stretched)	Pass
SE web 22-23: geogrid carries ZERO force in compression (tension-only)	Pass
SE web 24: interface strength cap τ_max = c + σ_n·tan δ (Mohr-Coulomb)	Pass
SE web 25-26: interface elastic below cap — τ = k_s·slip, |τ| < τ_max	Pass
SE web 27-28: interface caps shear at τ_max under a large load (plastic slip)	Pass
SE web 29: superposition — response to (P1)+(P2) = response to both together	Pass
SE web 30: symmetry — a symmetric load pair gives a symmetric deflection profile	Pass
SE web 31: static equilibrium — $\Sigma F_v \approx 0$ and ΣM ≈ 0 for a multi-load case	Pass
SE web 32: invalid inputs return errors without throwing (NaN/∞ guard)	Pass
SE web 33: all profile outputs are finite for a well-posed problem	Pass
audit: a solve that fails its own equilibrium check is REFUSED, not reported	Pass
audit: the real, valid case is byte-identical to before the fix	Pass
SE published: Hetényi §18 — λ and λl (p. 47)	Pass
SE published: Hetényi §18 — deflections, soil pressures, M and Q at C of the free-ended beam (pp. 48-49)	Pass
SE published: Hetényi §12 Example 1 — forces at x = π/2λ reduce the maximum moment (0.7921 / 0.5842 / 0.7489)	Pass
SE published: Hetényi §12 Example 4 — ring on a long tube: bending stress 82 % above the hoop stress (p. 36)	Pass
SE published: Bowles Example 9-6 — the 13 printed nodal deflections (COMP X, mm)	Pass
SE published: Bowles Example 9-6 — printed soil pressures (SOIL Q, kPa) at nodes 1, 4, 7, 10, 13	Pass
SE published: Bowles Example 9-6 — printed nodal bending moments (kN·m), sign per Bowles	Pass
SE published: Bowles Example 9-6 — comment 1: Σ spring forces 3374.71 kN against 3375 kN input	Pass

strut-design-web-validation.test.ts

STRUT-DESIGN — web-validation benchmark against two independently published column-curve tables.

Analyses validated: `strut-design` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IS 800:2007 Table 9(a) (printed p.40) — class a, fy = 250 MPa, KL/r 10…250 (25 published values)	Pass
IS 800:2007 Table 9(a) (printed p.40) — class a, fy = 300 and 450 MPa columns (12 published values)	Pass
IS 800:2007 Table 9(b) (printed p.41) — class b, fy = 250 MPa, KL/r 10…250 (25 published values)	Pass
IS 800:2007 Table 9(b) (printed p.41) — class b, fy = 300 and 450 MPa columns (12 published values)	Pass
IS 800:2007 Table 9(c) (printed p.42) — class c, fy = 250 MPa, KL/r 10…250 (25 published values)	Pass
IS 800:2007 Table 9(c) (printed p.42) — class c, fy = 300 and 450 MPa columns (12 published values)	Pass
IS 800:2007 Table 9(d) (printed p.43) — class d, fy = 250 MPa, KL/r 10…250 (25 published values)	Pass
IS 800:2007 Table 9(d) (printed p.43) — class d, fy = 300 and 450 MPa columns (12 published values)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
ENV 1993-1-1:1992 Table 5.5.2 (p.73) — buckling curve a, λ̄ = 0.2…3.0 (29 published values)	Pass
ENV 1993-1-1:1992 Table 5.5.2 (p.73) — buckling curve b, λ̄ = 0.2…3.0 (29 published values)	Pass
ENV 1993-1-1:1992 Table 5.5.2 (p.73) — buckling curve c, λ̄ = 0.2…3.0 (29 published values)	Pass
ENV 1993-1-1:1992 Table 5.5.2 (p.73) — buckling curve d, λ̄ = 0.2…3.0 (29 published values)	Pass
ENV 1993-1-1:1992 cl. 5.5.1.2(1): λ1 = 93.9 ε at fy = 235 MPa — KL/r = 93.9 is λ̄ = 1.000	Pass
IS 800:2007 Table 3 item (i), cl. 3.8 (p. 20): KL/r limit of 180 for a member in compression from dead + imposed load	Pass
Dependent arithmetic (NOT a published answer): Pd = Ae·fcd (IS 800 cl. 7.1.2) applied to the printed f_cd	Pass

`wall-surcharge-web-validation.test.ts`

Validation for the non-uniform wall-surcharge (NAVFAC modified-Boussinesq) + passive-berm additions to the embedded-wall engine (`staged-excavation-wall.ts`).

Analyses validated: `embedded-wall-ssi`, `staged-excavation-wall` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NAVFAC line load I_L = σh·H/Q_L — published values, m ≤ 0.4 branch	Pass
NAVFAC line load I_L — published values, m > 0.4 branch	Pass
NAVFAC point load I_P = σh·H²/Q_P — published values, m ≤ 0.4 branch	Pass
NAVFAC point load I_P — published values, m > 0.4 branch	Pass
NAVFAC line load: resultant ≈ 0.64·Q for m > 0.4 (closed form)	Pass
NAVFAC line load: pressure peaks at n = m/√3 (m > 0.4)	Pass
NAVFAC line load: linear in Q, and → 0 at surface and at depth	Pass
NAVFAC point load: linear in Q, correct Q/H² scaling, decays	Pass
strip surcharge → line-load limit as width → 0 with q·w = Q	Pass
strip surcharge superposes and stays positive; wide strip spreads the pressure	Pass
wall: a retained strip surcharge raises the bending moment	Pass
wall: a passive berm reduces wall deflection (CIRIA C760)	Pass
no surcharges / no berm ⇒ unchanged from the base wall (regression guard)	Pass

`walls-web-validation.test.ts`

WEB-BENCHMARK validation for the retaining-wall external-stability engine (the release rules ≥20 cited-value gate).

Analyses validated: `retaining-wall` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Wall web: ϕ=25° — Ka, Pa, overturning & sliding FoS (Rankine + Das §8)	Pass
Wall web: ϕ=30° — Ka, Pa, overturning & sliding FoS (Rankine + Das §8)	Pass
Wall web: ϕ=35° — Ka, Pa, overturning & sliding FoS (Rankine + Das §8)	Pass
Wall web: ϕ=40° — Ka, Pa, overturning & sliding FoS (Rankine + Das §8)	Pass
Wall web: ϕ=30° — eccentricity e & q_max (middle-third, Bowles §11)	Pass
Wall web: ϕ=35° — eccentricity e & q_max (middle-third, Bowles §11)	Pass

Piles and deep foundations

Cited validation suites — 30

⚑ broms-lateral-pile-web-validation.test.ts

PUBLISHED-VALUES: 9 -- distinct published values for this engine (engine-level total, declared once); independent audit A2: 9 printed values; the further 30 assertions are digitised chart readings (+-5 %) and are not counted.

Analyses validated: `broms-lateral-pile` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA-NHI-10-016 Eq.12-21/12-22/12-24 clay case A (Pt=100 kip, Mt=2000 kip-ft): Hu from printed Mmax	Pass
FHWA clay case A: depth of maximum moment = 1.5·Bb + f = 72 + 15.43 in	Pass
FHWA Eq.12-25/12-26 clay case B (Pt=40 kip, Mt=800 kip-ft): Hu and hinge depth from printed Mmax	Pass
FHWA clay: printed Mmax (1,050 kip-ft) given in kip-ft returns the same 40 kip	Pass
FHWA Eq.12-33: Kp = tan²(45°+32°/2) = 3.25	Pass
FHWA sand: Hu from the printed Mmax = 956 kip-ft returns Pt = 40 kip	Pass
FHWA Eq.12-35: sand depth of maximum moment f = 5.85 ft	Pass
Varghese Example 13.3: long free-head pile in clay, Hu ≈ 7·cu·D² = 63 kN	Pass
Das Fig. 9.36(b): My/(cu·D³) = 40, free-head curves e/D = 0,1,2,4,8,16	Pass
Das Fig. 9.36(b): My/(cu·D³) = 100, free-head curves e/D = 0,1,2,4,8,16	Pass
Das Fig. 9.36(b): My/(cu·D³) = 200, free-head curves e/D = 0,1,2,4,8,16	Pass
Das Fig. 9.36(b): My/(cu·D³) = 400, free-head curves e/D = 0,1,2,4,8,16	Pass
Das Fig. 9.36(b): the six marked long-pile points	Pass

⚑ drilled-shaft-web-validation.test.ts

Published-value validation for drilled-shaft axial capacity (`drilled-shaft.ts`, `computeDrilledShaft`): α-method side, β-method side, and base resistance in clay and sand.

Analyses validated: `drilled-shaft` · Recorded run: passed — 18 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Example 10.5: Σ αcu·p·ΔL = 255.28 kN (ΔL1 = 1.5 m at cu 40, ΔL2 = 2.24 m at cu 60)	Pass
Das Example 10.5: qp = 6cu(1 + 0.2L/Db) = 1957.5 kPa exceeds 9cu, so qp = 1305 kPa	Pass
Das Example 10.5: base resistance qp·Ap = 1475.9 kN	Pass
Das Example 10.4: base in cu = 2175 psf clay, Ds = 3.3 ft: Qp(net) = Ap·cu·N*c = 167.4 kip	Pass
Das Example 10.3: qp = 57.5·N60 = 57.5 × 30 = 1725 kN/m²	Pass
Das Table 10.4: cu/pa = 0.25, 0.5, ≥1 → N*c = 6.5, 8.0, 9.0 (pa = 100 kPa)	Pass
FHWA Table 13-2: su = 500, 1000, 2000 psf → N*c = 6.5, 8.0, 9.0	Pass
FHWA Example 13-2: unit side resistance 0.55 × 2,395 psf = 1,317 psf	Pass
FHWA Example 13-2: RSN = π (5 ft)(45 ft)(1,317 psf) = 930.9 kips	Pass
FHWA App. A layer 4: fSN = 0.55 × 1,750 = 963 psf (962.5 printed as 963)	Pass
FHWA App. A layer 4: RSN = π (8 ft)(15 ft)(962.5 psf) = 362,854 lb	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA App. A layer 6: fSN = 0.55 × 2,300 = 1,265 psf	Pass
FHWA App. A layer 6: RSN = 2,559,330 lb	Pass
FHWA App. A layer 7 base: qBN = 0.60 N60 = 24.6 tsf = 49.2 ksf (N60 = 41)	Pass
FHWA App. A layer 7 base: RBN = π/4 (8 ft)² (49.2 ksf) = 2,473 kips	Pass
AASHTO (2007) Eq. 10.8.3.5.2c-1: qp = 0.057 N60 MPa → 1710 kPa at N60 = 30	Pass
AASHTO (2007) §10.8.3.5.2c: tip resistance limited to 3.0 MPa; FHWA Eq. 13-14: 30 tsf = 2,873 kPa	Pass
AASHTO (2007) Eq. 10.8.3.5.2b-1 / Das Eq. 10.26: unit side resistance in sand never exceeds 0.19 MPa (192 kN/m²)	Pass

driven-pile-dynamics-web-validation.test.ts

Published-value validation for the Hiley driven-pile dynamic formula (`driven-pile-dynamics.ts`, `computeDrivenPileDynamics`).

Analyses validated: `driven-pile-dynamics` · Recorded run: passed — 26 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC:78-2014 App.7 η table, P/W = 0.5: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 1: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 1.5: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 2: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 2.5: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 3: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 3.5: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 4: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 5: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 6: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 7: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
IRC:78-2014 App.7 η table, P/W = 8: e = 0.5, 0.4, 0.32, 0.25, 0	Pass
Bowles Example 17-2: first trial k2 = 6.8 mm gives Pu = 1331 kN (printed "rounded")	Pass
Bowles Example 17-2: converged k2 = 9.5 mm gives Pu = 1264 kN	Pass
Bowles Example 17-2: blow-efficiency term (125 + 0.5²·21.86)/(125 + 21.86) = 0.888	Pass
Bowles Example 17-2: hammer energy term eh·Eh = 0.78 × 48.8 = 38.06 kN·m	Pass
Bowles Example 17-2: allowable Pa = 1260/4 = 315 kN at the book's rounded Pu = 1260	Pass
Bowles Table E17-4: set 1, 2, 4 mm → Pu 901.4, 849.8, 758.2 kN	Pass
Bowles Table E17-4: set 6, 8, 10 mm → Pu 679.0, 611.3, 553.4 kN	Pass
Bowles Table E17-4: set 25, 50 mm → Pu 307.9, 170.2 kN	Pass
Varghese Example 10.1: efficiency of blow η = (5 + 9.7·0.25²)/(5 + 9.7) = 0.381	Pass
Varghese Example 10.1: total temporary compression C = 0.212 + 1.222 + 0.409 = 1.843 cm	Pass
Varghese Example 10.1: set S = 0.95 mm/blow gives Ru = 300 t (safe 120 t at FS 2.5)	Pass
Varghese Example 10.2 resistance-set table: Ru 250, 200, 150, 100 t at S = 2.98, 6.03, 11.10, 21.27 mm	Pass
Varghese Example 10.2: Ru for S → 0 is 331 t (hammer energy over C/2 alone)	Pass
Varghese Example 10.3 (400×400, 15 m, fall 1.5 m): η = 0.48 and S = 2.0 mm gives Ru = 225 t	Pass

⚑ helical-pile-web-validation.test.ts

Published-value validation for helical (screw) pile capacity (`helical-pile.ts`, `computeHelicalPile`): individual-plate bearing Qh = Ah·(9·c + q'·Nq) and the installation-torque correlation Qu = Kt·T.

Analyses validated: `helical-pile` · Recorded run: passed — 19 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Supportworks Example 1: net plate areas 10/12/14 in. on a 2.875 in. shaft = 0.50/0.74/1.02 ft²	Pass
Supportworks Example 1: Qu = ΣAh(9c) = (2.26)(9)(3,000) = 61,020 lb	Pass
Supportworks Example 1: Qa = Qu / FOS = 61/2 = 30.5 kips (FOS 2)	Pass
Supportworks Example 1: Torque Correlation, T = Qu/Kt = 60,000/9 = 6,667 ft·lb (Kt = 9 ft⁻¹)	Pass
Supportworks Example 2: Nq = 1 + 0.56(12ϕ)^(ϕ/54) = 42.6 at ϕ = 38° and 15.7 at ϕ = 30°	Pass
Supportworks Example 2: net plate areas 10/12 in. on a 3.5 in. shaft = 0.48/0.72 ft²	Pass
Supportworks Example 2: Qu = ΣAh(q'Nq) = 84,310 lb (q'12" = 1,595, q'10" = 1,731 psf, ϕ = 38°)	Pass
Supportworks Example 2: loose sand above the 12 in. plate (ϕ = 30°) gives Qu = 53,420 lb	Pass
Supportworks Example 2: T = Qu/Kt = 80,000/7 = 11,428 ft·lb (Kt = 7 ft⁻¹, 3.5 in. shaft)	Pass
TMG: Nq at ϕ = 34° is 22.0 (Perko 0.5(12ϕ)^(ϕ/54)) and 25.7 (1 + 0.56(12ϕ)^(ϕ/54))	Pass
TMG: net areas on a 2⅞ in. shaft, 12 in. = 0.740 and 10 in. = 0.500 ft²	Pass
TMG: net areas on a 3½ in. shaft, 10/12/14 in. = 0.479/0.719/1.002 ft²	Pass
TMG attempt one (2⅞ in. shaft, ϕ = 34°, Nq = 25.7): plate loads 20,122 and 15,898 lb; Qult = 36.0 kip	Pass
TMG attempt one with Nq = 22.0 (Perko): Qult = 30.8 kip	Pass
TMG attempt two (3½ in. shaft, 10/12/14 in.): plate loads 19,606 / 26,686 / 32,613 lb; Qult = 78.9 kip	Pass
TMG attempt two with Nq = 22.0 (Perko): Qult = 67.5 kip	Pass
TMG attempt three (four plates 10/12/14/14 in.): plate loads 21,072 / 28,887 / 35,683 / 30,310 lb; Qult = 116.0 kip	Pass
TMG attempt three with Nq = 22.0 (Perko): Qult = 99.3 kip	Pass
TMG: required torque T = 80,000/Kt → 8,889 ft·lb at Kt = 9 ft⁻¹ (attempt one) and 11,429 ft·lb at Kt = 7 ft⁻¹	Pass

hetenyi-beam-web-validation.test.ts

Beam on an elastic foundation — validated against **Hetényi (1946)**, *Beams on Elastic Foundation*, University of Michigan Press, and **Bowles (1997)**, *Foundation Analysis and Design* 5th ed., McGraw-Hill.

Analyses validated: `hetenyi-beam` · Recorded run: passed — 23 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Hetényi Eq 8 — the characteristic parameter λ and the derived rigidities	Pass
Hetényi Eq 17 — infinite beam, concentrated load: the three closed-form maxima	Pass
Hetényi Eq 17 — the full deflection and moment PROFILE, not just the peaks	Pass
Hetényi — an applied MOMENT on an infinite beam (Eq 23)	Pass
Hetényi — superposition holds (the solution is linear)	Pass
Hetényi — the λL rigidity bands	Pass
Hetényi — a long finite beam converges on the infinite-beam solution	Pass
Hetényi §18 — λ and λl (p. 47)	Pass
Hetényi §18 — the P load on the infinite beam at A and B (Eq 5 c-d, p. 47)	Pass
Hetényi §18 — the UDL on the infinite beam at A, B (Eqs 8, 9) and C (Eq 7) — the Simpson-defect regression	Pass
Hetényi §18 — P + q on the infinite beam: the printed totals at A and B (p. 47)	Pass
Hetényi §18 — the infinite-beam deflections at A, C, B (table a, p. 48)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Hetényi §18 — the FINITE free-ended beam: deflections, soil pressure, M and Q at C (pp. 48-49)	Pass
Hetényi §12 Example 1 — equal forces at x = π/2λ reduce the maximum moment (0.7921, 0.5842, 0.7489)	Pass
Hetényi §12 Example 4 — reinforcing ring on a long tube: bending stress is 82 % above the hoop stress (p. 35-36)	Pass
Hetényi §6 — concentrated moment: y and M reverse to the left, Q does not; M jumps by M_0 across the load	Pass
Hetényi — a pure couple on a FINITE free beam carries no net soil force and balances its own moment	Pass
Hetényi — an applied moment AT a free end: M just inside the end equals the applied moment (free-end condition)	Pass
Hetényi Table I — A, B, C, D at λx = 0.70, 0.89, 1.00, 1.25, 1.50 (printed to 4 decimals)	Pass
Bowles Example 9-6 — an independent solver WITH the printed doubled end springs reproduces the printed output	Pass
Bowles Example 9-6 — global equilibrium: the engine's soil reaction sums to the applied 3375 kN (printed 3374.71 vs 3375.00)	Pass
Bowles Example 9-6 — the engine against the printed deflections, pressures and moments (model-limited band)	Pass
Bowles Example 9-6 — WHY the engine differs: against the same solver without the end-spring doubling it agrees	Pass

`lateral-pile-group-published-web-validation.test.ts`

Published-answer validation for the lateral pile-GROUP p-multiplier engine (`lateral-pile-group.ts`).

Analyses validated: `lateral-pile-group` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA Table 14-2, 3D c-c: lead 0.7, 2nd 0.5, 3rd+ 0.35	Pass
FHWA Table 14-2, 4D c-c: lead 0.85, 2nd 0.65, 3rd+ 0.5	Pass
FHWA Table 14-2, 5D c-c: lead 1.0, 2nd 0.85, 3rd+ 0.7	Pass
FHWA Table 14-2, ≥6D c-c: no group reduction in any row (1.0, 1.0, 1.0)	Pass
AASHTO (2007) Table 10.7.2.4-1, 3B spacing: Row 1 0.7, Row 2 0.5, Row 3 and higher 0.35	Pass
AASHTO (2007) Table 10.7.2.4-1, 5B spacing: Row 1 1.0, Row 2 0.85, Row 3 and higher 0.7	Pass
AASHTO Table 10.7.2.4-1 "Row 3 and higher": a 5th row still takes the row-3 value	Pass
FHWA §14.6.1 (2×2 group, s = 3D): weighted average Pm = [2(0.7)+2(0.5)]/4 = 0.6	Pass
FHWA §14.6.2 (2×3 group, three rows of two shafts, s = 3D): weighted average Pm = 0.52	Pass

`lateral-pile-group-web-validation.test.ts`

Formula-fidelity validation against Brown (1987) Table 14-2 (as tabulated in FHWA-NHI-10-016 Drilled Shafts Manual §14.5.1), IDENTICAL to AASHTO LRFD Bridge Design Table 10.7.2.4-1 -- the published p-multiplier (Pm) values by row and spaci…

Analyses validated: `lateral-pile-group` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-12] all 12 published table anchors (AASHTO LRFD Table 10.7.2.4-1 / Brown Table 14-2): rows 1-3 at spacing 3D/4D/5D/6D	Pass
[13-14] linear interpolation between anchors matches exactly: row1 at 3.5D = 0.775, row2 at 4.5D = 0.75	Pass
[15] spacing below 3D holds the 3D anchor (extrapolation is unsupported by the data, per the engine's own documented policy)	Pass
[16] spacing at or above 6D gives Pm=1.0 for every row (no shadowing at wide spacing)	Pass
[17] row 4+ shares the row-3+ column exactly, per the table's own "3rd+" grouping	Pass
[18-19] side-by-side factor matches the exact Reese & Van Impe (2011) closed-form 0.64.(s/D)^0.34: s/D=3 -> 0.929825, s/D=2 -> 0.810084	Pass
[20] side-by-side factor caps at 1.0 for wide spacing	Pass
[21] side-by-side factor defaults to 1.0 (no reduction) when spacing is not supplied, per the documented policy that it is second-order and off by default	Pass
[22] the leading row (highest Pm) always carries at least as much load per pile as trailing rows, at the common cap deflection	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[23] group efficiency is < 1 (shadowing reduces total capacity relative to isolated piles) and equals group load / (n . isolated load at the same deflection) exactly	Pass
[24] a manual p_multipliers override is used verbatim instead of the auto AASHTO table	Pass
[25] invalid inputs (zero diameter, spacing, or load) are refused	Pass

lateral-pile-matlock-reese-web-validation.test.ts

Web-benchmark validation for the p-y lateral-pile FDM solver against the EXACT Matlock & Reese (1960) nondimensional solution — the closed-form analytical benchmark that underlies COM624 / a p-y beam-column (Reese) solver.

Analyses validated: `lateral-pile` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
free-head lateral load → Matlock-Reese Ay = 2.435 and Am = 0.772	Pass
free-head applied moment → Matlock-Reese By = 1.623	Pass
fixed-head lateral load → 0.930·P·T³/EI deflection and −0.930·P·T moment	Pass
response is linear in load and follows the T-scaling law	Pass
the linear_subgrade p-y is exactly p = k·z·y (no cap, elastic reference)	Pass

lateral-pile-pdelta-web-validation.test.ts

Validation for the axial P-Δ (beam-column) term added to the laterally-loaded pile solver (`lateral-pile.ts`).

Analyses validated: `lateral-pile` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
P = 0 (and axial omitted) are byte-identical — regression guard	Pass
Axial compression amplifies head deflection and max moment (P-Δ)	Pass
Amplification grows monotonically and accelerates toward buckling	Pass
A very large axial load drives buckling/overload (no finite equilibrium)	Pass
Fixed-head pile also shows axial amplification	Pass
Amplification obeys the Timoshenko-Gere magnification law Af = 1/(1−P/Pcr), with Pcr ≈ Davisson-Robinson	Pass

micropile-web-validation.test.ts

Published-value validation for micropile capacity (`micropile.ts`, `computeMicropile`): structural allowable loads of the composite cased/uncased section and the grout-to-ground bond.

Analyses validated: `micropile` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA NHI-05-039 Eq. 5-1, Fig. 5-2 example: Pc-allowable = 276 kips	Pass
FHWA Appendix D Step 3: cased length Pt-allowable = 0.55 Fy (Abar + Acasing) = 620 kN	Pass
FHWA Appendix D Step 3: cased length Pc-allowable = 0.4 f′c Agrout + 0.47 Fy (Abar + Acasing) = 671 kN	Pass
FHWA Appendix D Step 4: uncased length Pt-allowable = 0.55 Fy-bar Abar = 415 kN	Pass
FHWA Appendix D Step 4: uncased length Pc-allowable = 730 kN	Pass
FHWA Appendix D Step 5 (Eq. 5-9): PG-allowable = (265/2.0)(3.14)(0.191)(7.5) = 596 kN at Lb = 7.5 m	Pass
FHWA Appendix D Step 5 (Eq. 5-10): the required bond length Lb = 7.48 m carries PG-allowable = 595 kN	Pass
FHWA Appendix D Step 6: the 595 kN design load is satisfied (671 / 730 / 596 kN allowables all ≥ 595) — "pile axial design is OK"	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA Chapter 6 Eq. 6-1: Pult = 66 kPa × 10 m × π × 0.229 m = 475 kN	Pass
FHWA Chapter 6 §6.7.4: Lbelow = 475/(515 π 0.229) × 2.0 = 2.6 m provides the 475 kN	Pass
FHWA Appendix E (Eq. 5-6): Pc-allowable = 0.4 (27.6)(0.0218) + 0.47 (552)(0.00863) = 2,479 kN	Pass
FHWA Appendix E: Fa = 0.47 Fy = 259.44 MPa is the steel compression stress in Pc-allowable	Pass
FHWA Appendix E: Fb-type allowable 0.55 Fy = 303.6 MPa is the steel tension stress in Pt-allowable	Pass

⚑ pile-axial-load-transfer-web-validation.test.ts

Axial load-transfer (t-z / q-w) engine (`pile-axial-load-transfer.ts`) compared with the PUBLISHED numbers that could actually be opened and that map onto something this engine computes.

Analyses validated: `pile-axial-load-transfer` · Recorded run: passed — 18 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] Das Table 4.2: N_q = 6.40 at ϕ' = 20°	Pass
[1] Das Table 4.2: N_q = 10.66 at ϕ' = 25°	Pass
[1] Das Table 4.2: N_q = 14.72 at ϕ' = 28°	Pass
[1] Das Table 4.2: N_q = 18.40 at ϕ' = 30°	Pass
[1] Das Table 4.2: N_q = 23.18 at ϕ' = 32°	Pass
[1] Das Table 4.2: N_q = 33.30 at ϕ' = 35°	Pass
[1] Das Table 4.2: N_q = 48.93 at ϕ' = 38°	Pass
[1] Das Table 4.2: N_q = 64.20 at ϕ' = 40°	Pass
[1] Das Table 4.2: N_q = 85.38 at ϕ' = 42°	Pass
[1] Das Table 4.2: N_q = 134.88 at ϕ' = 45°	Pass
[2] Bowles Table 4-4: N_q = 6.4 at ϕ = 20°	Pass
[2] Bowles Table 4-4: N_q = 10.7 at ϕ = 25°	Pass
[2] Bowles Table 4-4: N_q = 18.4 at ϕ = 30°	Pass
[2] Bowles Table 4-4: N_q = 29.4 at ϕ = 34°	Pass
[2] Bowles Table 4-4: N_q = 37.7 at ϕ = 36°	Pass
[2] Bowles Table 4-4: N_q = 64.1 at ϕ = 40°	Pass
[3] Varghese Ex 13.2 (Skempton): N_c = 9 for a deep clay base	Pass
[4] Mittal Ex 3.1 (Eq 3.12): N_c = 9.0	Pass

⚑ pile-buckling-web-validation.test.ts

Partially-embedded pile buckling (`pile-buckling.ts`, Davisson–Robinson equivalent cantilever) checked against PUBLISHED numbers.

Analyses validated: `pile-buckling` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] IS 800 Table 11: fixed-free column has effective length 2.0 L	Pass
[2] IS 800 Table 11: pinned-pinned column has effective length 1.0 L	Pass
[3] IS 800 Table 11: translation held, fixed one end and pinned at the other has effective length 0.8 L	Pass
[4] IS 800 Table 11: both ends fixed and translation held has effective length 0.65 L	Pass
[5] Tomlinson Eq 6.51 and NAVFAC DM 7.02: for a linearly increasing modulus z_f = 1.8 T	Pass
[6] Tomlinson Eq 6.50 and NAVFAC DM 7.02: for a constant modulus z_f = 1.4 R	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[7] Bowles Ex 16-14: 7.00 m free-standing part, EI = 200 000 MPa × 0.379×10⁻⁴ m⁴, fixed at the ground line (k = 2) → Euler load 381.7 kN	Pass
[8] Varghese Ex 13.3: R = [EI/(K_h B)]^¼ = 0.546 m for EI = 0.4 MN·m², K_h = 15 MN/m³, B = 0.3 m	Pass
[9] Varghese Ex 13.4: T = (EI/n_h)^⅕ = 1.32 m for EI = 40×10⁶ N·m², n_h = 10×10⁶ N/m³	Pass
[10] Mittal: T = 1.63 m for E = 28 500 MPa, I = 0.0031 m⁴ (as printed), n_h = 7750 kN/m³	Pass

pile-capacity-web-validation.test.ts

WEB-BENCHMARK validation for the axial pile-capacity engine (the release rules mandatory ≥20 cited-value gate).

Analyses validated: `pile-capacity` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
pile web-validation: Tomlinson / API adhesion factor α (PDCP curve)	Pass
pile web-validation: IS 2911-1 Annex B-2 Fig. 2 α (chart read-off ±0.02)	Pass
pile web-validation: Skempton Nc = 9 base resistance in clay (qb = 9·su)	Pass
pile web-validation: Reissner Nq at pile tip in sand (capped at Lc=15D)	Pass
pile web-validation: critical depth 15·D at ϕ ≤ 30° → 20·D at ϕ ≥ 40° (IS 2911-1 Annex B-1 Note 5)	Pass
pile web-validation: full Qult integration — hand-verified from cited factors	Pass
pile web-validation: INTERNATIONAL design paths — AASHTO LRFD + EC7 partial factors	Pass

pile-capacity-worked-examples-web-validation.test.ts

pile-capacity — FULL WORKED EXAMPLES (the ≥20-value gate).

Analyses validated: `pile-capacity` · Recorded run: passed — 28 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS] Ex 9.2 Meyerhof point resistance in clay Qp = 9·cu·Ap = 132.9 kN	Pass
[DAS] Ex 9.7 α method (Table 9.10 α) → Qs = 1050 kN	Pass
[DAS] Ex 9.7 α method, layer 1 shaft = 93.7 kN	Pass
[DAS] Ex 9.7 α method, layer 2 shaft = 297.5 kN	Pass
[DAS] Ex 9.7 α method, layer 3 shaft = 659.1 kN	Pass
[DAS] Ex 9.5 sand shaft, K = 1.3, δ = 0.8ϕ, L′ = 15D → Qs = 2094.43 kN on a 1.628 m perimeter	Pass
[BOW] Ex 16-3 very soft clay, single α = 1.05 → Qs = 284.9 kN	Pass
[BOW] Ex 16-3 point Ppu = 9·su·Ap = 7.7 kN	Pass
[BOW] Ex 16-4 upper soft clay (α 0.98): Qs,1 = 256 kN	Pass
[BOW] Ex 16-4 medium clay (α 0.88): 70.2 kN per metre	Pass
[BOW] Ex 16-4 point Qp = 9·su·Ap = 82 kN	Pass
[DUB] A.8.2 characteristic base Rb;k = 9·cu·Ab = 386 kN	Pass
[DUB] A.8.2 characteristic shaft Rs;k = 153 kN per metre (α 0.4)	Pass
[DUB] A.8.2 EC7_DA1_C1: R_c;d = 221 + 87.4·Ls at Ls = 8 m	Pass
[DUB] A.8.2 EC7_DA1_C1: R_c;d = 221 + 87.4·Ls at Ls = 16 m	Pass
[DUB] A.8.2 EC7_DA1_C2: R_c;d = 170 + 67.3·Ls at Ls = 8 m	Pass
[DUB] A.8.2 EC7_DA1_C2: R_c;d = 170 + 67.3·Ls at Ls = 16 m	Pass
[DUB] A.8.2 EC7_DA2: R_c;d = 201 + 79.5·Ls at Ls = 8 m	Pass
[DUB] A.8.2 EC7_DA2: R_c;d = 201 + 79.5·Ls at Ls = 16 m	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DUB] A.8.2 EC7_DA3: R_c;d = 158 + 62.3·Ls at Ls = 8 m	Pass
[DUB] A.8.2 EC7_DA3: R_c;d = 158 + 62.3·Ls at Ls = 16 m	Pass
[EN] EN Table A.6 driven R4 (DA1-C2): γb 1.3, γs 1.3	Pass
[EN] EN Table A.7 bored R1 (DA1-C1): γb 1.25, γs 1.0	Pass
[EN] EN Table A.7 bored R4 (DA1-C2): γb 1.6, γs 1.3	Pass
[AASHTO] Table 10.5.5.2.3-1 driven pile in clay, α-method: ϕ = 0.35	Pass
[AASHTO] Table 10.5.5.2.3-1 driven pile in sand, Nordlund/Thurman: ϕ = 0.45	Pass
[AASHTO] Table 10.5.5.2.4-1 drilled shaft in clay: side 0.45, tip 0.40	Pass
[AASHTO] Table 10.5.5.2.4-1 drilled shaft in sand: side 0.55, tip 0.50	Pass

pile-downdrag-web-validation.test.ts

PILE DOWNDRAG (negative skin friction) — web-validation benchmark.

Analyses validated: `pile-downdrag` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das Ex 9.19 — clay fill over granular, Eq (9.123): 6 published values	Pass
Das Ex 9.19 — Qn scales as Hf², which is what Eq (9.123) asserts	Pass
Das Ex 9.20 — neutral depth Eq (9.124) and drag Eq (9.126): 8 published values	Pass
Das Ex 9.20 — the closed-form root satisfies Eq (9.124) AS PRINTED, not just our rearrangement	Pass
E-54 — end-bearing vs floating is a factor of two on the drag force	Pass
Oslo harbour test pile — reproduces the published 2348 kN and lands within 6.1 % of the measured 2500 kN	Pass
E-55 (unsafe) — α banded by s_u gives 0.4 where FHWA §13.6.4 requires 1.0: 2.5x under-predicted drag	Pass
E-53 (conservative) — β interpolated on ϕ′ is 2.04x the K_o form the sources use	Pass
the general summation and the closed form agree on the Oslo clay layer	Pass
AASHTO LRFD downdrag load factors are 1.25 (max) and 0.35 (min)	Pass
LRFD check counts only the side resistance BELOW the neutral plane	Pass
vesic_bowles refuses to infer the idealisation from a layer stack	Pass
vesic_bowles validates its own envelope	Pass
Eq (9.124) always places the neutral plane between 50 % and 70.7 % of the penetrated clay	Pass
method labels cover every method, so no selector can render blank	Pass

pile-group-is2911-web-validation.test.ts

Pile group capacity — validated against **IS 2911 (Part 1/Sec 1):2010** (driven cast in-situ concrete piles) and the published efficiency formulae it refers to without mandating.

Analyses validated: `pile-group` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Converse-Labarre efficiency — 10 published configurations	Pass
IS 2911 Cl 6.7.2 — group capacity never exceeds N × single-pile capacity	Pass
IS 2911 Cl 6.7.3 — the block check, with Tomlinson §10.4 as the equation form	Pass
the block check is applied to cohesive soil and skipped for cohesionless (Cl 6.7.2)	Pass
Feld and Seiler-Keeney are offered as alternatives, and all three are bounded in (0, 1]	Pass
the references cite Cl 6.7.3, not the non-existent Annex F	Pass

⚑ pile-group-settlement-web-validation.test.ts

Pile-group settlement engine (`pile-group-settlement.ts`, Randolph–Wroth interaction factors) compared with what could actually be opened.

Analyses validated: `pile-group-settlement` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] Kouretzis Ex 6.10 (Poulos–Mattes chart): α = 0.42 at s/D = 5	Pass
[2] Kouretzis Ex 6.10: α = 0.35 at s/D = 7.07	Pass
[3] Kouretzis Ex 6.10: α = 0.27 at s/D = 10	Pass
[4] Kouretzis Ex 6.10: α = 0.25 at s/D = 11.2	Pass

pile-group-worked-examples-web-validation.test.ts

pile-group — PUBLISHED WORKED EXAMPLES (deep review 14, 2026-10-03).

Analyses validated: `pile-group` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[BW1] Bowles Ex 18-1: Converse-Labarre 5 × 3, D 400 mm, s 1000 mm → E_g = 0.64	Pass
[BW2] Bowles Ex 18-2: 15 × 486 kN = 7290 kN governs (η = 1, block does not govern)	Pass
[DS] Das Ex 9.21: block 4313 kip, ΣQu 3141.9 kip governs	Pass
[VG] Varghese Ex 13.1: 9 × 396 = 3564 kN, Q_safe = 3564/2.5 = 1426 kN; [IS] default FoS 2.5	Pass
[FD] Feld 1/16 rule: 3 × 3 → 0.722, 2 × 2 → 0.813	Pass
[SV] Structville 3 × 3 rigid cap: concentric 543.14 kN; eccentric −19.36 … 1105.64 kN	Pass
[VH] vulcanhammer Ex 3.1: 12 piles at 0.9 m, Q 2600 kN, M 520 / 390 kN·m → max 329, min 105 kN	Pass
a working reaction is checked against Qu/FoS, not against the ultimate Qu	Pass
FoS below 1 is refused; below 2.5 is warned with the clause	Pass
spacing warnings cite IS 2911-1 Cl 6.6 (2.5D end-bearing, 3D friction), not Cl 6.7	Pass
non-finite and impossible inputs are refused, never returned as η = NaN or an infinite group	Pass

pile-head-stiffness-web-validation.test.ts

Pile-head stiffness engine (`pile-head-stiffness.ts`) checked against PUBLISHED Matlock–Reese numbers.

Analyses validated: `pile-head-stiffness` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] PUBLISHED Das Table 9.15 (Z = 0): free-head deflection under a lateral load is A_x·Q·T³/EI with A_x = 2.435	Pass
[2] PUBLISHED Das Table 9.15 (Z = 0): free-head deflection under a head moment is B_x·M·T²/EI with B_x = 1.623	Pass
[3] PUBLISHED Das Example 9.14: HP 250×85 in n_h = 12 000 kN/m³ deflects 8 mm under Q_g = 53.59 kN (free head, M = 0)	Pass
[4] PUBLISHED Rocscience Example 1: the moment that holds the head against rotation is 271.1 kN·m (H = 200 kN)	Pass
[5] DERIVED K22 = (EI/T³)·|B_θ|/(A_x|B_θ| − B_x²) from the published coefficients	Pass
[6] DERIVED K33 = (EI/T)·A_x/(A_x|B_θ| − B_x²) from the published coefficients	Pass
[7] DERIVED |K23| = (EI/T²)·B_x/(A_x|B_θ| − B_x²) from the published coefficients	Pass

pile-load-test-is2911p4-web-validation.test.ts

Pile load test interpretation — validated against **IS 2911 (Part 4):2013**, *Code of Practice for Design and Construction of Pile Foundations, Part 4: Load Test on Piles* (2nd revision).

Analyses validated: `pile-load-test` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IS 2911-4 Cl 7.1.5(a) — piles ≤ 600 mm use the 12 mm displacement criterion	Pass
IS 2911-4 Cl 7.1.5(b) — piles > 600 mm use min(18 mm, 2 % of D) [E-33]	Pass
IS 2911-4 Cl 7.1.5 criterion (2) — 50 % of the load at 10 % of the pile diameter	Pass
the "unless otherwise required in a given case" override is honoured and disclosed	Pass
a test that never reaches the criteria must refuse to set a safe load	Pass
monotonicity and bounds across the criteria	Pass

pile-load-transfer-web-validation.test.ts

Validation for API axial load-transfer curves (`pile-load-transfer.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
API clay t-z table points (RP2GEO)	Pass
API clay t-z interpolates monotonically to the peak	Pass
API q-z tip table points (RP2GEO), peak at z/D=0.10	Pass
API sand t-z: linear to peak at 0.1 in then plateau	Pass

pile-raft-web-validation.test.ts

Web-benchmark validation for `pile-raft` — the Poulos "PDR" piled-raft stiffness method.

Analyses validated: `pile-raft` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the component stiffnesses follow their published definitions	Pass
a negative Poulos denominator falls back rather than returning a spurious K_pr	Pass
a well-conditioned case exercises the primary K_pr branch	Pass
load is conserved and the pile fraction stays in [0, 1] across a wide sweep	Pass
more piles carry more load and settle less	Pass
the Mayne & Poulos raft stiffness uses I_ρ = 0.95·√(B/L)	Pass
relative stiffness K_r = E_c·I_b/(E_s·B³) classifies rigid / intermediate / flexible	Pass
thickness and E_c without a soil modulus cannot classify, and says so	Pass
pile utilisation is against the WORKING load and warns past the PDR limit	Pass
invalid inputs are refused with zeroed stiffnesses	Pass

⚑ pile-section-mphi-web-validation.test.ts

Reinforced-concrete moment–curvature engine (`pile-section-mphi.ts`) checked against PUBLISHED numbers.

Analyses validated: `pile-section-mphi` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] the engine puts the bar centroid where Pincheira Ex 10.18.1 does: d1 = 2.64 in	Pass
[2] Pincheira Ex 10.18.1 Point 6 pure bending: Mn at Pn = 0.0 kip is 320.11 kip-ft	Pass
[2] Pincheira Ex 10.18.1 Point 5 εs = εy + 0.003 (tension-controlled limit): Mn at Pn = 29.5 kip is 328.13 kip-ft	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[2] Pincheira Ex 10.18.1 Point 4 fs = fy (balanced, c = 10.28 in): Mn at Pn = 518.93 kip is 407.73 kip-ft	Pass
[2] Pincheira Ex 10.18.1 Point 3 fs = 0.5 fy: Mn at Pn = 856.27 kip is 375.24 kip-ft	Pass
[2] Pincheira Ex 10.18.1 Point 2 fs = 0: Mn at Pn = 1312.64 kip is 277.54 kip-ft	Pass
[4] FHWA-NHI-10-016 Fig 12-24: the 48-in shaft with 12 #11 bars reaches Mult = 1791 kip-ft	Pass
[5] FHWA-NHI-10-016 §12.3.3.3.4: I = π·d⁴/64 = 260,576 in⁴ for the 48-in shaft (gross section)	Pass
[6] FHWA-NHI-10-016 Appendix A: I = 4,169,220 in⁴ for the 96-in shaft	Pass
[7] Wang Ex 3.11.1 singly reinforced, As = 7.74 in² (max tension-controlled): Mn = 855 kip-ft	Pass
[8] Wang Ex 3.11.1 doubly reinforced, As = 9.42 in², A's = 1.81 in²: Mn = 1048 kip-ft	Pass

pile-section-pm-interaction-ec2-web-validation.test.ts

EN 1992-1-1 code path of the P–M interaction engine (`pile-section-pm-interaction.ts`, `code: 'EN 1992-1-1'`) checked against PUBLISHED values.

Analyses validated: `pile-section-pm-interaction` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Concrete Centre App. C Fig C4c (p.208), d2/h=0.15, ρ_s=0.2 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4c (p.208), d2/h=0.15, ρ_s=0.4 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4c (p.208), d2/h=0.15, ρ_s=0.6 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4c (p.208), d2/h=0.15, ρ_s=0.8 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4c (p.208), d2/h=0.15, ρ_s=1 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4d (p.208), d2/h=0.2, ρ_s=0.2 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4d (p.208), d2/h=0.2, ρ_s=0.4 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4d (p.208), d2/h=0.2, ρ_s=0.6 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4d (p.208), d2/h=0.2, ρ_s=0.8 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C Fig C4d (p.208), d2/h=0.2, ρ_s=1 — M/(bh²fck) at four N/(bhfck) levels	Pass
Concrete Centre App. C charts supply 2×19 = 38 published values (≥ 20)	Pass
Concrete Centre §5.1 (p.135): 300×300 C30/37, 4H25, d2=49 — MRd at NEd=1620 kN is 76.1 kN·m	Pass
Concrete Centre §5.3 (p.146): 500×500 C50/50, 12H32, d2/h=0.20 — MRd at NEd=9000 kN is 356.3 kN·m	Pass
Concrete Centre §5.4 (p.157): 350×350 C30/37, 4H32+4T25, d2/h=0.25 — MRd at NEd=1824.1 kN is 205.8 kN·m	Pass
Concrete Centre §5.4 (p.157): 350×350 C30/37, 8T32, d2/h=0.25 — MRd at NEd=1824.1 kN is 240.5 kN·m	Pass

⚑ pile-section-pm-interaction-is456-web-validation.test.ts

IS 456 code path of the P–M interaction engine (`pile-section-pm-interaction.ts`, `code: 'IS 456'`) checked against PUBLISHED values.

Analyses validated: `pile-section-pm-interaction` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
SP 16:1980 Chart 33 (p.118), p/fck = 0.06 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass
SP 16:1980 Chart 33 (p.118), p/fck = 0.10 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass
SP 16:1980 Chart 33 (p.118), p/fck = 0.12 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass
SP 16:1980 Chart 33 (p.118), p/fck = 0.14 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass
SP 16:1980 Chart 33 (p.118), p/fck = 0.16 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass
SP 16:1980 Chart 33 (p.118), p/fck = 0.18 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
SP 16:1980 Chart 33 (p.118), p/fck = 0.20 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass
SP 16:1980 Chart 33 (p.118), p/fck = 0.22 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass
SP 16:1980 Chart 33 (p.118), p/fck = 0.25 — Mu/(fck·b·D²) at six Pu/(fck·b·D) levels	Pass
SP 16:1980 chart-valve count — the Chart 33 contours supply 9×6 = 54 published values (≥ 20)	Pass
SP 16:1980 Worked Example 6 (p.103): 450×450 M25 Fe415, Pu=2500 kN, Mu=200 kNm → p/fck=0.09 (As=4556 mm²), two sides	Pass
SP 16:1980 Worked Example 7 (pp.103–104): Ø500 M20 Fe250, 8 bars, Pu=1600 kN, Mu=125 kNm → p/fck=0.087 (As=3416 mm²)	Pass

⚑ pile-section-pm-interaction-web-validation.test.ts

P–M interaction engine (`pile-section-pm-interaction.ts`) checked against PUBLISHED numbers.

Analyses validated: `pile-section-pm-interaction` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] Pincheira §1.1: nominal axial strength at zero eccentricity P0 = 1902 kip	Pass
[2] Pincheira §7: maximum tension Pnt = fy·Ast = −609.60 kip	Pass
[3] Pincheira §1.3: maximum (allowable) factored axial strength ϕPn,max = 0.85·0.75·P0 = 1212.3 kip	Pass
[4] Pincheira §7: factored maximum tension ϕPnt = 0.90·609.60 = −548.64 kip	Pass
[5] FHWA-NHI-10-016 App. A: 96-in shaft, 40 #14, f'c 4 ksi, fy 60 ksi — "nominal crushing strength of 29,703 kips"	Pass
[6] Pincheira §6: pure bending Mn = 320.11 kip-ft	Pass
[7] Pincheira §5 εs = εy + 0.003: Mn(29.5 kip) = 328.13 kip-ft on the nominal envelope	Pass
[7] Pincheira §4 fs = fy: Mn(518.93 kip) = 407.73 kip-ft on the nominal envelope	Pass
[7] Pincheira §3 fs = 0.5 fy: Mn(856.27 kip) = 375.24 kip-ft on the nominal envelope	Pass
[7] Pincheira §2 fs = 0: Mn(1312.64 kip) = 277.54 kip-ft on the nominal envelope	Pass
[8] Pincheira Table 8 pure bending (ϕ = 0.90): ϕMn at ϕPn = 0 kip is 288.09 kip-ft	Pass
[8] Pincheira Table 8 tension-controlled limit: ϕMn at ϕPn = 26.55 kip is 295.31 kip-ft	Pass
[8] Pincheira Table 8 balanced (ϕ = 0.75): ϕMn at ϕPn = 389.2 kip is 305.8 kip-ft	Pass
[8] Pincheira Table 8 fs = 0.5 fy: ϕMn at ϕPn = 642.2 kip is 281.43 kip-ft	Pass
[8] Pincheira Table 8 fs = 0: ϕMn at ϕPn = 984.48 kip is 208.16 kip-ft	Pass

⚑ pile-settlement-vesic-web-validation.test.ts

Single-pile working-load settlement — validated against **Vesić's own report**, not a secondary account of it.

Analyses validated: `pile-settlement-vesic` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-3] Das §9.17 worked example: the published load split is reproduced exactly	Pass
[4-5] the published elastic shortening — and the transposition in the printed answer	Pass
[6] the equivalent diameter really does reproduce the published section area	Pass
[7-8] HAND CHECK (not a published value) — Vesić Eq 44: C_s = (0.93 + 0.16·√(D/B))·C_p, with HIS D = depth and HIS B = width	Pass
[9-11] HAND CHECK (not a published value) — Vesić Eqs 42 and 43 term by term, and the total is a plain sum	Pass
[12-13] HAND CHECK (not a published value) — the proportionalities, which the closed forms make exact	Pass
[14-19] Vesić Table 6 (p.33) is the admissible span for C_p, and it is enforced	Pass
[20-22] ξ is bounded by Vesić p.32 — 0.1 to 0.67, not the narrower band once claimed here	Pass
[23-24] the SCOPE of Table 6 is declared on every run, not assumed	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[25-27] the refusals are real, and a cleared box cannot produce a finite absurdity	Pass
[28-29] all of the load at the point, and all of it on the shaft, are both exact limits	Pass
[25] Canadian Foundation Engineering Manual Table 18.6 prints driven sand as 0.02–0.09; Vesić Table 6 and Das Table 9.14 print 0.02–0.04 — the engine accepts both	Pass
[26] CFEM Eq 18.21b: α_s = 0.5 for a uniform or parabolic skin-friction distribution and 0.67 for a linear one — both inside the engine's ξ span	Pass

py-curves-web-validation.test.ts

Validation for the p-y backbone library (`py-curves.ts`).

Analyses validated: py-curves · Recorded run: passed — 35 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Matlock 1970 — deep N_p caps at 9: p_u = 9·su·b	Pass
Matlock 1970 — surface N_p = 3: p_u = 3·su·b	Pass
Matlock 1970 — p(y50) = 0.5·p_u exactly	Pass
Matlock 1970 — cube-root branch: p(y50/8) = 0.5·p_u·(1/8)^(1/3) = 0.25·p_u	Pass
Matlock 1970 — monotonic non-decreasing to plateau	Pass
Welch-Reese 1972 — p(y50) = 0.5·p_ult; deep p_ult = 9·su·b	Pass
Welch-Reese 1972 — quarter-power branch: p(y50/16) = 0.5·pult·(1/16)^0.25 = 0.25·pult	Pass
Reese 1975 — deep wedge N_p caps at 11: p_u = 11·su·b	Pass
Reese 1975 — √ branch: p(y50) = 0.5·p_u	Pass
Reese 1974 sand — ultimate wedge p_s > 0 and increases with depth	Pass
Reese 1974 sand — backbone monotonic and reaches a plateau	Pass
Reese 1974 sand — initial branch stiffness = k·z near origin	Pass
API sand — p → A·p_u as y→∞ (A static = max(0.9, 3−0.8z/b))	Pass
API sand — initial slope $dp/dy\|_0 = k \cdot z$ (tanh′(0)=1)	Pass
API sand — static factor A ≥ 0.9 always (deep) and cyclic = 0.9	Pass
Rollins 2005 — exact anchor: z=2 m, b=1 m, y=100 mm ⇒ p = 44.914 kN/m	Pass
Rollins 2005 — exact anchor: z=3 m, b=0.6 m, y=50 mm ⇒ p = 17.942 kN/m	Pass
Rollins 2005 — displacement capped at 150 mm (p(200)=p(150))	Pass
Rollins 2005 — diameter clamped to [0.3, 2.6] m	Pass
Rollins 2005 — concave-up at shallow depth (C>1 ⇒ p(2y)>2·p(y))	Pass
Franke-Rollins 2013 — hybrid = min(p_clay, p_liq)	Pass
Reese-Nyman 1978 — α_r = 1−(2/3)·RQD and shallow p_ur plateau	Pass
Reese-Nyman 1978 — deep p_ur = 5.2·α_r·qu·b	Pass
Reese-Nyman 1978 — RQD=100 ⇒ α_r = 1/3	Pass
Simpson-Brown 2003 — Piedmont plateau past y/b = 0.0375	Pass
Simpson-Brown 2003 — Piedmont initial linear branch p = b·y·E_si for y/b<0.001	Pass
PY_FAMILIES catalogue lists 11 families, each with a citation	Pass
Johnson 2006 loess — p_u = 0.409·q_c·b, initial slope E_i = p_u/y_ref, plateau→p_u	Pass
pyBackbone dispatch matches direct calls (soft clay + liquefied)	Pass
pyBackboneCurve returns monotone-y grid starting at (0,0)	Pass
API RP2A sand — plateau p_u matches the published C1/C2/C3 chart (ϕ=30/35/40°)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Matlock 1970 — full normalized backbone p/p_u = 0.5·(y/y50)^(1/3)	Pass
Welch-Reese 1972 — full normalized backbone p/p_ult = 0.5·(y/y50)^0.25	Pass
Reese-Nyman 1978 weak rock — p/p_ur = 0.5·(y/y_rm)^0.25 on the power branch	Pass
Rollins 2005 — further exact liquefied-sand anchors (hand-computed)	Pass

`settlement-seepage-pile-web-validation.test.ts`

Web-benchmark validation for ELEVEN settlement, seepage/earth-pressure and lateral-pile runner engines.

Analyses validated: `basal-heave`, `broms-lateral-pile`, `burland-burbidge`, `elastic-settlement`, `flow-net-seepage`, `infinite-slope`, `is8009-settlement`, `retaining-wall`, `settlement`, `skempton-bjerrum` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
elastic-settlement reproduces the Steinbrenner F1/F2 factors and Bowles settlement	Pass
is8009-settlement obeys the IS 8009 structural identities	Pass
cv-oedometer uses the published T50 and T90 time factors	Pass
skempton-bjerrum applies μ = A + α(1 − A) from Skempton & Bjerrum (1957)	Pass
burland-burbidge reproduces the 1985 ICE paper expressions	Pass
flow-net-seepage computes q = k·h·N_f/N_d (Terzaghi & Peck)	Pass
retaining-wall reproduces Rankine thrust and wall statics exactly	Pass
infinite-slope reproduces the dry, seepage-parallel and r_u forms	Pass
basal-heave reproduces both methods and never publishes an unreconcilable FoS	Pass
pile-settlement-vesic reproduces the Vesic (1977) three components	Pass
broms-lateral-pile solves the Broms (1964) long-pile equations in clay and sand	Pass

`wave-equation-driving-web-validation.test.ts`

WEB-BENCHMARK validation for the wave-equation pile-driving engine (Smith 1960) — now with the DIESEL variable-stroke thermodynamics and RESIDUAL-STRESS ANALYSIS that close the GRLWEAP-parity gap.

Analyses validated: `wave-equation-driving` · Recorded run: passed — 37 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
WEAP 1: Vulcan-08 impact velocity = 3.61 m/s (matches WEAP87 11.84 ft/s exactly)	Pass
WEAP 2: v0 scales as √(energy)	Pass
WEAP 3: v0 scales as 1/√(ram weight)	Pass
WEAP 4: hammer_model overrides ram/energy/η (Delmag D30)	Pass
WEAP 5: custom (no model) keeps user-entered ram/energy	Pass
WEAP 6: the library exposes ≥5 inspectable hammers (vs GRLWEAP closed register)	Pass
WEAP 7: steel allowable = 0.90·f_y (default f_y 350 MPa ⇒ 315 MPa)	Pass
WEAP 8: steel allowable tracks the entered f_y	Pass
WEAP 9: prestressed concrete comp = 0.85·f′c − f_pe (35, 5 MPa ⇒ 24.75 MPa)	Pass
WEAP 10: prestressed concrete tension = f_pe + 0.25√f′c ⇒ 6.48 MPa	Pass
WEAP 11: timber allowable = 3× design stress	Pass
WEAP 12: bearing graph blow count is MONOTONE increasing in R_u	Pass
WEAP 13: higher R_u ⇒ harder driving (more blows/m) than lower R_u	Pass
WEAP 14: higher R_u ⇒ smaller permanent set	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
WEAP 15: free-end reflection ⇒ tensile stress appears (esp. at low resistance)	Pass
WEAP 16: compressive driving stress is significant (of order the impact stress)	Pass
WEAP 17: refusal — very high R_u ⇒ ≥800 blows/m or REFUSAL verdict	Pass
WEAP 18: overstress — tiny allowable ⇒ OVERSTRESS + stress_ok false	Pass
WEAP 19: a workable case ⇒ DRIVABLE/hard + stress_ok true	Pass
WEAP 20: stress utilisation = max(comp,tens)/allowable ·100	Pass
WEAP 21: WEAP87 order-of-magnitude — 400-kip (1779 kN) blow count in a plausible band	Pass
WEAP 22: transferred energy (ENTHRU) is positive and below the rated energy	Pass
WEAP 23: blows/250mm = blows/m ÷ 4	Pass
WEAP 24: invalid input ⇒ errors, no crash	Pass
WEAP 25: Delmag diesel uses the variable-stroke model (diesel_model = true)	Pass
WEAP 26: diesel stroke RISES with driving resistance (GRLWEAP behaviour)	Pass
WEAP 27: diesel energy per blow RISES with resistance and is ≤ rated at refusal cap	Pass
WEAP 28: diesel stroke approaches the rated stroke at refusal (calibration target)	Pass
WEAP 29: an external-combustion hammer (Vulcan-08) holds a FIXED stroke	Pass
WEAP 30: bearing graph carries the (variable, for diesel) stroke per R_u	Pass
WEAP 31: RSA runs, converges to a steady set, and labels itself	Pass
WEAP 32: RSA vs standard differ modestly (residual pre-stress effect), same order	Pass
WEAP 33: DIESEL transfer efficiency ≈ GRL measured 39% (band 29–49%, CoV 26%)	Pass
WEAP 34: single-acting AIR/STEAM efficiency ≈ GRL measured 56% (band 43–69%)	Pass
WEAP 35: HYDRAULIC efficiency ≈ GRL measured 69% (band 52–86%)	Pass
WEAP 36: transfer_efficiency_pct = 100·ENTHRU/rated (self-consistent)	Pass
WEAP 37: diesel refusal stroke ≈ 95% of rated (GRLWEAP §B2 P_max calibration)	Pass

Tunnels and underground works

FE kernel registry — 7 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`k5b-plaxis-verif-hoek-brown-tunnel`	plastic radius around the unsupported circular opening (R = 2 m, σ0 = 15 MPa, GSI 50, mi 10, σci 30 MPa) [m]	PLAXIS-Verification-Hoek-Brown-material-model.pdf, p. 1–4 (study case 1, p_i = 0: Rpl 3.80 m)	3.8	3.794	default policy (strict, then the PLAXIS criterion with the initial stiffness — D124 + D684): (λ: 1; Rpl m: 3.821; elastic-zone σr worst % of σ0: 1.2; steps (fallback): 10; iterations (fallback): 45); strict (verification mode, parityFallback false): stops at λ 0.9000 (20 steps / 27 cuts / 1219 it) — D683: a strict residual floor (active-set cycling at the tolerance, D380 class); at the carried p_i = 1500 kPa Rpl 2.873 m vs Carranza-Torres 2.853 m, σr 0.72 % of σ0	default policy Rpl vs PLAXIS 3.80: 0.55	+0.71 %	Pass
`k5d1-lame-normal-pressure` self-check	worst relative radial-displacement error on both faces of a thick cylinder loaded by a normal-pressure line load `pn` on its curved (polyline) inner face [relative error]	—	—	0.002	0.0008874	—	—	Pass
`k5d1-contraction-ring` self-check	radius change of a bonded elastic lining under a line contraction C_ref = 0.5 % [m]	PLAXIS-2D-2025.1-Reference-Manual §5.4.3, §9.4.2, p. p. 79, p. 445 (C_planar = C_ref/2)	—	-0.00178571	-0.00178701	—	+0.07 %	Pass
`k5d1-hb-tunnel-case2`	plastic radius around the circular opening supported by a 2500 kPa normal pressure [m]	PLAXIS-Verification-Hoek-Brown-material-model.pdf, p. 1–4 (study case 2, p_i = 2500 kPa: Rpl 2.58 m)	2.58	2.582	2.598	+0.70 %	+0.62 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k5d1-plaxis-2d-tut6-natm	NATM tunnel, β-method (60 % / 100 %) in two excavation stages: crown settlement, lining forces [mm, kNm/m, kN/m]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 108–120 (Fig. 6–11, 6–13: figures only)	—	—	crown uy phase 1..4 mm: [-7.45, -8.65, -9.17, -9.11]; crest (–7, 35) uy phase 4 mm: -19.77; liningTop M max/min kNm/m: [2.5, -4.8]; liningTop N min kN/m: -164; liningInvert M max/min kNm/m: [2.6, -3.3]; liningInvert N min kN/m: -59	—	—	Recorded, no published value
k5d1-plaxis-2d-tut5-building-tilt	building tilt at the end of phase 5 (lining), displacements from phase 2 on: (uy(15, 3) – uy(5, 3)) / 10 m [%]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 106–107 (Fig. 5–9: (5, 3) → (4.995, 2.981), (15, 3) → (14.995, 2.998))	0.168	—	0.1834	+9.17 %	—	Deviation
k5d1-plaxis-2d-tut5-contraction	applied plate contraction strain of the TBM (C_ref/2) [-]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 103 (§5.7 phase 3: Cref 0.5 %)	—	0.0025	0.0025	—	0.00 %	Pass

Cited validation suites — 9

⚑ shotcrete-age-stiffness-web-validation.test.ts

Web-validation for `shotcrete-age-stiffness.ts` — the time-dependent E(t) and fcu(t) of young shotcrete used in NATM / SEM lining modelling.

Analyses validated: `shotcrete-age-stiffness` · Recorded run: passed — 18 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
CEB-FIP s-parameters: s_stiff and s_strength from the printed equations (exact)	Pass
CEB-FIP law reproduces the 1-day and 28-day anchors exactly	Pass
CEB-FIP E(t) and fcu(t) are the exact printed closed form (Neuner Eqs. 5-8)	Pass
CEB-FIP vs measured Neuner series: documented model deviation (FINDING-2)	Pass
CEB-FIP very-early-age lower limit: fcu ≥ 0.005·fcu,28 (PLAXIS MM §14.3.1)	Pass
CEB-FIP stiffness is monotonic and constant beyond t_hydr	Pass
EN 14487-1 J2 class tabulated strengths at the printed ages (exact)	Pass
EN 14487-1 J1/J3 classes at 12 h and 24 h (printed Table 14–1)	Pass
EN 14487-1 → Oluokun bridge after 24 h reaches fcu,28 at 28 d	Pass
Oluokun fc(t) = αc·e^(−b_c/t) against the printed equation (exact)	Pass
Round-length helper: age at full load = (d + 2RT)/Lr × tr (definition)	Pass
Round-length helper warns when the ring is very young at full load (< 8 h)	Pass
wrapper: input validation and monotonicity warnings	Pass
Smaniotto 2022 §4.1: strength at 1 d is the STATED "50 %" of the 28-d strength (23.8 / 47.6 MPa) — engine anchors reproduce it	Pass
Smaniotto 2022 Table 5 / A.3: Young's modulus anchors 18 200 MPa (1 d) and 28 700 MPa (28 d) reproduced by the CEB-FIP law	Pass
Smaniotto 2022 Table A.3: Meschke-Kropik-Mang E(t), anchored at 1 d / 28 d, tracks the measured 2, 7, 14 d means within 2 SD	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Smaniotto 2022 Tables A.1/A.3 — FINDING: the two-anchor CEB-FIP law over-predicts the measured intermediate-age strength and stiffness by more than 2 SD at 2 d and 7 d	Pass
Smaniotto 2022 Table A.1 — the Oluokun law driven by the same anchors over-predicts the 7-d strength by more than CEB-FIP does	Pass

⚑ tunnel-face-pressure-web-validation.test.ts

Web-validation for `tunnel-face-pressure.ts` — the required closed-face TBM face support pressure by the DAUB 2016 wedge-silo and the undrained stability ratio.

Analyses validated: `tunnel-face-pressure` · Recorded run: passed — 18 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
DAUB §8.1: critical sliding angle θcrit = 66.56° (printed)	Pass
DAUB §8.1: wedge forces G, Pv, TR at θcrit (printed values)	Pass
DAUB §8.1: circular-face earth force Emax,ci = 3237.7 kN (printed)	Pass
DAUB §8.1: water force Wci = 14137.2 kN and total Sci = 19700.5 kN (printed)	Pass
DAUB §8.1: minimum crown pressure s_crown,min = 190.8 kN/m² (printed)	Pass
DAUB §8.1: working band 201 → 219 kN/m² (printed conclusion)	Pass
DAUB §8.1: water floor 1.05 × groundwater = 136.5 kN/m² (printed check)	Pass
Coefficient sets: Anagnostou & Kovári (K2=0.4) requires ≥ the DAUB/Jancsecz force	Pass
Deep overburden (t > 2D) engages the Janssen silo branch (DAUB Eq. 12)	Pass
Shallow overburden (t ≤ 2D) uses the full-overburden branch (DAUB Eq. 11)	Pass
DAUB §8.2: Atkinson & Mair Ncr = 6.537 and N = 4.358 (printed)	Pass
DAUB §8.2: support pressure at axis s_axis = 213.7 kN/m² (printed)	Pass
DAUB §8.2: minimum crown pressure s_crown,min = 143.7 kN/m² (printed)	Pass
DAUB §8.2: working band 174 → 211 kN/m² (printed conclusion)	Pass
DAUB §8.2: stability-ratio family — Broms ≤ 6, Davis lower bound ordering	Pass
DAUB §8.2: Davis local-failure check γ2,sat·D/cu ≤ 10.96 (Eq. 26)	Pass
wrapper: input validation	Pass
wrapper: shallow-cover warning fires below 1·D overburden	Pass

⚑ tunnel-ground-reaction-web-validation.test.ts

Dedicated validation for the tunnel ground reaction curve (`tunnel-ground-reaction.ts`) — the convergence-confinement closed form for a circular tunnel in a Mohr-Coulomb, zero-plastic-volume-change rock mass under a hydrostatic field stres…

Analyses validated: `mohr-coulomb`, `tunnel-ground-reaction` · Recorded run: passed — 16 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Hoek (2006) Fig.4: replicated spreadsheet inputs equal the printed intermediate values	Pass
Hoek (2006) Fig.4: engine reproduces the printed Output row (pi = 0)	Pass
Hoek (2012) RocSupport Fig.4: characteristic curve end point (pi = 0)	Pass
Brady & Brown (2004) §11.3: strength parameters and critical support pressure	Pass
Brady & Brown (2004) Table 11.1: elastic-branch wall displacement δi (m), 3 d.p. printed	Pass
Carranza-Torres (2003) Fig.5: intermediate computations and critical pressure	Pass
Carranza-Torres (2003) Fig.5: plastic radius and wall convergence (ψ = 0°)	Pass
Carranza-Torres (2004) App.A: engine HB parameters at GSI = 50 (self-consistent)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C-T&F (1999) §4.3: Hoek-Brown critical internal pressure p*i = 16 MPa	Pass
Shotcrete/concrete capacity — H&B (1980) Eq. (121) exact closed form (Table 17 cross-checked)	Pass
Shotcrete/concrete capacity — H&B (1980) Table 17 PRINTED values, read by the inner lining radius (ro = ri + tc)	Pass
Steel-set capacity — Hoek (2012) corrected Eq. (14), cross-checked (SOURCES-GRC §7.2)	Pass
Rockbolt capacity — H&B (1980) Table 17 rows H, I, J, K (Eq. 128/18, radius-independent)	Pass
Combined support stiffness and capacity — H&B (1980) Eq. (129) additivity	Pass
Equilibrium: FS = psmax/peq; support installed after ui0 (Hoek 2012 §5.3)	Pass
RocSupport Tutorial Example 1 — NOT ASSERTED (finding, not a widened tolerance)	Pass

⚑ tunnel-grout-pressure-web-validation.test.ts

Web-validation for `tunnel-grout-pressure.ts` — annular grout-pressure bounds and the shield conicity → PLAXIS contraction (volume-loss) relation.

Analyses validated: `tunnel-grout-pressure` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Conicity: volume loss = 1 − (Dl/Dexc)² (PLAXIS contraction), exact	Pass
Conicity: overcut enlarges the excavation diameter	Pass
Conicity: gap-closure fraction scales the volume loss	Pass
Conicity: >3% geometric loss trips the PLAXIS small-volume-loss warning	Pass
Conicity: Sophia Rail Tunnel geometry (D_exc 9.5 m, lining ext 8.7 m)	Pass
Sophia crown: overburden ≈ 200 kPa reproduces the printed figure	Pass
Sophia grout band: crown ≈ 200 kPa, invert ≈ 370 kPa from the gradient	Pass
Grout band: blow-out upper bound 0.9·σv,crown,min (DAUB Eq. 5 analogy)	Pass
Grout band: lower bound is max(effective overburden, pore pressure) + margin	Pass
Grout band: shallow cover closes the window and warns	Pass
Grout band: hydrostatic grout gradient is the floor for the injection gradient	Pass
wrapper: input validation	Pass
wrapper: lining larger than excavation warns	Pass

⚑ tunnel-ldp-web-validation.test.ts

Dedicated validation for the longitudinal displacement profile (`tunnel-ldp.ts`) — the radial wall displacement u(X) as a function of distance from the advancing face, for a circular tunnel in a hydrostatic stress field.

Analyses validated: `tunnel-ldp` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
V&D Eq. (5): normalised face displacement u0* against R* (exact closed form)	Pass
V&D §5/Fig. 12 example: R* = 5 → u0* ≈ 0.16 (Fig. 9 reading / printed example)	Pass
V&D Eq. (6): ahead of the face u* = u0*·e^(X*) (exact closed form)	Pass
V&D Eq. (7): behind the face u* = 1 − (1−u0*)·e^(−3X*/2R*) (exact closed form)	Pass
V&D continuity at the face (Eq. 6 ≡ Eq. 7 at X* = 0) and far-field asymptote u* → 1	Pass
V&D Fig. 4 ordering: larger R* closes later (B–E cases, RT = 5 m)	Pass
Panet Eq. (1): u* = 1/4 + 3/4·[1 − (3/4)²/(3/4+X*)²] (exact closed form)	Pass
Ünlü-Gerçek Eqs. (2)-(3): face value and both branches (exact closed form, ν = 0.25)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Hoek 2012 Fig. 6: printed face value uif/uim = 0.2622 at rpm/ro = 1.592	Pass
Hoek 2012 Fig. 6: printed face displacement uif = 0.011197 m from uim = 0.0427 m	Pass
Hoek 2012 Fig. 7: support 5 m behind face → printed ui = 0.0304 m	Pass
wrapper: X* normalisation and the R* > 2 squeezing warning (V&D §4)	Pass
wrapper: errors for non-positive radius / NaN, RP < RT clamped to elastic	Pass

`tunnel-lining-check-web-validation.test.ts`

Web validation for `tunnel-lining-check` — benchmark values from ITA WG2 Report n°22 (2019) "Guidelines for the design of segmental tunnel linings" (ISBN 978-2-9701242-1-4), with the joint equations reproduced in closed form.

Analyses validated: `tunnel-lining-check` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
ITA WG2 2019 published guideline values reproduce verbatim (≥20 cited)	Pass
contact-zone bursting reproduces ITA WG2 2019 Eqs 14–15 (closed form)	Pass
Janßen joint rotation reproduces ITA WG2 2019 Eqs 10–13 (closed form)	Pass
a lightly loaded joint stays closed (θ ≤ θ_crit, Eq. 10) with k_r from Eq. 12	Pass
M–N interaction has exactly four analytical corner points	Pass
reports a utilisation per ring, the governing ring, and each code path runs	Pass
the M–N utilisation is D/C at the demand axial load	Pass
rejects missing/invalid geometry rather than inventing a result	Pass

`tunnel-monitoring-web-validation.test.ts`

Web-validation of the tunnel-monitoring loop against PUBLISHED case-history values.

Analyses validated: `tunnel-ldp`, `tunnel-monitoring` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
A1: Nyren (1998) JLE St James's Park published geometry (D&G 2015 §2.2)	Pass
A2: Nyren towards-tunnel half-trough V_L = 1.8 % (the asymmetry finding)	Pass
A3: Peck (1969) clay K range 0.4–0.6 and O'Reilly & New K = 0.25 sand (cited values 7-10)	Pass
B: published V_L ranges bracket the back-analysed values (M-T-B 1996 §2.1)	Pass
C: CTRL EPBM measured V_L values back-analysed (ITA/AITES 2007 §4.3.7)	Pass
D: trigger defaults anchored to Rankin (1988) 10 mm screen; convergence red = 1 % of D (Hoek)	Pass
E: LDP fit on the V&D 2009 shape returns the imposed final convergence (Eq. 5 anchor)	Pass
FULL LOOP: design 1.1 % but measured 1.8 % (Nyren asymmetry) → amber/red + updated prediction	Pass

⚑ `tunnel-settlement-trough-extended-web-validation.test.ts`

Dedicated validation for the extended settlement-trough engine (`tunnel-settlement-trough-extended.ts`): the Peck (1969) Gaussian surface trough, the Mair, Taylor & Bracegirdle (1993) sub-surface trough, the Attewell/O'Reilly-New horizonta…

Analyses validated: `tunnel-settlement-trough-extended` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Smax identity: Smax = 0.31·Vl·D²/i = Vs/(i·√2π) (M-T-B 1996 eq 5)	Pass
Gaussian profile: Sv(y) = Smax·exp(−y²/2i²) — inflection at 0.606·Smax	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
O'Reilly & New K values: 0.5 clay / 0.25 sand (Mair & Taylor 1997 eq 5)	Pass
Sub-surface trough width: i(z)/z0 = 0.175 + 0.325(1−z/z0) (Divall & Goodey eq 4)	Pass
Sub-surface settlement: trough volume conserved, Smax grows with depth	Pass
Horizontal displacement: Shmax = 0.61·K·Smax at the inflection point (M&T 1997 eq 10)	Pass
Horizontal strain: compressive for |y| < i, tensile for |y| > i, zero at y = i	Pass
Twin-tunnel superposition: Sv = Svmax[exp(−y²/2i²) + exp(−(y−d)²/2i²)] (D&G eq 6)	Pass
Twin-tunnel interaction warning for clear spacing < 1 D (M-T-B 1996 §2.4)	Pass
Input validation: D, z0, Vl errors; K warning	Pass

⚑ `tunnel-settlement-trough-web-validation.test.ts`

Dedicated validation for the tunnel surface settlement trough (`tunnel-settlement-trough.ts`): the Gaussian transverse profile S(y) = Smax·exp(−y²/2i²) with i = K·z0 and Smax = VL·(πD²/4)/(i·√(2π)).

Analyses validated: `tunnel-settlement-trough` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Pound & Beveridge (2002) Table 3: printed Smax from printed z0, VL and K (D = 6.12 m)	Pass
Pound & Beveridge (2002) chainage 21320: two tunnels 18.0 m apart superpose to the printed 21.0 mm	Pass
Pound & Beveridge (2002) chainage 22670: tunnels 38 m apart give a double low point	Pass
Bowers, Hiller & New (1996) Table 1: type three sections, printed Smax from printed VL and K	Pass
Fillibeck & Vogt (2012) Fig.2: printed smax lies inside the engine range for the stated At = 35-42 m²	Pass
hand check: the engine profile integrates to its own trough volume and peaks at the inflection slope	Pass

Rock mechanics and rock slopes

FE kernel registry — 1 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`v-rs2-jointed-column-table-6-2`	uniaxial strength of a column with one joint set, β = 30… 90° (13 angles), FE column through the phase driver [kPa]	Rocscience-RS2-Stress-Verification-Kirsch-Salencon-Prandtl-LinedTunnel.pdf, p. PDF p. 37 (§6, Table 6.2; Jaeger & Cook 1979)	—	[3.4641, 3.57266, 3.93923, 4.73205, 6.51038, 8.57803]	[3.4641, 3.57266, 3.93923, 4.73205, 6.51038, 8.57803]	—	0.00 %	Pass

Closed-form engine registry — 1 published problems

ROW	PROBLEM	SOURCE	REFERENCE	OURS	Δ	TOLERANCE (WHY)	STATUS
`D2-ROCKPLANAR-SAUMAUPING`	Rock planar slide, no tension crack, saturated — Sau Mau Ping Road slope H 60 m, face 50°, plane 35°, c 100 kPa, ϕ 35°, γr 27, γw 10, α 0.08, no crack, Hw = H = 60 m	Rocscience RocPlane Verification Manual, Problem #1 (Hoek, Sau Mau Ping Road) — the 0.8184254 hand calculation is printed here; the equations (Fig. 6, eq. 4) are from Hoek, Practical Rock Engineering (Practical-Rock-Engineering-Full-Text.pdf), which does not print this value — VM #1, without tension crack, p. 8	0.8168425 factor of safety	0.818418425	0.00 %	± 0.1 % manual prints 7 s.f.	Pass

Cited validation suites — 9

`barton-bandis-web-validation.test.ts`

Validation for Barton-Bandis rock-joint strength (`barton-bandis.ts`).

Analyses validated: `barton-bandis` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
at σn′ = JCS the roughness term vanishes → ϕ_peak = ϕr	Pass
dilation increases as σn′ decreases (rougher engagement at low stress)	Pass
rougher joint (higher JRC) is stronger at the same σn′	Pass
friction cap prevents blow-up as σn′ → 0	Pass
peak friction = JRC·log10(JCS/σn) + ϕr (spot value)	Pass
Barton-Choubey ϕ_peak = JRC·log10(JCS/σn) + ϕr — cited sweep	Pass
Barton-Choubey dilation i = JRC·log10(JCS/σn) — cited sweep	Pass
Barton-Choubey shear strength τ = σn·tan ϕ_peak — cited values	Pass
Barton-Choubey: rougher joint (JRC) raises ϕ_peak by JRC·log10(JCS/σn) — cited	Pass
Wyllie & Mah §4.2.4 (p. 85): roughness angle i = 5·log10(8600/426) ≈ 7°	Pass
Wyllie & Mah §6.3.5 (p. 137): rough plane slope, σ = 281 kPa → τ 269, ϕ+i 44°, FS 1.66	Pass
Wyllie & Mah §6.3.5 (p. 137): rough plane slope, σ = 450 kPa → τ 387, ϕ+i 41°, FS 1.49	Pass
the published-value tally is 7 distinct printed numbers from 1 source; PARTIAL (short of 20 by 13)	Pass

rock-mechanics-published-web-validation.test.ts

rock-mechanics — deep review D13 (2026-10-02).

Analyses validated: `rock-mechanics` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[PRE12] RMR worked example — 12 + 13 + 10 + 22 + 7 − 5 = 59, Class III fair rock	Pass
[PRE12 Table E] soft filling < 5 mm rates 2 (not 1) — the same as hard filling > 5 mm	Pass
[PRE12 Table B] orientation adjustments: tunnels to −12, foundations to −25, slopes to −60 accepted; outside refused	Pass
[PRE12] Q worked example — (90/4)(3/1)(1/15) = 4.5, "Fair"	Pass
[HB02] σci 50, mi 10, GSI 45 — tunnel D 0: φ′ 47.16°, c′ 0.58 MPa; slope D 1: φ′ 27.61°, c′ 0.35 MPa	Pass
[PRE5] Athens schist — mi 9.6, GSI 20 → mb 0.55, s 0.0001, a 0.544	Pass
[PRE5 / SG 26.1] GSI uses RMR'89 — groundwater 15, orientation 0 — not the design RMR	Pass
[SG 26.2-26.3] At the RMR'89 floor, GSI = 9 ln Q' + 44 with Q' = (RQD/Jn)(Jr/Ja) when it gives GSI < 18	Pass

⚑ rock-mechanics-web-validation.test.ts

C.ROCK — `rock-mechanics` web-benchmark: the generalised Hoek-Brown parameters against the published equations, 34 cited values.

Analyses validated: `rock-mechanics` · Recorded run: passed — 17 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C.ROCK.1: 30 Hoek-Brown parameters match published Eqs (4)-(6) exactly	Pass
C.ROCK.2: the published intact-rock limit — s = 1 and a = 0.5 at GSI = 100, D = 0	Pass
C.ROCK.3: Eq (6) asymptote as GSI → 0	Pass
C.ROCK.4: disturbance D strictly weakens the rock mass (Eqs 4 and 5)	Pass
C.ROCK.5: Q-system formula identity and Barton class boundaries	Pass
C.ROCK.6: GSI ≈ RMR89 − 5 (Hoek & Brown 1997) with the published floor	Pass
C.ROCK.7: R4 sub-ratings sum and clamp per Bieniawski 1989 Table 4.4	Pass
C.ROCK.8: E-5 regression — a non-finite input must error, never yield NaN	Pass
C.ROCK.9: E-112 — a NaN Q must never be labelled "Exceptionally good"	Pass
C.ROCK.10: E-112 — Q is a product of positive ratios and cannot be negative	Pass
C.ROCK.11: E-112 — Hoek-Brown must reject blank inputs instead of returning NaN	Pass
C.ROCK.12: E-112 — s ≤ 1 always, because s = 1 IS intact rock (Hoek & Brown 2019 Eq. 5)	Pass
C.ROCK.13: E-112 — σ1 clamps to the tension cut-off instead of returning NaN	Pass
C.ROCK.14: E-112 — the Mohr-Coulomb fit must not return a modulus beside a NaN cohesion	Pass
C.ROCK.15: E-112 — the modulus engine must reject blanks, not return half a result	Pass
C.ROCK.16: E-112 — jcond89FromJrJa must not return the r→∞ limit for an invalid Ja	Pass
C.ROCK.17: E-112 — a failed RMR must not become a valid GSI downstream	Pass

rock-slope-stability-rocplane-web-validation.test.ts

rock-slope-stability — second dedicated validation suite beside the Example 6.1 suite already in `rock-slope-stability-web-validation.test.ts` (which rests on ONE source).

Analyses validated: `rock-slope-stability` · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[W] Example 6.1(c) drained: W·cosψp = 1017.14, W·sinψp = 712.21, c·A = 333.50 kN/m	Pass
[W] Example 6.1(b) crack full (zw = 4.35 m): U = 284.57, V·sinψp = 53.23, V·cosψp = 76.02 kN/m	Pass
[W] Example 2.2, east-dipping 50/090 face: plane failure possible on joint set 2 ONLY	Pass
[W] Example 2.2: cutting the east face at 40° (coincident with set 2) prevents sliding; ϕ > 40° also prevents it	Pass
[W] Example 2.2, north-dipping 50/360 face: no planar mode (wedge is the published mode)	Pass
[W] Example 2.2: wedge of sets 1 & 2 — line of intersection plunge ≈ 27°, possible at 50°, prevented by a 27° cut	Pass
[R1] Hoek/Sau Mau Ping, no crack: W = 28.6278 MN/m, A = 104.6068 m²/m	Pass
[R1] Hoek/Sau Mau Ping, with crack: z = 14.0092 m, W = 24.8439 MN/m, A = 80.1826 m²/m, FS = 1.0654738	Pass
[R6] Priest (1993): plane failure with 25 %-filled 15 m crack → FS = 1.049	Pass
[R8] Watts & West (1985) case 1: c′ = 0 t/ft², ϕ′ = 20° → FS = 0.364	Pass
[R8] Watts & West (1985) case 2: c′ = 1.1025 t/ft², ϕ′ = 20° → FS = 0.644	Pass
[R8] Watts & West (1985) case 3: c′ = 2.2051 t/ft², ϕ′ = 35° → FS = 1.26	Pass
[R3] RocPlane Table 1.3.3: 15 (z/H, c) points of the tension-crack / cohesion sensitivity grid	Pass
[R3] dry, no-crack, no-cohesion limit is tanϕ/tanψp = 0.824542 (printed first row, c = 0)	Pass

rock-slope-stability-web-validation.test.ts

REAL PUBLISHED TEXTBOOK WORKED EXAMPLE (not formula-fidelity -- an independently-published answer) from Wyllie & Mah, "Rock Slope Engineering -- Civil and Mining", 4th ed.

Analyses validated: `rock-slope-stability` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] (c) fully drained (zw=0): published W=1241.70 kN/m, A=13.34 m2/m, FS=1.54	Pass
[3-5] (a) water to 3m above the sliding surface (zw=3): published U=196.31 kN/m, V=44.15 kN/m, FS=1.25	Pass
[6] (b) tension crack completely full (zw=4.35m): published FS=1.07	Pass
[7] (d) drained AND cohesion reduced to zero: published FS=1.08	Pass
[8] status classification bands (unstable<1.0, marginal<1.3, else stable) match the published FS=1.25 marginal call	Pass
[9] the drained case (FS=1.54) is classified stable, matching the textbook's own qualitative call	Pass
[10] the fully-flooded case (FS=1.07) is classified marginal, matching the textbook noting it "is close to failure"	Pass
[11] kinematic admissibility for this exact published geometry: the plane daylights (psi_p=35 < psi_f=60) and exceeds friction (35 > 37 is FALSE -- so planar_admissible must be FALSE, since 35 < 37)	Pass
[12] invalid inputs (zero height, dip/face angle outside 0-90, tension crack >= height) are refused	Pass
[VAL-1] Example 6.1(e): critical crack depth of the dry slope = 4.32 m (z/H = 0.36, chart) — engine FS minimum and closed form agree within the chart resolution	Pass

rock-wedge-3d-independent-web-validation.test.ts

INDEPENDENT-SOURCE validation, 3-D rock wedge engine (`rock-wedge-3d.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[S1] §1.1 Table 1.1.5 (T35): joints 45/141 & 45/219, face 70/180 ⇒ plunge 37.852°; FS ≅ 1	Pass
[S1] §1.1 Table 1.1.5 (T33 & T37): dip/ϕ 42.7/33 ⇒ 35.645°; 47.5/37 ⇒ 40.301°	Pass
[S1] §1.3 (Kumsar et al. 2000 Case 3, Ankara Castle): FS = 0.7123	Pass
[S1] §1.4 (Kumsar et al. 2000 Case 4, Dinar, static): FS = 2.0203	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[S1] §3.1 Table 3.1.3 (ponded-water problem, dry row): FS = 0.9218	Pass
[S1 §1.1] Kovári & Fritz closed form: λ = 1/sin ω and FS = λ·cos i_a·tanϕ/sin i_a	Pass
[S2] §5.3: wedge factors A = 0.91 and B = 0.80	Pass
[S2] §5.3: drained FS = 1.23 and cohesion destroyed ⇒ FS = 1.01	Pass
[S3] Ch 8: line of intersection αi = 349°, βi = 39° (stereonet reading) and 348.5°/39.3° (Table 8.1)	Pass
[S3] Ch 8 + Table 8.1: H = 25 m toe-to-crest ⇒ W = 7,203,843 kg, FS = 0.875 (c ≠ 0), 0.686 (c = 0); Kliche FS 0.879	Pass

rock-wedge-3d-web-validation.test.ts

3-D wedge engine vs the published worked wedges in Wyllie & Mah (2004) "Rock Slope Engineering — Civil and Mining" 4th ed., Spon (source on disk: Wyllie-Mah-Rock-Slope-Engineering-Civil-and-Mining-4e.pdf).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Table 7.2: the line of intersection plunges ψ5 = 31.2° and the wedge is a valid, daylighting two-plane wedge	Pass
Table 7.2: wedge factors A = 1.548 and B = 0.956 (eqs 7.12-7.13)	Pass
§7.5 eq 7.14 / Table 7.2: friction-only FS = A·tanϕA + B·tanϕB = 1.24	Pass
§7.4: completely drained FS with cohesion = 1.98	Pass
Table 7.2: saturated FS with cohesion = 1.36	Pass
§7.4: zero cohesion and maximum water pressure (saturated) = 0.62 — the worst case, unstable	Pass
Table 7.2 ordering holds: drained 1.98 > saturated 1.36 > friction-only 1.24 > worst case 0.62	Pass
§7.6.3 case (i): planes 60/360 and 54/118, ϕ = 30°, c = 0, dry ⇒ FS = 1.05	Pass
§7.6.3 case (i) is size-independent: the same orientations at H = 5 m and H = 200 m give the same FS	Pass

rockfall-trajectory-web-validation.test.ts

Web-validation for the rockfall-trajectory engine (`rockfall-trajectory.ts`).

Analyses validated: `rockfall-trajectory` · Recorded run: passed — 23 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
A. frictionless slide toe velocity = √(2gH) for H=10 m	Pass
A. frictionless slide toe velocity = √(2gH) for H=20 m	Pass
A. frictionless slide toe velocity = √(2gH) for H=30 m	Pass
A. frictionless slide toe velocity = √(2gH) for H=50 m	Pass
A. frictionless slide toe velocity = √(2gH) for H=100 m	Pass
B. friction slide v_toe = √(2gH(1−μ/tanβ)) for H=30 β=60 μ=0.4	Pass
B. friction slide v_toe = √(2gH(1−μ/tanβ)) for H=20 β=45 μ=0.3	Pass
B. friction slide v_toe = √(2gH(1−μ/tanβ)) for H=40 β=70 μ=0.5	Pass
B. friction slide v_toe = √(2gH(1−μ/tanβ)) for H=15 β=50 μ=0.35	Pass
B. friction slide v_toe = √(2gH(1−μ/tanβ)) for H=25 β=55 μ=0.45	Pass
C1. kinetic energy at the toe = ½ m v² (definition)	Pass
C2. higher normal restitution R_n → longer runout & higher bounce	Pass
C3. elastic (R_n=R_t=1) conserves energy → block does not arrest (runs to cap)	Pass
C4. more dissipative bounces (lower R) → fewer/shorter → shorter runout	Pass
D. Ritchie ditch for H=5 β=45 → 3.7 m × 1 m	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
D. Ritchie ditch for H=15 β=60 → 7 m × 1.5 m	Pass
D. Ritchie ditch for H=25 β=80 → 7.6 m × 1.8 m	Pass
D. Ritchie ditch for H=8 β=40 → 3.7 m × 1.2 m	Pass
E1. taller slope → higher toe velocity	Pass
E2. steeper face → higher toe velocity (larger downslope gravity component)	Pass
F. μ ≥ tanβ (friction angle ≥ slope angle) → block arrests on the face	Pass
G1. a low barrier in the bounce path is overtopped (inadequate)	Pass
G2. a tall, strong barrier is adequate	Pass

`stereonet-web-validation.test.ts`

Stereonet + kinematic screening vs the published worked examples in Wyllie & Mah (2004) "Rock Slope Engineering — Civil and Mining" 4th ed., Spon, Ch 2: Example Problem 2.1 (stereo plots of structural geology data, p.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Example 2.1(b): clustering the 17 poles finds the book's three sets and sets 80/010 aside	Pass
Example 2.1(b): mean poles agree with the book's 78/305, 40/081, 20/163 to within 2° of arc	Pass
Example 2.1(c): angle between the mean poles of sets 1 and 3 is 94° (included angle 86°)	Pass
Example 2.1(e): the line of intersection of sets 1 and 2 plunges 27° toward 029°	Pass
Example 2.2: east-dipping 50° face, ϕ = 25° ⇒ plane failure on set 2 only	Pass
Example 2.2: cutting the east slope at 40°, coincident with set 2, prevents sliding on set 2	Pass
Example 2.2: if the friction angle exceeded the 40° dip, sliding on set 2 would not occur	Pass
Example 2.2: north-dipping 50° face ⇒ wedge failure on sets 1 and 2, and no plane failure	Pass
Example 2.2: cutting the north slope at 27° (the intersection plunge) is not undercut by the wedge	Pass
closed form: the wedge daylights exactly when ψf exceeds atan(tanψi / cos(αi − αf)) (≈ 30.3° for sets 1+2 on a north face)	Pass

Groundwater flow and seepage

FE kernel registry — 32 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-verif-concrete-dam-I-Q	Dam I: total discharge under the dam [m³/s/m]	PLAXIS-Verification-Concrete-dam-confined-flow.pdf, p. 4 (Table 2)	1.030e-5	1.029e-5	1.031e-5	+0.06 %	+0.15 %	Pass
plaxis-verif-concrete-dam-II-Q	Dam II (upstream screen): total discharge [m³/s/m]	PLAXIS-Verification-Concrete-dam-confined-flow.pdf, p. 4 (Table 2)	8.681e-6	8.840e-6	8.686e-6	+0.06 %	−1.74 %	Pass
plaxis-verif-concrete-dam-III-Q	Dam III (downstream screen): total discharge [m³/s/m]	PLAXIS-Verification-Concrete-dam-confined-flow.pdf, p. 4 (Table 2)	8.679e-6	8.840e-6	8.686e-6	+0.08 %	−1.74 %	Pass
plaxis-verif-concrete-dam-I-uplift	Dam I: uplift pressure head at A (dam toe) [m]	PLAXIS-Verification-Concrete-dam-confined-flow.pdf, p. 4 (Table 3)	2.18	2.25	2.181	+0.05 %	−3.07 %	Pass
plaxis-verif-concrete-dam-II-uplift	Dam II: uplift pressure head at A [m]	PLAXIS-Verification-Concrete-dam-confined-flow.pdf, p. 4 (Table 3)	2.08	2.13	2.073	−0.34 %	−2.68 %	Pass
plaxis-verif-concrete-dam-III-uplift	Dam III: uplift pressure head at A (upstream side of the screen) [m]	PLAXIS-Verification-Concrete-dam-confined-flow.pdf, p. 4 (Table 3)	4.01	3.87	4.004	−0.15 %	+3.46 %	Pass
plaxis-verif-seepage-length	seepage face length along the slope above the tail water [m]	PLAXIS-Verification-Seepage-length.pdf, p. 5 (Table 1)	25.35	25.5	25.375	+0.10 %	−0.49 %	Pass
plaxis-verif-muskat	seepage face height on the downstream boundary above the tail water [m]	PLAXIS-Verification-Muskat-problem-2018.pdf, p. 4 (Table 1)	1.611	1.55	1.5867	−1.51 %	+2.37 %	Pass
plaxis-verif-sand-layer-Q	total discharge through an unconfined sand layer [m³/day/m]	PLAXIS-Verification-Unconfined-flow-sand-layer.pdf, p. 3 (Table 1)	0.154	0.15	0.15387	−0.08 %	+2.58 %	Pass
plaxis-verif-earth-dam-Q	total discharge through the earth dam [m³/s/m]	PLAXIS-Verification-Unconfined-flow-earth-dam.pdf, p. 2 (Table 1)	0.000544	0.000536	0.00054579	+0.33 %	+1.83 %	Pass
plaxis-verif-triangular-dam-Q	total discharge Q = kL/2 through the triangular dam [m³/day/m]	PLAXIS-Verification-Triangular-earth-dam.pdf, p. 2–5	0.5	0.5	0.5	0.00 %	0.00 %	Pass
plaxis-verif-theis-thiem-r10	steady head at r = 10 m (pumping well, axisymmetric) [m]	PLAXIS-Verification-Theis-Thiem.pdf, p. 4	13.534	13.5342	13.5342	+1.0e-3 %	0.00 %	Pass
plaxis-verif-theis-thiem-r100	steady head at r = 100 m [m]	PLAXIS-Verification-Theis-Thiem.pdf, p. 4	14.267	14.2678	14.2678	+5.0e-3 %	0.00 %	Pass
plaxis-verif-infiltration-steady	steady suction head profile, worst |ψ − Gardner| over y = 0.5…3 m [m]	PLAXIS-Verification-One-dimensional-infiltration.pdf, p. 1–4 (Eq. 4; Fig. 3)	—	0	3.490e-7	—	—	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-verif-infiltration-transient	transient suction head, worst |ψ – Srivastava & Yeh| at t = 0.1/0.25/0.5/1/5 d [m]	PLAXIS-Verification-One-dimensional-infiltration.pdf, p. 1–4 (Eq. 5–7; Fig. 4)	—	0	0.0014	—	—	Pass
plaxis-verif-evaporation-steady	steady suction head, worst |ψ – Gardner| [m]	PLAXIS-Verification-One-dimensional-evaporation.pdf, p. 1–4	—	0	9.800e-5	—	—	Pass
plaxis-verif-evaporation-transient	transient suction head, worst |ψ – Srivastava & Yeh| [m]	PLAXIS-Verification-One-dimensional-evaporation.pdf, p. 1–4	—	0	0.0018	—	—	Pass
k4-gate-confined-box	confined flow box: discharge and linear head (P2/P1 and equal order) [m³/day/m]	—	—	1	1	—	0.00 %	Pass
k4-gate-dupuit	unconfined flow, sharp vG soil: discharge vs Dupuit [m³/s/m]	—	—	2.100e-5	2.117e-5	—	+0.82 %	Pass
k4-gate-thiem	Thiem steady drawdown (see plaxis-verif-theis-thiem-*) [m]	—	—	13.5342	13.5342	—	0.00 %	Pass
k4-crosscheck-fe-seepage-layers	fe-seepage (TS oracle) layered column discharge [m³/s/m]	—	—	5.600e-5	5.600e-5	—	0.00 %	Pass
k4-crosscheck-fe-seepage-block self-check	fe-seepage block with a cutoff: discharge vs the oracle 80×40 Q4 [m³/s/m]	—	—	1.229e-5	1.229e-5	—	+7.0e-3 %	Pass
k4-crosscheck-unconfined self-check	unconfined-seepage (TS oracle): discharge (Hypres coarse vG) [m³/s/m]	—	—	2.087e-5	2.109e-5	—	+1.07 %	Pass
k9-sy-rainfall-hyetograph	worst |ψ – Srivastava & Yeh| under a rainfall table (24 values, 4 global times) [m]	PLAXIS-Verification-One-dimensional-infiltration.pdf, p. pp. 1–4 (Eqs. 5–7)	—	0	0.0015	—	—	Pass
k9-drawdown-ramp-8m	Δh at 8 m depth after 1 day of a 0.5 m/day head ramp [m]	—, p. C&J §2.5	—	-0.185	-0.185	—	0.00 %	Pass
k9-fxh-kr-10kPa	Fredlund–Xing–Huang k_r at 10 kPa (a 10, n 2, m 1, ψr 3000, aev 5) [–]	Fredlund-Rahardjo-Fredlund-2012_Unsaturated-Soil-Mechanics-in-Engineering-Practice_Wiley_939p.pdf, p. Eq. 8.21, Fig. 5.29 parameters	—	0.210374	0.210328	—	−0.02 %	Pass
k9-kisch-liner-Q	leakage through a clay blanket (Yolo light clay / Superstition sand) [m/s]	Seequent-GeoStudio-SEEPW-Verification-Kisch-Clay-Liner-Unsaturated.pdf, p. pp. 2–7; FRF 2012 Table 8.2	—	1.323e-7	1.323e-7	—	−7.6e-3 %	Pass
v-plaxis-infiltration-transient-asserted	worst |ψ – Srivastava & Yeh| at t = 0.1/0.25/0.5/1/5 d, y = 0.5…3 m (ASSERTED < 5 mm); infiltration 0.1 m/d [m]	PLAXIS-Verification-One-dimensional-infiltration.pdf, p. pp. 1–4 (Eqs. 4–7; Fig. 3–4)	—	0	0.0014	—	—	Pass
v-plaxis-evaporation-transient-asserted	worst |ψ – Srivastava & Yeh| at the same times (ASSERTED < 5 mm); evaporation 0.002 m/d [m]	PLAXIS-Verification-One-dimensional-evaporation.pdf, p. pp. 1–4	—	0	0.00185	—	—	Pass
v-k9-flow-function-rainfall	worst |ψ – S&Y superposed| under a table flow function (re-run 3 Nov 2026) [m]	PLAXIS-Verification-One-dimensional-infiltration.pdf, p. pp. 1–4 (Eqs. 5–7)	—	0	0.0015	—	—	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`v-k9-flow-function-drawdown`	Δh at 8 m after 1 d of a 0.5 m/d head ramp (head and level functions; re-run 3 Nov 2026) [m]	—, p. Carslaw & Jaeger 1959 §2.5	—	-0.185	-0.185	—	—	Pass
`v-rocscience-ponded-water-effective-stress`	worst |σ′yy − (−(γsat − γw)·d)| of a 2 m drained column (γsat 20, γw 10) under 0 / 1.5 / 3 m of standing water above its surface [kPa]	—	—	0	5.862e-13	—	—	Pass

Cited validation suites — 19

`capillary-rise-web-validation.test.ts`

Validation for `capillary-rise` — Hazen/Terzaghi capillary rise h_c = C/(e·D10) and suction (`capillary-rise.ts`, `computeCapillaryRise`).

Analyses validated: `capillary-rise` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Terzaghi–Peck–Mesri Eq. 15.23 at the printed C limits (0.01 and 0.05, D10 in mm, h_c in m)	Pass
the engine's C warning band is exactly the published 0.01–0.05 (= 0.1–0.5 cm²)	Pass
Terzaghi–Peck Eq. 15.21 and Craig p. 40: suction = γw·h_c with γw = 9.81 kN/m³	Pass
Terzaghi–Peck Art. 15.6.1: rise grows as the effective size falls, and is ∝ 1/D10 and ∝ 1/e	Pass
Holtz & Kovacs Table 6-1 / Example 6.3: a clay with D10 = 1 µm rises at least 10 m	Pass
Acharya (2021) lecture-note problem: soil A (D10 = 0.06 mm) rises 60 cm; soil B (D10 = 0.1 mm, same e) ⇒ 360 mm	Pass

`darcy-velocity-web-validation.test.ts`

darcy-velocity — validation of Darcy's law (discharge velocity, seepage velocity, flow rate) against PUBLISHED worked numbers.

Analyses validated: `darcy-velocity` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Lambe & Whitman 1969 Fig 17.8: k = 0.5 cm/s, 3.6 m over 1.8 m → v = 1 cm/s	Pass
Lambe & Whitman 1969 Fig 17.8: n = 0.33 → seepage velocity "3 cm/sec"	Pass
Lambe & Whitman 1969 Fig 18.1: 4.8 m over 10 × 0.3 m → gradient 1.6	Pass
Lambe & Whitman 1969 Fig 18.1: Q = kiA over the 1.2 × 1.2 m tube = 0.00115 m³/s	Pass
Holtz & Kovacs 1981 Ex 7.1: printed k = 0.08 cm/s reproduces the collected volume (945.7 cm³ in 1 min) to its 1-s.f. precision	Pass
Holtz & Kovacs 1981 Ex 7.1: cross-sectional area of the 7.3 cm sample is 41.9 cm² (printed)	Pass
v_s > v for every porosity below 1 (Lambe & Whitman Eq. 17.3: v_s = v/n)	Pass
a cleared flow length is refused rather than reported as v = 3e9 m/s	Pass

`dewatering-system-web-validation.test.ts`

Dedicated validation for the equivalent-well dewatering system (`dewatering-system.ts`): steady discharge of a ring of wells idealised as one large well, Q = πk(H²−h²)/ln(R/re) (unconfined) and Q = 2πkbs/ln(R/re) (confined), with the Sicha…

Analyses validated: `dewatering-system` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Cashman & Preene Design Example 1: printed Q (m³/s) from the printed re and R0	Pass
Cashman & Preene Design Example 1: engine Sichardt R plus re equals the printed R0 (Eq. 13.15 structure)	Pass
Cashman & Preene Design Example 1: the engine default (no R0 added) is the conservative side, +0.7 to +2.7 %	Pass
Textbook Example 4.2.2 (confined, b = 25 m): K = 16.8 m/day reproduces Q = 0.05 m³/s = 4320 m³/day	Pass
Textbook Example 4.2.2 (confined, b = 30 m, 1 m dia well): K = 13.3 m/day, head at well 34.5 m, R = 79 m → Q = 113 m³/h	Pass
Textbook Example 4.2.3 (unconfined, h0 = 25 m): K = 18.3 m/day reproduces Q = 0.05 m³/s = 4320 m³/day	Pass
Textbook Example 4.2.4 (unconfined, 33 m saturated, 0.5 m dia well): K = 12.68 m/day, head at well 27.7 m, R = 198 m → Q = 1920 m³/day	Pass
Course handout Example 9.7 (confined well): printed drawdown 127 ft reproduces Q = 2000 gpm	Pass
Course handout Example 9.8 (unconfined well): printed drawdown 38.2 ft reproduces Q = 600 gpm	Pass

earth-dam-seepage-web-validation.test.ts

PUBLISHED-VALUES: 10 -- distinct published values for this engine (engine-level total, declared once); independent audit A4: ten values, all from one worked example (Craig Ex 2.4).

Analyses validated: `earth-dam-seepage` · Recorded run: passed — 16 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Craig 2012 Ex 2.4: focal distance x0 = 1.90 m (engine y0/2)	Pass
Craig 2012 Ex 2.4: parabola ordinate at the focus, z0 = 2·x0 = 3.80 m (TABLE E, x = 0)	Pass
Craig 2012 Ex 2.4: seepage from the basic parabola q = 2·k'·x0 = 1.0e-7 m³/s per metre	Pass
Craig 2012 Ex 2.4: analytic q agrees with the same example's hand-drawn flow net (1.1e-7) to its own scatter	Pass
Craig 2012 TABLE E: point (x=-5.0, z=7.24) lies on the parabola with y0 = 3.80 m	Pass
Craig 2012 TABLE E: point (x=-10.0, z=9.51) lies on the parabola with y0 = 3.80 m	Pass
Craig 2012 TABLE E: point (x=-20.0, z=12.9) lies on the parabola with y0 = 3.80 m	Pass
Craig 2012 TABLE E: point (x=-30.0, z=15.57) lies on the parabola with y0 = 3.80 m	Pass
Craig 2012 TABLE E: ordinate at x=-5.0 m is z=7.24 m (engine parabola y(L/2))	Pass
Craig 2012 TABLE E: ordinate at x=-10.0 m is z=9.51 m (engine parabola y(L/2))	Pass
Craig 2012 TABLE E: ordinate at x=-20.0 m is z=12.9 m (engine parabola y(L/2))	Pass
Craig 2012 TABLE E: ordinate at x=-30.0 m is z=15.57 m (engine parabola y(L/2))	Pass
Casagrande 1937 Eq.(16): q = k·y0 = 2·k·a0, with focal distance a0 = y0/2	Pass
Casagrande 1937 Eq.(15): y0 = $\sqrt{(d^2+h^2)} - d$ (hand evaluation at Craig's d = 40.80, h = 18.00)	Pass
Casagrande 1937: seepage is independent of the number of channels drawn — doubling k doubles q, h→0 gives q→0	Pass
freeboard check: Craig Ex 2.4 crest (20.00 m) over the 18.00 m pool leaves 2.00 m	Pass

fe-seepage-web-validation.test.ts

Web-benchmark validation for `fe-seepage` — steady confined FE seepage and the unconfined free-surface solve.

Analyses validated: `fe-seepage`, `unconfined-seepage` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
1-D confined flow reproduces Q = k·(Δh/L)·H exactly	Pass
the head field is linear in x, to machine precision	Pass
Q scales exactly with k, with the gradient, and with the flow area	Pass
refining the mesh drives Q toward the closed form	Pass
two zones in series give the harmonic-mean equivalent k (exact)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
pure horizontal flow has no upward gradient, so piping is withheld not zeroed	Pass
upward flow produces a real exit gradient and a finite piping FoS	Pass
the unconfined solve reports the exact Dupuit discharge q = k(h₁² − h₂²)/(2L)	Pass
the free surface falls monotonically from upstream to downstream	Pass
a domain with no fixed head is refused rather than solved as all-zero	Pass
invalid geometry, conductivity and mesh divisions are all refused	Pass
the unconfined solve refuses a downstream head above the upstream one	Pass

field-permeability-web-validation.test.ts

Web-benchmark validation for `field-permeability` — in-situ borehole permeability.

Analyses validated: `field-permeability` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
flush-bottom shape factor is Hvorslev F = 2.75·D	Pass
screened shape factor is F = 2π·L/sinh⁻¹(L/D), with the published asymptote	Pass
variable-head k matches Hvorslev (1951) on a hand-computed case	Pass
a rising-head test gives the same k as the falling-head equivalent	Pass
constant-head k matches Hvorslev k = Q/(F·H)	Pass
using the flush-bottom factor for a screened interval changes k materially	Pass
a short screened interval (L/D < 4) is flagged, not silently trusted	Pass
permeability classes break at the Terzaghi-Peck decade boundaries	Pass
a poor ln(H)-vs-t fit is flagged with its R²	Pass

⚑ filter-design-web-validation.test.ts

PUBLISHED-VALUES: 6 -- distinct published values for this engine (engine-level total, declared once); independent audit A4: the sources publish filter LIMITS, not worked filter-design answers.

Analyses validated: `filter-design` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Lambe & Whitman 1969 Eq 19.10 / Craig 2012 Eq 2.41: D15f/D85s = 4.95 (< 5) passes the USACE retention limit	Pass
Lambe & Whitman 1969 Eq 19.10 / Craig 2012 Eq 2.41: D15f/D85s = 5.05 (> 5) fails the USACE retention limit	Pass
EM 1110-2-2300 Table B-2 (category 4, "D15 < 4 to 5 × d85"): the Terzaghi end of the band is 4 — 3.96 passes, 4.04 fails	Pass
Craig 2012 Eq 2.42: D15f/D15s = 5.05 (> 5) passes the USACE permeability limit, 4.95 fails	Pass
Lambe & Whitman 1969 Eq 19.11 (lower bound 4): D15f/D15s = 4.04 passes the Terzaghi permeability limit, 3.96 fails	Pass
Lambe & Whitman 1969 Eq 19.12: D50f/D50s = 24.75 (< 25) passes, 25.25 fails	Pass
EM 1110-2-2300 App. B step f: filter D15 = 0.1 mm is acceptable, 0.099 mm is not	Pass
EM 1110-2-2300 App. B step g: a filter D85 of 75 mm raises no oversize advisory, 75.1 mm does	Pass
EM 1110-2-2300 ¶B-6: with the total-sample d85 = 5.2 mm a D15 = 2 mm filter retains the base (ratio 0.38)	Pass
EM 1110-2-2300 ¶B-6: with the matrix d85 = 0.1 mm the same D15 = 2 mm filter fails retention (ratio 20)	Pass
ratios: 3 mm filter on the base D15/D50/D85 = 0.02/0.1/1 mm gives 3, 150 and 30 (hand arithmetic)	Pass
a cleared base D85 is refused rather than giving a ratio of 6e8	Pass

flow-net-seepage-web-validation.test.ts

flow-net-seepage — validation against PUBLISHED worked flow-net examples.

Analyses validated: `flow-net-seepage` · Recorded run: passed — 18 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Craig 2012 Fig 2.8: sheet piling, Nf=3 Nd=8 → shape factor 0.375, q = 2.25e-5 m³/s/m	Pass
Craig 2012 Ex 2.1: cofferdam, Nf=6 Nd=10 H=4.50 → k = 2.6e-5 m/s from q = 0.25 m³/h/m	Pass
Craig 2012 Ex 2.1: forward check — printed k = 2.6e-5 reproduces printed inflow 0.25 m³/h/m	Pass
Craig 2012 Ex 2.1: hydraulic gradient below the excavation i = 0.50 (Δh = 4.50/10, Δs = 0.9 m)	Pass
Craig 2012 Ex 2.2: dam spillway Nf=3 Nd=10 → shape factor 0.3, q = 3.75e-5 m³/s/m	Pass
Craig 2012 Ex 2.2: a 60 m long spillway passes 60 × the per-metre seepage	Pass
Lambe & Whitman 1969 Fig 18.1: nf=4 nd=10 → shape factor 0.4	Pass
Lambe & Whitman 1969 Fig 18.1: Q/L = 0.00096 m³/s/m (per metre), Q = 0.00115 m³/s over 1.2 m	Pass
Lambe & Whitman 1969 Fig 18.1: gradient i = H/(10 × 0.3) = 1.6	Pass
Lambe & Whitman 1969 Ex 18.1: sheet pile wall → shape ½, Q/L = 18.75e-9 m³/s/m, exit i = 0.27	Pass
Lambe & Whitman 1969 Ex 18.2: concrete dam nf=4 nd=12.6 → shape factor 0.317	Pass
Lambe & Whitman 1969 Ex 18.2: Q/L = 0.00124 m³/s/m and gradient in square X = 0.19	Pass
Lambe & Whitman 1969 Ex 18.4: earth dam nf=2.65 nd=9 → shape factor 0.294	Pass
Lambe & Whitman 1969 Ex 18.4: Q/L = 5.36e-4 m³/s/m and gradient in square I = 0.40	Pass
NAVFAC DM-7.01 Fig 1: dry-dock underseepage nf=6 nd=15 → 0.4 ft³/min per ft	Pass
Craig 2012 p.52: refining the net (Nf,Nd) = (3,8) → (6,16) leaves q unchanged	Pass
zero head loss → zero seepage and exit gradient (Darcy: no gradient, no flow)	Pass
invalid flow net (Nd = 0) is rejected, not silently floored (q would be 1e5 × too large)	Pass

frost-depth-web-validation.test.ts

Validation for `frost-depth` — Stefan and modified-Berggren frost penetration (`frost-depth.ts`, `computeFrostDepth`).

Analyses validated: `frost-depth` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
TM 5-852-6 ¶3-3: volumetric latent heat 144·100·0.15 = 2160 Btu/ft³	Pass
TM 5-852-6 ¶3-3: modified Berggren depth ≈ 5.8 ft (printed arithmetic 5.90 ft)	Pass
Canadian Foundation Engineering Manual §13.4: L = 334 kJ/kg of water and 334 MJ/m³ of pure water	Pass
Mitchell & Soga Eq. 9.172 / 9.173: the modified depth is λ times the Stefan depth	Pass

grain-size-permeability-web-validation.test.ts

grain-size-permeability — validation of the Hazen branch (and the temperature dependence used by the Kozeny–Carman branch) against PUBLISHED tabulated values.

Analyses validated: `grain-size-permeability` · Recorded run: passed — 32 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.1 mm → k = 1e-4 m/s	Pass
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.2 mm → k = 4e-4 m/s	Pass
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.3 mm → k = 0.9e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.4 mm → k = 1.6e-3 m/s	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.5 mm → k = 2.5e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.6 mm → k = 3.6e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.7 mm → k = 4.9e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.8 mm → k = 6.4e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 0.9 mm → k = 0.8e-2 m/s	Pass
Look 2007 Table 8.3 (row C = 0.10 ≙ engine C = 1.0): D10 = 1.0 mm → k = 1.0e-2 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.1 mm → k = 1.5e-4 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.2 mm → k = 6e-4 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.3 mm → k = 1.4e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.4 mm → k = 2.4e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.5 mm → k = 3.8e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.6 mm → k = 5.4e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.7 mm → k = 7.4e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.8 mm → k = 9.6e-3 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 0.9 mm → k = 1.2e-2 m/s	Pass
Look 2007 Table 8.3 (row C = 0.15 ≙ engine C = 1.5): D10 = 1.0 mm → k = 1.5e-2 m/s	Pass
Look 2007 Table 8.3 "C = 0.15" row lies outside FHWA Eq. 5-14 (C = 0.4–1.2): the engine warns	Pass
Craig 2012 Eq 2.4: k = 10^{-2} $D10^2$ m/s — D10 = 0.3 mm ⇒ 9e-4 m/s with the default C	Pass
Freeze & Cherry 1979 Eq 8.47: A = 1.0 for K in cm/s and d10 in mm — the engine default	Pass
FHWA 2006 Eq 5-14: Hazen is valid for D10 from 0.1 to 3.0 mm (inclusive) and not outside	Pass
Look 2007 §8.3: Hazen is "ideally for uniformly graded material with U < 5"	Pass
USACE EM 1110-2-1906 Table VII-1: R_T(10 °C) = 1.301 ⇒ k(10)/k(20) = 0.769	Pass
USACE EM 1110-2-1906 Table VII-1: R_T(15 °C) = 1.135 ⇒ k(15)/k(20) = 0.881	Pass
USACE EM 1110-2-1906 Table VII-1: R_T(25 °C) = 0.889 ⇒ k(25)/k(20) = 1.125	Pass
USACE EM 1110-2-1906 Table VII-1: R_T(30 °C) = 0.797 ⇒ k(30)/k(20) = 1.255	Pass
USACE EM 1110-2-1906 Table VII-1: R_T(40 °C) = 0.653 ⇒ k(40)/k(20) = 1.531	Pass
Craig 2012 p.41: at 10 °C the permeability is 77 % of its 20 °C value	Pass
a cleared D10 is refused rather than reported as k = 1e-18 cm/s ("impermeable")	Pass

`insitu-groundwater-web-validation.test.ts`

Web-benchmark validation for TWELVE anchor/pile, in-situ-test, groundwater and liquefaction-residual runner engines.

Analyses validated: `cptu-dissipation`, `dewatering-system`, `drilled-shaft`, `earth-dam-seepage`, `ground-anchor`, `micropile`, `post-liquefaction-strength`, `spt-correction`, `subgrade-reaction`, `triaxial-csl`, `vacuum-preload`, `well-foundation` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
ground-anchor uses the BS 8081 grout-ground bond and the tendon limit	Pass
vacuum-preload combines the effective vacuum with Terzaghi 1-D settlement	Pass
drilled-shaft uses the O'Neill-Reese α method and N_c = 9 base	Pass
micropile applies the FHWA-NHI-05-039 bond and composite-section limits	Pass
triaxial-csl fits the CSL through p-q states and recovers ϕ′	Pass
cptu-dissipation reproduces Teh & Houlsby (1991)	Pass
dewatering-system uses the Sichardt radius and the Dupuit unconfined flow	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
earth-dam-seepage reproduces the Casagrande (1937) basic parabola	Pass
subgrade-reaction returns k_s = q/δ and converts units consistently	Pass
well-foundation uses Coulomb K_a/K_p and IRC 45 elastic theory	Pass
spt-correction applies the Peck overburden factor over the IS 6403 bearing zone	Pass
post-liquefaction-strength applies Olson & Stark (2002)	Pass

⚑ layered-permeability-web-validation.test.ts

layered-permeability — validation of the equivalent horizontal (arithmetic) and vertical (harmonic) permeability of a layered deposit against PUBLISHED numbers.

Analyses validated: `layered-permeability` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NPTEL 105101084 Lecture 24: k = 1, 0.5, 2 (×10⁻⁴ m/s), H = 6, 4, 3 m → k_h = 1.077e-4 m/s	Pass
Freeze & Cherry 1979 §2.5: couplets K1 = 10⁴, K2 = 10² → Kx/Kz = 25	Pass
Freeze & Cherry 1979 §2.5: couplets K1 = 10⁴, K2 = 1 → Kx/Kz = 2500	Pass
Freeze & Cherry 1979 §2.5: "Kx > Kz for all possible sets of values of K1 … Kn"	Pass
Lambe & Whitman 1969 Ex 18.5(b): parallel tubes A (0.05 cm/s) + B (0.005 cm/s) → total Q/L = 0.495e-3 m³/s/m	Pass
a zero-permeability layer is refused rather than reported as an impermeable profile	Pass

percolation-web-validation.test.ts

Web-benchmark validation for `percolation` — falling-head percolation / infiltration test used to size soak pits and storm-water recharge.

Analyses validated: `percolation` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the percolation rate is the steady-state drop rate, with a consistent unit chain	Pass
the reference drop is configurable but the CLASS stays per 25 mm	Pass
suitability bands break at the published 4 / 12 / 30 / 60 min-per-25 mm edges	Pass
an unsuitable result warns, and a rapid one warns about groundwater	Pass
Porchet k matches the published cylindrical falling-head relation	Pass
Porchet is withheld, with a reason, when the head cannot support it	Pass
soak-pit area is design flow over the allowable infiltration, with FoS 2	Pass
sizing an area always carries the septic-effluent under-sizing warning	Pass
a hole that was not pre-soaked for 24 h is flagged	Pass
a rate that has not stabilised is flagged rather than averaged away	Pass
only the last three intervals set the rate — earlier transients are excluded	Pass

pump-test-web-validation.test.ts

PUBLISHED-VALUES: 17 -- distinct published values for this engine (engine-level total, declared once); author's own count of published numbers, excluding 2 pass/fail verdicts.

Analyses validated: `pump-test` · Recorded run: passed — 19 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Kruseman & de Ridder Ex 3.4: Oude Korendijk, Δs = 0.375 m → KD = 385 m²/d	Pass
Kruseman & de Ridder Ex 3.4: Oude Korendijk, t0 = 0.25 min, r = 30 m → S = 1.7e-4	Pass
Kruseman & de Ridder Ex 3.4: S = 1.7e-4 is classified as a confined aquifer, as the book treats the test	Pass
Kruseman & de Ridder Ex 3.6: Δs = 0.33 m → KD = 437 m²/d	Pass
Kruseman & de Ridder Ex 3.6: (t/r²)0 = 2.45e-4 min/m² → S = 1.7e-4	Pass
Kruseman & de Ridder Ex 8.1: Papadopulos test, Δs = 1.15 m → (KD)e = 173 m²/d	Pass
Kruseman & de Ridder Ex 8.1: OW-1 S/KD = 7.22e-7 d/m²	Pass
Kruseman & de Ridder Ex 8.1: OW-2 S/KD = 9.35e-7 d/m²	Pass
Kruseman & de Ridder Ex 8.1: OW-3 S/KD = 9.39e-7 d/m²	Pass
Kruseman & de Ridder Ex 15.1: Hoogezand, Q = 28.7 m³/h, Δs = 0.07 m → KD = 1800 m²/d	Pass
Kruseman & de Ridder Ex 17.1: UE-25b#1, Δs = 1.70 m → T = 333 m²/d	Pass
Kruseman & de Ridder Ex 17.1: t2 = 3.4e-3 min, r_w = 0.11 m → S = 0.15 (printed 0.146)	Pass
Kruseman & de Ridder Ex 17.1: S = 0.15 is "the specific yield of unconfined aquifers" (book, p.261)	Pass
Freeze & Cherry 1979 Eq 8.45: SI coefficient C = 0.18 in T = C·Q/Δs	Pass
Freeze & Cherry 1979 Eq 8.46: SI coefficient D = 2.25 in S = D·T·t0/r²	Pass
Freeze & Cherry 1979 Eq 8.45: US-unit coefficient C = 264 (T in gal/day/ft, Q in gal/min, Δs in ft)	Pass
Freeze & Cherry 1979 Eq 8.46: US-unit coefficient D = 0.3 (T in gal/day/ft, t in days, r in ft)	Pass
k = T/b is arithmetic on the engine's T (hand check: 385.1/7 = 55.0 m/d)	Pass
a cleared Δs is refused rather than giving T ≈ 1e11 (the measured failure of the old floor)	Pass

`quick-condition-web-validation.test.ts`

quick-condition — validation of the critical hydraulic gradient, exit gradient and factor of safety against heave/boiling against PUBLISHED worked examples and tables.

Analyses validated: `quick-condition` · Recorded run: passed — 17 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Holtz & Kovacs 1981 Table 7-1: dense sand e = 0.5, Gs = 2.68 → i_c = 1.12	Pass
Holtz & Kovacs 1981 Table 7-1: medium sand e = 0.75, Gs = 2.68 → i_c = 0.96	Pass
Holtz & Kovacs 1981 Table 7-1: loose sand e = 1, Gs = 2.68 → i_c = 0.84	Pass
Holtz & Kovacs 1981 Ex 7.13: Gs = 2.65, e = 0.65 → i_c = 1.0	Pass
Holtz & Kovacs 1981 Ex 7.13: a head of 5.0 m over the 5 m sample is exactly the quick condition (FoS = 1)	Pass
Holtz & Kovacs 1981 Ex 7.13: the engine calls i = i_c a quick condition (effective stress is zero there)	Pass
Holtz & Kovacs 1981 Ex 7.14: seepage force per unit volume at quick conditions j = 9.81 kN/m³	Pass
Holtz & Kovacs 1981 Ex 7.19: exit gradient = (12/10.4)/8.5 = 0.14, "not critical"	Pass
Lambe & Whitman 1969 Ex 18.1: sheet pile, Δh = 7.5/8 m over l = 3.45 m → exit gradient 0.27	Pass
Lambe & Whitman 1969 Ex 18.2: concrete dam, Δh = 7.8/12.6 m over l = 3.3 m → gradient in square X = 0.19	Pass
Lambe & Whitman 1969 Ex 18.4: earth dam, Δh = 12/9 m over l = 3.36 m → gradient in square I = 0.40	Pass
Craig 2012 Ex 3.4: γsat = 20 kN/m³ → γ′ = 10.2 kN/m³ and i_cr = 1.04	Pass
Craig 2012 Ex 3.4: h_m = 2.6 m over 6 m → average gradient i_m = 0.43 and F = 2.4	Pass
Bond et al. 2013 EC7 A.6.2: h_r = 2.13 m over t = 6.60 m → gradient 0.32	Pass
Bond et al. 2013 EC7 A.6.2: γ′ = 10 kN/m³ when i_cr = 1 and γw = 10 kN/m³	Pass
Das 2016 §15.8: FoS = 1.5 is where the engine stops calling the state marginal	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
a cleared seepage length is refused, not floored to 1e-9 m	Pass

seepage-fe-mesh-web-validation.test.ts

Web-benchmark validation for the TerraCore general-mesh 2-D seepage FE (`seepage-fe-mesh.ts`).

Analyses validated: `mesh-viewer`, `seepage` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
1-D confined: linear head, Darcy q and velocity (Harr §2, Das Ch.8)	Pass
confined discharge scales linearly with k (Darcy)	Pass
anisotropic ky does not change purely horizontal discharge	Pass
1-D confined on an unstructured Delaunay mesh reproduces the linear field	Pass
flow-net: Q/(k·Δh) equals the shape factor N_f/N_d = H/L (Cedergren §4)	Pass
Thiem radial: logarithmic head + Q_θ = θ·k·Δh/ln(R/r_w) (Thiem 1906, Harr §5)	Pass
unconfined dam section: q = (k/2L)(h1²−h2²) (Dupuit 1863 / Charny 1951, Harr §2.6)	Pass

seepage-web-validation.test.ts

Formula-fidelity validation against Terzaghi & Peck; Das, "Principles of Geotechnical Engineering" Sec.7-8; Casagrande (1937) transformed-section method; Thiem (1906) and Dupuit (1863) steady-state well-flow theory; Sichardt's empirical ra…

Analyses validated: `seepage` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] flow-net discharge q = k.H.(Nf/Nd): k=1e-5 m/s, H=5m, Nf=6, Nd=12 -> q=2.5e-5 m3/s per unit width	Pass
[2] critical hydraulic gradient ic = (Gs-1)/(1+e): Gs=2.65, e=0.6 -> ic=1.031250	Pass
[3] piping factor of safety FoS = ic/i_exit: ic=1.03, i_exit=0.5 -> FoS=2.06	Pass
[4] Thiem (1906) confined well discharge Q = 2.pi.T.s/ln(R/rw): k=1e-5, b=10m, s=3m, R=200m, rw=0.15m -> Q=2.619654e-4 m3/s	Pass
[5] Dupuit (1863) unconfined well discharge Q = pi.k.(H^2-hw^2)/ln(R/rw): k=1e-5, H=15m, hw=8m, R=200m, rw=0.15m -> Q=7.029405e-4 m3/s	Pass
[6] Sichardt empirical radius of influence R = 3000.s.sqrt(k): s=3m, k=1e-5 m/s -> R=28.460499m	Pass
[7] Casagrande equivalent isotropic permeability k_eq = sqrt(kx.ky): kx=2e-5, ky=8e-6 -> k_eq=1.264911e-5 m/s	Pass
[8] Casagrande transformed-section horizontal scale factor = sqrt(ky/kx): kx=2e-5, ky=8e-6 -> scale=0.632456	Pass
[9] critical gradient at the exact physical boundary (Gs=1 or e undefined) returns NaN, never a fabricated finite number	Pass
[10] piping FoS at zero exit gradient returns Infinity (no upward flow, no piping risk), not a divide-by-zero NaN	Pass
[11] Thiem discharge scales exactly linearly with drawdown s, per the closed-form (Q proportional to s)	Pass
[12] invalid inputs throw rather than returning a silently-fabricated number (Nd<=0, kx/ky<=0)	Pass

transient-seepage-web-validation.test.ts

Validation for the transient unsaturated-seepage (Richards) engine (`transient-seepage.ts`).

Analyses validated: `transient-seepage` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Celia-Bouloutas-Zarba (1990) benchmark θ(ψ) — the canonical Richards test soil	Pass
van Genuchten SWCC + Mualem K anchors	Pass
mass is conserved (Celia et al. 1990): infiltration = Δstorage + drainage	Pass
a wetting front advances monotonically under infiltration	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the surface wets toward θs under infiltration; θ stays within [θr, θs]	Pass
unit-gradient steady state: drainage rate → applied flux (q < Ks)	Pass
ponded-head top BC infiltrates faster than a small flux; input validation	Pass
audit: a fully non-converged solve is REFUSED, not reported from the imposed flux	Pass
audit: K_s far outside any real soil is refused before the solve even runs	Pass
audit: an implausible infiltration flux is refused before the solve	Pass
audit: a refused run is NaN, not 0 — the client renders "—", not "0.0 mm"	Pass
audit: the real, valid case is unaffected by the new bounds	Pass

`unconfined-seepage-web-validation.test.ts`

C.FE.3 — FE unconfined (free-surface / phreatic) seepage web-benchmark.

Analyses validated: `fe-seepage`, `unconfined-seepage` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C.FE.3: FE discharge matches the exact Dupuit q within 8%	Pass
C.FE.3: phreatic line follows the Dupuit parabola h(x)²=h1²−(h1²−h2²)x/L	Pass
C.FE.3: free surface starts at h1 upstream and is monotonically falling	Pass
C.FE.3: discharge scales linearly with k and quadratically with head	Pass
C.FE.3: near-equal reservoir levels → near-zero discharge	Pass
C.FE.3: input guards return clean errors, not NaN/crash	Pass

Heat transfer, freezing and solute transport

FE kernel registry — 18 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k9-rs2-plate-centre	T(0.5, 0.5), square plate 100 / 500 °C [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §1 pp. 5–10 (Eq. 1.8)	—	200	200	—	0.00 %	Pass
k9-rs2-plate-0.5-0.75	T(0.5, 0.75) [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §1 (Eq. 1.8)	—	316.212	316.212	—	0.00 %	Pass
k9-rs2-rod-x0	T(0, 1), unit flux into a rod [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §3 pp. 13–14 (Eq. 3.1; Nithiarasu & Lewis Ex. 6.4.2)	—	1.12838	1.12833	—	−4.4e-3 %	Pass
k9-rs2-rod-x1	T(1, 1) [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §3 (Eq. 3.1)	—	0.39928	0.39928	—	0.00 %	Pass
k9-rs2-rod-x2	T(2, 1) [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §3 (Eq. 3.1)	—	0.10051	0.10051	—	0.00 %	Pass
k9-rs2-convective-1h	surface T after 1 h (h 40, T∞ −15, from 20 °C) [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §4 pp. 15–17 (C&J)	—	-4.8568	-4.8506	—	+0.13 %	Pass
k9-rs2-convective-1d	surface T after 1 day [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §4 (C&J)	—	-12.6642	-12.6634	—	+6.3e-3 %	Pass
k9-nafems-t4	T_E, NAFEMS T4 (steady, convection) [°C]	Midas-GTS-NX-2019-v2.1-Benchmarks-Verification-Chapter_8_HeatTransferAnalysis.pdf, p. §8.1 Table 8.1.1	—	18.3	18.2558	—	−0.24 %	Pass
k9-nafems-t3	T_C(32 s), harmonic end temperature 100 sin(πt/40) [°C]	Midas-GTS-NX-2019-v2.1-Benchmarks-Verification-Chapter_8_HeatTransferAnalysis.pdf, p. §8.3 Table 8.3.1	—	36.6	36.6029	—	+7.9e-3 %	Pass
k9-barlow-davis	T_C(58 s), Barlow & Davis 1987 [°C]	Midas-GTS-NX-2019-v2.1-Benchmarks-Verification-Chapter_8_HeatTransferAnalysis.pdf, p. §8.4 Table 8.4.1	—	9.62	9.6095	—	−0.11 %	Pass
k9-rs2-forced-convection-npe	Péclet number N_PE = C_w q L / λ [–]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §7 pp. 25–27 (Eq. 7.3)	—	4.186	4.186	—	0.00 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k9-rs2-forced-convection-down-y0.05	T(0.05 m), downward flow [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §7 (Eq. 7.2)	—	0.51001	0.51001	—	0.00 %	Pass
k9-rs2-forced-convection-up-y0.25	T(0.25 m), upward flow [°C]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §7 (Eq. 7.2)	—	0.48999	0.48999	—	0.00 %	Pass
k9-neumann-front-100d	thaw front after 100 days [m]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §5 pp. 18–20 (set-up); C&J §11.2	—	0.3748	0.3748	—	0.00 %	Pass
k9-neumann-front-10d	thaw front after 10 days [m]	Rocscience-RS2-Thermal-Analysis-Verification.pdf, p. §5; C&J §11.2	—	0.1185	0.1186	—	+0.08 %	Pass
k9-hollow-cylinder-q	heat flow through a hollow cylinder (axisymmetric, per radian) [W/rad]	—, p. C&J §7.2	—	11.6769	11.6769	—	0.00 %	Pass
k9-ogata-banks-x1.2-t3	c/c0 at 1.2 m after 3 days (v 0.4 m/d, D 0.0041 m²/d) [–]	—, p. Ogata & Banks (1961) USGS PP 411-A	—	0.526	0.5256	—	−0.08 %	Pass
k9-vga-retarded-decay-x0.4-t4	c/c0 at 0.4 m after 4 days (R 2.6, t½ 2 d) [–]	—, p. van Genuchten & Alves (1982)	—	0.4097	0.4096	—	−0.02 %	Pass

Cited validation suites — 1

unsaturated-thermal-web-validation.test.ts

Web-validation for the unsaturated-soil + thermal (THM) engine (`unsaturated-thermal.ts`).

Analyses validated: `unsaturated-thermal` · Recorded run: passed — 23 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
van Genuchten: Se(ψ=0)=1 and θ(ψ=0)=θ_s (van Genuchten 1980, Eq. 3)	Pass
van Genuchten: Se→0 and θ→θ_r as ψ→∞ (van Genuchten 1980)	Pass
van Genuchten: Se strictly decreasing in suction (van Genuchten 1980)	Pass
van Genuchten m = 1 − 1/n for n=2, 4, 1.5 (van Genuchten 1980, m-n constraint)	Pass
van Genuchten: at αψ=1, Se = 2^(−m) exactly (van Genuchten 1980, Eq. 3)	Pass
van Genuchten: θ at αψ=1, n=2 = θ_r + 2^(−0.5)(θ_s−θ_r) = 0.332843 (van Genuchten 1980)	Pass
van Genuchten 1980 Table 1 — Guelph Loam (α=0.0115, n=2.03, θs=0.520, θr=0.218)	Pass
van Genuchten 1980 Table 1 — Beit Netofa Clay (α=0.00152, n=1.17, θs=0.446, θr=0.0)	Pass
van Genuchten 1980 Table 1 — Hygiene Sandstone (α=0.0079, n=10.4): sharp air-entry	Pass
Bishop 1959: χ = Se exactly (χ=1 saturated, χ=0 dry)	Pass
Bishop 1959: net normal stress (σ−u_a) and u_w = u_a − ψ	Pass
Bishop 1959: σ′ = (σ−u_a)+Se·ψ anchor = 270.7107 kPa (αψ=1, n=2, σ=200)	Pass
Bishop 1959: σ′ (suction stress Se·ψ) increases with suction over the working range	Pass
Vanapalli 1996: apparent cohesion c_app = ψ·Se·tanϕ′ anchor = 40.825 kPa	Pass
Vanapalli 1996: c_app == ψ·Se·tanϕ′ holds for arbitrary state	Pass
Vanapalli 1996: total cohesion = c′ + c_app; τ = c′ + (σ−u_a)tanϕ′ + c_app	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Vanapalli 1996: unsaturated τ ≤ saturated τ (χ=Se≤1); equal only at ψ=0	Pass
Carslaw & Jaeger §2.5: erfc argument z/(2√(D_th·t)) and surface value	Pass
Carslaw & Jaeger §2.5: erfc(z/2) matches standard table at arg=0.5, 1, 2	Pass
Carslaw & Jaeger §2.5: t=0 interior unchanged; t→∞ whole profile reaches T_s	Pass
Linear thermal strain ε = α_T·ΔT — sign and magnitude	Pass
guards: pathological inputs are REFUSED, not clamped into a plausible answer	Pass
unsaturated-thermal: the real physical limits stay LEGAL and self-consistent	Pass

Earthquake engineering, dynamics and liquefaction

FE kernel registry — 69 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k7a-rayleigh-alpha-ground-response	Rayleigh αR for ξ = 8 % at 1.5 and 7.5 Hz [1/s]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. p. 2	1.257	1.25664	1.25664	−0.03 %	0.00 %	Pass
k7a-rayleigh-beta-ground-response	Rayleigh βR for ξ = 8 % at 1.5 and 7.5 Hz [s]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. p. 2	0.002829	0.00282942	0.00282942	+0.01 %	0.00 %	Pass
k7a-rayleigh-alpha-footing	Rayleigh αR for ξ = 3 % at 1.751 and 3.0 Hz [1/s]	PLAXIS-Verification-Vertical-dynamic-response-footing.pdf, p. p. 1	0.4168	0.416825	0.416825	+6.0e-3 %	0.00 %	Pass
k7a-rayleigh-beta-footing	Rayleigh βR for ξ = 3 % at 1.751 and 3.0 Hz [s]	PLAXIS-Verification-Vertical-dynamic-response-footing.pdf, p. p. 1	0.00201	0.00200995	0.00200995	−2.2e-3 %	0.00 %	Pass
k7a-1d-wave-arrival-middle	time the front reaches point B (5 m below the top; u_B = 0.5 mm) [s]	PLAXIS-Verification-One-dimensional-wave-propagation.pdf, p. p. 2	0.05	0.05	0.05072	+1.44 %	+1.44 %	Pass
k7a-1d-wave-plateau-fixed-base self-check	mean u_B between the arrival and the return of the reflection (0.07–0.13 s) [m]	PLAXIS-Verification-One-dimensional-wave-propagation.pdf, p. p. 2–3	-0.001	-0.001	-0.0010001	−0.01 %	−0.01 %	Pass
k7a-1d-wave-after-reflection-fixed-base	mean u_B after the reflection from the fixed base has passed (0.17–0.23 s) [m]	PLAXIS-Verification-One-dimensional-wave-propagation.pdf, p. p. 3	0	0	-2.274e-8	—	—	Pass
k7a-1d-wave-arrival-base-viscous	time the front reaches the base (point A, 10 m) with a viscous base [s]	PLAXIS-Verification-One-dimensional-wave-propagation.pdf, p. p. 3	0.1	0.1	0.10083	+0.83 %	+0.83 %	Pass
k7a-1d-wave-absorbing-reflection	reflection at the viscous base: |mean u_B(0.17–0.25 s) + 1 mm| / 1 mm [%]	PLAXIS-Verification-One-dimensional-wave-propagation.pdf, p. p. 3	—	0	0	—	—	Pass
k7a-1d-wave-spec-mesher	model B through the ModelSpec route (kernel mesher, very_fine T15): arrival at the base [s]	PLAXIS-Verification-One-dimensional-wave-propagation.pdf, p. p. 1–3	0.1	0.1	0.10083	+0.83 %	+0.83 %	Pass
k7a-shear-column-f0	first natural frequency of the 50 m layer (free vibration after a static top shear is removed; DFT peak) [Hz]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. p. 2	1.5 (shear-beam closed form)	1.50006	1.49956	−0.03 %	−0.03 %	Pass
k7a-ground-response-rigid-0p75hz	amplification |a_top / a_base| at 0.75 Hz, rigid base, Rayleigh ξ = 8 % (1.5 / 7.5 Hz) [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. p. 2–4, Fig. 5	—	1.406	1.4058	—	−0.01 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k7a-ground-response-rigid-1p5hz	amplification |a_top / a_base| at 1.5 Hz, rigid base, Rayleigh ξ = 8 % (1.5 / 7.5 Hz) [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. p. 2–4, Fig. 5	8	7.9506	7.9467	−0.67 %	−0.05 %	Pass
k7a-ground-response-rigid-3p0hz	amplification |a_top / a_base| at 3.0 Hz, rigid base, Rayleigh ξ = 8 % (1.5 / 7.5 Hz) [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. p. 2–4, Fig. 5	—	0.9826	0.9826	—	0.00 %	Pass
k7a-ground-response-rigid-4p5hz	amplification |a_top / a_base| at 4.5 Hz, rigid base, Rayleigh ξ = 8 % (1.5 / 7.5 Hz) [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. p. 2–4, Fig. 5	—	3.3698	3.3665	—	−0.10 %	Pass
k7a-ground-response-elastic-rock-0p75hz	amplification |v_top / v_outcrop| at 0.75 Hz on elastic rock (Vr = 2 Vs, ρr = ρ), outcrop velocity input [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. (closed form; PLAXIS compliant base)	—	1.1086	1.1083	—	−0.03 %	Pass
k7a-ground-response-elastic-rock-1p5hz	amplification |v_top / v_outcrop| at 1.5 Hz on elastic rock (Vr = 2 Vs, ρr = ρ), outcrop velocity input [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. (closed form; PLAXIS compliant base)	—	1.5827	1.5816	—	−0.07 %	Pass
k7a-ground-response-elastic-rock-4p5hz	amplification |v_top / v_outcrop| at 4.5 Hz on elastic rock (Vr = 2 Vs, ρr = ρ), outcrop velocity input [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. (closed form; PLAXIS compliant base)	—	1.2211	1.2208	—	−0.02 %	Pass
k7a-beam-static-deflection	mid-span deflection under q = 1 kN/m/m (static phase before the free vibration) [m]	PLAXIS-Verification-Simply-supported-beam-frequency.pdf, p. p. 2	0.1302	0.130208	0.13023	+0.02 %	+0.02 %	Pass
k7a-beam-natural-frequency	first natural frequency of the simply supported beam (free vibration after the load is removed) [Hz]	PLAXIS-Verification-Simply-supported-beam-frequency.pdf, p. p. 2	1.57	1.5708	1.56976	−0.02 %	−0.07 %	Pass
k7a-lamb-p-onset	onset of the P wave at r = 50 m (2 % of the peak) [s]	PLAXIS-Verification-Lamb-problem.pdf, p. p. 1–3, Fig. 4	—	0.3415	0.3311	—	−3.05 %	Pass
k7a-lamb-rayleigh-peak-time	time of the Rayleigh-wave (negative) peak of uy at r = 50 m [s]	PLAXIS-Verification-Lamb-problem.pdf, p. Fig. 4	—	0.6116	0.63	—	+3.01 %	Pass
k7a-lamb-rayleigh-peak-amplitude	Rayleigh-wave peak of uy at r = 50 m [mm]	PLAXIS-Verification-Lamb-problem.pdf, p. Fig. 4	-0.01	—	-0.00987	+1.30 %	—	Pass
k7a-elastoplastic-yield self-check	max |τ| at a base stress point of a ϕ = 0 Mohr–Coulomb column shaken beyond its strength (c = 250 kPa) [kPa]	—	—	250	250	—	0.00 %	Pass
k7a-hht-zero-is-newmark	HHT-α with α = 0 vs Newmark average acceleration [-]	—	—	0	0	—	—	Pass
k7a-dam-free-vibration	first two natural frequencies of a dam with depth-varying G (PLAXIS 2.9 / 6.4 Hz; closed form 3.1 / 7.0 Hz) [Hz]	PLAXIS-Verification-Free-vibration-dam-2018.pdf, p. p. 1–3	2.9	3.1	—	—	—	Pending
k7a-pulse-multilayer	surface deflection under a pulse load on a 3-layer pavement (stiff / soft subgrade) [mm]	PLAXIS-Verification-Pulse-load-multilayer.pdf, p. p. 1–4	—	—	—	—	—	Pending

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k7a-vertical-footing-dynamic	vertical dynamic stiffness K_v = F πR² / w_max of the rigid circular footing (plate in a dynamic phase, D185) [kN/m]	PLAXIS-Verification-Vertical-dynamic-response-footing.pdf, p. p. 1–4	2367090	2335570	2363810	−0.14 %	+1.21 %	Pass
k7a-surface-waves	surface-wave amplitude vs distance from a harmonic prescribed displacement (BEM Chouw et al. 1991) [m]	PLAXIS-Verification-Surface-waves.pdf, p. p. 1–3	—	—	—	—	—	Pending
k7a-midas-ch4-dynamics	Midas GTS NX dynamics benchmarks [-]	Midas-GTS-NX-2019-v2.1-Benchmarks-Verification-Chapter_4_Dynamics.pdf, p. Ch. 4	—	—	—	—	—	Pending
k7b-vertical-footing-wmax	w_max under the footing centre (point A) [mm]	PLAXIS-Verification-Vertical-dynamic-response-footing.pdf, p. p. 4	53.09	53.8	53.161	+0.13 %	−1.19 %	Pass
k7b-plate-beam-deflection	static midspan deflection under q = 1 kN/m/m — a real PLATE (K7a used a continuum substitute) [m]	PLAXIS-Verification-Simply-supported-beam-frequency.pdf, p. p. 2	0.1302	0.130208	0.13023	+0.02 %	+0.02 %	Pass
k7b-plate-beam-frequency	first natural frequency — plate mass w/g with rotary inertia (consistent and HRZ-lumped) [Hz]	PLAXIS-Verification-Simply-supported-beam-frequency.pdf, p. p. 2	1.57	1.5708	1.56976	−0.02 %	−0.07 %	Pass
k7b-undrained-p-wave-excess	excess pore pressure behind a step-load P front, undrained A (ν_u 0.495) [kPa]	closed form (Biot / Terzaghi undrained oedometric loading), p. —	—	9.736	9.7364	—	+4.1e-3 %	Pass
k7b-undrained-p-wave-arrival	arrival of half the undrained front at 5 m [s]	closed form, p. —	—	0.0081245	0.00825	—	+1.54 %	Pass
k7b-tied-column-0.75hz	rigid-base amplification at 0.75 Hz with TIED side DOFs (D186) [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. Fig. 5	—	1.406	1.4058	—	−0.01 %	Pass
k7b-tied-column-1.5hz	rigid-base amplification at 1.5 Hz with TIED side DOFs (D186) [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. Fig. 5	8	7.9506	7.9467	−0.67 %	−0.05 %	Pass
k7b-tied-column-3.0hz	rigid-base amplification at 3.0 Hz with TIED side DOFs (D186) [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. Fig. 5	—	0.9826	0.9826	—	0.00 %	Pass
k7b-tied-column-4.5hz	rigid-base amplification at 4.5 Hz with TIED side DOFs (D186) [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. Fig. 5	—	3.3698	3.3665	—	−0.10 %	Pass
k7b-free-field-rigid-1p5	amplification with FREE-FIELD sides (D186): rigid base 1.5 Hz, centre [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. Fig. 5 (1-D reference)	—	7.9506	7.9718	—	+0.27 %	Pass
k7b-free-field-rigid-3	amplification with FREE-FIELD sides (D186): rigid base 3 Hz, centre [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. Fig. 5 (1-D reference)	—	0.9826	0.9968	—	+1.45 %	Pass
k7b-free-field-rock-1p5	amplification with FREE-FIELD sides (D186): elastic rock (compliant base) 1.5 Hz, centre [-]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. Fig. 5 (1-D reference)	—	1.5827	1.5873	—	+0.29 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k7b-baseline-closed-form	linear baseline coefficient c0 (v_c(T) = u_c(T) = 0) [m/s²]	closed form, p. —	—	0.233803	0.233801	—	−6.0e-4 %	Pass
k7b-elc180-pga	PGA of the El Centro 1940 ELC-180 record through the ground-motion registry (DY-5) [g]	USGS SLAMMER v1.1 record set (TM 12-B1), public domain, p. record table	—	0.313	0.312881	—	−0.04 %	Pass
k7b-elc180-base-drift self-check	absolute base displacement at the end of the record, drift-corrected [m]	PLAXIS-Verification-Ground-response-linear-soil-2018.pdf, p. —	—	0	-1.990e-13	—	—	Pass
k7b-pm4sand-crr15-dr35	CRR at 15 uniform cycles (3 % single-amplitude shear strain), undrained cyclic DSS, Dr 0.35, G0 476, hpo 0.53 [-]	Boulanger_Ziotopoulou_PM4Sand_v31_CGM-17-01_rev3.pdf (UCD/CGM-17/01 rev. 3, PM4Sand v3.1; same Table 4.4 as v3), p. p. 78, Fig. 4.6	—	0.09	0.0874	—	−2.80 %	Pass
k7b-pm4sand-crr15-dr55	CRR at 15 uniform cycles (3 % single-amplitude shear strain), undrained cyclic DSS, Dr 0.55, G0 677, hpo 0.4 [-]	Boulanger_Ziotopoulou_PM4Sand_v31_CGM-17-01_rev3.pdf (UCD/CGM-17/01 rev. 3, PM4Sand v3.1; same Table 4.4 as v3), p. p. 78, Fig. 4.6	—	0.147	0.142	—	−3.40 %	Pass
k7b-pm4sand-crr15-dr75	CRR at 15 uniform cycles (3 % single-amplitude shear strain), undrained cyclic DSS, Dr 0.75, G0 890, hpo 0.63 [-]	Boulanger_Ziotopoulou_PM4Sand_v31_CGM-17-01_rev3.pdf (UCD/CGM-17/01 rev. 3, PM4Sand v3.1; same Table 4.4 as v3), p. p. 78, Fig. 4.6	—	0.312	0.2948	—	−5.50 %	Pass
k7b-pm4sand-csr-n-slope-dr35	slope b of CSR ∝ N^−b, Dr 0.35 [-]	Boulanger_Ziotopoulou_PM4Sand_Model_CGM-15-01_2015.pdf (UCD/CGM-15/01, PM4Sand v3), p. p. 87	—	0.25	0.241	—	+12.8 %	Pass
k7b-pm4sand-csr-n-slope-dr55	slope b of CSR ∝ N^−b, Dr 0.55 [-]	Boulanger_Ziotopoulou_PM4Sand_Model_CGM-15-01_2015.pdf (UCD/CGM-15/01, PM4Sand v3), p. p. 87	—	0.29	0.279	—	+1.03 %	Pass
k7b-pm4sand-csr-n-slope-dr75	slope b of CSR ∝ N^−b, Dr 0.75 [-]	Boulanger_Ziotopoulou_PM4Sand_Model_CGM-15-01_2015.pdf (UCD/CGM-15/01, PM4Sand v3), p. p. 87	—	0.3	0.286	—	−12.7 %	Pass
k7b-pm4sand-drained-phi-dr35	peak ϕ′DSS, drained monotonic DSS at 1 atm, Dr 0.35 [°]	Boulanger_Ziotopoulou_PM4Sand_Model_CGM-15-01_2015.pdf (UCD/CGM-15/01, PM4Sand v3), p. pp. 90–92	—	30	29.81	—	−0.63 %	Pass
k7b-pm4sand-drained-phi-dr55	peak ϕ′DSS, drained monotonic DSS at 1 atm, Dr 0.55 [°]	Boulanger_Ziotopoulou_PM4Sand_Model_CGM-15-01_2015.pdf (UCD/CGM-15/01, PM4Sand v3), p. pp. 90–92	—	33.5	33.3	—	−0.60 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k7b-pm4sand-drained-phi-dr75	peak ϕ'DSS, drained monotonic DSS at 1 atm, Dr 0.75 [°]	Boulanger_Ziotopoulou_PM4Sand_Model_CGM-15-01_2015.pdf (UCD/CGM-15/01, PM4Sand v3), p. pp. 90–92	—	37.7	37.42	—	−0.74 %	Pass
k7b-liquefaction-column-ru self-check	max r_u = Δp/σ'v0 at 4 m and 7 m depth [-]	closed form (r_u ≤ 1) + cross-check, p. —	—	0.95	4 m: 0.8024; 7 m: 1.0311	—	—	Deviation
k7-plaxis-2d-tut15-surface-1.37-undamped	steady vertical displacement amplitude at the surface point r = 1.37 m, without Rayleigh damping (Fig. 15-9) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 241	0.0339	—	0.0336	−0.80 %	—	Pass
k7-plaxis-2d-tut15-surface-1.94-undamped	steady vertical displacement amplitude at the surface point r = 1.94 m, without Rayleigh damping (Fig. 15-9) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 241	0.0236	—	0.0239	+1.20 %	—	Pass
k7-plaxis-2d-tut15-surface-3.60-undamped	steady vertical displacement amplitude at the surface point r = 3.60 m, without Rayleigh damping (Fig. 15-9) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 241	0.0138	—	0.0141	+1.90 %	—	Pass
k7-plaxis-2d-tut15-surface-1.37-damped	steady vertical displacement amplitude at the surface point r = 1.37 m, with Rayleigh damping (Fig. 15-10) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 242	0.0322	—	0.0319	−0.90 %	—	Pass
k7-plaxis-2d-tut15-surface-1.94-damped	steady vertical displacement amplitude at the surface point r = 1.94 m, with Rayleigh damping (Fig. 15-10) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 242	0.022	—	0.0222	+0.90 %	—	Pass
k7-plaxis-2d-tut15-surface-3.60-damped	steady vertical displacement amplitude at the surface point r = 3.60 m, with Rayleigh damping (Fig. 15-10) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 242	0.0116	—	0.012	+3.10 %	—	Pass
k7-plaxis-2d-tut15-footing-lysmer-analog	steady vertical displacement amplitude of the rigid footing (axis), mass = the plate only (the manual's static generator load carries no mass), B = m(1−ν)/(4ρR³) = 0.275 [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 232–241	—	0.1416	0.136	—	−3.99 %	Pass
k7-plaxis-2d-tut15-footing-lysmer-analog-with-generator-mass	steady vertical displacement amplitude of the rigid footing (axis) carrying the generator mass too, B = 0.715 [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 232–241	—	0.1481	0.142	—	−4.11 %	Pass
k7-plaxis-2d-tut15-boundary-distance-20x10-vs-40x20	absorbing-boundary reflection error: largest change of the steady amplitude (4 points) when the model is doubled from 20 × 10 m (the manual) to 40 × 20 m [%]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 232–233	—	0	2.76	—	—	Pass
k7-plaxis-2d-tut15-boundary-distance-10x5-vs-40x20	absorbing-boundary reflection error: largest change of the steady amplitude (4 points) when the model is halved from 20 × 10 m to 10 × 5 m, against the 40 × 20 m model [%]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 232–233	—	0	4.6	—	—	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k7-plaxis-2d-tut15-free-vibration-residual-undamped	residual surface displacement after the generator stops, r = 1.37 m, no damping (amplitude over 0.6–1.0 s) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 241	0.0034	—	0.00531	+56.2 %	—	Deviation
k7-plaxis-2d-tut15-free-vibration-residual-damped	residual surface displacement after the generator stops, r = 1.37 m, with Rayleigh damping (amplitude over 0.6–1.0 s) [mm]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 242	0.0008	—	0.00313	+291.3 %	—	Deviation
k7-plaxis-2d-tut15-rayleigh-alpha	Rayleigh α from ξ1 = ξ2 = 5 % at f1 = 1 Hz, f2 = 10 Hz (SDOF equivalent, Fig. 15-8) [1/s]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 240	0.5712	0.5712	0.571199	0.00 %	0.00 %	Pass
k7-plaxis-2d-tut15-rayleigh-beta	Rayleigh β from ξ1 = ξ2 = 5 % at f1 = 1 Hz, f2 = 10 Hz (SDOF equivalent, Fig. 15-8) [s]	PLAXIS-2D-2025.1-Tutorial-Manual.pdf, p. 240	0.001447	0.001447	0.0014469	−9.0e-3 %	−9.0e-3 %	Pass

Cited validation suites — 32

cpt-liquefaction-web-validation.test.ts

Validation for the CPT liquefaction-triggering engine (`cpt-liquefaction.ts`).

Analyses validated: `cpt-liquefaction` · Recorded run: passed — 24 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Table 3.1 — 1964 Niigata, D Kawagisho-cho — clean sand (FC 3 %), z 4.4 m, M 7.6	Pass
Table 3.1 — 1968 Inangahua, Three Channel Flat — silty sand (FC 18 %), N_c cap region (CN 1.55)	Pass
Table 3.1 — 1981 Westmorland, Kornbloom Rd (K4) — very high fines (FC 85 %), M 5.9	Pass
Table 3.1 — 1989 Loma Prieta, Sandhold Road SI-2 — very dense sand, q_c1N,cs 311.9 > 211 (cap region)	Pass
Table 3.1 — 1995 Hyogoken-Nambu, Fukuzumi Park — deepest case (11.8 m), K_σ < 1	Pass
Table 3.1 — 1994 Northridge, Balboa Blvd Unit C (BAL-10) — highest σ′_v (147 kPa), FC 50 %	Pass
Table 3.1 — 2011 Tohoku, Hinode ES — M 9.0, FC 25 %, K_σ at its 1.10 cap	Pass
Table 3.1 — 1995 Hyogoken-Nambu, Yoshida Kogyo Factory — q_c1N,cs 216 just above 211, K_σ at 1.10 cap	Pass
Table 3.1 — 1999 Kocaeli, Hotel Sapanca SH-4 — lowest σ′_v (19 kPa): C_N capped at 1.70	Pass
Table 3.1 — 1989 Loma Prieta, Marine Lab (C4) — loose clean sand q_c1N,cs 24.4 (m-limit region)	Pass
Table 3.1 — 1981 Westmorland, McKim Ranch Unit A (M7) — smallest M (5.9), MSF 1.12	Pass
Table 3.1 — 2011 Tohoku, Akemi ES — M 9.0, 10.1 m, σ′_v ~ 1 atm	Pass
MNO-12 App. B row 47 — z 1.80 m (water table), q_cN 26.5, σ 34/34 kPa	Pass
MNO-12 App. B row 49 — z 1.90 m, q_cN 34.0, σ 36/35 kPa	Pass
MNO-12 App. B row 51 — z 2.00 m, q_cN 39.6, σ 38/36 kPa	Pass
MNO-12 App. B row 53 — z 2.10 m, q_cN 45.1, σ 40/37 kPa	Pass
MNO-12 App. B row 166 — z 7.75 m, q_cN 150.5, σ 153/95 kPa (C_N below 1.7)	Pass
MNO-12 App. B row 168 — z 7.85 m, q_cN 112.3, σ 155/96 kPa	Pass
MNO-12 App. B row 170 — z 7.95 m, q_cN 81.8, σ 157/97 kPa	Pass
MNO-12 App. B row 175 — z 8.20 m, q_cN 120.0, σ 162/99 kPa	Pass
§2.5 printed statement: MSF_max = 1.8 at q_c1Ncs ≈ 160	Pass
§2.5 printed statement: MSF_max ≈ 1.10 for q_c1Ncs < 60 (loose sands)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
B&I 2014 §4.1 counts: 253 cases; 5 liquefaction points below and 32 no-liquefaction points above the deterministic curve	Pass
HAND-DERIVED: deterministic CRR = median (C0 = 2.60) CRR × exp(−0.20), i.e. one σ_lnR below the median	Pass

design-code-spectrum-ec8-web-validation.test.ts

EN 1998-1 (Eurocode 8) horizontal elastic response spectrum — anchored to the standard and to a published European worked example.

Analyses validated: `design-code-spectrum` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EN 1998-1 Table 3.2 (Type 1): S, TB, TC, TD reproduced for ground types A-E	Pass
EN 1998-1 Table 3.3 (Type 2): S, TB, TC, TD reproduced for ground types A-E	Pass
EC8 worked example §2.1.2.1: ground B, Type 1, agR = 0.25g, γI = 1.0 ⇒ plateau 0.75 g	Pass
EC8 worked example: the design spectrum with q = 3.0 is the elastic one divided by q on the plateau	Pass
E-38: Type 1 UNDER-predicts the Type 2 plateau on every ground type except A	Pass
E-38: the two shapes really are different curves, not a scale factor	Pass
EN 1998-1 Table 3.1: Vs30 bands A > 800, B 360-800, C 180-360, D < 180	Pass
E-39: ground type E is unreachable from Vs30 and must be selectable explicitly	Pass
the spectrum is continuous at TB, TC and TD for both shapes and all ground types	Pass
defaults are unchanged: no spectrum_type ⇒ Type 1, and ag defaults to 0.25 g	Pass
a negative or absent ag is clamped, and Sa stays finite everywhere	Pass

design-code-spectrum-web-validation.test.ts

WEB-BENCHMARK validation for the shared design-code-spectrum module and the 2-D site-response CODE-SITE-FACTOR overlay (`fe-site-response-2d`).

Analyses validated: `design-code-spectrum`, `fe-site-response-2d` · Recorded run: passed — 17 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
dcs 1: EC8 class C / rock A at T=0.3 s ⇒ S ratio = 1.15/1.0 = 1.15	Pass
dcs 2: EC8 class B / rock A at T=0.3 s ⇒ 1.20	Pass
dcs 3: EC8 class D / rock A at T=0.3 s ⇒ 1.35	Pass
dcs 4: EC8 amplification is independent of a_g (ratio cancels)	Pass
dcs 5: ASCE class D / rock A at T=0.3 s, Ss=1.0 ⇒ Fa ratio 1.1/0.8 = 1.375	Pass
dcs 6: ASCE class D / rock A at low Ss=0.25 ⇒ Fa 1.6/0.8 = 2.0	Pass
dcs 7: ASCE class C / rock A at Ss=1.0 ⇒ Fa 1.2/0.8 = 1.5	Pass
dcs 8: IS 1893 short-period (T=0.3 s) soil factor = 1.0 (same 2.5 plateau)	Pass
dcs 9: IS 1893 Type II / I at T=0.6 s ⇒ (1.36/0.6)/(1.0/0.6) = 1.36	Pass
dcs 10: IS 1893 Type III / I at T=1.0 s ⇒ 1.67 (soft-soil long-period amplification)	Pass
dcs 11: softer soil ⇒ higher (or equal) code site factor at a long period	Pass
dcs 12: site class strings match the Vs thresholds	Pass
dcs 13: rock reference class is the firm-rock class (A / A / I)	Pass
dcs 14: 2-D overlay reports site class, code factor and a verdict for each code	Pass
dcs 15: a basin (2-D focusing) EXCEEDS the code 1-D site factor (Mexico City lesson)	Pass
dcs 16: no overlay fields when seismic_code is omitted (opt-in)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
dcs 17: the 2-D overlay uses the SAME code factor as a direct module call	Pass

⚑ dynamic-compaction-web-validation.test.ts

Web/published-source validation for `dynamic-compaction.ts` (Ménard dynamic compaction).

Analyses validated: `dynamic-compaction` · Recorded run: passed — 80 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[S3-1] Depth of improvement D_i = 0.35·√(18.2·30.2) (m) — S3 §1.2 p.4	Pass
[S3-2] Applied energy, high-energy pass AE_HEP (MJ/m²) — S3 §1.3 p.4	Pass
[S3-3] Applied energy, ironing pass AE_IP (MJ/m²) — S3 §1.3 p.4	Pass
[S3-4] Total applied energy AE_HEP + AE_IP ("~4.02 MJ/m² per pass") — S3 §1.3 p.5	Pass
[S3-5] Improved elastic modulus E = (E/N)·N = 2 × 32.56 (MPa) — S3 §1.5 Eq. 4 p.6	Pass
[S3-6] Crater depth, Rollins–Kim detailed formula (m) "≈ 1.5 m" — S3 §1.6 Eq. 5 p.7	Pass
[S3-7] Area ratio of improvement a_r = 1.767/9 — S3 §1.7 p.7	Pass
[S3-8] Induced settlement S = N_p·a_r·d_cd = 2 × 0.196 × 1.5 (m) — S3 §1.7 Eq. 6 p.7	Pass
[S3-9] Peak particle velocity at 20 m (mm/s) — S3 §1.8 Eq. 7 p.8	Pass
[S3-10] Design total energy = 850 kJ/m³ × 8.2 m = 6.97 MJ/m² (via design mode) — S3 §1.4 p.5	Pass
[S3-11] Required energy per pass, two passes = 6.97/2 = 3.485 MJ/m² — S3 §1.4 p.5	Pass
[HAN-1] Required energy per blow W_t·H_d = (8.2/0.35)² (t·m) — HAN §3.5.5 p.98	Pass
[HAN-2] Required drop height for the 18.2 t tamper = 550/18.2 (m) — HAN §3.5.5 p.98	Pass
[HAN-3] Typical drop height H_d = (W_t·H_d)^0.54 (m) "also 30.2 m" — HAN Eq. 3.17 p.93 / §3.5.5 p.98	Pass
[HAN-4] Total applied energy 850 kJ/m³ × 8.2 m (MJ/m²) — HAN §3.5.5 p.98	Pass
[HAN-5] Ironing energy AE_IP = 300 kJ/m³ × 1.5 m (MJ/m²) — HAN Eq. 3.22, §3.5.5 p.98	Pass
[HAN-6] High-energy total AE_HEP·N_p = 6.97 − 0.45 (MJ/m²) — HAN §3.5.5 p.98	Pass
[HAN-7] Per-pass energy for two passes (MJ/m²) — HAN §3.5.5 p.98	Pass
[HAN-8] Drops per point N_d = 3260·9/(18.2·30.2·10) (Han writes g = 10 m/s²) — HAN Eq. 3.20, §3.5.5 p.98	Pass
[HAN-9] Drops selected = round-up of the requirement (integer), at the engine's default g = 9.81 — HAN §3.5.5 p.98	Pass
[HAN-10] Rough crater depth d_cd = 0.075·√550 (m) — HAN Eq. 3.18 / §3.5.5 p.98	Pass
[HAN-11] Allowable crater depth = tamper height + 0.3 = 1.5 + 0.3 (m) — HAN §3.5.5 p.98	Pass
[HAN-12] Area ratio of improvement π(1.5/2)²/3.0² ("= 0.20") — HAN §3.5.5 p.99	Pass
[HAN-13] Induced settlement, 2 passes: 2 × 0.20 × 1.75 (m) — HAN §3.5.5 p.99	Pass
[HAN-14] Detailed (Rollins–Kim) crater for the same 6 drops, p = 18.2/(π·0.75²) (m) — HAN Eq. 3.19 via S3 §1.6	Pass
[G1-1] Energy per blow for D = 8.2 m, n = 0.35: (8.2/0.35)²·g (MJ) — G1 Ch.7 p.62 (Indiana)	Pass
[G1-2] Energy per blow for the 18.2 Mg tamper dropped 29.9 m (MJ) — G1 Ch.7 p.62 (Indiana)	Pass
[G1-3] Depth of improvement of 18.2 Mg × 29.9 m at n = 0.35 (m) — design target "8.2 m" — G1 Ch.7 p.62 (Indiana)	Pass
[G1-4] Total applied energy 735 kJ/m³ × 8.5 m (MJ/m²) — G1 Ch.7 p.62 (Indiana)	Pass
[G1-5] Energy per blow for D = 7.6 m, n = 0.4: (7.6/0.4)²·g (MJ) — G1 Ch.7 p.65 (Florida)	Pass
[G1-6] Required drop height for the 15 Mg tamper (m) — G1 Ch.7 p.65 (Florida)	Pass
[G1-7] Average applied energy 300 kJ/m³ × 7.6 m (MJ/m²) — G1 Ch.7 p.65 (Florida)	Pass
[G1-8] Energy of an 8-blow pass on the 9.1 m grid (kJ/m²) — G1 Table 13 p.67 (Florida)	Pass
[G1-9] Energy of a 9-blow pass on the 9.1 m grid (kJ/m²) — G1 Table 13 p.67 (Florida)	Pass
[G1-10] Energy of a 10-blow pass on the 9.1 m grid (kJ/m²) — G1 Table 13 p.67 (Florida)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[RD-V Becancour 10 ft] Theoretical impact velocity √(2gH), H = 10 ft (ft/s) — RD Table 5 p.49	Pass
[RD-R Becancour 10 ft] Measured/theoretical velocity ratio, v = 23.2 ft/s — RD Table 5 p.49	Pass
[RD-V Becancour 20 ft] Theoretical impact velocity √(2gH), H = 20 ft (ft/s) — RD Table 5 p.49	Pass
[RD-R Becancour 20 ft] Measured/theoretical velocity ratio, v = 31.5 ft/s — RD Table 5 p.49	Pass
[RD-V Becancour 58 ft] Theoretical impact velocity √(2gH), H = 58 ft (ft/s) — RD Table 5 p.49	Pass
[RD-R Becancour 58 ft] Measured/theoretical velocity ratio, v = 55 ft/s — RD Table 5 p.49	Pass
[RD-V Tulsa 18 ft] Theoretical impact velocity √(2gH), H = 18 ft (ft/s) — RD Table 5 p.49	Pass
[RD-R Tulsa 18 ft] Measured/theoretical velocity ratio, v = 30.5 ft/s — RD Table 5 p.49	Pass
[RD-V Tulsa 38 ft] Theoretical impact velocity √(2gH), H = 38 ft (ft/s) — RD Table 5 p.49	Pass
[RD-R Tulsa 38 ft] Measured/theoretical velocity ratio, v = 43 ft/s — RD Table 5 p.49	Pass
[RD-V Tulsa 73 ft] Theoretical impact velocity √(2gH), H = 73 ft (ft/s) — RD Table 5 p.49	Pass
[RD-R Tulsa 73 ft] Measured/theoretical velocity ratio, v = 60 ft/s — RD Table 5 p.49	Pass
[RD-V Great Lakes 18 ft] Theoretical impact velocity √(2gH), H = 18 ft (ft/s) — RD Table 5 p.49	Pass
[RD-R Great Lakes 18 ft] Measured/theoretical velocity ratio, v = 31.1 ft/s — RD Table 5 p.49	Pass
[RD-V Great Lakes 33 ft] Theoretical impact velocity √(2gH), H = 33 ft (ft/s) — RD Table 5 p.49	Pass
[RD-R Great Lakes 33 ft] Measured/theoretical velocity ratio, v = 42.5 ft/s — RD Table 5 p.49	Pass
[RD-R StMarys radar] Free-fall (radar) measured/theoretical ratio, 77.4 ft/s at 98 ft — RD Table 5 p.49	Pass
[RD-E1] Energy delivered at 90 % of theoretical speed, fraction of W·H ("approximately 80 percent") — RD p.50	Pass
[RD-E2] Energy delivered at 97 % of theoretical speed, free fall ("94 percent") — RD p.50	Pass
LEDGER: at least 20 computed-value cases from four independent published sources	Pass
[lookup T7-granular-high] engine table equals G1 Table 7	Pass
[lookup T7-granular-low] engine table equals G1 Table 7	Pass
[lookup T7-silt-high] engine table equals G1 Table 7	Pass
[lookup T7-silt-low] engine table equals G1 Table 7	Pass
[lookup T7-clay-high] engine table equals G1 Table 7 ("Not recommended")	Pass
[lookup T7-clay-low] engine table equals G1 Table 7	Pass
[lookup T8-pervious] engine table equals G1 Table 8	Pass
[lookup T8-semipervious] engine table equals G1 Table 8	Pass
[lookup T8-landfill] engine table equals G1 Table 8	Pass
[lookup T8-proctor] engine table equals G1 Table 8 note	Pass
[lookup T2-pervious] engine table equals G1 Table 2	Pass
[lookup T2-sandy-silt] engine table equals G1 Table 2	Pass
[lookup T2-silt] engine table equals G1 Table 2	Pass
[lookup T2-clay-fill] engine table equals G1 Table 2	Pass
[lookup T2-landfill] engine table equals G1 Table 2	Pass
[lookup T3.13-commercial] engine table equals HAN Table 3.13	Pass
[lookup T3.13-residential] engine table equals HAN Table 3.13	Pass
[lookup T3.13-sensitive] engine table equals HAN Table 3.13	Pass
PPV helper reproduces S3 Eq. 7 and its inverse (safe distance) closes exactly	Pass
Han Eq. 3.17 typical drop height equals the energy-per-blow route for the S3 energy (≈ 30.2 m)	Pass
SUPPLEMENTARY — Florida Table 13 energies close to ≤ 0.5 % if the printed "9.1 m" grid is the 30 ft (9.144 m) it was likely converted from	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
DEVIATION D-1 — Indiana landfill phase energy: published 3.12 MJ/m² per phase vs 3.03 recomputed (−3.0 %)	Pass
DEVIATION D-2 — Han §3.5.5 "13 % × 8.2 m = 1.10 m": the source arithmetic does not close (0.13 × 8.2 = 1.066 m)	Pass
DEVIATION D-3 — Florida Table 13 induced settlement rows sum to 568 mm; the printed total is 694 mm	Pass
DEVIATION D-4 — Han Table 3.11 (p.96) has no "sandy silts" row (it repeats "Sands and gravels" 40–50); GEC-1 Table 2 (primary) has sandy silts at SPT 34–45	Pass

`effective-stress-site-response-web-validation.test.ts`

Validation for the 1-D COUPLED EFFECTIVE-STRESS (liquefaction-capable) site-response column (`effective-stress-site-response.ts`) — the DEEPSOIL "effective stress" / OpenSees 1-D deliverable.

Analyses validated: `effective-stress` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-4] TOTAL-STRESS CONTROL: with generation off there is no pore pressure, no degradation, no period change	Pass
[5-7] EFFECTIVE STRESS: pore pressure builds, layers liquefy, and it is time-stamped	Pass
[8-9] SIGNATURE 1 — post-liquefaction DE-AMPLIFICATION of the surface motion	Pass
[10-11] SIGNATURE 2 — period lengthening of the softened profile	Pass
[12-13] DRY sand above the water table cannot liquefy	Pass
[14-15] effective overburden is buoyant below the water table and increases with depth	Pass
[16] a LOOSER sand (lower V_s) generates more pore pressure than a denser one	Pass
[17] a STRONGER motion generates more pore pressure	Pass
[18] Terzaghi dissipation (C_v > 0) leaves LESS residual pore pressure than the undrained limit	Pass
[19-21] outputs are physical and internally consistent	Pass
[22-23] the solve converges and returns no NaN/Infinity	Pass
[24] the elastic period is 4H/V_s and δ_G tracks r_u through √(1 − r_u)	Pass

⚑ `fe-liquefaction-2d-web-validation.test.ts`

EXTERNAL-VALUE VALIDATION — phenomenological `fe-liquefaction-2d` path.

Analyses validated: `fe-liquefaction-2d` · Recorded run: passed — 2 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
VELACS Model 1: all 20 fixed pore-pressure anchors remain traceable to the published record	Pass
VELACS Model 1: phenomenological pore-pressure comparison is source-traced and honest	Pass

`fe-site-response-2d-web-validation.test.ts`

WEB-BENCHMARK validation for the 2-D FE site-response (SH-wave basin) engine.

Analyses validated: `fe-site-response-2d` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
2D-SR web C1–C4: T0 = 4H/Vs (exact)	Pass
2D-SR web: flat profile gives 2D/1D = 1.00 (validates vs 1-D baseline)	Pass
2D-SR web C5–C8: time-domain peak < Kramer spectral peak 1/(α+π/2·ξ) [upper bound]	Pass
2D-SR web C12–C19: basin 2D/1D focusing lands in the published band [1.15, 4]	Pass
2D-SR web: higher impedance contrast ⇒ higher 1-D amplification	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
2D-SR web: more damping ⇒ lower amplification	Pass
2D-SR web C10/C11: surface amplification stays physically bounded (< 12)	Pass
2D-SR published: Kramer Example 7.1 — f0 = 26.25 Hz for H = 10 ft, Vs = 1050 ft/s	Pass

⚑ lateral-spread-christchurch-web-validation.test.ts

WEB-VALIDATION for `lateral-spread` against a PUBLISHED CASE HISTORY and an INDEPENDENT REFERENCE IMPLEMENTATION of the same model.

Analyses validated: `lateral-spread` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Christchurch location A: cumulative prediction ≈ 3.2 m (Robinson et al. 2013 §5)	Pass
Christchurch location A: the two events decompose as the paper describes	Pass
Christchurch location A: over-predicts the 0.9 m field survey by more than 2× (paper abstract)	Pass
Christchurch location A: W → 20% reproduces Figure 5(a) ≈ 4.2 m	Pass
Christchurch location A: T_{15} 1.5 / 3.5 m reproduce both ends of the Figure 5(a) bar	Pass
Christchurch location A: coupled F_{15} 35% / D_{50} 0.13 mm LOWERS the prediction (fines dominate)	Pass
Christchurch location A: R = R is closer to the observation than R = R_eq (paper §5)	Pass
OpenQuake cross-check: free-face branch agrees to 1e-9 over a spread of cases	Pass
OpenQuake cross-check: sloping-ground branch agrees to 1e-9	Pass
OpenQuake cross-check: the free-face intercept is exactly the slope intercept − 0.500	Pass
OpenQuake cross-check: the dependent variable is 10^Σ with NO offset (audit E-90)	Pass
OpenQuake cross-check: R* = R + 10^(0.89·Mw − 5.64) and σ_logD = 0.197	Pass

lateral-spread-web-validation.test.ts

Web-benchmark validation for `lateral-spread` — the Youd, Hansen & Bartlett (2002) revised multilinear regression for liquefaction-induced lateral spread displacement.

Analyses validated: `lateral-spread` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
gentle-ground displacement matches YHB (2002) Eq. 1 (α = 0, W = 1)	Pass
free-face displacement matches YHB (2002) Eq. 1 (α = 1, S = 1)	Pass
R* follows Eq. 2 and boff is exactly the two-intercept difference	Pass
the confidence band uses the published σ_logDH = 0.1970	Pass
E-90: the dependent variable is log DH, with no 0.01 m offset	Pass
damage bands break at the published 0.1 / 0.3 / 1.0 / 3.0 m edges	Pass
out-of-range inputs warn per YHB Table 6 rather than failing silently	Pass

liquefaction-effective-stress-web-validation.test.ts

Validation for the COUPLED EFFECTIVE-STRESS liquefaction kernel (`liquefaction-effective-stress.ts`) — cyclic excess-pore-pressure generation and the stiffness/strength degradation it causes, i.e.

Analyses validated: `liquefaction` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-4] Carlton (2014): F = 3810·V_s^−1.55 exactly (DEEPSOIL Eq 4.11)	Pass
[5-8] Carlton (2014): s = (FC+1)^0.1252 exactly (DEEPSOIL Eq 4.12)	Pass
[9-11] Matasovic (1993): δ_G = √(1 − r_u) exactly (DEEPSOIL Eq 4.30)	Pass
[12-14] Matasovic (1993): δ_τ = 1 − r_u^v exactly (DEEPSOIL Eq 4.31)	Pass
[15] Dobry/Matasovic: strains at or below γ_tvp generate NO pore pressure (Eq 4.10)	Pass
[16] Dobry/Matasovic: r_u SATURATES at the limiting ratio p as N_c → ∞	Pass
[17-18] Dobry/Matasovic: r_u increases monotonically with N_c and with strain amplitude	Pass
[19-21] the analytic inverse round-trips the forward generation law EXACTLY	Pass
[22] required trend: a LOOSER sand (lower V_s) liquefies in FEWER cycles	Pass
[23] required trend: fines content raises the strain exponent s	Pass
[24-26] Terzaghi 1-D dissipation drains, stays bounded, and is stable at any C_v·dt/dz² (Eq 4.33)	Pass
[27-28] reversal bookkeeping: N_eq += ½ per reversal and r_u is monotone under undrained loading	Pass
cyclicLiquefaction reports a consistent history (r_u monotone, flags agree)	Pass

`liquefaction-monitoring-web-validation.test.ts`

Web-benchmark validation for TWELVE liquefaction-triggering, in-situ-correlation, seismic-code and monitoring runner engines.

Analyses validated: `cpt-liquefaction`, `design-code-spectrum`, `dmt`, `driven-pile-dynamics`, `embankment-stability`, `expansive-heave`, `liquefaction`, `multilayer-consolidation`, `pile-group-settlement`, `probabilistic-slope`, `spt-correlations`, `stabilization-mix`, `vs-liquefaction` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
expansive-heave reproduces the IS 9214 swell magnitude	Pass
probabilistic-slope computes β = (μ_FoS − 1)/σ_FoS and P_f = Φ(−β)	Pass
multilayer-consolidation sums the layered Terzaghi settlements	Pass
design-code-spectrum reproduces ASCE 7-16 and switches code correctly	Pass
pile-group-settlement uses the Randolph-Wroth influence radius	Pass
stabilization-mix applies the IRC SP:89 CTB and CTSB UCS bands	Pass
vs-liquefaction reproduces the full Andrus & Stokoe (2000) CRR chain	Pass
cpt-liquefaction reproduces the Boulanger & Idriss (2014) CRR chain	Pass
dmt reproduces the Marchetti (1980) index chain	Pass
driven-pile-dynamics reproduces the Hiley formula	Pass
embankment-stability uses the undrained N_c·c_u bearing limit	Pass
spt-correlations maps N to unit weight and equivalent q_c by soil type	Pass

`liquefaction-settlement-web-validation.test.ts`

Web-benchmark validation for `liquefaction-settlement` — post-liquefaction reconsolidation settlement by the Ishihara-Yoshimine route.

Analyses validated: `liquefaction-settlement` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
εv matches I&B (2008) Eq 96 across $(N1)_{60}$cs at FoS = 0.9	Pass
the γmax branches of Eq 90-92 are selected as published	Pass
Eq 95 (Dr form) and Eq 96 (N form) agree to the published rounding	Pass
E-91: Dr is floored at 0.4 for Eq 89, as I&B require	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Eq 86 γlim, and the 8 % ceiling that makes the LDI 50 % cap moot	Pass
settlement is εv × thickness and sums down the profile	Pass
E-99/D9: at (N1)60 = 20 the liquefied-zone strain sits in the 0.9-1.5 % band Fig 6 is drawn from	Pass
E-99/D9: the report's envelope — 2-3 % for loose-to-medium sand, higher for very loose	Pass
E-99: the T&S path still behaves monotonically and stays finite	Pass

`liquefaction-triggering-variants-web-validation.test.ts`

G9 — liquefaction-triggering VARIANTS: Robertson & Wride (1998) / Youd et al.

Analyses validated: `cpt-liquefaction`, `cpt-sbt-ic`, `liquefaction` · Recorded run: passed — 32 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Φ and Φ^{-1}: MethodsX Eq 43 Φ(1.77) = 0.96 and Eq 51c Φ(1.30) = 0.90; inverse round-trips	Pass
[C18] Eq 29-30: rd(5.5 m, Mw 6.8, amax 0.28, Vs12 220) = 0.97, σεrd = 0.084	Pass
[C18] Eq 32: mean CSR at the critical depth = 0.23 (σv 105.2, σ'v 80.7)	Pass
[C18] Eq 39: CRR(N1,60 11.4, FC 14, Mw 6.8, σ'v 80.7, PL 50 %) = 0.15	Pass
[C18] Eq 43: PL = Φ(1.77) = 0.96 at CSR 0.23	Pass
[C18] Eq 42: (N1)60cs = 11.4 + 14·(0.00167·11.4 + 0.089) = 12.9	Pass
[C18] Eqs 45, 47: Kσ(80.7 kPa) = 1.08, KMw(6.8) = 1.26	Pass
[C18] Eqs 49, 53, 54: CSR_ref = 0.17 and FS = CRR/CSR = 0.65 both ways	Pass
[C18] Eqs 51a-51c: σtot from σinput 7.01 = 4.03; PL with input uncertainty = Φ(1.30) = 0.90	Pass
[C18] Table 2 corrections reproduce Table 3: CN (σ'v) and CR (rod = depth + 1.2 m)	Pass
[C18] engine run of the Table 3 profile (procedure cetin_2018): N1,60 and CSR at every saturated depth	Pass
[C18] engine at the critical-layer means reproduces FS 0.65 and PL 0.96	Pass
[CGM10] Cetin 2004 MSF = (Mw/7.5)^−2.217: 1.99 at M 5.5, 0.76 at M 8.5	Pass
[CGM10] Cetin 2004 Kσ = (σ'v/Pa)^−0.278, limited to 1.5	Pass
[CGM10] Cetin 2004 CFINES, FC < 5 % → 0, and (N1)60 = 0 does not divide by zero	Pass
[CGM10] Cetin 2004 engine: FoS scales with Mw exactly by the published MSF	Pass
[MOSS] rd Eq 4.13 reproduces Table 4.1 rd (mid-depth of the critical layer) to its 2 dp	Pass
[CGM10] Moss 2006 embedded MSF = (Mw/7.5)^−0.118 and Kσ = (σ'v/Pa)^−0.00028	Pass
[MOSS] PL and CRR are consistent inverses; deterministic default PL = 15 % (§5.3)	Pass
[MOSS] c (Eq 4.2) against the c column of Table 4.1 — chart-read values, median |Δc| ≤ 0.06	Pass
[BI14] R&W Ic (n = 0.5 branch) reproduces the printed Ic of 13 Table 3.1 cases to ±0.015	Pass
[MOSS Fig 5.8 / Youd 2001 Eq 19] Kc: 1.0 at Ic 1.64, 2.14 at 2.36, 3.31 at 2.60	Pass
Youd 2001 Eq 11: the two CRR7.5 branches meet at (qc1N)cs = 50; MSF(7.5) = 1.0 within 0.5 %	Pass
Robertson 2009 Ic iteration is the already-validated cpt-sbt-ic implementation	Pass
cpt-liquefaction: default procedure is unchanged (B&I 2014) and ignores sleeve friction	Pass
cpt-liquefaction: R&W / Robertson 2009 / Moss require sleeve friction	Pass
cpt-liquefaction R&W: clay-like Ic > 2.6 is non-susceptible, not a FoS	Pass
cpt-liquefaction R&W: (qc1N)cs ≥ 160 → too dense to liquefy (Youd 2001 validity limit)	Pass
cpt-liquefaction R&W hand-chain: FoS = CRR7.5(Kc·qc1N)·MSF·Kσ / CSR with NCEER rd	Pass
cpt-liquefaction Robertson 2009: Kc = 1 in the 1.64 < Ic < 2.36, F < 0.5 % zone (R&C 2012)	Pass
liquefaction (SPT): default procedure unchanged; Cetin procedures report PL; edge cases	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
liquefaction (SPT): probability input validated; deterministic PL changes CRR monotonically	Pass

liquefaction-web-validation.test.ts

Formula-fidelity validation against Boulanger & Idriss (2014) "CPT and SPT Based Liquefaction Triggering Procedures", Report No.

Analyses validated: `liquefaction` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] EXISTING GOLDEN CASE (B&I 2014 Ex 8.1-class, M7.5, 0.36g, loose silty sand): FoS in the hand-computed 0.25-0.40 band, status liquefiable	Pass
[2] CRR_M7.5,sv=1atm matches Eq. 2.25 exactly, re-derived from the engine's own reported N160cs	Pass
[3] Ksigma matches Eq. 2.16a-c exactly, re-derived from the engine's own reported N160cs and effective stress	Pass
[4] MSF matches Eq. 2.18-2.21 exactly, re-derived from the engine's own reported N160cs and the case magnitude	Pass
[5] the final CRR (case-specific) equals CRR_M7.5,sv=1atm . MSF . Ksigma exactly (Miller/Idriss chain of corrections)	Pass
[6] FoS = CRR/CSR exactly	Pass
[7] CN overburden correction never exceeds the published 1.7 cap (Eq. 2.15a), even at very low overburden stress	Pass
[8] looser sand (larger m-exponent per Eq. 2.15c) gives a larger CN at the same effective stress than denser sand	Pass
[9] saturated unit weight raises total stress below the water table by exactly the submerged increment	Pass
[10] a higher PGA increases CSR and hence lowers the factor of safety, all else equal	Pass
[11] invalid inputs (zero PGA, zero SPT-N, magnitude out of range) are refused	Pass

liquefaction-worked-examples-web-validation.test.ts

liquefaction — FULL WORKED EXAMPLES (the ≥20-value gate), end-to-end through computeLiquefaction.

Analyses validated: `liquefaction` · Recorded run: passed — 70 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[MNO12] App. A z = 1.8 m: (N1)60cs = 8.5	Pass
[MNO12] App. A z = 1.8 m: CSR = 0.181	Pass
[MNO12] App. A z = 1.8 m: Kσ = 1.09	Pass
[MNO12] App. A z = 1.8 m: CRR_M7.5,σ=1 = 0.108	Pass
[MNO12] App. A z = 2.6 m: (N1)60cs = 7.05	Pass
[MNO12] App. A z = 2.6 m: CSR = 0.211	Pass
[MNO12] App. A z = 2.6 m: Kσ = 1.07	Pass
[MNO12] App. A z = 2.6 m: CRR_M7.5,σ=1 = 0.098	Pass
[MNO12] App. A z = 3.4 m: (N1)60cs = 9.37	Pass
[MNO12] App. A z = 3.4 m: CSR = 0.23	Pass
[MNO12] App. A z = 3.4 m: Kσ = 1.06	Pass
[MNO12] App. A z = 3.4 m: CRR_M7.5,σ=1 = 0.114	Pass
[MNO12] App. A z = 4.1 m: (N1)60cs = 11.39	Pass
[MNO12] App. A z = 4.1 m: CSR = 0.243	Pass
[MNO12] App. A z = 4.1 m: Kσ = 1.05	Pass
[MNO12] App. A z = 4.1 m: CRR_M7.5,σ=1 = 0.128	Pass
[MNO12] App. A z = 4.9 m: (N1)60cs = 13.29	Pass
[MNO12] App. A z = 4.9 m: CSR = 0.252	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[MNO12] App. A z = 4.9 m: Kσ = 1.05	Pass
[MNO12] App. A z = 4.9 m: CRR_M7.5,σ=1 = 0.142	Pass
[MNO12] App. A z = 5.6 m: (N1)60cs = 28.14	Pass
[MNO12] App. A z = 5.6 m: CSR = 0.257	Pass
[MNO12] App. A z = 5.6 m: Kσ = 1.06	Pass
[MNO12] App. A z = 5.6 m: CRR_M7.5,σ=1 = 0.389	Pass
[MNO12] App. A z = 6.4 m: (N1)60cs = 23.4	Pass
[MNO12] App. A z = 6.4 m: CSR = 0.261	Pass
[MNO12] App. A z = 6.4 m: Kσ = 1.03	Pass
[MNO12] App. A z = 6.4 m: CRR_M7.5,σ=1 = 0.257	Pass
[MNO12] App. A z = 7.2 m: (N1)60cs = 32.28	Pass
[MNO12] App. A z = 7.2 m: CSR = 0.263	Pass
[MNO12] App. A z = 7.2 m: Kσ = 1.03	Pass
[MNO12] App. A z = 7.2 m: CRR_M7.5,σ=1 = 0.674	Pass
[MNO12] App. A z = 7.9 m: (N1)60cs = 24.18	Pass
[MNO12] App. A z = 7.9 m: CSR = 0.264	Pass
[MNO12] App. A z = 7.9 m: Kσ = 1.01	Pass
[MNO12] App. A z = 7.9 m: CRR_M7.5,σ=1 = 0.272	Pass
[MNO12] App. A z = 9.4 m: (N1)60cs = 25.13	Pass
[MNO12] App. A z = 9.4 m: CSR = 0.264	Pass
[MNO12] App. A z = 9.4 m: Kσ = 0.98	Pass
[MNO12] App. A z = 9.4 m: CRR_M7.5,σ=1 = 0.293	Pass
[MNO12] App. A z = 10.2 m: (N1)60cs = 15.57	Pass
[MNO12] App. A z = 10.2 m: CSR = 0.262	Pass
[MNO12] App. A z = 10.2 m: Kσ = 0.98	Pass
[MNO12] App. A z = 10.2 m: CRR_M7.5,σ=1 = 0.161	Pass
[MNO12] App. A z = 11 m: (N1)60cs = 13.52	Pass
[MNO12] App. A z = 11 m: CSR = 0.261	Pass
[MNO12] App. A z = 11 m: Kσ = 0.98	Pass
[MNO12] App. A z = 11 m: CRR_M7.5,σ=1 = 0.144	Pass
[MNO12] App. A: the two CH rows (PI 30) and the unsaturated 1.1 m row are not analysed	Pass
[CGM10] Table 3.1 1964 Niigata, Showa Br. 2: (N1)60cs = 8.2	Pass
[CGM10] Table 3.1 1964 Niigata, Showa Br. 2: CSR = 0.21	Pass
[CGM10] Table 3.1 1968 Tokachi-Oki, Aomori Station: (N1)60cs = 16.5	Pass
[CGM10] Table 3.1 1968 Tokachi-Oki, Aomori Station: CSR = 0.335	Pass
[CGM10] Table 3.1 1948 Fukui, Shonenji Temple: (N1)60cs = 11.8	Pass
[CGM10] Table 3.1 1948 Fukui, Shonenji Temple: CSR = 0.39	Pass
[CGM10] Table 3.1 1948 Fukui, Takaya 45: (N1)60cs = 21.1	Pass
[CGM10] Table 3.1 1948 Fukui, Takaya 45: CSR = 0.283	Pass
[CGM10] Table 3.1 1964 Niigata, Old Town 2: (N1)60cs = 23.5	Pass
[CGM10] Table 3.1 1964 Niigata, Old Town 2: CSR = 0.184	Pass
[CGM14] Table 6.1 1999 Chi-Chi, Wufeng Site A1: MSF = 0.97	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[CGM14] Table 6.1 1999 Kocaeli, Degirmendere DN-1: MSF = 1	Pass
[CGM14] Table 6.1 1999 Kocaeli, Building C3: MSF = 1	Pass
[CGM14] Table 6.1 1999 Chi-Chi, Yuanlin BH-31: MSF = 0.99	Pass
[YOUD] Table 3 / IS 1893 Annex F Step 5: MSF(Mw 5.5) = 2.2	Pass
[YOUD] Table 3 / IS 1893 Annex F Step 5: MSF(Mw 6) = 1.76	Pass
[YOUD] Table 3 / IS 1893 Annex F Step 5: MSF(Mw 6.5) = 1.44	Pass
[YOUD] Table 3 / IS 1893 Annex F Step 5: MSF(Mw 7) = 1.19	Pass
[YOUD] Table 3 / IS 1893 Annex F Step 5: MSF(Mw 7.5) = 1	Pass
[YOUD] Table 3 / IS 1893 Annex F Step 5: MSF(Mw 8) = 0.84	Pass
[YOUD] Table 3 / IS 1893 Annex F Step 5: MSF(Mw 8.5) = 0.72	Pass

⚑ machine-foundation-web-validation.test.ts

Dedicated validation for the block machine-foundation vertical mode (`machine-foundation.ts`): Barkan/IS 2974 stiffness kz = Cu·A, natural frequency fnz = (1/2π)√(kz/m), frequency ratio r = f/fnz, damped magnification M = 1/√((1−r²)² + (2D…

Analyses validated: `machine-foundation` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Varghese (2005) Example 23.1: vertical frequency, frequency ratio and undamped amplitude	Pass
Bowles (1997) Example 20-1A: printed natural frequency WN and frequency ratios W/WN	Pass
Bowles (1997) Example 20-1A: printed YP/YS (magnification) and YP (mm) at 800, 900, 1000 rpm	Pass
Vora (2018) Example 1: printed program results for the gas-engine foundation	Pass
hand check: elastic half-space stiffness kz = 4 G r0 / (1 – ν) for the Bowles base (equivalent circle)	Pass

makdisi-seed-web-validation.test.ts

makdisi-seed — dedicated validation against PUBLISHED worked answers (`makdisi-seed.ts`).

Analyses validated: `makdisi-seed` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[K] Example 7.6 dam (H = 150 ft, Vs = 1200 ft/s): T0 = 0.33 s (printed in Ex. 10.5) and f = 3.1 Hz (Problem 10.9)	Pass
[K] Example 10.5: ky/kmax = 0.24/0.442 = 0.54	Pass
[K] Example 10.5: chart value 0.04 → u = 0.19 ft = 2.3 in	Pass
[M] Appendix A example (h = 150 ft, vs = 600 fps): first period T1 = 0.65 s	Pass
[M] p. 29-30: kmax = 0.2, ky = 0.14 → ky/kmax = 0.7	Pass
[M] p. 29-30: U/(kmax·g·T0) = 0.013 s, T0 = 0.99 s → U = 0.08 ft = 2.4 cm	Pass
HAND-CHECK: U = norm·kmax·g·T0 and ky ≥ kmax is reported as not mobilised	Pass
invalid inputs are refused (no fabricated displacement): zero H, Vs, kmax; negative ky or chart value	Pass

nonlinear-site-response-codespectrum-web-validation.test.ts

WEB-BENCHMARK validation for the CODE DESIGN-SPECTRUM OVERLAY added to the nonlinear-site-response engine (IS 1893:2016 + ASCE 7-16).

Analyses validated: `nonlinear-site-response` · Recorded run: passed — 20 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
overlay 1: IS site class — Vs=250 ⇒ Type II (medium)	Pass
overlay 2: IS site class — Vs=500 ⇒ Type I (rock/hard)	Pass
overlay 3: IS site class — Vs=150 ⇒ Type III (soft)	Pass
overlay 4: ASCE site class — Vs=250 ⇒ D (stiff soil); Vs=500 ⇒ C	Pass
overlay 5: IS plateau — T=0.2 s ⇒ Sa = (Z/2)·2.5 = 0.20 g	Pass
overlay 6: IS rising branch — T=0.05 s ⇒ (Z/2)·(1+15·0.05) = 0.14 g	Pass
overlay 7: IS Type-II falling branch — T=1.0 s ⇒ (Z/2)·(1.36/1.0) = 0.1088 g	Pass
overlay 8: IS design Sa scales linearly with Z	Pass
overlay 9: ASCE plateau — T=0.5 s (T0<T<Ts) ⇒ Sa = SDS = 1.0 g	Pass
overlay 10: ASCE falling branch — T=1.0 s ⇒ SD1/T = 0.68 g	Pass
overlay 11: ASCE — T=2.0 s ⇒ SD1/T = 0.34 g	Pass
overlay 12: code spectrum is aligned 1:1 with the site-specific spectrum	Pass
overlay 13: verdict matches the site-vs-code comparison at the structure period	Pass
overlay 14: no structure period ⇒ verdict prompts to enter one	Pass
overlay 15: default code is IS 1893 (India-first)	Pass
overlay 16: EC8 ground type — Vs=250⇒C, Vs=500⇒B, Vs=900⇒A	Pass
overlay 17: EC8 plateau — T=0.4 s ⇒ ag·S·2.5 = 0.25·1.15·2.5 = 0.71875 g	Pass
overlay 18: EC8 falling branch — T=1.0 s ⇒ ag·S·2.5·(TC/T) = 0.43125 g	Pass
overlay 19: EC8 rising branch — T=0.1 s ⇒ ag·S·(1+T/TB·1.5) = 0.503125 g	Pass
overlay 20: EC8 design Sa scales linearly with ag	Pass

nonlinear-site-response-web-validation.test.ts

WEB-BENCHMARK validation for the 1-D nonlinear time-domain site-response engine.

Analyses validated: `nonlinear-site-response` · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NLSR web C1–C6: T0 = 4H/Vs (exact)	Pass
NLSR web C7–C10: weak-motion amplification decreases monotonically with damping	Pass
NLSR web C11–C13: strong motion DE-amplifies vs weak (period lengthening + hysteretic damping)	Pass
NLSR web C16–C18: max shear strain grows monotonically with input PGA	Pass
NLSR web C17: soft site (Vs≤200) + PGA≥0.1 g ⇒ strains large enough that NL matters	Pass
NLSR web C20–C21: softer profile ⇒ longer site period	Pass
NLSR web C24–C25: NEHRP-style deamplification — amplification falls as input PGA rises	Pass
NLSR web: surface history + response spectrum are finite and non-empty	Pass
NLSR web: elastic transfer function peaks at f_0, $3f_0$, $5f_0$	Pass
NLSR web: strain/stress depth profiles + hysteresis loop are physical	Pass
NLSR web: input accel history aligns with time + surface, peaks at the input PGA	Pass
NLSR web: G/Gmax degrades + damping rises with strain (per-layer stiffness)	Pass
NLSR web: vel/disp histories + Arias intensity + $D_{5\text{-}95}$ are physical	Pass
NLSR web: surface Fourier spectrum peaks near the site period f_0	Pass

pm4sand-web-validation.test.ts

Validation for the PM4Sand engine (`pm4sand.ts`).

Analyses validated: `pm4sand` · Recorded run: passed — 37 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
CGM-15-01 eq 14 — M = 2·sin(33°) = 1.089	Pass
CGM-15-01 eqs 12-13 — surfaces coincide at critical state (ξ_R = 0)	Pass
CGM-15-01 eqs 12-13 — dense-of-critical gives M^b > M > M^d	Pass
CGM-15-01 eq 45 — Bolton A_do = 1.26 at ξ_R = −0.1 (nb=0.5, nd=0.1)	Pass
CGM-15-01 eq 45 — Bolton A_do = 1.45 at ξ_R = −0.7	Pass
CGM-15-01 eq 97 — G_o = 167·√((N1)₆₀+2.5): 678 & 892 at N=14 & 26	Pass
CGM-15-01 eq 96 — Vs1 = 85·((N1)₆₀+2.5)^0.25: 171 & 196 at N=14 & 26	Pass
CGM-15-01 eq 92 — D_R = √((N1)₆₀/46): 0.552 & 0.752 at N=14 & 26	Pass
Idriss-Boulanger 2008 — CRR at N=6/14/26 ≈ 0.090/0.147/0.312 (targets)	Pass
Idriss-Boulanger CRR is monotonically increasing with density	Pass
Boulanger-Idriss 2004 — Kσ = 1 at 1 atm and < 1 above 1 atm	Pass
Idriss-Boulanger 2008 — MSF = 1 at M=7.5 and > 1 for smaller M	Pass
CGM-15-01 eq 10-11 — relative-state index negative for dense sand	Pass
CGM-15-01 Table 4.2 — default h_o = max((0.25+Dr)/2, 0.30)	Pass
CGM-15-01 Table 4.2 — default z_max = 0.7 at ξ_R0 = 0, capped at 20	Pass
Pezeshk/IB-2014 — $CRR_{7.5}$ matches the worked table across 13 $(N1)_{60}cs$ values	Pass
Pezeshk/IB-2014 — Kσ matches the worked table across 5 rows	Pass
Idriss-Boulanger CRR caps at 2.0 for very dense sand ($(N1)_{60}cs \geq \sim 38$)	Pass
Pezeshk/IB-2014 — r_d(z, M=7.7) matches the worked table across 8 depths	Pass
Pezeshk/IB-2014 — CSR = 0.65·(a_max/g)·(σv/σ′v)·r_d matches 8 rows	Pass
Pezeshk/IB-2014 — end-to-end FoS via the a_max path matches the table (0.469)	Pass
Integrator — undrained cyclic DSS reaches full liquefaction (r_u → ~1)	Pass
Integrator — cycles-to-liquefaction decreases as CSR increases (CRR-N trend)	Pass
Integrator — mid-density element CRR matches I&B target 0.147 within 12%	Pass
Integrator — h_po (contraction knob) monotonically raises element CRR	Pass
Integrator — stress path shows p reduction toward liquefaction	Pass
computePm4Sand — end-to-end wrapper returns a factor of safety and CRRs	Pass
cyclesToLiquefactionFromFoS — N = 15 at FoS = 1, monotone in FoS	Pass
Dense sand no longer contradicts FoS — N45/CSR0.5 safe, N30/CSR0.1 safe	Pass
Loose sand triggers fast — N6/CSR0.35 FoS<1 and cycles<15	Pass
cycles-to-liquefaction is monotone: denser/weaker shaking ⇒ more cycles	Pass
audit: CSR = 0 is REFUSED, not reported as FoS ≈ 110 929	Pass
audit: negative n160 / sigmaVc are REFUSED, not silently turned into NaN with errors: []	Pass
audit: maxCycles is bounded — no heap exhaustion from an extreme value	Pass
audit: the kernel bounds stored series in place even for a run that never triggers	Pass
audit: the real, valid case is BYTE-IDENTICAL to before the fix	Pass
audit: n160 = 0 (very loose sand) stays LEGAL	Pass

pore-pressure-generation-web-validation.test.ts

Formula-fidelity validation for the tool surfaced at /tools/liquefaction- response (module: pore-pressure-generation.ts, NOT named after the slug -- one of the documented module-resolution traps).

Analyses validated: `liquefaction-response` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-5] equivalent uniform cycles N_eq matches the published Seed & Idriss (1982) table anchors exactly: M5.25=2.5, M6.0=5, M6.75=10, M7.5=15, M8.5=26	Pass
[6] ru=1 exactly at cycle ratio N/NL=1 (the defining anchor of initial liquefaction, per Seed-Martin-Lysmer 1976)	Pass
[7-8] ru matches the exact Seed-Martin-Lysmer closed-form at two intermediate ratios: ratio=0.5 -> ru=0.417265, ratio=0.25 -> ru=0.242312	Pass
[9] ru=0 exactly at N=0 (no cycles, no pore pressure generated)	Pass
[10-13] CROSS-ENGINE CHECK: feeding this engine the actual B&I 2014 CRR/CSR from the already-validated liquefaction.ts engine (see liquefaction-web-validation.test.ts) reproduces the exact expected FS, Neq, and NL	Pass
[14] a non-liquefying case (FS>1) is correctly flagged, and the final ru stays below 1	Pass
[15] the stiffness ratio G/Gmax = sqrt(1-ru) exactly, per Hardin & Drnevich (1972) stress dependence	Pass
[16] the effective stress path sigma_v_eff = sigma_v0.(1-ru) exactly, when sigma_v0 is supplied	Pass
[17] invalid inputs (zero CSR/CRR, magnitude outside 4-9.5) are refused	Pass

response-spectrum-web-validation.test.ts

Validation for the seismic response spectrum (`response-spectrum.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
PGA of the sinusoid = amplitude A	Pass
rigid limit: Sa(T→0) → PGA	Pass
resonance: Sa ≈ PGA/(2ζ) for a SDOF tuned to the input frequency	Pass
pseudo-spectral relations Sv=ω·Sd, Sa=ω²·Sd hold	Pass
zero ground motion → zero response	Pass
Arias intensity closed form Ia = (π/2g)∫a²dt	Pass

rvt-site-response-web-validation.test.ts

Validation for the RVT site-response engine (`rvt-site-response.ts`).

Analyses validated: `rvt-site-response`, `site-response-multilayer` · Recorded run: passed — 34 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
spectral moment m0 = 2A²(f2−f1)	Pass
spectral moment m2 = 2A²(2π)²(f2³−f1³)/3	Pass
spectral moment m4 = 2A²(2π)⁴(f2⁵−f1⁵)/5	Pass
moments scale with A²	Pass
RVT bandwidth ξ = $\sqrt{(m_2^2/(m_0 m_4))}$ of [0,fmax] white noise = $\sqrt{5}/3$ (exact)	Pass
zero-crossing rate = 2·fmax/$\sqrt{3}$ for [0,fmax] white	Pass
extrema rate = 2·fmax·$\sqrt{(3/5)}$ for [0,fmax] white	Pass
n_extrema ≥ n_zero	Pass
peak factor > 1	Pass
peak factor increases with duration	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
CLH peak factor ≈ Davenport asymptote (broadband)	Pass
peak factor is O(√(2 ln Ne))	Pass
rms duration → D_gm at long period	Pass
rms duration → D_gm + Tn/(2πβ) at short period	Pass
rms duration ≥ D_gm	Pass
rms duration decreases with damping	Pass
PSA(T→0) approaches PGA	Pass
response spectrum positive & finite	Pass
lower oscillator damping → higher Sa	Pass
Brune corner frequency drops with magnitude	Pass
single-layer site period ≈ 4H/Vs	Pass
soft-soil amplification > 1	Pass
surface PGA ≥ rock PGA	Pass
surface Sa peak ≥ surface PGA	Pass
softer soil → longer period + more amplification	Pass
fundamental period within physical band of 4H/Vs	Pass
Kramer Eq 7.19 — single layer over rigid rock: |F|(f0) = 1/(ξ·π/2)	Pass
Kramer — single layer over elastic rock: |F|(f0) = 1/α_z (undamped soil)	Pass
Kramer — fundamental period T0 = 4H/Vs across cases	Pass
Kramer — odd higher modes resonate: |F|(3f0) > |F|(2f0)	Pass
Toro 1995 Vs randomization — median ≈ base, ordered p16 ≤ median ≤ p84, deterministic	Pass
audit: bedrock damping far beyond 100% critical is REFUSED	Pass
audit: a negated layer (thickness, Vs, unit weight, damping) is REFUSED, not a plausible period	Pass
audit: the real, valid single-layer case is unaffected by the new per-field checks	Pass

⚑ seismic-site-class-crosscode-web-validation.test.ts

seismic-site-class — deep review D11 (2026-10-02).

Analyses validated: `seismic-site-class` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[IDOT] N̄ (Method B) on five published 100-ft profiles — 9, 7, 21, 19, 23 blows/ft	Pass
[IDOT] s̄u (Method C, cohesive layers only) — 0.68, 2.17, 4.62, 3.51, 4.62 ksf	Pass
[IDOT] the published class for each measure (AASHTO 3.10.3.1-1 = ASCE 7-16 Table 20.3-1 limits)	Pass
[IDOT] → IS 1893 Table 4 on the published N̄: 9, 7 → Type III; 21, 19, 23 → Type II	Pass
[PEER] Dobry et al. 2000 example: 18 m @ 90 m/s over 12 m @ 260 m/s → Vs30 = 122 m/s (arithmetic 158)	Pass
[CE] travel-time Vs30 solved problems — 372.2, 308 and 424 m/s	Pass
[EQ03] IS 1893:2016 Example 1 — Zone V, I 1, R 5, Type II, T 0.28 s → Sa/g 2.5, Ah 0.09	Pass
[STAAD] IS 1893:2016 static seismic — Z 0.36, I 1.2, R 5, hard soil, Ta 0.39 s → Sa/g 2.5, Ah 0.108, VBmin 2.4 %	Pass
[IS] Table 7 minimum VB/W for buildings — 0.7, 1.1, 1.6, 2.4 % (Zones II-V)	Pass
[IS] Cl 6.4.2(a) vs (b): a rigid structure gets 2.5 by the equivalent static method, 1 + 15T by the response spectrum method	Pass
[IS] Cl 6.3.5.3 — the liquefaction N limit is 15 in Zones III-V and 10 in Zone II, and no site type is exempt	Pass
[EN] Table 3.2 / 3.3 recommended spectrum parameters on ground types C and D	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[JRC] Worked example §3.2: clay with cu,d = 300 kPa (270 kPa seismic) is ground type B	Pass
[EN] Table 3.1 ground type E — 5-20 m of vs < 360 m/s directly over vs > 800 m/s	Pass
D11 regressions — averaging tracks true depth, s̄u stays on the cohesive layers, s̄u alone never gives Type I	Pass

seismic-site-class-is1893-web-validation.test.ts

Seismic site classification and design coefficient — validated against **IS 1893 (Part 1):2016**, *Criteria for Earthquake Resistant Design of Structures*, Part 1 General Provisions and Buildings (6th revision).

Analyses validated: `seismic-site-class` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IS 1893:2016 Table 3 — the four published zone factors Z	Pass
Q-3 / E-8 — omitting the seismic zone is REFUSED, never a silent Ah = 0	Pass
IS 1893:2016 Cl 6.4.2 Fig 2(b) — the design acceleration spectrum, all three site classes	Pass
E-31 — the T > 4 s floor exists, and the old behaviour would have been unconservative	Pass
IS 1893:2016 Cl 6.4.2 — Ah = (Z/2)·(I/R)·(Sa/g), end to end	Pass
the references cite the tables that were actually used, with the corrected numbers	Pass

site-response-design-chain-web-validation.test.ts

Web-benchmark validation for the SEVEN remaining inline runner engines: 1-D site response (equivalent-linear, nonlinear and effective-stress), climate/EICM, the staged embedded wall, and the two probabilistic/full-chain foundation engines.

Analyses validated: `bearing-capacity-reliability`, `climate-zone-eicm`, `effective-stress-liquefaction`, `foundation-analysis`, `nonlinear-site-response`, `site-response`, `site-response-multilayer`, `staged-excavation-wall` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
site-response-multilayer reports both the exact and quarter-wavelength periods	Pass
nonlinear-site-response uses T = 4H/V_s and overlays the code spectrum	Pass
effective-stress-liquefaction keeps r_u bounded and its outputs mutually consistent	Pass
climate-zone-eicm returns distinct, physically ordered values for all six zones	Pass
staged-excavation-wall uses Rankine K_a/K_p and keeps the wall check consistent	Pass
bearing-capacity-reliability takes the EC7 characteristic value as the 5th percentile	Pass
foundation-analysis takes the LESSER of shear and settlement capacity at every width	Pass

site-response-eql-web-validation.test.ts

Validation for the equivalent-linear site-response engine + G/Gmax–damping curve library (`site-response-eql.ts`, `gmax-damping-curves.ts`).

Analyses validated: `site-response-eql` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Vucetic-Dobry (1991): G/Gmax anchors at γ = 0.1% vs PI	Pass
Vucetic-Dobry (1991): damping anchors at γ = 0.1% vs PI	Pass
Vucetic-Dobry: small-strain plateau and large-strain degradation	Pass
Seed-Idriss (1970) sand: mean G/Gmax and damping anchors	Pass
Darendeli (2001): reference strain and D_min for PI=0, 1 atm	Pass
Darendeli (2001): G/Gmax = 0.5 at γ = γr (definition of the reference strain)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EQL reduces to the linear transfer function at very low input	Pass
EQL lengthens the period and de-amplifies under strong motion (Kramer §7)	Pass
EQL effective-strain ratio R_γ tracks magnitude (Seed-Idriss)	Pass
EQL input validation	Pass
EQL small-strain fundamental period = 4H/Vs (Kramer Eq 7.16 + Ex 7.1/7.2)	Pass

site-response-fe-1d-web-validation.test.ts

WEB-VALIDATION for the 1-D site-response FE by Newmark-β time integration (`site-response-fe-1d.ts`).

Analyses validated: `site-response` · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
A1. Newmark SDOF resonance r=1 → Rd = 1/(2ζ) = 10.000 (Chopra §3.2)	Pass
A2. Newmark SDOF r=0.5 → Rd = 1.33038 (Chopra §3.2)	Pass
A3. Newmark SDOF r=2.0 → Rd = 0.33260 (Chopra §3.2)	Pass
A4. Newmark SDOF quasi-static r=0.1 → Rd → 1.0 (Chopra §3.2)	Pass
A5. Newmark undamped free vibration preserves period + amplitude	Pass
B1. fundamental frequency f1 = Vs/(4H) = 2.00 Hz (Kramer Eq. 7.13)	Pass
B2. peak mode-1 amplification = 2/(πζ) = 12.7324 (Kramer Eq. 7.20)	Pass
B3. 2nd resonance at f2 = 3·f1 = 6.0 Hz, amp = 2/(3πζ) = 4.2441 (Kramer)	Pass
B4. low-frequency limit → amplification ≈ 1 (surface rides the base)	Pass
B5. second uniform site Vs=180, H=30 → f1 = 1.50 Hz (Kramer Eq. 7.13)	Pass
C1. Rayleigh a0,a1 match the closed form and give ζ at both controls	Pass
D1. Newmark time-domain surface/base ratio at f1 = FD transfer fn ≈ 2/(πζ)	Pass
E1. computeSiteResponseFE1D reports f1, peak amp and runs a base motion	Pass
E2. edge cases: invalid inputs surface errors, not NaN	Pass

site-response-web-validation.test.ts

Formula-fidelity validation against Kramer, "Geotechnical Earthquake Engineering" Ch.7 -- the classical single-layer, vertically-propagating SH-wave transfer function on an elastic half-space.

Analyses validated: `site-response` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] fundamental period T0=4H/Vs=0.4s, fundamental frequency f0=1/T0=2.5Hz	Pass
[3] resonant frequencies fn=(2n-1).Vs/(4H) for n=1,2,3: 2.5, 7.5, 12.5 Hz	Pass
[4] impedance ratio alpha = (rho_soil.Vs_soil)/(rho_rock.Vs_rock) matches exactly: 0.215311	Pass
[5] peak damped amplification A_max = 1/(alpha + (pi/2).xi) matches exactly: 3.403087	Pass
[6] surface PGA equals rock PGA times the peak amplification exactly	Pass
[7] a softer soil column (lower impedance ratio) produces MORE amplification -- the classical soft-site resonance danger	Pass
[8] a deeper soil layer lowers the fundamental frequency (longer period), all else equal	Pass
[9] more damping reduces the peak amplification, all else equal	Pass
[10] the amplification spectrum starts at exactly 1.0 at zero frequency (no dynamic effect at DC)	Pass
[11] a bedrock softer than the soil column is refused (Vs_rock >= Vs_soil is required for the model to be physically meaningful)	Pass
[12] invalid inputs (zero thickness, zero Vs, damping outside [0,1)) are refused	Pass

spectral-matching-web-validation.test.ts

Validation for the RSPMatch-style time-domain spectral matcher (`spectral-matching.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
spectral matching dramatically reduces the misfit vs the seed	Pass
match is within ~10% over the well-resolved period range T ≥ 0.5 s	Pass
matched motion has no baseline drift (final velocity ≈ 0)	Pass
non-stationarity preserved: PGA and Arias stay the same order as the seed	Pass
deterministic: same seed + target ⇒ identical matched motion	Pass
config wrapper returns misfit in % and preserves the record length	Pass

topographic-amplification-web-validation.test.ts

WEB-BENCHMARK validation for the 2-D topographic-amplification (SH ridge/crest) engine.

Analyses validated: `site-response-multilayer`, `topographic-amplification` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
topo web EC8: flat surface S_T = 1.00 across geometries (3 cases)	Pass
topo web Trifunac: S_T < 2 for every ridge shape (6 cases, incl. steep)	Pass
topo web EC8: 15°–30° slopes give S_T ≥ 1.2 (4 cases)	Pass
topo web EC8: >30° ridges give S_T ≥ 1.4 (3 cases)	Pass
topo web Ashford-Sitar: steep ridges (60°, 70°) amplify 1.4–2.0, never de-amplify	Pass
topo web EC8: gentle ridges (slope ~6°, ~10°) ⇒ S_T ≈ 1.0–1.25	Pass
topo web: S_T rises monotonically with slope angle (5°→10°→20°→30°→45°)	Pass
topo web EC8: crest is the surface-profile peak, base ≈ free-field	Pass
topo web Geli: resonant crest amplification is in the 1.3–2.0 band for a steep ridge	Pass
topo web: dimensionless frequency η at the peak is reported and physical (0.3–2)	Pass

vs-liquefaction-web-validation.test.ts

Validation for the shear-wave-velocity liquefaction-triggering engine (`vs-liquefaction.ts`, Andrus & Stokoe 2000 simplified procedure as adopted by the NCEER workshop).

Analyses validated: `vs-liquefaction` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Youd & Idriss (2001) Table 3 — revised Idriss MSF at Mw 5.5 … 8.5	Pass
Youd & Idriss (2001) p. 825 — CRR_7.5 = 0.033 at V_s1 = 100 m/s (clean sand)	Pass
Youd & Idriss (2001) p. 825 — V*_s1 = 215 m/s (FC ≤ 5 %) … 200 m/s (FC ≥ 35 %)	Pass
Treasure Island crosshole, 4.57 m — V_s1, V*_s1, CSR, CRR and F_S of the worked example	Pass
Treasure Island crosshole, 5.49 m — Table 3.2 row 2 (V_s1 150 m/s, r_d 0.96)	Pass
Treasure Island crosshole, 6.40 m — Table 3.2 row 3 (V_s1 158 m/s, r_d 0.95, CSR 0.14)	Pass
Treasure Island SASW, 5.34 m — Table 3.3 (V_s1 149 m/s, r_d 0.96) and the F_S = 0.75 minimum	Pass
Marina District School, 3.02 m — Table 3.4 row 1 (V_s1 104 m/s, r_d 0.98, CSR 0.10) and F_S = 0.42	Pass
Marina District School, 3.94 m — Table 3.4 row 2 (V_s1 156 m/s, r_d 0.97, CSR 0.11) and F_S = 0.90	Pass

Constitutive models and element tests

FE kernel registry — 48 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-verif-cavity-pressure	normalised cavity pressure p/c at (a − a0)/a0 = 4 (also 0.4 / 1.2 / 2.8 within 0.15 %) [-]	PLAXIS-Verification-Cylindrical-cavity-expansion.pdf, p. 3 (Verification, small displacements; Figure 4)	—	7.6846	7.6812	—	−0.04 %	Pass
plaxis-verif-cavity-rp	radius of the plastic zone at a = 5 m (outermost plastic integration point) [m]	PLAXIS-Verification-Cylindrical-cavity-expansion.pdf, p. 3 (Table 1, small displacements)	28.01	28.28	28.003	−0.03 %	−0.99 %	Pass
plaxis-verif-cavity-large-pressure	normalised cavity pressure p/c at (a − a0)/a0 = 4, updated mesh (worst step over the curve −0.22 %) [-]	PLAXIS-Verification-Cylindrical-cavity-expansion.pdf, p. 3 (Verification, large displacements; Figure 4)	—	5.5668	5.5628	—	−0.07 %	Pass
plaxis-verif-cavity-large-rp	radius of the plastic zone at a = 5 m, current configuration (outermost plastic integration point) [m]	PLAXIS-Verification-Cylindrical-cavity-expansion.pdf, p. 3 (Table 1, large displacements)	48.85	49.11	48.74	−0.23 %	−0.76 %	Pass
plaxis-verif-biaxial-le self-check	ux / uy of the corner nodes [mm]	PLAXIS-Verification-Biaxial-compression-linear-elastic.pdf, p. 1–2	−0.9375 / 0.3125 …	identical	identical to 1e-13	0.00 %	0.00 %	Pass
plaxis-verif-biaxial-shear	γxy [-]	PLAXIS-Verification-Biaxial-shearing-linear-elastic.pdf, p. 1–2	0.0025	0.0025	0.0025	0.00 %	0.00 %	Pass
plaxis-verif-biaxial-mc	failure σ1 (load control) [kPa]	PLAXIS-Verification-Biaxial-Mohr-Coulomb.pdf, p. 1–3	-6.4641	-6.4641	-6.4641	0.00 %	0.00 %	Pass
k5b-hs-triaxial-element-compression	HS drained triaxial compression: σ'1 at failure (σ'3 = −100 kPa) [kPa]	PLAXIS-Verification-Triaxial-Hardening-Soil-2018.pdf, p. 2–3 (Table 1)	-372.86	-372.86	-372.859	+2.0e-4 %	+2.0e-4 %	Pass
k5b-hs-triaxial-element-extension	HS drained triaxial extension: σ'1 at failure [kPa]	PLAXIS-Verification-Triaxial-Hardening-Soil-2018.pdf, p. 2–3 (Table 1)	-26.06	-26.06	-26.0579	+8.1e-3 %	+8.1e-3 %	Pass
k5b-hs-triaxial-fe-compression	HS triaxial through the FE solver: σ'1 at failure (stops at λ 0.779598 of −100 → −450; honest collapse) [kPa]	PLAXIS-Verification-Triaxial-Hardening-Soil-2018.pdf, p. 1–3	-372.86	-372.86	-372.859	+3.0e-4 %	+3.0e-4 %	Pass
k5b-hs-triaxial-fe-extension	HS triaxial extension through the FE solver: σ'1 at failure (λ 0.739421) [kPa]	PLAXIS-Verification-Triaxial-Hardening-Soil-2018.pdf, p. 1–3	-26.06	-26.06	-26.058	+7.7e-3 %	+7.7e-3 %	Pass
k5b-hs-hyperbola-e50	HS drained triaxial at σ'3 = −pref, normally consolidated (cap active — the STANDARD test): secant E50 at qf/2 (and, with the cap out of the way, max |ε1 − hyperbola of the internal Ei^ref|/ε1 up to 0.55 qf) [kPa]	PLAXIS_2D_Material_Models_Manual.pdf (2025.1; _new_2026-06-30/), p. ch. 6, Eqs 6-1…6-5	—	20000	19999.6	—	−2.0e-3 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k5b-hs-small-dss-reloading	HS small: simple-shear secant G(γ) = G0/(1 + 0.385 γ/γ0.7) (worst relative error) [-]	PLAXIS_2D_Material_Models_Manual.pdf (2025.1; _new_2026-06-30/); Benz 2007 App. A, p. ch. 7, Eqs 7-1…7-6	—	0	7.000e-15	—	—	Pass
k5b-hs-small-triaxial-failure	HS small (G0ref 3 Gur, γ0.7 1e-4) drained triaxial: σ'1 at failure [kPa]	PLAXIS-Verification-Triaxial-Hardening-Soil-2018.pdf, p. 2–3	-372.86	-372.86	-372.859	+2.0e-4 %	+2.0e-4 %	Pass
k5b-ss-isotropic-lambda-kappa	Soft Soil isotropic NC compression / unloading: recovered λ*, κ* (input 0.1055 / 0.01635) [-]	PLAXIS_2D_Material_Models_Manual.pdf (2025.1; _new_2026-06-30/), p. ch. 10, Eqs 10-1…10-3	—	0.1055 / 0.01635	0.105515 / 0.016335	—	—	Pass
k5b-ss-oedometer-k0nc self-check	Soft Soil oedometer: σ'h/σ'v on the NC line [-]	PLAXIS_2D_Material_Models_Manual.pdf (2025.1; _new_2026-06-30/), p. ch. 10, Eq. 10-8 (M from K0nc)	—	0.61	0.609978	—	−3.6e-3 %	Pass
k5b-ssc-isotropic-creep	Soft Soil Creep: isotropic creep strain at 1012 d under constant p' (backward Euler, 5 % growing steps) [-]	PLAXIS_2D_Material_Models_Manual.pdf (2025.1; _new_2026-06-30/), p. ch. 11, Eqs 11-1…11-9	—	0.027681	0.027585	—	−0.35 %	Pass
k5b-ssc-haney-pp	Haney clay: p_p^eq after POP 432.4 initialisation [kPa]	PLAXIS-Verification-Soft-Soil-Creep-Haney-clay-2018.pdf, p. 2	373	—	372.99	−2.7e-3 %	—	Pass
k5b-ssc-haney-rate-effect self-check	Haney clay undrained triaxial peak q at 0.00094 / 0.15 / 1.10 %/min [kPa]	PLAXIS-Verification-Soft-Soil-Creep-Haney-clay-2018.pdf, p. 1–5 (Fig. 2: curves only)	—	—	A: 269.7; B: 327.3; C: 353	—	—	Pass
k5b-mcc-undrained-nc	MCC undrained triaxial on NC clay (p'0 200, λ 0.25, κ 0.05, M 0.9): p' at critical state [kPa]	PLAXIS_2D_Material_Models_Manual.pdf (2025.1; _new_2026-06-30/); Wood 1990 §7, p. ch. 8	—	114.87	114.859	—	−9.1e-3 %	Pass
k5b-hb-envelope	Hoek–Brown triaxial strength at σ3 = 0, −1, −5, −15 MPa (GSI 50, mi 10, σci 30 MPa): max relative miss [-]	PLAXIS_2D_Material_Models_Manual.pdf (2025.1; _new_2026-06-30/); Hoek, Carranza-Torres & Corkum 2002, p. ch. 4, Eqs 4-1…4-4	—	0	< 1e-6 (asserted)	—	—	Pass
k5b-ngi-adp-strengths self-check	NGI-ADP plane-strain strengths s_u^A / s_u^P / s_u^DSS (input 50 / 25 / 35) [kPa]	PLAXIS_2D_Material_Models_Manual.pdf (2025.1; _new_2026-06-30/); Grimstad, Andresen & Jostad 2012, p. ch. 9	—	50 / 25 / 35	50.0000 / 25.0000 / 35.0000	—	—	Pass
k5b-tangent-check	consistent tangent vs central FD, worst relative error (4×4 through Plane<M>; 6×6 on fully 3-D states) [-]	kernel	—	0	4x4 worst: 2.400e-7; 6x6 HS: 2.800e-8; HSs: 2.500e-8; SS: 2.800e-7; SSC: 2.800e-7; MCC: 9.800e-8; HB: 3.900e-9; NGI-ADP: 1.200e-9	—	—	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
k5b-return-robustness	random-state return-mapping sweep: failed returns per 4000 (HS, HSs, SS, SSC, MCC, HB, HB ψ, NGI-ADP) [-]	kernel	—	0	0	—	—	Pass
k5a-einc-column	top settlement of a confined column with E(y) = E_ref + E_inc (y_ref − y) [m]	—	—	0.0204028	0.0204028	—	0.00 %	Pass
k5a-arc-length-biaxial-limit	limit load factor ΣMstage of the load-controlled bi-axial MC test under arc-length control [-]	PLAXIS-Verification-Biaxial-Mohr-Coulomb.pdf, p. 1–2	—	0.607122	0.607122	—	0.00 %	Pass
k5a-mc-principal-tangent self-check	consistent tangent of the principal-space MC + tension cut-off return, non-associated (ϕ/ψ/σt = 30/0/0, 32/2/0, 25/0/1, 35/10/0) vs central FD and AD [|ΔD|/E]	—	—	1.000e-6	5.430e-7	—	—	Pass
k5d1-hb-strength-factorisation self-check	Hoek–Brown Safety reduction f = σ3 − σ1 − f(σ3)/η(σ3): the reduced envelope is the local tangent Mohr–Coulomb reduced by ΣMsf [-]	PLAXIS-2D-2025.1-Reference-Manual §7.4.5.2, p. Eqs. 7-10…7-13 (p. 319)	—	1.000e-6	—	—	—	Pass
v-hs-published-curve-1 self-check	HS-1 εv medium (drained TC, MMM Fig 13.3): max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM 2015 Figs 13.2–13.5	—	1	2.452	—	—	Deviation
v-hs-published-curve-2 self-check	HS-1 εv dense: max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM 2015 Figs 13.2–13.5	—	1	1.347	—	—	Deviation
v-hs-published-curve-3 self-check	HS-4 εv dense (Hostun): max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM 2025.1 Figs 17-9/17-10	—	1	1.001	—	—	Deviation
v-hs-published-curve-4 self-check	HS-2 q medium (undrained): max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM Figs 13.4/13.5	—	1	3.595	—	—	Deviation
v-hs-published-curve-5 self-check	HS-2 q dense: max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM Figs 13.4/13.5	—	1	3.704	—	—	Deviation
v-hs-published-curve-6 self-check	HS-2 P_excess medium: max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM Figs 13.4/13.5	—	1	1.334	—	—	Deviation
v-hs-published-curve-7 self-check	HS-2 P_excess dense: max normalised distance to the published markers (rule ≤ 1) [-]	PLAXIS-2D-Material-Models-Manual.pdf, p. MMM Figs 13.4/13.5	—	1	7.456	—	—	Deviation
v-hs-published-curve-8 self-check	HSS-1 G dense σ3 100 kPa (Benz 2007 Fig 8.2/8.3): max normalised distance to the published markers (rule ≤ 1) [-]	benz-2007-small-strain-stiffness-of-soils-numerical-consequences.pdf, p. Benz 2007 Figs 8.2/8.3	—	1	1.562	—	—	Deviation
v-hs-published-curve-9 self-check	HSS-1 G loose σ3 100 kPa: max normalised distance to the published markers (rule ≤ 1) [-]	benz-2007-small-strain-stiffness-of-soils-numerical-consequences.pdf, p. Benz 2007 Figs 8.2/8.3	—	1	2.765	—	—	Deviation

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`geostudio-sigmaw-transversely-isotropic-amadei`	wall displacement and tangential stress around a hole in transversely isotropic rock, vs the Amadei closed form [-]	RS2 Stress Analysis Verification Manual (Rocscience), §8, plus Amadei (1983) / Lekhnitskii (1963) closed form, p. §8	—	—	—	—	+0.18 %	Pass
`geostudio-sigmaw-bbm-lambda-suction-alonso`	lambda(s) for suction s = 0.04 / 0.06 / 0.09 MPa [-]	Alonso, Gens & Josa (1990) Geotechnique 40(3), Fig 17(b) p.421-422 and Table 1 p.424, p. Fig 17(b) p.421-422; Table 1 p.424	—	0.06	0.0601	—	+0.17 %	Pass
`geostudio-sigmaw-bbm-lc-yield-alonso`	LC yield-curve preconsolidation pressure p0(s) for s = 0.06 / 0.09 MPa [kPa]	Alonso, Gens & Josa (1990) Geotechnique 40(3), Fig 17(b) p.421-422 and Table 1 p.424, p. Fig 17(b) p.421-422; Table 1 p.424	—	85	85.1	—	+0.12 %	Pass
`geostudio-sigmaw-ss1-mmm-isotropic-compression`	volumetric strain epsilon_v on four load steps (isotropic compression) [-]	PLAXIS 2D 2025.1 Material Models Manual §17.6 Table 17-12, p. §17.6 Table 17-12	—	—	—	—	+2.26 %	Pass
`m17-norsand-cs-plane-strain-lode0`	NorSand drained plane-strain biaxial compression (sigma_3 constant, eps_2 = 0) to eps_1 = 150 %, dense psi_0 = -0.1 (Fig. 3.18a base set): critical stress ratio eta [-]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. App. C eq. C.7 (p. 487), App. A eqs. A.11-A.12 (p. 456); critical-state plane-strain argument: coaxial flow with eps_2 = 0 gives s_2 = 0, theta = 0	—	0.990034	0.99008	—	+5.0e-3 %	Pass
`m17-norsand-cs-triaxial-extension`	NorSand undrained triaxial EXTENSION from a loose isotropic state (psi_0 = +0.03, 200 kPa) to eps_q = 50 %: critical stress ratio eta [-]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. App. C eq. C.7 (p. 487) at theta = -30 deg (A.11, p. 456); Mohr-Coulomb relation M_te = 6 sin(phi)/(3 + sin(phi)) re-derived	—	0.882353	0.88235	—	0.00 %	Pass
`m17-norsand-general-vs-triaxial-reference` self-check	General-stress return vs the pre-M17 triaxial integrator on 6 book paths (Fig. 3.18a drained psi_0 = -0.2, -0.1, 0, +0.04; Fig. 6.19 undrained L601, C609): max |difference| of p', q, eps_v over all output points [relative to p_0 / strain]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. Figs. 3.18a (p. 133) and 6.19 (p. 247): the curves of tests/norsand_book.rs, plus the pre-M17 integrator kept in norsand/triaxial_reference.rs	—	0	7.224e-9	—	+7.2e-7 %	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`m17-norsand-brasted-plane-strain-peak-loose`	NorSand drained plane strain (Cornforth apparatus, sigma_3 = 276 kPa, eps_2 = 0, K0 start), Brasted sand, loose (test A10-14): peak major principal stress sigma_1 [kPa]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. Fig. 3.23 (p. 142, PDF 164), Table 3.4 (p. 140), Table 2.1, Fig. 2.45 (p. 92)	—	1033	1100	—	+6.50 %	Deviation
`m17-norsand-brasted-plane-strain-peak-compact`	NorSand drained plane strain (Cornforth apparatus, sigma_3 = 276 kPa, eps_2 = 0, K0 start), Brasted sand, compact (test A10-12): peak major principal stress sigma_1 [kPa]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. Fig. 3.23 (p. 142, PDF 164), Table 3.4 (p. 140), Table 2.1, Fig. 2.45 (p. 92)	—	1186	1303	—	+9.90 %	Deviation
`m17-norsand-brasted-plane-strain-peak-dense`	NorSand drained plane strain (Cornforth apparatus, sigma_3 = 276 kPa, eps_2 = 0, K0 start), Brasted sand, dense (test A10-17): peak major principal stress sigma_1 [kPa]	books/Jefferies-Been-2016-Soil-Liquefaction-A-Critical-State-Approach-2e-CRC-712p.pdf, p. Fig. 3.23 (p. 142, PDF 164), Table 3.4 (p. 140), Table 2.1, Fig. 2.45 (p. 92)	—	1488	1646	—	+10.6 %	Deviation
`m17-norsand-fe-plane-strain-vs-element` self-check	1 m x 1 m plane-strain T6 sample, isotropic p_0 = 100 kPa then biaxial compression (sigma_x held; drained: sigma_y +90 kPa; undrained-a with Biot K_w = 2e6 kPa: total sigma_y +36 kPa), NorSand through the phase driver vs the single-point element driver on the same load steps: worst |d eps|/|eps| over 20 steps [relative]	tests/f_norsand_fe.rs (self-consistency of the FE driver and the Gauss-point driver; not a published case)	—	0	7.227e-9	—	+7.2e-7 %	Pass

Cited validation suites — 27

`cam-clay-triaxial-web-validation.test.ts`

Validation for the Modified Cam-Clay integrator (`cam-clay-triaxial.ts`).

Analyses validated: `cam-clay-triaxial`, `soil-models` · Recorded run: passed — 20 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
M = 6sinϕ/(3−sinϕ): ϕ_cs=20° → M≈0.772	Pass
M = 6sinϕ/(3−sinϕ): ϕ_cs=25.4° → M≈1.0008	Pass
M = 6sinϕ/(3−sinϕ): ϕ_cs=30° → M≈1.2	Pass
M = 6sinϕ/(3−sinϕ): ϕ_cs=33.4° → M≈1.3484	Pass
NCL void ratio at p′=50: e = N−λ·ln p′ −1	Pass
NCL void ratio at p′=100: e = N−λ·ln p′ −1	Pass
NCL void ratio at p′=200: e = N−λ·ln p′ −1	Pass
NCL void ratio at p′=400: e = N−λ·ln p′ −1	Pass
NC CIU su/p′₀ = (M/2)(½)^Λ: M=0.89, λ=0.16, κ=0.03	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NC CIU su/p′₀ = (M/2)(½)^Λ: M=1, λ=0.2, κ=0.04	Pass
NC CIU su/p′₀ = (M/2)(½)^Λ: M=1.2, λ=0.1, κ=0.02	Pass
NC CIU su/p′₀ = (M/2)(½)^Λ: M=0.95, λ=0.25, κ=0.05	Pass
yield ellipse: CSL intersects at p′=p_c/2, q=M·p_c/2	Pass
MCC elastic step (inside the ellipse) is non-plastic	Pass
NC sample (p=pc) yields under shear (plastic)	Pass
derived κ puts the MCC critical-state line at the printed Γ = 3.16 (hand check, not counted)	Pass
Atkinson & Bransby Ex 10-1 (p. 193): undrained NC test v₀ = 2.0517, q_f = 240, p_f = 255	Pass
Atkinson & Bransby Ex 10-2 (pp. 195–196): drained NC test v_f = 1.886, ε_v = 8.09 %	Pass
Atkinson & Bransby Ex 11-2 (pp. 229–230), sample A: q_f = 239, u_f = 225 kN/m²	Pass
the published-value tally is 7 distinct printed numbers from 1 source; PARTIAL (short of 20 by 13)	Pass

`constitutive-tools-web-validation.test.ts`

constitutive-tools-web-validation.test.ts

Analyses validated: `cam-clay-triaxial`, `drucker-prager`, `duncan-chang`, `ngi-adp`, `soft-soil-creep`, `von-mises` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Drucker-Prager: cone constants equal the de Souza Neto §8.3 compression-corner match (6 anchors)	Pass
Drucker-Prager: the matched cone reproduces the Mohr-Coulomb triaxial deviator EXACTLY (4 anchors)	Pass
Drucker-Prager: ϕ=30°, c=10 kPa, σ₃=100 kPa → q_f = 234.641 kPa, and ψ sets β independently	Pass
Duncan-Chang: E_i, q_f and q_ult on the registry defaults (K=300, n=0.5, σ₃=100 kPa)	Pass
Duncan-Chang: the hyperbola q = ε/(1/E_i + ε/q_ult) at 1 % axial strain	Pass
Duncan-Chang: the model behaves as Duncan & Chang describe (5 monotonicity anchors)	Pass
NGI-ADP: the three anisotropic strengths are the declared ratios of s_u^A (4 anchors)	Pass
NGI-ADP: anisotropy ordering and the isotropic limit (5 anchors)	Pass
Cam-Clay: M, Λ and p′_cs/p′₀ = (½)^Λ on the registry defaults (5 anchors)	Pass
Cam-Clay: s_u/p′₀ = ½ M (½)^Λ, so the undrained strength follows from the CSL alone	Pass
Soft-Soil-Creep: λ*, κ*, μ* and M from the published definitions (6 anchors)	Pass
Soft-Soil-Creep: creep strain per log-decade is μ*·ln10, and λ* > κ* > μ* for a real clay	Pass
von Mises: q from the principal stresses, plus the yield decision (6 anchors)	Pass
every constitutive tool returns finite numbers on its defaults and at parameter extremes	Pass
duncan-chang: σ₃ = 0 is an UNCONFINED test, which the hyperbolic fit cannot represent	Pass

`dp-material-point-web-validation.test.ts`

Web-benchmark validation for the Drucker-Prager material-point integrator (`dp-material-point.ts`).

Analyses validated: `mohr-coulomb`, `soil-models` · Recorded run: passed — 24 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
DP q_f == MC q_f (compression corner): σ3=50, c=10, ϕ=30	Pass
DP q_f == MC q_f (compression corner): σ3=100, c=10, ϕ=30	Pass
DP q_f == MC q_f (compression corner): σ3=200, c=10, ϕ=30	Pass
DP q_f == MC q_f (compression corner): σ3=100, c=0, ϕ=35	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
DP q_f == MC q_f (compression corner): σ3=200, c=0, ϕ=35	Pass
DP q_f == MC q_f (compression corner): σ3=300, c=0, ϕ=40	Pass
DP q_f == MC q_f (compression corner): σ3=100, c=25, ϕ=0	Pass
DP q_f == MC q_f (compression corner): σ3=50, c=50, ϕ=0	Pass
DP q_f == MC q_f (compression corner): σ3=300, c=1, ϕ=34	Pass
DP q_f == MC q_f (compression corner): σ3=10, c=5, ϕ=25	Pass
DP q_f == MC q_f (compression corner): σ3=500, c=20, ϕ=38	Pass
DP apex return → p = −c·cotϕ, c=10, ϕ=30	Pass
DP apex return → p = −c·cotϕ, c=20, ϕ=35	Pass
DP elastic step below yield returns exact elastic stress	Pass
DP plastic return lands on the cone (f≈0), ϕ=20	Pass
DP plastic return lands on the cone (f≈0), ϕ=30	Pass
DP plastic return lands on the cone (f≈0), ϕ=40	Pass
DP dilatancy (ψ>0) raises mean stress vs ψ=0	Pass
DP drained triaxial integrates to q_f (multi-step), ϕ=30, c=10	Pass
DP drained triaxial integrates to q_f (multi-step), ϕ=35, c=0	Pass
general DP (axis-aligned) equals the principal integrator	Pass
general DP return lands on the cone for a shear state, ϕ=25	Pass
general DP return lands on the cone for a shear state, ϕ=35	Pass
general DP objectivity: I1 invariant across shear plane	Pass

drucker-prager-web-validation.test.ts

Validation for the Drucker-Prager cone runner (`dp-material-point.ts`: `computeDruckerPragerRunner`, `dpConstants`, `dpTriaxialFailure`) — slug `drucker-prager`.

Analyses validated: `drucker-prager` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Lambe & Whitman Ex 11.1 (p. 140): DP compression failure σ1f = σ3 + q_f at the printed ϕ, four tests	Pass
Craig Ex 5.2 (p. 178): printed σ′1 lies in the ±0.5° bracket of the printed secant ϕ′	Pass
PLAXIS 3DF §2.4 and COMSOL Table 2: DP compression failure stress 372.9 and 1064.9 kPa	Pass
de Souza Neto et al. §8.4.3: plane-strain footing limit load of the compression-matched cone, P_lim/c ≈ 35.7	Pass
the published-value tally is 10 distinct printed numbers from 5 sources; PARTIAL (short of 20 by 10)	Pass

duncan-chang-web-validation.test.ts

Validation for the Duncan-Chang hyperbolic model (`duncan-chang.ts`).

Analyses validated: `duncan-chang`, `soil-models` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
MC failure deviator matches the closed form	Pass
initial tangent modulus Ei = K·pa·(σ3/pa)^n	Pass
initial slope of q(ε) equals Ei	Pass
deviator asymptotes to (σ1−σ3)_ult = qf/Rf	Pass
tangent modulus: Et=Ei at SL=0, (1−Rf)²Ei at SL=1	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
deviator always below failure for finite strain	Pass
Duncan-Chang MC failure deviator q_f = (2c·cosϕ + 2σ₃·sinϕ)/(1−sinϕ) — cited sweep	Pass
Duncan-Chang initial tangent modulus Ei = K·pa·(σ₃/pa)^n — cited sweep	Pass
Duncan-Chang tangent modulus Et = (1−Rf·SL)²·Ei — cited SL sweep (σ₃=100)	Pass
Duncan-Chang hyperbolic q(ε) = ε/(1/Ei + ε·Rf/q_f) — cited values (σ₃=100)	Pass

fe-interface-2d-web-validation.test.ts

Validation for the 2-D SSI elements embedded in the continuum (`fe-interface-2d.ts`): the zero-thickness Goodman INTERFACE (elastic normal/shear + Mohr-Coulomb slip) and the Euler-Bernoulli PLATE/beam sharing continuum node DOFs.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
interface elastic shear transfer: slip = τ/k_s, σ_n from the applied normal load (below slip)	Pass
interface Mohr-Coulomb slip: shear capped at c + σ_n·tanδ	Pass
frictionless interface (c=0, δ=0) slips under any shear	Pass
plate cantilever: tip deflection PL³/3EI and rotation PL²/2EI (Euler-Bernoulli)	Pass
plate axial: u = PL/EA	Pass
interface + continuum solve converges (slip state settles)	Pass

hardening-soil-double-web-validation.test.ts

Validation for the FULL double-hardening Hardening-Soil integrator (`hardening-soil-double.ts`).

Analyses validated: `hardening-soil` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
HS-double: MC failure cap σ₁_f = 1064.9 kPa at σ₃=300 (COMSOL 6.3 Table 2, closed-form MC value)	Pass
HS-double WEB: $E_{50}(\sigma_3)$ matches the HS power law (100→20 MPa, 300→40.6 MPa)	Pass
HS-double: secant modulus at q_f/2 = E_{50} (self-consistent hardening)	Pass
HS-double: primary backbone matches the closed-form hardening-soil SoilTest	Pass
HS-double: unload–reload loop stiffness ≈ E_ur ≫ loading secant (Schanz-Vermeer)	Pass
HS-double: plastic shear/volumetric strain tracked; dense sand dilates near failure	Pass
HS-double CAP: oedometer plastic compression + K_0^{Nc} = 1 − sinϕ	Pass

hardening-soil-web-validation.test.ts

Validation for the Hardening-Soil (HS) SoilTest engine (`hardening-soil.ts`).

Analyses validated: `hardening-soil` · Recorded run: passed — 21 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
HS web A1: E50(σ3=pref) = E50ref [Berlin]	Pass
HS web A2: Eur(σ3=pref) = Eurref [Berlin]	Pass
HS web A4: Ei = 2·E50/(2−Rf) = 81.818 MPa [Berlin σ3=100]	Pass
HS web A5–A8: E50 stress scaling [Berlin]	Pass
HS web A9–A13: qf = 2(c·cosϕ+σ3·sinϕ)/(1−sinϕ) [Berlin]	Pass
HS web: σ1f = σ3 + qf [Berlin σ3=50,200]	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
HS web A14: Ei = 119.324 MPa [Berlin σ3=200]	Pass
HS web A15: Eur = 327.67 MPa [Berlin σ3=300]	Pass
HS web A16: Eur/E50 = 4.0 stress-independent [Berlin]	Pass
HS web A17: ϕ_cv = 30.80° [Berlin ϕ=35,ψ=5]	Pass
HS web A18: COMSOL Table 2 σ1f = 1064.9 kPa [σ3=300] (MC cap, not SVB)	Pass
HS web A19–A21: Monterey Ei = 2·E50/(2−Rf) identity [identity, parameter set untraced]	Pass
HS web A22: secant modulus at qf/2 = E50 (E50_secant_error ≈ 0)	Pass
HS web A23: Ei/E50 = 2/(2−Rf) across Rf	Pass
HS web A3: Eoed(σ=pref) = Eoedref [Berlin oedometer]	Pass
PLAXIS 3DF Validation Manual §2.4: HS triaxial failure σ1 = 372.9 (theory) / 373.3 (FE), σ3 = 100	Pass
COMSOL Table 2: σ1f = 1064.9 kPa (MC cap, independent of E50, m, Rf)	Pass
PLAXIS Material Models Manual (2015) Tables 13.1/13.2/13.13: K0nc = 1 − sinϕ at ϕ = 30, 34, 35, 38, 40, 41°	Pass
default E_ur = 3·E50 reproduces the printed E_ur columns (PMM Table 13.1, RS3 Table 15.1)	Pass
PLAXIS default values: p_ref = 100, R_f = 0.9, E_oed = E50 (PMM 2015 pp. 7, 66, 71)	Pass
the published-value tally is 16 distinct printed numbers; PARTIAL (short of 20 by 4)	Pass

hs-cap-oedometer-web-validation.test.ts

Validation for the HS CAP OEDOMETER / K_0 BRANCH — the combined shear+cap axisymmetric return-map (`integrateHsAxiStep` / `hsOedometerRun`) and the implicit two-parameter (M, K_s/K_c) ← (K_0^{NC}, E_oed^ref) calibration (`calibrateHsCap`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
EXACT limit — cap off (K_s/K_c ≤ 1) reproduces the validated shear-only triaxial	Pass
EXACT limit — isotropic strain keeps the deviator exactly zero (axisymmetric cap flow)	Pass
implicit calibration reproduces BOTH K_0^{NC} and E_oed^ref	Pass
INDEPENDENT cross-check: E_oed(σv) matches the validated computeHsDouble power law	Pass
K_0 stays constant along NC loading (a radial stress path — the calibrated-cap signature)	Pass
consistent-γ^p / p_p initialisers leave BOTH surfaces exactly satisfied at a K_0 state	Pass

hs-cap-web-validation.test.ts

Validation for the HS VOLUMETRIC CAP (compaction hardening) — the second HS yield surface (`hs-material-point.ts`: hsCapParams / integrateHardeningSoilVolumetric / hsIsotropicCompression).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
cap parameters: K_s^ref = E_ur^ref/(3(1−2ν_ur)) and K_s/K_c > 1 (Eq 6.23)	Pass
cap DISABLED when E_oed^ref omitted (shear-hardening only, no regression)	Pass
K_c = K_s^ref/(K_s/K_c) and K_s = K_s^ref at the reference pressure (Eq 6.22)	Pass
both moduli follow the (p/p_ref)^m stress-dependency	Pass
pre-consolidation (OCR): elastic inside the cap, plastic once p reaches p_p	Pass
p_p hardens to track the maximum mean stress under virgin (NC) loading	Pass
isotropic loading is softer than swelling (K_c < K_s) — the defining compaction-hardening signature	Pass

hs-material-point-web-validation.test.ts

Validation for the Hardening-Soil material-point integrator (`hs-material-point.ts`) — the general SVB return-map (shear/cone hardening) that the 2-D FE will use.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
HS return-map reproduces the SVB drained-triaxial hyperbola at σ_3=100 kPa (<3%)	Pass
HS return-map reproduces the SVB drained-triaxial hyperbola at σ_3=200 kPa (<3%)	Pass
HS return-map reproduces the SVB drained-triaxial hyperbola at σ_3=300 kPa (<3%)	Pass
HS return-map reproduces the SVB drained-triaxial hyperbola at σ_3=600 kPa (<3%)	Pass
failure deviator = MC: σ_1_f(σ_3=300) = 1064.9 kPa (COMSOL 6.3 Table 2 closed-form MC value, not an SVB number)	Pass
the driven deviator approaches the MC failure envelope q_f at large strain	Pass
secant modulus at q_f/2 equals E_{50}(σ_3) (the HS E_{50} definition)	Pass
isotropic (deviator-free) loading stays elastic on the shear surface (γ^p unchanged)	Pass
mobilised friction hardens with plastic shear strain toward the peak φ	Pass
higher confining pressure → higher failure deviator and stiffer response	Pass
general Cartesian material point: isotropic + deviatoric strain returns a coaxial plastic state	Pass
general Cartesian material point handles an off-axis shear strain increment (finite, hardening)	Pass

hs-small-fe-web-validation.test.ts

Validation for the HS-Small small-strain constitutive OVERLAY (`hs-small-stiffness.ts`): the stress-dependent very-small-strain modulus G0(σ3) and the simple-shear constitutive integrator `hsSmallSimpleShear` — the per-integration-point st…

Analyses validated: `hs-small`, `soil-models` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
tangent integrates exactly to the Hardin-Drnevich secant (below the G_ur cut-off)	Pass
G_s(γ0.7)/G0 = 0.722 (definition of γ0.7)	Pass
stress-dependent G0(σ3) follows the (σ3/p_ref)^m power law	Pass
tangent floors at G_ur beyond the cut-off strain (never softer than unload-reload)	Pass
secant modulus degrades monotonically with shear strain	Pass

hs-small-general-web-validation.test.ts

Validation for the GENERAL-STRESS (Voigt6) HS-Small material point `integrateHsSmallGeneral` — the FE Gauss-point entry that couples the Benz (2007) Small-Strain Overlay to the Hardening-Soil return map.

Analyses validated: `hs-small` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
HS-Small with G0 = Gur^ref reduces to plain HS (1e-9)	Pass
HS-Small: an elastic (inside-the-cone) path follows the reloading curve G0/(1 + aγ/(2γ0.7)) (γ = 3/2 εq)	Pass
ENG-2: HS-Small γHist of an undrained triaxial increment equals ε1 − ε3 (PLAXIS Eq. 7.6)	Pass
HS-Small: mobilised shear modulus floors at the HS Eur modulus at large strain	Pass
HS-Small: general shear-coupled increment returns a finite stress	Pass

hs-small-kernel-law-web-validation.test.ts

HS-small (Benz 2007) — the kernel's law in the TypeScript twin (KB-2, 12 Nov 2026).

Analyses validated: `hs-small`, `soil-models` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
G1 small-strain limit: G = G0 exactly below γHist 1e-6; G → G0 as γ → 0 on the reloading curve	Pass
G2 first loading: Gm·Gur of a virgin step is the Hardin–Drnevich secant G0/(1 + 0.385γ/γ0.7)	Pass
G2 kernel expectations (hs_small_gamma_hist.rs): γHist measure, history accumulation, Gm over [γ9, γ10]	Pass
G3 Gur cut-off: Gur beyond γc(reload); the straddling step integrates the cut-off; never below Gur	Pass
G3 1-D calculator: the secant beyond γc integrates the tangent cut-off (Benz Fig. 7.6), = 31 494 kPa at γ = 2e-3	Pass
G4 Masing after one reversal: back to G0 on the 2·γ0.7 curve; Gm keeps its minimum	Pass
G5 h_i attenuation: one drained triaxial step from 100 kPa isotropic matches the hand form to 1e-6	Pass
G6 KB-2a: from an isotropic state HS-small is never softer than plain HS, and ≥ 3× stiffer at γxy = 1e-5	Pass
G7 G0 = Gur^ref: the overlay is inert and HS-small is plain HS over a path (1e-9)	Pass
G8 refusals: the kernel's HsParams::validate rules	Pass

hs-small-stiffness-web-validation.test.ts

Validation for the HS-Small small-strain stiffness overlay (`hs-small-stiffness.ts`).

Analyses validated: `hs-small`, `soil-models` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
G_s → G0 as γ → 0	Pass
G_s = 0.722·G0 exactly at γ = γ0.7 (definition)	Pass
tangent modulus below secant, and G_t = G0/(1+aγ/γ07)²	Pass
monotonic decay of G_s with increasing γ	Pass
cut-off at G_ur: G never below G_ur; cut-off strain consistent	Pass

mc-general-stress-web-validation.test.ts

Web-benchmark validation for the symmetric-3×3 eigensolver + general-stress (Cartesian) Mohr-Coulomb material point (`tensor-3x3.ts` + the general MC entry in `mc-material-point.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
eigSym3 of a diagonal matrix returns sorted diagonal	Pass
eigSym3 of a 2×2 shear block: [[2,1],[1,2]] → 3 and 1	Pass
eigSym3 reconstruct: Σ λ n⊗n recovers the original tensor	Pass
general MC (axis-aligned) equals the principal integrator	Pass
general MC return lands on the surface for a shear state, ϕ=20	Pass
general MC return lands on the surface for a shear state, ϕ=30	Pass
general MC return lands on the surface for a shear state, ϕ=40	Pass
objectivity: I1 and J2 of the returned stress are rotation-invariant	Pass
general MC small step stays elastic	Pass

mc-material-point-web-validation.test.ts

Web-benchmark validation for the Mohr-Coulomb material-point integrator (`mc-material-point.ts`).

Analyses validated: `mohr-coulomb` · Recorded run: passed — 23 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
MC failure deviator matches closed form: σ3=50, c=10, ϕ=30	Pass
MC failure deviator matches closed form: σ3=100, c=10, ϕ=30	Pass
MC failure deviator matches closed form: σ3=200, c=10, ϕ=30	Pass
MC failure deviator matches closed form: σ3=100, c=0, ϕ=35	Pass
MC failure deviator matches closed form: σ3=200, c=0, ϕ=35	Pass
MC failure deviator matches closed form: σ3=300, c=0, ϕ=40	Pass
MC failure deviator matches closed form: σ3=100, c=25, ϕ=0	Pass
MC failure deviator matches closed form: σ3=50, c=50, ϕ=0	Pass
MC failure deviator matches closed form: σ3=300, c=1, ϕ=34	Pass
MC failure deviator matches closed form: σ3=10, c=5, ϕ=25	Pass
MC failure deviator matches closed form: σ3=500, c=20, ϕ=38	Pass
COMSOL 6.3 Table 2 MC benchmark: σ3=300, ϕ=34°, c=1 → σ1f ≈ 1064.9 kPa	Pass
elastic step below yield returns the exact elastic stress (no plastic)	Pass
elastic deviatoric step just inside the surface stays elastic	Pass
plastic return lands ON the yield surface (f≈0), ϕ=20	Pass
plastic return lands ON the yield surface (f≈0), ϕ=30	Pass
plastic return lands ON the yield surface (f≈0), ϕ=40	Pass
returned stress satisfies the MC criterion σ1 = σ3·Nϕ + 2c√Nϕ	Pass
apex return: isotropic tensile pull → σ = −c·cotϕ, c=10, ϕ=30	Pass
apex return: isotropic tensile pull → σ = −c·cotϕ, c=20, ϕ=35	Pass
associated (ψ=ϕ) dilates; ψ=0 is (near) isochoric plastic flow	Pass
drained triaxial integrates to q_f (multi-step), ϕ=30, c=10	Pass
drained triaxial integrates to q_f (multi-step), ϕ=35, c=0	Pass

mcc-general-web-validation.test.ts

Validation for the GENERAL-STRESS (Voigt6) Modified Cam-Clay material point `integrateModifiedCamClayGeneral` — the FE Gauss-point entry that lets the general T6 solver run critical-state plasticity.

Analyses validated: `cam-clay-triaxial`, `soil-models` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
MCC general ≡ triaxial mccStep on a triaxial path (dilatant shear)	Pass
MCC general ≡ triaxial mccStep on a triaxial path (isotropic compression)	Pass
MCC general ≡ triaxial mccStep on a triaxial path (near-undrained shear)	Pass
MCC general undrained NC critical state (ϕ_cs=25.4°)	Pass
MCC general undrained NC critical state (ϕ_cs=30°)	Pass
MCC general undrained NC critical state (ϕ_cs=22°)	Pass
MCC general elastic step is non-plastic and exact	Pass
MCC general: plastic state lies on the yield surface (triaxial)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
MCC general: plastic state on the yield surface under shear strain	Pass

mohr-coulomb-web-validation.test.ts

PUBLISHED-VALUES(mohr-coulomb): 17 -- distinct published values for this engine (engine-level total, declared once); re-run author's strict count: the 21 includes 4 Lambe & Whitman sigma1f/ratio pairs that are the same four experiments pri…

Analyses validated: `mohr-coulomb` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
N_φ = tan²(45° + φ/2) — the published flow factor at 8 friction angles	Pass
σ1f = σ3·N_φ + 2c·√N_φ — 12 published failure states	Pass
undrained clay (φ = 0): the deviator at failure is 2c, independent of confining stress	Pass
unconfined compressive strength q_u = 2c·√N_φ	Pass
failure-plane geometry: θ_f = 45° + φ/2, and σ_n / τ_f from the same Mohr circle	Pass
monotonicity and finiteness across the admissible parameter range	Pass
Lambe & Whitman Ex 11.1 (p. 140): σ1f from printed σ3f and φ, four tests	Pass
Lambe & Whitman Ex 11.1 (p. 140): θcr = 45° + φ/2 = 66° for the average φ = 42.1°	Pass
Lambe & Whitman Ex 11.2 (p. 142): sinφ = tanα = 0.675 on the p–q diagram, φ = 42.5°	Pass
Craig Ex 5.2 (p. 178): printed σ′1 lies in the ±0.5° bracket of the printed secant φ′	Pass
Lambe & Whitman Fig. 21.6 (p. 308): p–q intercept a = c·cosφ′ = 6.9 kN/m² for c = 7.4, φ′ = 21.5°	Pass
PLAXIS 3DF Validation Manual §2.3 (pp. 2-5/2-6): MC bi-axial failure stress 6.46 (theory), 6.48 (FE)	Pass
PLAXIS 3DF Validation Manual §2.4 (pp. 2-7/2-8): 372.9 and 373.3 compression, 26.1 extension	Pass
COMSOL HS triaxial Table 2: MC failure stress 1064.9 kPa compression, 83.7 kPa extension (c = 1, φ = 34°, σ3 = 300)	Pass
the published-value tally is 21 distinct printed numbers from 4 sources	Pass

ngi-adp-web-validation.test.ts

Web-benchmark validation for the NGI-ADP anisotropic undrained material point (`ngi-adp.ts`).

Analyses validated: `ngi-adp` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NGI-ADP ellipse constants RA, RB, RD (Grimstad 2012 Eq 12.22)	Pass
NGI-ADP Active strength → suA (P1=40, P2=100)	Pass
NGI-ADP Passive strength → suP (P1=16, P2=60)	Pass
NGI-ADP DSS strength → suDSS (P1=26.4, P2=80)	Pass
NGI-ADP f=0 at Active/Passive/DSS failure points (Eq 12.3)	Pass
NGI-ADP isotropic → Tresca: su=25 ⇒ q=2su=50	Pass
NGI-ADP isotropic → Tresca: su=50 ⇒ q=2su=100	Pass
NGI-ADP isotropic → Tresca: su=120 ⇒ q=2su=240	Pass
NGI-ADP τ0 = ½σ'v0(1−K0)	Pass
NGI-ADP hardening κ(γp) endpoints + peak (Eq 12.2)	Pass
NGI-ADP envelope sweep — all points satisfy f=0	Pass
NGI-ADP interior f<0, exterior f>0	Pass
NGI-ADP M from φ (6sinφ/(3−sinφ))	Pass
NGI-ADP integrator: monotone vertical shear → peak τ = suA (Active)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NGI-ADP integrator: pure shear at the ellipse-centre deviator → peak τxy = suDSS	Pass

soft-soil-creep-web-validation.test.ts

Web-benchmark validation for the Soft-Soil-Creep material point (`soft-soil-creep.ts`).

Analyses validated: `soft-soil-creep` · Recorded run: passed — 15 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
SSC M = 6sinϕ/(3−sinϕ) (Eq 9.19)	Pass
SSC ϕ↔M round-trip (inverse of Eq 9.19)	Pass
SSC parameter conversion Cc/Cs/Cα/e0 → λ*,κ*,μ* (Eqs 9.6/9.9/9.22)	Pass
SSC parameter conversion — soft-clay set 2	Pass
SSC creep strain per log-decade = μ*·ln10 = Cα/(1+e0) (Mesri & Godlewski)	Pass
SSC Buisman 1-D creep: t′=τc → μ*·ln2 ; per decade → μ*·ln10	Pass
SSC creep rate at NC (OCR=1) = μ*/τ (Eq 9.23)	Pass
SSC creep rate decreases with OCR (over-consolidation slows creep)	Pass
SSC μ*=0 → zero creep rate (Soft-Soil limit)	Pass
SSC ageing pre-consolidation grows with creep (Bjerrum)	Pass
SSC equivalent stress (Eq 9.18): q=0 → p^eq=p′ ; on CSL q=Mp′ → 2p′	Pass
SSC elastic swelling κ*·ln(p′/p′0) (Eq 9.28)	Pass
SSC oedometer creep ODE integrates to Buisman μ*·ln(1+t/τ)	Pass
SSC oedometer late-time slope → μ*·ln10 per decade	Pass
SSC step μ*=0: pure elastic κ* response, no creep	Pass

soil-calibration-web-validation.test.ts

Validation for the SoilTest calibration lab (`soil-calibration.ts`).

Analyses validated: `mohr-coulomb`, `soil-calibration` · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
fit MC recovers c=15, ϕ=28 from clean triaxial points	Pass
fit MC recovers c=0, ϕ=35 from clean triaxial points	Pass
fit MC recovers c=25, ϕ=20 from clean triaxial points	Pass
fit MC recovers c=5, ϕ=40 from clean triaxial points	Pass
fit MC is robust to measurement noise	Pass
fit undrained su = q_f/2	Pass
fit oedometer recovers Cc and Cr	Pass
fit E50 = (q_f/2)/ε at half failure	Pass
fit CSL M from critical-state points	Pass
published: Craig Example 5.4(a) UU triaxial → c_u = 85 kPa, ϕ_u = 0	Pass
published: Craig Example 5.4(b) CD triaxial → c′ = 0, ϕ′ = 27°	Pass
published: Craig Example 4.1 oedometer Table 4.1 → C_c = 0.31 on the linear part	Pass
published: Das Example 2.12 → C_c = 0.333 from (140 kPa, e 0.92) and (212 kPa, e 0.86)	Pass
published: Lambe & Whitman Example 11.1 — four triaxial peaks on dense sand → ϕ = 42.1°, c = 0	Pass

soil-structure-interface-web-validation.test.ts

WEB-BENCHMARK validation for the soil-structure interface (Goodman joint) engine.

Analyses validated: `soil-structure-interface` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
SSI web A1–A6: interface friction δ = atan(R_inter·tanφ)	Pass
SSI web A7–A9: interface adhesion c_i = R_inter·c	Pass
SSI web A10–A13: τ_max = c_i + σ_n·tanδ	Pass
SSI web A14: R_inter=1 ⇒ interface strength = soil strength	Pass
SSI web A15–A17: strength reduction ≈ R_inter (c=0)	Pass
SSI web A18–A19: Potyondy steel/sand δ/φ in [0.5, 0.8]	Pass
SSI web A20: Potyondy concrete/sand δ/φ ≈ 0.84–1.0	Pass
SSI web A21: Goodman elastic-plastic load-slip (slope k_s, plateau τ_max)	Pass

ssc-general-web-validation.test.ts

Validation for the GENERAL-STRESS (Voigt6) Soft-Soil-Creep material point `integrateSoftSoilCreepGeneral` — the FE Gauss-point entry for time-dependent secondary compression / creep, so the general T6 solver can run SSC.

Analyses validated: `soft-soil-creep` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
SSC general ≡ (p′,q) sscStep on a triaxial path (compression + shear)	Pass
SSC general ≡ (p′,q) sscStep on a triaxial path (isotropic compression)	Pass
SSC general: NC (OCR=1) creep rate is μ*/τ	Pass
SSC general: μ*=0 gives no creep and an exact elastic step	Pass
SSC general: pre-consolidation ages upward under sustained creep	Pass
SSC general: shear-coupled increment returns a finite stress	Pass

stress-path-web-validation.test.ts

Validation for `stress-path` — p-q (Cambridge) and s-t (MIT) stress-path invariants, mobilised friction and the failure check (`stress-path.ts`).

Analyses validated: `stress-path` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Head & Epps Fig. 16.14(a): s′ and t at 0.67, 1.12 and 1.54 % strain	Pass
Head & Epps Fig. 16.14(a): s′ and t at 2.18 and 3.06 % strain	Pass
L&W Example 11.1: printed p = ½(σ1 + σ3) and q = ½(σ1 − σ3) for the four peak states	Pass
L&W Example 11.1: mobilised friction at peak = 42.2°, 41.6°, 42.7°, 42.1° (c = 0)	Pass
Craig Example 5.2: secant φ′ of circles (a), (b), (c) = 35°, 33°, 31°	Pass
Craig Example 5.6: drained failure point q_f = 374, p′f = 425, η = M = 0.88, path slope 3	Pass
Craig 7th Solutions CU test: printed s′ = 411, 402, 389, 351, 326 and t = 40, 79, 107, 139, 159 kPa	Pass

⚑ triaxial-csl-web-validation.test.ts

PUBLISHED-VALUES(triaxial-csl): 13 -- distinct published values for this engine (engine-level total, declared once); re-run author's count: of 21 values only 13 are failure states in and a book answer out; 8 feed states built on a publishe…

Analyses validated: `triaxial-csl` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
L&W Example 11.1: four peak states → ϕ_f average 42.1°	Pass
L&W Weald clay: Kf line a = 6.9, α = 20.3° → ϕ = 21.5°, c = 7.4 kN/m²	Pass
L&W NC Weald clay: Kf line through the origin with α = 20½° → ϕ = 22°, no cohesion	Pass
Head & Epps Fig. 16.14(b): Kf line θ = 20.5°, t0 = 12 kPa → ϕ′ = 22°, c′ = 13 kPa	Pass
Craig 8th Ex 5.2: effective-stress failure states → tangent c′ = 20 kPa, ϕ′ = 29° (graphical, 200-300 kPa)	Pass
Craig 8th Ex 5.4(a): UU states (370,200), (564,400), (772,600) → cu = 85 kPa, ϕu = 0	Pass
Craig 8th Ex 5.4(b): drained states (530,200), (1091,400), (1620,600) → c′ = 0, ϕ′ = 27°	Pass
Craig 8th Ex 5.6: states on q = 0.88 p′ → ϕ′cv = 23°	Pass
Craig 7th Solutions Q4.2: sand σ3 = 100…800, σ1 − σ3 = 452…3624 → ϕ′ = 44°	Pass
Craig 7th Solutions Q4.3: UU σ3 = 200, 400, 600, σ1 − σ3 = 222, 218, 220 → cu = 110 kN/m², ϕu = 0	Pass
Craig 7th Solutions Q4.4: a′ = 13 kN/m², α′ = 26° → ϕ′ = 29°, c′ = 15 kN/m²	Pass
Craig 7th Solutions Q4.5: CU clay effective states (171,68), (333,131), (503,198), (679,269) → c′ = 0, ϕ′ = 25½°	Pass

von-mises-material-point-web-validation.test.ts

Validation for the von Mises (J2) radial-return material point (`von-mises-material-point.ts`: `vonMisesQ`, `integrateVonMises`) — slug `von-mises`.

Analyses validated: `von-mises` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
elastic below yield: pure shear stays elastic and q correct	Pass
after plastic return, q = σ_y exactly (multiple strain paths)	Pass
plastic flow is isochoric: mean stress unchanged by the return	Pass
uniaxial: yields when axial stress reaches σ_y	Pass
vonMisesQ of a uniaxial stress equals the axial stress	Pass
de Souza Neto et al. §7.5.1 (p. 246): cylinder limit pressure P_lim = Y·ln(b/a) = 0.19209 GPa	Pass
de Souza Neto et al. §7.5.1 (p. 247): at P = 0.18 GPa the plastic front is at c ≈ 159.79 mm	Pass
de Souza Neto et al. §7.5.2 (p. 248): sphere limit pressure P_lim = 2(σ_θ−σ_r)_y·ln(b/a) = 0.33271 GPa	Pass
the published-value tally is 3 distinct printed numbers from 1 source; PARTIAL (short of 20 by 17)	Pass

Finite-element meshing, solvers and procedures

FE kernel registry — 8 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
plaxis-verif-k5-set	plaxis-verif-k5-set	Hoek-Brown-material-model, Triaxial-Hardening-Soil, Soft-Soil-Creep-Haney-clay, Phi-c-reduction-vs-Bishop, Benchmark-embankment-soft-clay	—	—	—	—	—	Superseded
plaxis-verif-v2-set	plaxis-verif-v2-set	Lamb-problem, Surface-waves, Pulse-load-multilayer, One-dimensional-wave-propagation, Vertical-dynamic-response-footing, Free-vibration-dam, Ground-response-linear-soil	—	—	—	—	—	Superseded
v-gravity-loading-layered-column	σ'yy = −Σγh and σ'xx = ν/(1−ν) σ'yy at 240 Gauss points; crest settlement ∫σ'yy/E_oed dy, two layers [kPa, m]	—, p. Das, Principles of Geotechnical Engineering (overburden); Lambe & Whitman ch. 7; constrained modulus	—	-0.046371	-0.046371	—	0.00 %	Pass
v-reset-displacements-closed-form	crest displacement after a surcharge phase with reset: q Σh/E_oed; without reset: gravity + q Σh/E_oed [m]	PLAXIS-2D-2025.1-Reference-Manual-Seequent-Bentley.pdf, p. p. 343 (§7.9.2.3)	—	[-0.031071, -0.077443]	[-0.031071, -0.077443]	—	[0, 0]	Pass
v-rm-global-coarseness-r_e	r_e of the five levels [-]	PLAXIS-2D-2025.1-Reference-Manual-Seequent-Bentley.pdf, p. p. 299 (§7.1.2)	—	[2, 1.33, 1, 0.67, 0.5]	[2, 1.33, 1, 0.67, 0.5]	—	0.00 %	Pass
v-rm-global-coarseness-le	l_e / (r_e · diagonal) [-]	PLAXIS-2D-2025.1-Reference-Manual-Seequent-Bentley.pdf, p. p. 299 (Eq. 7-1)	—	0.06	0.06	—	0.00 %	Pass
v-rocscience-mesh-quality-shape-stats	min interior angle of a 3-4-5 triangle via mesh2d::report::shape_stats (what the model screen prints as 'Min. angle') [deg]	—	—	36.8699	36.8699	—	0.00 %	Pass
v-rocscience-mesh-sizing	element size rule l_e = r_e/20·diagonal on a 30 × 40 m box ('medium'); graded ceiling h(x)=min(l_e, f·l_e+0.5·d); area conservation [m]	—	—	2.5	2.5	—	0.00 %	Pass

Cited validation suites — 17

classical-closed-forms-web-validation.test.ts

Web-benchmark validation for EIGHT classical closed-form runner engines.

Analyses validated: `capillary-rise`, `circular-load-stress`, `darcy-velocity`, `effective-stress`, `k0-at-rest`, `layered-permeability`, `line-load-stress`, `strip-load-stress` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
circular-load-stress reproduces the Boussinesq on-axis solution	Pass
line-load-stress reproduces Boussinesq $\Delta\sigma_z = 2Pz^3/[\pi(x^2 + z^2)^2]$	Pass
strip-load-stress reproduces the strip solution and brackets the 2:1 method	Pass
k0-at-rest follows Jaky $K_o = 1 - \sin\phi'$ with the triangular thrust	Pass
capillary-rise follows $h_c = C/(e \cdot D_{10})$ with consistent units	Pass
darcy-velocity separates discharge velocity from seepage velocity	Pass
layered-permeability gives the weighted arithmetic k_h and harmonic k_v	Pass
effective-stress is Terzaghi $\sigma' = \sigma - u$ with the water table respected	Pass

fe-assemble-t6-web-validation.test.ts

Validation for the T6 global assembly/solver (`fe-assemble-t6.ts`).

Analyses validated: `mesh-viewer` · Recorded run: passed — 3 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
T6 mesh builder dedups mid-side nodes by edge	Pass
constant-strain patch test on a T6 mesh (εxx=g)	Pass
T6 reproduces a LINEAR strain field: u=(a·x², 0) → εxx = 2a·x	Pass

fe-core-2d-web-validation.test.ts

Web-benchmark validation for the TerraCore 2-D plane-strain FE core (`fe-core-2d.ts`).

Analyses validated: `mesh-viewer` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
planeStrainD matches the closed form	Pass
patch test: uniform εxx reproduced exactly in every element	Pass
uniaxial-strain confined ratio σyy/σxx = ν/(1−ν)	Pass
rigid-body translation produces zero strain/stress	Pass

fe-core-t6-web-validation.test.ts

Validation for the T6 quadratic element (`fe-core-t6.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Jacobian: detJ = 2·area (=4) for the straight-sided T6	Pass
constant-strain patch: linear u=(g·x,0) → εxx=g at every Gauss point	Pass
LINEAR strain patch: quadratic u=(a·x²,0) → εxx=2a·x EXACTLY (T6 advantage)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
shear quadratic field u=(0, b·x²) → γxy = 2b·x reproduced exactly	Pass
T6 stiffness is symmetric and rigid-body/rank consistent	Pass

fe-gravity-web-validation.test.ts

Validation for FE self-weight (gravity) loading (`gravityLoad` in fe-core-2d).

Analyses validated: `geometry-editor`, `mesh-viewer` · Recorded run: passed — 2 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
self-weight column: σyy(y) = −γ·(H−y) (geostatic, linear with depth)	Pass
confined self-weight: horizontal stress σxx = K0·σyy with K0 = ν/(1−ν)	Pass

fe-plastic-2d-web-validation.test.ts

Web-benchmark validation for the elasto-plastic FE solver (`fe-plastic-2d.ts`).

Analyses validated: `mesh-viewer` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FE-plastic below yield equals the linear-elastic core	Pass
FE element stress == material point (uniform εyy=-0.001)	Pass
FE element stress == material point (uniform εyy=-0.003)	Pass
FE element stress == material point (uniform εyy=-0.008)	Pass
deviatoric stress is capped by MC yield as shear strain increases	Pass
yielded FE stress state satisfies MC on its principal stresses	Pass

fe-plastic-cg-web-validation.test.ts

Validation for the matrix-free CG elasto-plastic solver (`fe-plastic-cg.ts`).

Analyses validated: `geometry-editor`, `mesh-viewer` · Recorded run: passed — 3 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
CG plastic == material point on a uniform confined field	Pass
CG plastic reaction equilibrium (top = −base)	Pass
CG plastic solves a fine mesh (20×20) in reasonable time	Pass

fe-plastic-general-web-validation.test.ts

Validation for the GENERAL incremental elasto-plastic T6 solver (`fe-plastic-general.ts`) — the unified-constitutive staged solver.

Analyses validated: `mesh-viewer` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
MC patch: single-increment Gauss stress equals integrateMohrCoulombGeneral exactly	Pass
HS patch: N-increment Gauss stress equals the incrementally-integrated material point (state carry)	Pass
HS behavioural: vertical stress magnitude grows monotonically and stays below MC failure	Pass
DP patch: single-increment Gauss stress equals integrateDruckerPragerGeneral exactly	Pass
Von Mises patch: single-increment Gauss stress equals integrateVonMises exactly (yielded)	Pass
per-element regression: [MC] on 1 element equals the single-model solver exactly	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
per-element dispatch: 2-element mesh, each element uses its OWN model (different E → different stress)	Pass

fe-plastic-t6-web-validation.test.ts

Validation for the T6 elasto-plastic solver (`fe-plastic-t6.ts`).

Analyses validated: `mesh-viewer` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
T6 plastic below yield equals the linear-elastic T6 core	Pass
T6 element stress == material point (uniform εyy=-0.001)	Pass
T6 element stress == material point (uniform εyy=-0.004)	Pass
T6 deviator capped by MC under an increasing shear field	Pass
T6 reaction (internalForce at fixed DOFs) balances the applied load	Pass

fe-pressure-load-web-validation.test.ts

Validation for FE uniform-pressure loading (`uniformPressureLoad`).

Analyses validated: `coupled-consolidation`, `geometry-editor`, `mesh-viewer` · Recorded run: passed — 3 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
total applied load = p · loaded width	Pass
confined block under uniform top pressure → σyy = −p everywhere	Pass
partial-width (footing) pressure applies only over the strip	Pass

fe-solve-cg-web-validation.test.ts

Validation for the matrix-free CG FE solver (`fe-solve-cg.ts`).

Analyses validated: `geometry-editor`, `mesh-viewer` · Recorded run: passed — 3 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
CG solver reproduces the dense solver (patch test, εxx=g)	Pass
CG solver matches dense on a loaded (non-trivial) problem	Pass
CG scales to a fine mesh (40×40 → ~3400 DOF) — dense would be too slow	Pass

geometry-editor-web-validation.test.ts

Validation for the `geometry-editor` tool — the polygon → PSLG → mesh path it drives through `pslgFromPolygons` + `generateMesh` (public API of mesh-cdt.ts only; the mesher is being rewritten concurrently, so every assertion below is an IN…

Analyses validated: `coupled-consolidation`, `geometry-editor`, `mesh-viewer` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
geometry: a right triangle meshes to exactly ½·b·h (analytic area)	Pass
geometry: an L-shaped (concave) polygon — area 3 and area-weighted centroid (5/6, 5/6)	Pass
geometry: a square with a square hole — area = outer − hole, no element inside the hole	Pass
geometry: two stacked materials — conforming interface, correct tags by point-in-polygon, total area	Pass
geometry: the result does not depend on the order the polygons are drawn	Pass
geometry: polygon winding (CW vs CCW) does not change the meshed area	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
geometry: a translated model (real-world coordinates) meshes to the same area and element count	Pass
geometry: the mesher honours its minimum-angle target on an ordinary polygon	Pass

limit-analysis-fe-web-validation.test.ts

WEB-VALIDATION (the release rules gate) for `limit-analysis-fe.ts` — the FE strength-reduction slope FoS + displacement-controlled bearing-capacity limit load, built on the matrix-free CG elasto-plastic Mohr-Coulomb kernel.

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
reduceStrength: c_f = c/F and tanϕ_f = tanϕ/F (GL99 eqs 1–2)	Pass
SRM slope: ϕ=30°, 2:1 → FoS ≈ tanϕ/tanβ = 1.155 (within 3%)	Pass
SRM slope: ϕ=35°, 2:1 → FoS ≈ 1.400 (within 3%)	Pass
SRM slope: ϕ=45°, 2:1 → FoS ≈ 2.000 (within 3%)	Pass
SRM slope: ϕ=40°, 1.5:1 → FoS ≈ 1.259 (achieved +~8%, within 12%)	Pass
SRM slope: FoS increases with ϕ, and a gentler slope is safer	Pass
Bearing ϕ=0: mobilised N_c vs Prandtl 5.14 (CST over-predicts, honest)	Pass
Bearing ϕ=0: FE brackets Prandtl 5.14 on the load–settlement curve (±10%)	Pass
Bearing ϕ=0: refining the mesh reduces N_c toward Prandtl (from above)	Pass
Bearing ϕ=0: N_c independent of s_u; q_ult ∝ s_u (dimensional exactness)	Pass
Bearing ϕ=0: q_ult independent of footing width B (weightless Prandtl)	Pass

linear-solver-cg-web-validation.test.ts

Validation for the CG linear solver (`linear-solver-cg.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
CG solves a small dense SPD system to a known solution	Pass
CG solves the 1-D Poisson system (tridiagonal −1,2,−1)	Pass
CG residual decreases monotonically to tolerance	Pass
CG matches a dense-solve reference on a random SPD system	Pass

mesh-contour-web-validation.test.ts

Validation for the contouring backbone (`mesh-contour.ts`).

Analyses validated: `coupled-consolidation`, `geometry-editor`, `mesh-viewer` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
nodal averaging of a uniform element field is uniform	Pass
iso-contour of a linear field lies exactly on the analytic line	Pass
no iso-segments outside the field range	Pass
contourLevels returns evenly spaced interior levels	Pass
a diagonal iso-line spans the domain (connected coverage)	Pass

mesh-delaunay-web-validation.test.ts

Validation for the TerraCore Delaunay mesher (`mesh-delaunay.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
circumcircle of a right triangle centres on the hypotenuse midpoint	Pass
unit square triangulates into 2 triangles, total area 1	Pass
Delaunay empty-circumcircle property holds (random set 1)	Pass
Delaunay empty-circumcircle property holds (random set 2)	Pass
Delaunay empty-circumcircle property holds (random set 3)	Pass
triangle count matches Euler for a 5×5 grid	Pass
area refinement of a square adds nodes, caps element area, stays Delaunay	Pass

mesh-viewer-web-validation.test.ts

Validation for the `mesh-viewer` tool — what it DISPLAYS: element quality metrics, iso-contours of a nodal field, recovered (SPR) stress fields, and the elastic plane-strain solution underneath them.

Analyses validated: `coupled-consolidation`, `geometry-editor`, `mesh-viewer` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
quality: an equilateral triangle is perfect on every metric	Pass
quality: a right-isosceles triangle — 45/45/90, edge ratio $\sqrt{2}$, radius ratio $2(\sqrt{2}-1)$	Pass
quality: a 30-60-90 triangle and a sliver rank in the right order	Pass
quality: meshQuality on a structured CST grid — every element is 45/45/90	Pass
topology: rectMesh covers W×H exactly and satisfies Euler V − E + F = 1	Pass
contours: the iso-line of f = x at x = 0.3·W is the vertical line x = 0.3·W, length H	Pass
contours: a diagonal field f = x + y has straight 45° iso-lines; levels span the field range	Pass
contours: nodal averaging of a constant element field returns that constant at every node	Pass
SPR: a linear element field f = 2 + 3x − 1.5y is recovered EXACTLY at every node (patch exactness)	Pass
solve: self-weight column — element $\sigma_{yy} \approx -\gamma(H - y_{mid})$ and $\sigma_{xx} \approx K_0 \cdot \sigma_{yy}$ with $K_0 = \nu/(1-\nu)$	Pass
solve: self-weight column — nodal settlement $\approx -\gamma(2Hy - y^2)/(2M)$, $M = E(1-\nu)/((1+\nu)(1-2\nu))$	Pass
solve: uniform strip pressure on a confined column gives $\sigma_{yy} = -p$ everywhere and $u_{top} = -pH/M$	Pass
solve: the consistent gravity load vector sums to the total self-weight $-\gamma \cdot W \cdot H$	Pass

Three-dimensional analysis

FE kernel registry — 12 rows

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`k11-3d-tut1-a-k0-stationary`	max |u| at the end of the Initial (K0 procedure) phase [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	0	0	—	—	Pass
`k11-3d-tut1-a-control-centre`	flexible control: centre settlement under 66 kPa surface pressure on the 36 m × 36 m footprint (elastic clay, same mesh and fixities) [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	160.2	161.74	—	+0.96 %	Pass
`k11-3d-tut1-a-control-corner`	flexible control: footprint-corner settlement (x = y = 18 m) under 66 kPa surface pressure (elastic clay) [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	45.14	50.08	—	+10.9 %	Deviation
`k11-3d-tut1-a-basement-settlement`	Tutorial 1 Case A as written (Table 1–1 Mohr–Coulomb clay): mean settlement of the basement underside (z = −2 m), base mesh [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	115.38	99.23	—	−14.0 %	Deviation
`k11-3d-tut1-a-basement-settlement-fine` self-check	Tutorial 1 Case A as written: mean basement-underside settlement, bisected mesh [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	115.38	102.19	—	−11.4 %	Deviation
`k11-3d-tut1-a-max-displacement`	Tutorial 1 Case A as written: max |u| over the model at the end of Phase 1 'Building', base mesh [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	—	108.75	—	—	Pass

ROW	QUANTITY	SOURCE, PAGE	VENDOR	REFERENCE	OURS	MISS VS VENDOR	MISS VS REF.	STATUS
`k11-3d-tut1-a-mesh-change` self-check	Tutorial 1 Case A as written: change of the mean basement settlement when every mesh interval is bisected [%]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	—	2.98	—	—	Pass
`k11-3d-hs-linear-range`	|HS − MC| top settlement of the oedometric column in the HS unloading/reloading range (OCR 4, σ′v0 −100 kPa, +10 kPa), m = 0.5 [%]	books/PLAXIS-3D-2025.1-Material-Models-Manual-Seequent.pdf, p. Eq 6-6 (Eur) p. 70; elastic oedometer M = E(1−ν)/((1+ν)(1−2ν))	—	0	7.772e-14	—	—	Pass
`k11-3d-hs-oedometer-m05`	NC oedometric strain, σ′v 50 → 400 kPa on the K0nc path, m = 0.5, finest step (stress ratio 1.005, 417 stages): % from the compression line [%]	books/PLAXIS-3D-2025.1-Material-Models-Manual-Seequent.pdf, p. Eq 6-19 p. 73; Eqs 10-1..10-3 pp. 108-109	—	0	0.0642	—	+0.06 %	Pass
`k11-3d-hs-oedometer-m1`	NC oedometric strain, σ′v 50 → 400 kPa on the K0nc path, m = 1, finest step (stress ratio 1.005, 417 stages): % from the compression line [%]	books/PLAXIS-3D-2025.1-Material-Models-Manual-Seequent.pdf, p. Eq 6-19 p. 73; Eqs 10-1..10-3 pp. 108-109	—	0	0.1236	—	+0.12 %	Pass
`k11-3d-hs-tut1-basement`	Tutorial 1 Case A with the clay as Hardening Soil: mean settlement of the basement underside (z = −2 m), base mesh [mm]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	—	75.228	—	—	Recorded, no published value
`k11-3d-hs-tut1-vs-mc`	Tutorial 1 Case A: HS basement settlement relative to the Mohr–Coulomb run (row k11-3d-tut1-a-basement-settlement, 99.231 mm) [%]	books/PLAXIS-3D-2025.1-Tutorial-Manual-Seequent.pdf, p. 13 (Table 1–1, inputs); 11–23 (§1.3 geometry, phases); 25 (Fig 1–18, the only result: a figure)	—	—	-24.19	—	—	Recorded, no published value

Cited validation suites — 8

`fe-consolidation-3d-web-validation.test.ts`

Web-benchmark validation for the 3-D COUPLED CONSOLIDATION FE (`fe-consolidation-3d.ts`).

Analyses validated: `consolidation-3d` · Recorded run: passed — 28 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1..16] Newmark corner influence factor reproduces Das (2016) Table 6.4	Pass
[17] Newmark I → 1/4 as m,n → ∞ (the whole surface loaded, four quadrants make q)	Pass
[18] Δσ_z under the centre: = q at the surface, and 4·I(m=n=1)·q at z = B/2	Pass
[19] confined final settlement = q·H/E_oed exactly, for every ν and every mesh	Pass
[20] VOLUMETRIC LOCKING: confined settlement stays exact as ν → ½	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[21] confined undrained settlement is EXACTLY zero on any mesh	Pass
[22] Terzaghi's initial condition: confined initial excess pore pressure = q exactly	Pass
[23] E_oed and c_v = k·E_oed/γ_w follow the closed forms	Pass
[24] the loaded-area resultant is exact (consistent traction on a graded mesh)	Pass
[25] terzaghiU / terzaghiTv reproduce the published U–Tv table	Pass
[26] the confined solve follows the Terzaghi U(Tv) curve	Pass
[27] the confined solve reproduces the Terzaghi t50 and t90	Pass
[28] confined U increases monotonically and the excess pore pressure decays away	Pass
[28b] the peak excess pore pressure never exceeds the load, and converges to it	Pass
[29] double drainage divides t50 by four (the drainage path is halved)	Pass
[30] settlement is linear in the applied pressure, and t50 is independent of it	Pass
[31] settlement ∝ 1/E, and c_v ∝ E so t50 ∝ 1/E	Pass
[32] t50 ∝ 1/k with the settlement unchanged	Pass
[33] geometric similarity: doubling every length doubles s and quadruples t50	Pass
[34] a finite footprint consolidates FASTER than 1-D, increasingly so with H/B	Pass
[35] the Skempton-Bjerrum μ is below 1 and falls with H/B (Das Fig 7.22 trend)	Pass
[36] the confined limit is recovered continuously as the footprint widens	Pass
[37] the undrained instant equals a drained solve at ν → ½ with the same shear modulus	Pass
[38] the mixed undrained settlement is mesh-converged	Pass
[39] the Q2–Q1 pair is inf-sup stable on every mesh the engine will build	Pass
[40] every reported number is finite — no NaN or Infinity anywhere	Pass
[41] invalid input is rejected with a message, never with a plausible-looking number	Pass
[42] the config wrapper exposes days, a verdict and the 1-D comparison	Pass

`fe-footing-3d-web-validation.test.ts`

Validation for the 3-D elasto-plastic continuum footing FE (`fe-footing-3d.ts`) — the closed-form cross-check (Vesić 1973 factors + Skempton/Meyerhof shape factors) that anchors the 3-D BVP and its shape effect.

Analyses validated: `footing-bearing-3d` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Vesić (1973) bearing-capacity factors (3-D engine) — published table (13 anchors)	Pass
Skempton (1951): square/circular footing ϕ=0 shape factor s_c = 1.2 (N_c·s_c ≈ 6.2)	Pass
Meyerhof/Vesić shape factors s_q, s_γ (square, ϕ=30°)	Pass
shape factors interpolate B/L: strip → 1, square = max, rectangle between	Pass
3-D shape effect: a square footing carries more than the strip (the reason for a 3-D solve)	Pass

`fe-slope-3d-web-validation.test.ts`

Web-benchmark validation for `fe-slope-3d` — 3-D FE strength-reduction slope stability (20-node hex, viscoplastic Mohr-Coulomb).

Analyses validated: `fe-slope-3d` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
a 2:1 slope solves and reports a physical FoS with its mesh size	Pass
the 3-D FoS is at least the plane-strain FoS (Cavounidis 1987)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the 3-D strengthening effect decreases as the slope widens (Griffiths & Marquez 2007)	Pass
FoS rises with cohesion and with friction angle	Pass
FoS falls with height, with unit weight, and with a steeper slope	Pass
the stability number c/(γH) governs — geometrically similar slopes agree	Pass
a slope at collapse is reported as unstable rather than left to look converged	Pass
a caller-supplied time budget cannot truncate the search: the legacy keys change nothing (D426)	Pass
invalid geometry and strength are refused with NaN, not a plausible FoS	Pass

⚑ footing-3d-web-validation.test.ts

C.FOOT3D — `footing-bearing-3d` web-benchmark (46 cited published values).

Analyses validated: `footing-bearing-3d` · Recorded run: passed — 9 test block(s), 1 skipped

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C.FOOT3D.1: 30 published Vesić bearing-capacity factors within 0.5%	Pass
C.FOOT3D.2: N_c = 2+π = 5.14 and N_γ = 0 at ϕ = 0 (Prandtl 1920)	Pass
C.FOOT3D.3: 12 published Vesić shape factors, square footing (B/L = 1)	Pass
C.FOOT3D.4: closed-form q_ult matches 4 hand-worked Vesić totals within 0.5%	Pass
C.FOOT3D.4b: solveFooting3D reports the SAME closed form it assembles internally	Pass
C.FOOT3D.5: ϕ=0 square footing reproduces the Skempton N_c ≈ 6.2 form	Pass
C.FOOT3D.6: ϕ = 0 clay square — the FE limit load obeys physical bounds and its D509 lock (always run)	Pass
C.FOOT3D.6h: c-ϕ square with γ and D_f — physical bounds and its D509 lock (HEAVY tier) Why: GEOTECH_HEAVY=1 (minutes in TS; the Python twin runs it in validate_fe_footing_3d.py)	Skipped
C.FOOT3D.7: monotonic in strength — more c, ϕ, γ or D_f cannot lower q_ult	Pass
C.FOOT3D.8: mesh sizing is pinned (guards the P0-1 rounding tie)	Pass

⚑ pile-group-3d-web-validation.test.ts

Rigid-cap pile-group load distribution (`pile-group-3d.ts`) checked against PUBLISHED worked examples.

Analyses validated: `pile-group-3d` · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] Mittal Ex 6.4: vertical term P/n = 201/4 = 50.3 t	Pass
[2] Mittal Ex 6.4: moment term for M = 4.8 t·m is 1.8 t	Pass
[3] Mittal Ex 6.4: moment term for M = 6.4 t·m (other axis) is 2.4 t	Pass
[4] Mittal Ex 6.4: moment term for M = 37.2 t·m (VL + EQ at 45°) is 13.8 t	Pass
[5] Mittal Ex 6.4: moment term for M = 46.9 t·m (VL + EQ at 67.5°) is 17.4 t	Pass
[6] Mittal Ex 6.4 case (i): P = 201, M_{45} = 4.8, $M_{67.5}$ = 6.4 → maximum pile load 54.5 t	Pass
[7] Mittal Ex 6.4 case (ii): P = 201, M_{45} = 37.2, $M_{67.5}$ = 6.4 → maximum pile load 66.5 t	Pass
[8] Mittal Ex 6.4 case (iii): P = 201, M_{45} = 4.8, $M_{67.5}$ = 46.9 → maximum pile load 69.5 t	Pass
[9] Mittal Ex 6.4 case (ii): earthquake shear 12.4 t over 4 piles is 3.1 t per pile	Pass
[10] Mittal Ex 6.5: vertical term 895/20 = 44.8 t	Pass
[11] Mittal Ex 6.5: moment term for M_{25} = 69.6 t·m is 2.6 t	Pass
[12] Mittal Ex 6.5: moment term for M_{90} = 42.9 t·m is 1.9 t	Pass
[13] Mittal Ex 6.5 case (i): P = 895, M_{25} = 69.6, M_{90} = 42.9 → maximum pile load 49.3 t	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[14] Mittal Ex 6.5 case (ii): earthquake shear 12.0 t over 20 piles is 0.6 t per pile	Pass

slope-3d-dem-web-validation.test.ts

WEB-BENCHMARK validation for the arbitrary-DEM 3-D slope engine (Scoops3D reimplementation).

Analyses validated: `slope-3d-dem` · Recorded run: passed — 22 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
dem 1: a planar-slope DEM produces a converged critical sphere	Pass
dem 2: DEM Bishop-3D MATCHES the validated 2-D engine ($F_2D \le F_3D \le \sim 1.4 \cdot F_2D$)	Pass
dem 3: Ordinary-3D ≤ Bishop-3D (Fellenius conservative)	Pass
dem 4: the failure mass has a real volume, area and column count	Pass
dem 5: the auto fall direction points down-slope (−x for a slope rising in +x)	Pass
dem 6: more cohesion ⇒ higher FoS	Pass
dem 7: higher friction angle ⇒ higher FoS	Pass
dem 8: a steeper slope ⇒ lower FoS	Pass
dem 9: a taller slope ⇒ lower FoS	Pass
dem 10: a high water table ⇒ lower FoS than dry	Pass
dem 11: ru pore-pressure ratio lowers FoS	Pass
dem 12: a weak lower layer lowers FoS vs uniform strong soil	Pass
dem 13: two-material honoured — heavier soil (more driving) ⇒ ≤ FoS of lighter	Pass
dem 14: a finer search evaluates more spheres and returns a sensible minimum ≥ F_2D	Pass
dem 15: method=ordinary headlines the Ordinary FoS	Pass
dem 16: an explicit slip direction is honoured	Pass
dem 17: a tiny/invalid DEM errors cleanly (no crash)	Pass
dem 18: missing materials errors cleanly	Pass
dem 19: a nearly-flat DEM is very stable (high FoS)	Pass
dem 20: bilinear DEM interpolation — result is stable to a half-cell origin shift	Pass
DEM E-116: an INVERTED material band must be rejected, not read as the deepest one	Pass
DEM E-116: non-finite and non-physical material properties must be named, not blamed on the DEM	Pass

slope-3d-web-validation.test.ts

WEB-BENCHMARK validation for the 3-D slope-stability engine — now the GENUINE Hungr (1987) 3-D simplified-Bishop COLUMN method on an ellipsoidal slip surface (vertical-column grid, true 3-D base normal n_y, per-column moment arm R_z), not…

Analyses validated: `slope-stability` · Recorded run: passed — 34 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
slope3d 1: Zhang (1988) ellipsoid F_3D in the published band 2.12–2.26	Pass
slope3d 2: Zhang F_3D/F_2D sits in the rotational band and exceeds 1 (Cavounidis)	Pass
slope3d 3: $F_3D \ge F_2D$ — c–ϕ soil (Cavounidis 1987 theorem)	Pass
slope3d 4: $F_3D \ge F_2D$ — purely cohesive (ϕ=0) soil	Pass
slope3d 5: $F_3D \ge F_2D$ — nearly cohesionless (c=5, ϕ=35) soil	Pass
slope3d 6: on the symmetry plane the column method reduces to 2-D Bishop (F_2D exact)	Pass
slope3d 6b: ru pore-pressure lowers F_3D (Bishop-3D (W − u·A_h) effective-stress term)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
slope3d 7: F_2D cross-checks our rigorous Spencer FoS (independent kernel)	Pass
slope3d 8: cohesive (ϕ=0) shows a LARGER 3-D effect than frictional (Stark & Eid 1998)	Pass
slope3d 9: F_3D/F_2D within the Duncan (1996) rotational band 1.03–1.55 (typical geometry)	Pass
slope3d 10: narrower slide ⇒ stronger (higher F_3D/F_2D)	Pass
slope3d 11: the F_3D/F_2D-vs-aspect curve is monotone decreasing	Pass
slope3d 12: PURE-ELLIPSOID limit — very long slide ⇒ ratio plateaus > 1 (NOT → 1)	Pass
slope3d 13: ϕ=0 near-spherical slide (aspect≈1) has a strong 3-D effect (ratio > 1.15)	Pass
slope3d 14: more cohesion ⇒ higher F_2D and F_3D	Pass
slope3d 15: steeper slope ⇒ lower F_3D	Pass
slope3d 16: a high water table ⇒ lower F_3D (effective-stress reduction)	Pass
slope3d 17: verdict PASS when F_3D ≥ required, FAIL when below	Pass
slope3d 18: verdict headlines both F_2D and F_3D + the % insight	Pass
slope3d 19: translational mode flags the model + names Hungr conservative default	Pass
slope3d 20: invalid slide length ⇒ errors, no crash	Pass
slope3d 21: converged flag set + a real column grid was built	Pass
slope3d 22: reports critical-circle radius and z semi-axis (=L/2)	Pass
slope3d 23: ru pore-pressure ratio lowers F_3D vs drained	Pass
slope3d 24: refining the column grid changes F_3D by < 2 % (numerical convergence)	Pass
slope3d 25: the 3-D search finds a critical F_3D ≤ the extruded 2-D-circle F_3D	Pass
slope3d 26: the searched critical F_3D still satisfies Cavounidis $F_3D \geq F_2D$	Pass
slope3d 27: search is on by default and reports how many surfaces it scanned	Pass
slope3d 28: search lowers (or holds) the Zhang F_3D toward the published 2.12–2.26	Pass
slope3d 29: reports Ordinary, Bishop, rigorous Spencer AND GLE 3-D side-by-side	Pass
slope3d 30: Ordinary ≤ Bishop and rigorous Spencer within 2 % of Bishop (all soils)	Pass
slope3d 31: rigorous Spencer-3D agrees with Bishop-3D within ~10 % (Hungr 1987; Lam-Fredlund 1993)	Pass
slope3d 32: selecting method=spencer makes the headline F_3D the Spencer value	Pass
slope3d 33: each 3-D method reduces to its 2-D counterpart at the prismatic limit	Pass

`tet-mesh-3d-web-validation.test.ts`

Validation for the TerraCore 3-D tetrahedral mesher (`tet-mesh-3d.ts`).

Analyses validated: `tet-mesh-3d` · Recorded run: passed — 18 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
reference tet volume is 1/6	Pass
circumsphere of the reference tet centres at (½,½,½), R=√3/2	Pass
regular tetrahedron: quality ρ=1 and dihedral 70.5288°	Pass
structured 1×1×1 box → $6 \cdot n^3 = 6$ tets, $(n+1)^3 = 8$ nodes	Pass
structured 2×2×2 box → $6 \cdot n^3 = 48$ tets, $(n+1)^3 = 27$ nodes	Pass
structured 3×3×3 box → $6 \cdot n^3 = 162$ tets, $(n+1)^3 = 64$ nodes	Pass
structured 4×4×4 box → $6 \cdot n^3 = 384$ tets, $(n+1)^3 = 125$ nodes	Pass
box 3×2×4 m, 3×3×3 cells: volume, Euler, positivity, conformity, quality	Pass
extruded rectangle 5×3 through depth 2, 4 layers: Σ vol = 30, conforming, Euler	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
extruded triangle (legs 4,6) through depth 5: Σ vol = ½·4·6·5 = 60	Pass
extruded L-shape polygon: Σ vol = plan_area·depth, conforming	Pass
Delaunay empty-circumsphere property holds (random 3-D set, seed 1)	Pass
Delaunay empty-circumsphere property holds (random 3-D set, seed 7)	Pass
Delaunay empty-circumsphere property holds (random 3-D set, seed 42)	Pass
Delaunay of 8 unit-cube corners tiles volume 1 and is Delaunay after restriction	Pass
boundary point-cloud path: convex hull volume, Delaunay, positive, dihedral>0	Pass
radius-ratio quality is invariant under uniform scaling	Pass
degenerate box (zero height) returns an error, not NaN	Pass

Pavements and airfields

Closed-form engine registry — 2 published problems

ROW	PROBLEM	SOURCE	REFERENCE	OURS	Δ	TOLERANCE (WHY)	STATUS
D1-IRC37-DUAL-WHEEL	IRC:37 Annex I Fig I.3 — εt at the bottom of the bituminous layer, dual-wheel standard axle 3000 / 450 / 75 MPa, ν 0.35, h 140 / 500 mm; 2 × 20 kN at 0.56 MPa, 310 mm c/c; points R = 0 and 155 mm	IRC:37-2018 Guidelines for the Design of Flexible Pavements, Annex I, Fig. I.3 (IITPAVE output) — Fig. I.3, p. 78 (PDF 88)	128.3 με εt (IITPAVE)	128.481	+0.14 %	± 2 % 53 D1 exit: strains within 2 %	Pass
D1-IRC37-DUAL-WHEEL-EV	IRC:37 Annex I Fig I.3 — εv on top of the subgrade, dual-wheel standard axle as εt row	IRC:37-2018 Guidelines for the Design of Flexible Pavements, Annex I, Fig. I.3 (IITPAVE output) — Fig. I.3, p. 78 (PDF 88)	205.3 με εv (IITPAVE)	205.59	+0.14 %	± 2 % 53 D1 exit: strains within 2 %	Pass

Cited validation suites — 62

⚑ aashto-rigid-1993-web-validation.test.ts

AASHTO 1993 RIGID (PCC slab) PAVEMENT — Eq.

Analyses validated: `aashto-rigid-1993`, `pavement-aashto-1993` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Appendix I §1.1 — first-year design-lane traffic 357,000 × 0.80 × 0.50 = 142,800 and the per-stage reliabilities	Pass
Appendix I §1.2 — slab thickness 9 in for the 25-year traffic (Figure 3.7, no swelling)	Pass
Appendix I Table I.3 — a 9 in slab carries 4.6×10⁶ ESALs at ΔPSI_TR 1.75 (iteration 1) and 4.5×10⁶ at 1.74 (iteration 2)	Pass
Appendix I Table I.3 — those capacities correspond to 22.9 and 22.8 years on the Figure I.1 traffic curve	Pass
Appendix I §1.2 Step 7 — the design "will reach its terminal serviceability in approximately 23 years"	Pass
FHWA §6.2.1 baseline rigid design — k_eff 38 pci → D = 10.4 in (10.5 in after rounding)	Pass
FHWA §6.3.1 soft subgrade — k_eff 27 pci → D = 10.5 in, and the baseline slab then carries 15.5×10⁶ ESALs	Pass
FHWA §6.5.1 low-quality subbase — k_eff 17 pci, Cd 0.85 → D = 11.5 in, baseline slab carries 8.3×10⁶ ESALs	Pass
FHWA §6.6.1 poor drainage — k_eff 12 pci, Cd 0.75 → D = 12.3 in, baseline slab carries 5.2×10⁶ ESALs	Pass
FHWA §6.2.1 — the 10.4 in baseline slab at k 38 pci carries the 16.4×10⁶ ESALs it was designed for	Pass
AASHTO Table 4.1 — Z_R for every tabulated reliability, as reported by the rigid design engine	Pass

acn-pcn-airfield-published-web-validation.test.ts

PUBLISHED-VALUES: 15 -- distinct published values for this engine (engine-level total, declared once); independent audit A1: about 15 published values, 6 of them from a source the auditor could not reach.

Analyses validated: `acn-pcn-airfield` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
ICAO Doc 9157 Part 3 Ch.2 (via Hayhoe 2010): 10 % flexible and 5 % rigid occasional-overload limits	Pass
Boeing ACAP §7.10 / ICAO: ACN ≤ PCN operates without restriction (ratio ≤ 1)	Pass
Hayhoe (2010) Eq. 5: ACN/PCN = (t2/t1)², so √ratio reproduces the printed thickness ratios 1.049 and 1.0247	Pass
Boeing ACAP §7.10 ACN table (737 family at maximum taxi weight) against the published overload rule — expected status HAND-DERIVED	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
published ACNs sit inside the engine's plausibility window (ACAP 737 table: 13 … 63; warning only above 2000)	Pass

acn-pcn-airfield-web-validation.test.ts

Formula-fidelity validation against ICAO Annex 14 Vol I §2.6, ICAO Doc 9157 Part 3, and FAA AC 150/5335-5 — the ACN/PCN aircraft-pavement strength compatibility check and its published occasional-overload limits (10% for flexible pavements…

Analyses validated: `acn-pcn-airfield` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-3] ACN 45 / PCN 50 (ratio 0.90, flexible): unrestricted, overload=0%, limit=10%	Pass
[4-6] ACN 55 / PCN 50 (ratio 1.10, flexible): exactly at the 10% occasional limit -> permitted	Pass
[7-9] ACN 55 / PCN 50 (ratio 1.10, RIGID): exceeds the 5% rigid limit -> not permitted	Pass
[10-11] ACN 60 / PCN 50 (ratio 1.20, flexible): 20% overload exceeds the 10% limit	Pass
[12] rigid vs flexible use different overload limits at otherwise identical inputs	Pass
[13] ACN=PCN exactly (ratio=1.0) is unrestricted with zero overload	Pass
[14] default pavement type (unspecified) is treated as flexible (10% limit)	Pass
[15] ACN or PCN <= 0 is refused, not silently floored to a denominator of 1e-6	Pass
[16] the ratio is scale-invariant (ACN/PCN unaffected by proportional scaling), but implausible raw magnitudes still warn	Pass

aircraft-gear-response-web-validation.test.ts

Published-value validation of the multi-wheel landing-gear response engine `aircraft-gear-response` (Burmister layered-elastic superposition over the wheels of a gear, maximum vertical strain at the top of the subgrade), against the FAARFI…

Analyses validated: `aircraft-gear-response`, `layered-elastic-pavement` · Recorded run: passed — 2 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
maximum subgrade strain of the 2D (4-wheel) and 6-wheel 3D gears reproduces TC-17/28 Appendix B (με)	Pass
wrapper outputs: contact radius from the Appendix A wheel load / tyre pressure, and the single-wheel identity	Pass

aircraft-library-web-validation.test.ts

Web-benchmark validation for the airfield aircraft library — pins every gear-geometry value to the FAARFIELD standard-library / ACAP baselines that a PE (or FAARFIELD itself) would use, so our airfield engines run on the SAME aircraft inpu…

Analyses validated: `faarfield-mix-cdf` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
B747-8 gear geometry matches the FAARFIELD/ACAP baseline	Pass
A320-200 gear geometry matches the FAARFIELD/ACAP baseline	Pass
A330-300 gear geometry matches the FAARFIELD/ACAP baseline	Pass
B737-800 is a dual-gear narrowbody (FAARFIELD standard library)	Pass
wheel load = gross · %-on-leg / wheels-per-leg (at max taxi weight)	Pass
a heavy widebody mix produces a higher subgrade CDF than a narrowbody mix	Pass
picking a1_aircraft/a2_aircraft reproduces the manual-geometry result exactly	Pass
picking overrides deliberately-wrong manual fields (geometry comes from the library)	Pass
the library covers the 4 Appendix-H benchmark aircraft with valid specs	Pass

asphalt-institute-design-published-web-validation.test.ts

ASPHALT INSTITUTE FATIGUE / SUBGRADE-RUTTING CRITERIA — `asphaltInstituteFatigueLife` and `asphaltInstituteRuttingLife` (the two functions `computeAsphaltInstituteDesign` applies to the layered-elastic strains) checked against PUBLISHED ST…

Analyses validated: `asphalt-institute-design` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Maher (2022) KENLAYER — fatigue: five printed tensile strains → allowable repetitions (E_1 = 500 000 psi)	Pass
Maher (2022) KENLAYER — subgrade rutting: five printed compressive strains → allowable repetitions	Pass
Maher (2022) — the hand calculation in the notes: εt 1.423E-04 → 4,940,000 and the differential 6.63E-05 → 60,890,000	Pass
Maher (2022) — Miner summation of the printed strains reproduces the summary: ΣD 3.946E-02 (fatigue), 5.174E-02 (rutting), 19.33 years	Pass
Rahmawati & Adiyasa (2021) Table 3 — εt 2.998E-04 with E = 1 200 000 kPa gives Nf = 1,047,484.63; εc 4.022E-04 gives Nd = 2,172,928.92	Pass
Rahmawati & Adiyasa (2021) Table 5 — two alternative designs: Nd at εc 1.979E-04 and 1.912E-04, and the Nf ratio of εt 9.501E-05 to 9.331E-05	Pass

asphalt-institute-design-web-validation.test.ts

Formula-fidelity validation against Asphalt Institute MS-1 "Thickness Design" (1981/1999) and Huang, "Pavement Analysis and Design" 2nd ed.

Analyses validated: `asphalt-institute-design` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-6] base case: Nf and Nr independently re-derived from the engine's own reported strains match its output exactly (formula fidelity of the AI transfer functions)	Pass
[7] the specific reference case cited in the engine's own defect-fix comment reproduces exactly: Nf ~= 1.987e6, governing = subgrade rutting, CDF ~= 1.35	Pass
[8] doubling the AC modulus reduces the fatigue allowable Nf by exactly 2^0.854 per the published -0.854 exponent, at fixed strain	Pass
[9] design_esals=0 gives exactly zero damage ratios, labelled as definitional	Pass
[10] a thicker/stiffer section reduces both strains and both damage ratios (basic M-E design trend)	Pass
[11] the classification bands match the CDF thresholds (<=0.5 ample, <=1.0 within limit, >1.0 inadequate)	Pass
[12] every load-bearing input is refused at 0 or below, never silently floored to an unbounded allowable	Pass

axle-load-spectra-published-web-validation.test.ts

Published-value checks for the axle-load spectrum → equivalent-axle engine `axle-load-spectra` (fourth-power load-equivalency law per axle group, truck factor, wander factor).

Analyses validated: `axle-load-spectra` · Recorded run: passed — 3 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC:37-2018 Eq. 4.2: a single axle with dual wheels is equivalent to (load / 80)^4 standard axles	Pass
IRC:37-2018 Annex II.2 dumper: 2×(120/80)^4 + (80/65)^4 = 12.41, × 200 repetitions = 2483 standard axles	Pass
IRC:37-2018 Eq. 4.2 fixes the 80 kN standard the engine uses for the single-axle group	Pass

axle-load-spectra-web-validation.test.ts

Formula-fidelity validation against AASHTO Guide for Design of Pavement Structures (1993) App.

Analyses validated: `axle-load-spectra` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-6] single-axle group, fourth-power law: truck factor=1.8488, ESALs=1848828.1, mean=82.0kN, %above-std=35.0%	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[7-12] per-bin LEF values match (P/Pstd)^4 exactly for each of the six bins	Pass
[13] tandem group uses the 140 kN standard load, not 80 kN	Pass
[14] tridem group uses the 210 kN standard load	Pass
[15] a custom power exponent (n=3.9) changes every LEF and the resulting ESALs, per the fourth-power law generalisation	Pass
[16-18] traffic wander factor: MEPDG default (tire=300mm, sigma=254mm) = 0.445179; channelised (sigma=0) = 1; narrow wander (sigma=50mm) = 0.997300	Pass
[19] design ESALs at the critical point equals raw ESALs times the wander factor (within the engine's own rounding of each intermediate to a fixed number of decimals)	Pass
[20] total_axles=0 gives exactly zero ESALs, labelled as definitional rather than a low-damage spectrum	Pass
[21] spectrum percentages that do not sum to 100 are normalised internally and warned about	Pass
[22] empty spectrum or negative total axles are refused	Pass

⚑ benkelman-overlay-published-web-validation.test.ts

BENKELMAN-BEAM OVERLAY DESIGN — `computeBenkelmanOverlay` (IRC:81-1997 characteristic deflection, with the §4.4.3 temperature and §4.5.4 seasonal corrections) checked against PUBLISHED WORKED EXAMPLES.

Analyses validated: `benkelman-overlay` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC:81-1997 §4.4.3 — at 37 °C the correction is 0.02 mm and is subtracted	Pass
CSIR-CRRI slides — 0.80 mm measured at 37 °C → 0.78 mm, and at 32 °C → 0.83 mm at the 35 °C standard	Pass
Unattributed (2020) IRC overlay-design slides — 0.8 mm at 38 °C → 0.8 − 3 × 0.01 = 0.77 mm	Pass
Unattributed (2020) IRC overlay-design slides — eleven readings have mean deflection 0.95 mm	Pass
4-BBD slides — uncorrected statistics: mean 1.45 mm, standard deviation 0.107 mm, Dc = 1.45 + 2(0.107) = 1.664 mm	Pass
4-BBD slides — temperature correction 0.01 × (35 − 30) = +0.05 mm gives Dc = 1.714 mm	Pass
4-BBD slides — seasonal factor 1.4 gives the corrected characteristic deflection 2.3996 mm	Pass

⚑ benkelman-overlay-web-validation.test.ts

Formula-fidelity validation against IRC 81:1997 Cl 6 (characteristic deflection Dc = mean + k.sigma, k=2 major roads Eq.4 / k=1 minor roads Eq.5) and Cl 5.4/5.5 (temperature/seasonal correction factors).

Analyses validated: `benkelman-overlay` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-5] major road (k=2, Eq.4), corrected by CT=1.05, CS=1.02: mean=1.371951mm, sd=0.117154mm, Dc=1.606258mm, overlay required, reduction=0.106258mm	Pass
[6-7] minor road (k=1, Eq.5), same data and allowable: Dc=1.489105mm, no overlay required	Pass
[8] no allowable supplied -> overlay_required is null (NOT ASSESSED), never false	Pass
[9] a generous allowable above Dc gives overlay_required=false with zero reduction	Pass
[10] a non-positive allowable is refused outright, not silently treated as "no overlay needed"	Pass
[11] correction factors default to 1.0 when not supplied, so mean/Dc equal the uncorrected statistics	Pass
[12] fewer than 10 readings warns about IRC 81-1997 Cl 4.3.1's minimum sample size	Pass
[13] no readings, or a negative reading, is refused	Pass

climate-zone-eicm-web-validation.test.ts

PUBLISHED-VALUES: 8 -- distinct published values for this engine (engine-level total, declared once); independent audit A1: eight Koppen-Geiger / Peel threshold values and no published numeric answer for the engine.

Analyses validated: `climate-zone-eicm` · Recorded run: passed — 33 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
every zone the engine offers is one of the six Koppen-labelled zones and returns 12 monthly temperatures	Pass
tropical: Peel 2007 Table 1 "A": Tcold >= 18 degC (coldest monthly mean)	Pass
tropical: Kottek 2006 Table 1 "A": Tmin >= +18 degC	Pass
tropical: Af rainforest needs Pmin >= 60 mm in EVERY month (Peel/Kottek) => MAP >= 12 x 60 = 720 mm; engine 2000 mm	Pass
tropical: not arid - Peel "B": MAP < 10 Pthreshold must FAIL; the largest Pthreshold (summer-dominant rain) is 2 MAT + 28	Pass
tropical: a frost-free climate has no sub-zero month, so its freezing index must be 0 (consequence of Tcold >= 18)	Pass
arid_hot: Peel "BW": MAP < 5 Pthreshold holds under the SMALLEST Pthreshold (winter-dominant rain, 2 MAT)	Pass
arid_hot: Kottek "BW": Pann <= 5 Pth under the same smallest Pth	Pass
arid_hot: Peel "h" (hot): MAT >= 18 degC	Pass
arid_hot: the mean of the 12 monthly temperatures reproduces the stated MAT (the Koppen MAT the "h" test is applied to)	Pass
arid_hot: not polar - Peel/Kottek "E" needs Thot < 10; the hottest month is well above it	Pass
arid_hot: a frost-free desert (coldest month >= 18) has freezing index 0	Pass
temperate: Peel "C": Thot > 10 and 0 < Tcold < 18	Pass
temperate: Kottek "C": -3 < Tmin < +18 degC	Pass
temperate: not arid - Peel "B" fails: MAP >= 10 x the LARGEST Pthreshold (2 MAT + 28)	Pass
temperate: Peel "a" (hot summer) Thot >= 22, so Cfa is the right third letter; Kottek "a" Tmax >= +22 agrees	Pass
temperate: a zone whose coldest month is above 0 degC can still carry a small frost index (daily extremes), but never a negative one	Pass
continental_cold: Peel "D": Thot > 10 and Tcold <= 0	Pass
continental_cold: Kottek "D": Tmin <= -3 degC (the stricter Koppen boundary)	Pass
continental_cold: Peel "b" (warm summer): NOT "a" (Thot < 22) and Tmon10 >= 4; Kottek "b": at least 4 months >= +10	Pass
continental_cold: not arid - MAP >= 10 x the largest Pthreshold (2 MAT + 28)	Pass
continental_cold: a climate with Tcold <= -3 must have freezing weather, so FI > 0	Pass
subarctic: Peel "D": Thot > 10 and Tcold <= 0	Pass
subarctic: Kottek "D": Tmin <= -3 degC	Pass
subarctic: Peel "c" (cold summer): NOT a, b or d. Not "a" (Thot < 22) and not "b" (Tmon10 < 4) - i.e. 1 <= Tmon10 < 4	Pass
subarctic: not "d" (very cold winter): Peel needs Tcold < -38; Kottek "d" Tmin <= -38. The engine is far warmer	Pass
subarctic: not arid - MAP >= 10 x the largest Pthreshold (2 MAT + 28, with MAT = -2)	Pass
subarctic: Tcold <= -3 again implies freezing weather, so FI > 0	Pass
mediterranean: Peel "C": Thot > 10 and 0 < Tcold < 18	Pass
mediterranean: Kottek "C": -3 < Tmin < +18 degC	Pass
mediterranean: Peel "a" (hot summer, the "a" of Csa): Thot >= 22; Kottek "a" Tmax >= +22	Pass
mediterranean: not arid - a dry-summer climate has winter-dominant rain, so Pthreshold is 2 MAT or 2 MAT + 14; MAP >= 10 x the larger	Pass
southern hemisphere: Tcold, Thot and Tmon10 are unchanged by the phase flip, so every class test above still holds	Pass

crcp-punchout-published-web-validation.test.ts

CRCP punchout (MEPDG 2nd ed.

Analyses validated: `crcp-punchout` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Table 9-9 Interstate "Adequate < 5 punchouts/lane-mi": just below 5 the engine says "below the typical 10/mi terminal"	Pass
Table 9-9 Interstate "Marginal 5 to 10": just above 5 the engine leaves the "below" band and says "approaching the terminal"	Pass
Table 9-9 / Sakulneya 2024: just below the 10 punchouts/mi terminal the engine still says "approaching"	Pass
Table 9-9 Interstate "Inadequate > 10" and Sakulneya 2024 "<= 10": just above 10 the engine says "exceeds the typical terminal"	Pass
Eq. 5-26 upper asymptote APO = 216.8421 /mi: at the engine's largest damage (1e9) PO is within 0.05 % of the printed APO and never above it	Pass
Eq. 5-26 is monotone increasing in damage and stays below APO across six decades of DIPO	Pass
NIST SP 811 App. B.8: 1 mi = 1.609344 km exactly, so punchouts/km = punchouts/mi / 1.609344	Pass
Table i-1: the engine implements the 2nd-ed. (2015) constants, NOT the MEPDG v1.1 ones - at DI = 1 the two models differ by > 10 %	Pass

`crcp-punchout-web-validation.test.ts`

Formula-fidelity validation against AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `crcp-punchout` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] DI=1 -> PO=6.348229 punchouts/mi (Eq. 5-26 exact)	Pass
[2] DI=5 -> PO=15.667781 punchouts/mi	Pass
[3] DI=10 -> PO=22.745760 punchouts/mi	Pass
[4] DI=20 -> PO=32.504608 punchouts/mi	Pass
[5] DI=50 -> PO=50.376631 punchouts/mi	Pass
[6] DI=100 -> PO=67.846404 punchouts/mi	Pass
[7] DI=500 -> PO=117.186387 punchouts/mi	Pass
[8] DI=1000 -> PO=138.542458 punchouts/mi	Pass
[9] DI=0 -> PO=0 exactly (definitional, guarded above Eq. 5-26 for the DI<=0 branch)	Pass
[10] km conversion is exact: PO/mi / 1.609344 = PO/km at DI=10	Pass
[11] monotone increasing in DI (fatigue damage), asymptotic toward APO=216.8421	Pass
[12] classification bands match the terminal thresholds used in the engine (below 5, 5-10, >10 punchouts/mi)	Pass

⚑ `dcp-web-validation.test.ts`

`dcp` — anchored to ASTM D6951/D6951M – 09 (Reapproved 2015).

Analyses validated: `dcp` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
ASTM D6951 expression (1): CBR = 292/DPI^1.12 for all soils but CL<10 and CH	Pass
ASTM D6951 expression (3): CL soils with CBR < 10 use CBR = 1/(0.017019·DPI)²	Pass
ASTM D6951 expression (5): CH soils use CBR = 1/(0.002871·DPI)	Pass
the mm/blow and in./blow coefficients differ by exactly 25.4 — proof of transcription	Pass
ASTM D6951 Table 2: all 64 tabulated CBR values reproduced within the table's own rounding	Pass
ASTM D6951 Table 2: CBR is strictly decreasing across the table, and the ends match its caps	Pass
end-to-end: a uniform profile returns the DCP index and CBR the standard predicts	Pass
E-40: the 4.6 kg hammer factor is ASTM's integer 2, not the 8/4.6 mass ratio	Pass
a non-standard hammer mass is extrapolated BEYOND ASTM and says so	Pass
end-to-end: a layered profile splits at the change of penetration rate	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the alternative correlations are the published ones, and differ from ASTM as documented	Pass
every output is finite, and a refusal (zero penetration) is not reported as strong ground	Pass

faa-airfield-thickness-published-web-validation.test.ts

Source-agreement checks for the closed-form airfield thickness engine `faa-airfield-thickness` (Corps/FAA CBR equation + Westergaard free-edge rigid design).

Analyses validated: `faa-airfield-thickness` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
rigid: radius of relative stiffness uses the printed constants E = 4,000,000 psi and ν = 0.15 (AC 6D para 337, AC 6G Table 3-2)	Pass
rigid: the solved slab satisfies the edge-stress criterion σ_edge = R / DF with Mathew Eq. 15.4 and b from Eq. 15.2	Pass
rigid: stress ∝ 1/h² dependence (Mathew Eq. 15.4) — a stronger concrete gives a thinner slab	Pass
flexible: the Corps CBR form t = α·√(P/(8.1·CBR) − A/π) gives zero cover when the tyre footprint alone spreads the load	Pass

faa-airfield-thickness-web-validation.test.ts

Formula-fidelity validation against FAA AC 150/5320-6D Ch.3 (flexible, U.S.

Analyses validated: `faa-airfield-thickness` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-3] flexible: P=30000lb, p=200psi, CBR=8%, C=25000 -> alpha=1.161526, t=23.668258in (601.174mm)	Pass
[4-6] flexible: heavier load, worse CBR: P=45000lb, p=220psi, CBR=6%, C=50000 -> alpha=1.230763, t=36.110201in	Pass
[7-10] rigid: P=30000lb, p=200psi, k=300pci, R=700psi, DF=1.3 -> h=10.032231in, sigma=allow=538.461538psi, l=32.730929in	Pass
[11] rigid: at the converged thickness, edge stress equals the allowable stress to within the bisection tolerance	Pass
[12] rigid: default design factor is 1.3 when not supplied	Pass
[13] flexible: a stronger subgrade (higher CBR) or lighter load reduces the required cover thickness	Pass
[14] flexible: coverages < 1 clamps to C=1 (alpha only defined for C>=1) and warns	Pass
[15] flexible: CBR, wheel load, or tire pressure at 0 or below is refused	Pass
[16] rigid: k, R, or DF at 0 or below is refused	Pass

faarfield-ac-cdf-published-web-validation.test.ts

Source-agreement checks for the FAARFIELD HMA fatigue CDF engine `faarfield-ac-cdf` (RDEC plateau-value model: PV from strain / stiffness / volumetrics / gradation, then Nf from PV).

Analyses validated: `faarfield-ac-cdf` · Recorded run: passed — 2 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
engine Nf(PV) is the inverse of the published Shen-Carpenter PV–Nf50 relation across stiffness and strain	Pass
the published relation is monotone the way the engine assumes: a larger plateau value means a shorter fatigue life	Pass

faarfield-ac-cdf-web-validation.test.ts

Formula-fidelity validation against Carpenter & Shen (2006) "A Dissipated Energy Approach to Fatigue Evaluation," Road Mater.

Analyses validated: `faarfield-ac-cdf` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] volumetric parameter VP = Va/(Va+Vb) and gradation parameter GP = (PNMS-PPCS)/P200 match exactly for the base case	Pass
[3-6] PV, Nf, applied coverages, and CDF independently re-derived from the engine's own reported strain match its output exactly	Pass
[7] the specific reference case cited in the engine's own header reproduces the correct order of magnitude: et~250ue, S~3447MPa -> Nf order 1e6	Pass
[8] the PV exponent on strain (5.14) is exactly reproduced: doubling et raises PV by exactly 2^5.14	Pass
[9] a higher pass-to-coverage ratio (more wander) reduces applied coverages, and hence the CDF, proportionally	Pass
[10] annual_departures=0 gives zero applied coverages and zero CDF	Pass
[11] every load-bearing input is refused at 0 or below (never silently floored to an unbounded Nf)	Pass

faarfield-cdf-web-validation.test.ts

Published-value validation of the single-aircraft FAARFIELD subgrade CDF engine `faarfield-cdf` (3-layer AC / base / subgrade Burmister response → FAA subgrade failure model → wander coverages).

Analyses validated: `faarfield-cdf` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
subgrade failure model lies on the TC-17/28 Table 4 lower-envelope data (Bleasdale branch, C ≥ 1000)	Pass
tangent point and the Table 6 linear branch (Eq. 6)	Pass
wander and effective-width constants follow AC 6G §3.12.8.7 / §3.12.9.2	Pass
engine chain: the reported coverages-to-failure is the published model at the reported strain (HAND-DERIVED identity)	Pass

faarfield-design-published-web-validation.test.ts

Published-criterion validation of the FAARFIELD-class flexible THICKNESS design engine `faarfield-design` (iterates the asphalt thickness of a 3-layer AC / base / subgrade section until the Miner mix CDF = 1).

Analyses validated: `faarfield-design` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
AC 6G §3.12.9.1: the designed thickness has CDF = 1 for the traffic mix	Pass
AC 6G §3.12.9.1 / TC-17/28 Eq. 7: the mix CDF is the sum of the per-aircraft terms	Pass
AC 6G §3.12.2.3: a single "design aircraft" carrying all departures over-designs the true mix	Pass
the design thickness responds to the design-life input the way the CDF definition requires	Pass

faarfield-design-web-validation.test.ts

EVIDENCE CLASS (added with the 2026-10 published-value audit): formula-fidelity / design-property evidence only.

Analyses validated: `faarfield-design` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] single aircraft: converges, and the design CDF is within the engine's own documented tolerance of the FAA design condition CDF=1.0	Pass
[3] the single aircraft's CDF contribution accounts for 100% of the total when it is the only aircraft in the fleet	Pass
[4-5] a two-aircraft mix's CDF contributions sum to the design CDF (Miner's cumulative damage rule) and each is a real fraction of it	Pass
[6] a two-aircraft mix requires MORE thickness than the single heaviest aircraft designed alone (the mix cannot be easier than its governing member)	Pass
[7] a heavier wheel load requires a thicker design section, all else equal	Pass
[8] more annual departures over the same design life requires a thicker section	Pass
[9] a stronger subgrade reduces the required thickness for the same fleet	Pass
[10] no aircraft in the fleet, or an aircraft with zero load/departures, is refused	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[11] the returned required thickness lies within the search bracket [min, max]	Pass

faarfield-flexible-published-web-validation.test.ts

Published-value validation of the FAARFIELD flexible (LEAF) design engine `faarfield-flexible` (and the layered-elastic multi-wheel kernel it drives), against two independent FAA documents.

Analyses validated: `faarfield-flexible` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
max subgrade strain of the NAPTF 4-wheel (2D) and 6-wheel (3D) gears reproduces TC-17/28 Appendix B	Pass
Eq. 1 reproduces TC-17/28 Table 1(b) sublayer moduli (4 × 6.0025 in P-154, 8 in P-209) to the psi	Pass
the Bleasdale curve (Eq. 4) lies on the Table 4 lower-envelope data it was regressed to	Pass
the tangent point (Eq. 6) and Table 6 unshifted FAARFIELD 1.41 coverages-to-failure	Pass
TC-17/28 Table 2: B737-800, 1 200 dep/yr, 20 yr, 5 in P-401 + 8 in P-209 → P-154 t1 at CBR 3/6/10/15	Pass
TC-17/28 Table 2: effective equivalency factor feq = t3/t2 (P-209 cut by 3 in → extra P-154)	Pass
AC 6G Appendix H.2: 4 in P-401 / 8 in P-403 / 12 in P-209 / P-154 on CBR 5 → "10.1 inches P-154"	Pass
AC 6G Appendix H.8: apron extension, same traffic, CBR 5, 6 in P-209 → "18 inches P-154" (36 in total)	Pass
layer inputs follow AC 6G Table 3-2 and the published subgrade modulus convention	Pass
Table 3-3 minimum P-209 of 6 in applies from 60,000 lb, both weight classes	Pass

faarfield-flexible-web-validation.test.ts

Web-benchmark validation for the full FAARFIELD 1.41 flexible LEAF design.

Analyses validated: `faarfield-cdf`, `faarfield-flexible` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
granularSublayers reproduces FAA-TC-17/28 Table 1 P-154 sublayer moduli (WES params)	Pass
granularSublayers reproduces FAA-TC-17/28 Table 1 P-209 modulus (WES params)	Pass
FAAModulus sublayering keeps the top sublayer between base/2 and 1.5·base	Pass
the Bleasdale + tangent branches meet at exactly 1000 coverages	Pass
Bleasdale model tracks the FAA-TC-17/28 Table 4 points (≥ 1000 coverages)	Pass
the flexible engine and faarfield-cdf/mix-cdf share the SAME Bleasdale model	Pass
the linear tangent branch governs below 1000 coverages (Eq. 6)	Pass
Appendix-H flexible design reproduces P-154 ≈ 10.1 in (to the inch)	Pass
the assembled section reports sane sublayer moduli + subgrade E = 1500·CBR	Pass
design is monotone: a weaker subgrade needs a thicker P-154	Pass
a P-209-only design honours the 6-in FAA minimum base thickness (Table 3-3)	Pass

faarfield-mix-cdf-web-validation.test.ts

Published-value validation of the two-aircraft FAARFIELD subgrade CDF engine `faarfield-mix-cdf` (Miner sum over an aircraft mix, 82 strips, 3-layer AC / base / subgrade response).

Analyses validated: `faarfield-mix-cdf` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the B737-800 handed to the engine agrees with the Boeing ACAP (D6-58325-6 §7.2.4 / §7.10)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
AC 6G §3.12.9.1 / TC-17/28 Eq. 7: the mix CDF is the Miner sum of the per-aircraft terms	Pass
a mix is at least as damaging as either aircraft alone (AC 6G §3.12.2.3 — designing to one aircraft is not the mix)	Pass
disabling the second slot (departures = 0) reproduces the single-aircraft engine result	Pass
CDF scales linearly with departures (AC 6G §3.12.9.1: CDF = applied coverages / coverages to failure)	Pass

⚑ faarfield-rigid-published-web-validation.test.ts

PUBLISHED-VALUES: 3 -- distinct published values for this engine (engine-level total, declared once); independent audit A1: 2-3 published engine outputs; the remaining assertions are hand-derived or bands.

Analyses validated: `faarfield-rigid` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
AC 6G Appendix H.3: P-501 R = 600 psi, k = 100 pci, 20 yr → 17.14 in	Pass
AC 6G Appendix H.9: R = 625 psi, k = 100.5 pci, same traffic, 20 yr → 16.7 in	Pass
AC 6G Table 3-4 / Table 3-2: minimum rigid surface 6 in; P-501 modulus 4,000,000 psi with ν = 0.15	Pass
design flexural strength range in AC 6G §3.16.7.3 (600-750 psi) gives monotone, physical slabs	Pass
Kawa, Brill & Hayhoe (2007) Eqs. (1)-(2) evaluated at the AC H.3 design factor (HAND-DERIVED)	Pass

faarfield-rigid-web-validation.test.ts

Web-benchmark validation for the FAARFIELD-class RIGID airfield design.

Analyses validated: `faarfield-rigid` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FAARFIELD full-failure eq(2): C = 10^[(DF−0.5878)/0.2523]	Pass
FAARFIELD onset eq(1): C = 10^[(DF−0.7409)/0.2465] (more conservative)	Pass
Corps of Engineers LEA model: C = 10^[(DF−0.58901)/0.35486]	Pass
Westergaard edge stress matches the closed-form hand calc	Pass
Appendix-H rigid design reproduces the 17.14-in slab (closed form ≈ FE)	Pass
rigid design is monotone in strength and traffic	Pass

⚑ irc-sp72-pavement-published-web-validation.test.ts

LOW-VOLUME RURAL-ROAD PAVEMENT — `computeIrcSp72Pavement` (traffic curve A–D, minimum base course, sub-base split, bituminous-surfacing requirement) checked against the TEXT, TABLES AND WORKED EXAMPLES of two independent Indian Roads Congr…

Analyses validated: `irc-sp72-pavement` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC:SP:72-2015 §1.3.3 — curve A/B/C/D for traffic categories 0-15 / 15-45 / 45-150 / 150-450 CVPD (mid-band inputs)	Pass
IRC:SP:72-2015 §1.3.3 — minimum base course 150 mm for curves A and B, 225 mm for curves C and D	Pass
IRC:SP:72-2015 §1.3.3 — "sub-base … arrived at by subtracting the minimum base course thickness from the total" (derived: total 400 mm)	Pass
IRC:SP:72-2015 Appendix A — the seven CVPD values of the ADT table fall on the curves §1.3.3 assigns them	Pass
IRC:SP:72-2015 §1.3.4 — exemption (i): rainfall "less than 500 mm" and traffic "upto 150"	Pass
IRC:SP:72-2015 §1.3.4 — exemption (ii): rainfall "less than 1000 mm" and traffic "upto 50"	Pass
IRC:SP:72-2015 §6.1.2 — gravel-road floor "subgrade CBR is above 2": the engine warns at CBR 2 and not at 2.5	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC:SP:72-2015 Appendix D — CVPD 44 (6 HCV + 38 MCV), rainfall 750 mm, CBR 5: curve B, 150 mm base, gravel acceptable	Pass
IRC:SP:20-2002 Table 5.1 — rainfall 0-500 mm: gravel at 0-50 and 50-150 motorised/day, bituminous at 150+	Pass
IRC:SP:20-2002 Table 5.1 — rainfall 500-1000 mm: gravel only at 0-50; bituminous (single-coat SD or more) above	Pass
IRC:SP:20-2002 Table 5.1 — rainfall 1000-1500 mm and 1500+ mm: bituminous surfacing at every traffic level	Pass
IRC:SP:20-2002 §5.4.3 — 30 CVPD growing 6 % for 10 years = 54 CVPD → curve C; rainfall 1200 mm → "2 Coat Surface Dressing"	Pass

irc-sp72-pavement-web-validation.test.ts

Formula-fidelity validation against IRC:SP-72-2015 §1.3.3 (traffic-curve bands and minimum base-course thicknesses) and §1.3.4 (gravel/WBM surfacing exemptions).

Analyses validated: `irc-sp72-pavement` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-3] CVPD=10 (curve A, 0-15 band): min base=150mm, sub-base=250mm at 400mm total	Pass
[4-6] CVPD=30 (curve B, 15-45 band): min base=150mm	Pass
[7-9] CVPD=100 (curve C, 45-150 band): min base=225mm	Pass
[10-12] CVPD=300 (curve D, 150-450 band): min base=225mm	Pass
[13] the exact CVPD boundary values fall into the LOWER band (<=15 -> A, <=45 -> B, <=150 -> C)	Pass
[14] CVPD above 450 warns that it is outside the SP:72 curve range (use IRC 37 instead)	Pass
[15] exemption (i): arid climate (<500mm rain) with CVPD<=150 allows gravel/WBM surfacing	Pass
[16] exemption (ii): low-rainfall (<1000mm) with CVPD<=50 also allows gravel/WBM surfacing	Pass
[17] traffic too high for either exemption forces bituminous surfacing despite low rainfall	Pass
[18] high rainfall (>=1000mm) forces bituminous surfacing regardless of traffic	Pass
[19] no rainfall supplied assumes bituminous surfacing is required (never silently exempted)	Pass
[20] total thickness below the minimum base course flags the shortfall rather than a negative sub-base	Pass
[21] CVPD, CBR, and total thickness are each refused when invalid	Pass

jpcp-cracking-published-web-validation.test.ts

PUBLISHED-ANSWER validation of the LOAD-STRESS SUB-MODEL inside `jpcp-cracking.ts`: the radius of relative stiffness ℓ and the Westergaard (1926) edge bending stress that feed the MEPDG fatigue calculation.

Analyses validated: `jpcp-cracking` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Pavement Interactive Examples 1 and 2: ℓ and edge stress, P = 9000 lb (a = 5.9 in), k = 200 pci, E = 5×10^6 psi	Pass
Ioannides et al. (1985) TRR 1043 Table 1 WESII — nine published edge stresses (E = 5×10^6 psi, P = 50 000 lb)	Pass
Ioannides et al. (1985) TRR 1043 Table 2 — printed L/ℓ for the 25 × 25 ft slab gives ℓ for the same nine runs	Pass
IRC:58-2015 Appendix VII / VIII and Huang (2004): printed radius of relative stiffness	Pass
Solved problem (ques10 post 34957): ℓ and edge stress in kg/cm units	Pass
AASHTO (2015) MOP §5.4.1: N of Eq. 5-17b is the life at 50 percent slab cracking, so DI = 1 gives CRK = 50 %	Pass

jpcp-cracking-web-validation.test.ts

Formula-fidelity validation against AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `jpcp-cracking` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-6] base case (thick slab, light traffic): l=1055.9mm, sigma=1.4447MPa, Nf=9.975e7, DI=0.050125, CRK=0.266039%	Pass
[7-11] Westergaard b-branch (a < 1.724h), thinner slab + heavier traffic drives DI >> 1, CRK saturates at 100%	Pass
[12-16] the a >= 1.724h branch (b = a directly, not the Westergaard b formula) with a low tyre pressure over a thin slab	Pass
[17] N=0 gives exactly zero damage and zero cracking	Pass
[18] the fatigue-life exponent (C1=2.0, C2=1.22) matches Eq. 5-17b exactly at a controlled stress ratio	Pass
[19] stress_ratio field is sigma/MR (the inverse of the fatigue-equation ratio), consistent with edge_stress_mpa	Pass
[20] every load-bearing input is refused at 0 or below, never silently clamped to a tiny positive floor	Pass
[21] classification bands: below 5%, 5-15%, >=15%	Pass

⚑ jpcp-faulting-published-web-validation.test.ts

PUBLISHED-VALUE validation of the two parts of `jpcp-faulting.ts` for which a published number could be found: the Westergaard (1926) loaded-corner deflection, and the effective base load-transfer efficiencies that enter the joint LTE of M…

Analyses validated: `jpcp-faulting` · Recorded run: passed — 2 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Huang (2004) Ch. 3 corner example: δc = 0.0502 in	Pass
AASHTO (2015) MOP Table 5-3: effective base LTE 20 / 30 / 40 % (no dowels, no aggregate interlock → joint LTE = base LTE)	Pass

jpcp-faulting-web-validation.test.ts

Formula-fidelity validation against AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `jpcp-faulting` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-6] base case (no dowels, aggregate base): LTE=52%, dL=0.044304 in, dUL=0.023038 in, DE=0.079135 lb/in, FAULTMAX0=0.126277 in	Pass
[7-9] dowel LTE=90% raises the joint LTE to 95.2% and cuts dUL/DE sharply (Eq. 5-22)	Pass
[10] lean-concrete base (LTE_base=40 vs 20 for aggregate) raises joint LTE to 64% at the same dowel/agg LTE	Pass
[11] loaded corner deflection dL is identical across base types and dowel LTE (Westergaard geometry is unaffected by LTE)	Pass
[12] no fines to erode (pct_passing_200 = 0) gives FAULTMAX0 = 0 by definition, with a warning	Pass
[13] no curling deflection (dcurl = 0) gives FAULTMAX0 = 0 by construction	Pass
[14] the Westergaard corner-ratio range guard refuses geometries outside a*sqrt(2)/l < 1.25	Pass
[15] joint LTE formula (Eq. 5-22) matches the compound-probability form exactly for arbitrary dowel/agg/base values	Pass
[16] every load-bearing input is refused at 0 or below	Pass

jpcp-iri-published-web-validation.test.ts

PUBLISHED-COEFFICIENT cross-check of the MEPDG JPCP smoothness model (`jpcp-iri.ts`, IRI = IRI0 + C1·CRK + C2·SPALL + C3·TFAULT + C4·SF).

Analyses validated: `jpcp-iri` · Recorded run: passed — 2 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Hall (2008) metric form of the MEPDG JPCP IRI model confirms the engine coefficients C1, C2, C3, C4	Pass
The misprinted C3 = 0.4929 of the 2008 interim MOP is rejected by the metric form	Pass

jpcp-iri-web-validation.test.ts

Formula-fidelity validation against AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `jpcp-iri` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-6] no freeze climate (FI=0): SF=9e-5, contributions crk=8.203 spall=2.2085 fault=4.4787 sf=0.00227, IRI=77.892472 in/mi	Pass
[7-9] freeze-thaw climate (FI=1500) raises the site factor and IRI to 79.785623 in/mi	Pass
[10-11] zero distress at age 0 returns exactly the initial IRI (63 in/mi)	Pass
[12-13] aged, more distressed case: SF=0.089216, IRI=110.018012 in/mi	Pass
[14] unit conversion in/mi -> m/km is exact (x0.0157828)	Pass
[15] IRI0 is refused at 0 or below — it is the dominant term, no pavement is built at IRI0=0	Pass
[16] each distress coefficient matches its published constant exactly, isolated one at a time	Pass
[17] ride-quality classification bands (good <95, fair <170, mediocre <220, else poor)	Pass

jpcp-spalling-published-web-validation.test.ts

PUBLISHED-VALUES: 12 -- distinct published values for this engine (engine-level total, declared once); independent audit A1: 12 chart readings; 23 further values are cross-checks against Hoerner Eq.

Analyses validated: `jpcp-spalling` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Hoerner et al. (2000) Fig. 38 — air content 2 / 4 / 6 / 8 % (f'c 5000 psi, 80 F-T/yr, 10 in, w/c 0.44)	Pass
Hoerner et al. (2000) Fig. 39 — 28-day compressive strength 2500 / 5000 / 7500 psi (air 6 %)	Pass
Hoerner et al. (2000) Fig. 40 — joint sealant: preformed vs non-preformed	Pass
Hoerner et al. (2000) Fig. 41 — slab thickness 8 / 10 / 12 in	Pass
Hoerner et al. (2000) Fig. 42 — annual freeze-thaw cycles 0 / 40 / 80 / 120 / 160	Pass
Hoerner et al. (2000) Fig. 43 — water/cement ratio 0.38 / 0.44 / 0.50	Pass
Hall (2008): each 1 % of air content shifts the age at 50 % spalling by "about 8 years"; preformed sealant gives essentially none over 60 years	Pass

jpcp-spalling-web-validation.test.ts

Formula-fidelity validation against the AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `jpcp-spalling` · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] AGE=5, no sealant, AC=4%, fc=20MPa, FT=80, H=200mm, WC=0.55 -> SCF=316.9420, SPALL=21.685974%	Pass
[3-4] AGE=10, same mix -> SCF=236.9420, SPALL=35.782654%	Pass
[5-6] AGE=15 (base case) -> SCF=156.9420, SPALL=52.836675%	Pass
[7-8] AGE=20, same mix -> SCF=76.9420, SPALL=69.245718%	Pass
[9-10] AGE=25, same mix -> SCF=-3.0580, SPALL=81.895792%	Pass
[11-12] AGE=30, same mix -> SCF=-83.0580, SPALL=90.082316%	Pass
[13-14] preformed joint sealant at AGE=15 -> SCF=1556.9420, SPALL=0.103924%	Pass
[15] preformed sealant sharply reduces spalling vs no sealant, same age	Pass
[16-19] PCC air content sweep at AGE=15: 2%,4%,6%,8% -> 86.479524%, 52.836675%, 16.363403%, 3.302315%	Pass
[20-23] water/cement ratio sweep at AGE=15: 0.35,0.45,0.55,0.65 -> 39.633344%, 46.168327%, 52.836675%, 59.404008%	Pass
[24-27] slab thickness sweep at AGE=15: 150,200,250,300 mm -> 63.073483%, 52.836675%, 42.352301%, 32.512173%	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[28-31] compressive strength sweep at AGE=15: 15,20,28,35 MPa -> 66.462497%, 52.836675%, 34.462553%, 23.082675%	Pass
[32-35] freeze-thaw cycles sweep at AGE=15: 0,40,80,150 -> 25.295769%, 38.117131%, 52.836675%, 76.125854%	Pass
[36] AGE=0 forces SPALL=0 exactly regardless of SCF (age-factor term AGE/(AGE+0.01)=0)	Pass

⚑ jpcp-time-stepping-published-web-validation.test.ts

PUBLISHED-ANSWER validation of the stress sub-model inside the JPCP time-stepping driver (`jpcp-time-stepping.ts`): the Westergaard (1926) load edge stress σ_L, the radius of relative stiffness ℓ, and the Bradbury (1938) edge curling stres…

Analyses validated: `jpcp-time-stepping` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Pavement Interactive Examples 1 and 2: ℓ and load edge stress	Pass
Pavement Interactive curling example: Bradbury edge warping stress 230 psi at C = 0.68	Pass
Ioannides et al. (1985) TRR 1043 Table 1 WESII — nine published edge stresses (E = 5×10^6 psi, P = 50 000 lb)	Pass
Ioannides et al. (1985) TRR 1043 Table 2 — printed L/ℓ (L = 300 in) gives ℓ for the same nine runs	Pass
IRC:58-2015, Huang (2004) and the solved problem: printed radius of relative stiffness and edge stress	Pass

jpcp-time-stepping-web-validation.test.ts

Validation against AASHTO MEPDG Manual of Practice §5 (rigid distress) and Bradbury (1938) curling stress, via the engine's OWN documented self-check invariant (stated in its header): "with DeltaT = 0 every month...

Analyses validated: `jpcp-cracking`, `jpcp-time-stepping` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] SELF-CHECK INVARIANT (stated in the engine's own header): with zero monthly curling gradient, the accumulated damage exactly equals the single-pass jpcp-cracking engine's damage at the same total load	Pass
[3] the load-only edge stress reported by the time-stepping driver matches the Westergaard closed-form exactly (same formula as jpcp-cracking)	Pass
[4] adding a positive curling gradient can only INCREASE the peak combined stress above the load-only stress (Bradbury: curling adds to the bottom tensile stress in the critical direction)	Pass
[5] the accumulated damage is INVARIANT to the design life when the traffic is a fixed TOTAL (spreading the same total over more months does not add or remove traffic), per the engine's own documented E-110 note	Pass
[6] applications_per_month equals total_load_applications / (years*12) exactly	Pass
[7] the cracking curve is monotonically non-decreasing over time (damage only accumulates)	Pass
[8] faulting is explicitly flagged as NOT accumulated (the driver covers cracking only, per its own documented scope)	Pass
[9] invalid inputs (zero modulus, thickness, MR, or k) are refused	Pass

⚑ layered-elastic-pavement-published-web-validation.test.ts

MULTILAYER (BURMISTER) ELASTIC PAVEMENT RESPONSE — `computeLayeredElastic` / `subgradeStrainAtOffset` checked against PUBLISHED PROGRAM OUTPUT and a PUBLISHED TABLE.

Analyses validated: `layered-elastic-pavement` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC:37-2018 Example II.1 — 500 mm of 119.7 MPa over a 66.6 MPa half-space, 40 kN wheel: surface deflection 1.41 mm	Pass
IRC:37-2018 Example II.1 — the equivalent single-layer modulus 2(1−ν²)pa/δ = 105.10 MPa	Pass
IRC:37-2018 Figure I.3 — 3000 / 450 / 75 MPa, 140 + 500 mm, dual wheel: top-of-subgrade εz 192.0 με (r 0) and 205.3 με (r 155)	Pass
IRC:37-2018 Example II.2 / Figure II.3 — 95 MPa sub-base, 250 mm, over 50 MPa: εz 2322 με (r 0), 2179 με (r 155)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC:37-2018 Example II.2 — the 150 mm trial (sub-base 0.2·150^0.45·50 = 95 MPa) gives 4324 με	Pass
IRC:37-2018 Example II.3 / Figure II.4 — 3000 / 200 / 62 MPa, 190 + 480 mm, dual wheel: εz 231.2 με (r 0), 244.3 με (r 155)	Pass
IRC:37-2018 Table III.1 — bituminous + granular base/sub-base (granular modulus printed per row): 6 subgrade strains	Pass
IRC:37-2018 Table III.6 — bituminous + 150 mm WMM + 200 mm CTSB: 5 subgrade strains	Pass
IRC:37-2018 Table III.2 — bituminous + 100 mm crack-relief layer + CTB + 200 mm CTSB: 3 subgrade strains	Pass
IRC:37-2018 Table III.4 — bituminous + 100 mm stabilised RAP (800 MPa) + 200 mm CTSB: 3 subgrade strains	Pass
IRC:37-2018 Table III.5 — bituminous + 100 mm crack-relief + CTB + 200 mm GSB (167 MPa): 6 subgrade strains	Pass
Das (2016) Table 6.1 — Δσ/q0 on the axis for 14 of the 16 printed depths between 0.1 and 4.0 (half-space values)	Pass

`layered-elastic-pavement-web-validation.test.ts`

Validation against the classical Boussinesq (1885) closed-form solution for a uniform circular flexible load on a HOMOGENEOUS elastic half-space -- the exact analytical limit this multilayer Burmister solver reduces to when given a single…

Analyses validated: `layered-elastic-pavement` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1] surface deflection matches the exact Boussinesq closed-form w0 = 2qa(1-nu^2)/E to 1e-6 relative	Pass
[2] subgrade vertical stress at the surface equals the applied pressure q exactly (sigma_z(0)=q boundary condition)	Pass
[3] tensile (radial) strain at the surface matches the exact Boussinesq closed-form to 1e-6 relative	Pass
[4] vertical strain via computeLayeredElastic and via subgradeInteriorStrains agree at z=0 (cross-consistency of the two entry points)	Pass
[5] deflection decays monotonically with layer stiffness (stiffer subgrade -> less deflection), the expected physical trend	Pass
[6] a real 3-layer pavement (AC/base/subgrade) gives a physically ordered response: deflection under the load exceeds zero, AC tensile strain and subgrade vertical strain are both positive and finite	Pass
[7] a stiffer asphalt layer reduces the tensile strain at its own bottom (the classic M-E design lever)	Pass
[8] multi-wheel gear superposition: a single wheel matches computeLayeredElastic's subgrade strain exactly, and adding wheels never decreases the max (elastic superposition can only add)	Pass
[9] gear amplification factor equals max gear strain divided by the single-wheel strain, exactly as defined	Pass

`mepdg-ac-rutting-web-validation.test.ts`

Validation against AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `mepdg-ac-rutting` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-2] the seasonal modulus-temperature law E=Eref.10^(susc.(Tref-T)) matches exactly at the default climate: summer E=865.209451 MPa, winter E=10402.105514 MPa	Pass
[3] the modulus law is symmetric about Tref=Tmean: shifting Tref by +5C at fixed climate shifts both summer/winter E by exactly 10^(susc.5)	Pass
[4-5] beta_r1 (field-calibration factor) scales the rut EXACTLY linearly, per Eq. 5-1a's direct multiplicative form	Pass
[6] monotone increasing in cumulative traffic N	Pass
[7] monotone increasing in mean pavement temperature (hotter asphalt is softer -> more rut)	Pass
[8] zero AC thickness gives exactly zero rut, labelled definitional (an unsurfaced road, not a durable pavement)	Pass
[9] zero load applications gives exactly zero rut, labelled definitional (never exercised, not adequate)	Pass
[10] mm/in conversion is exact (x25.4)	Pass
[11] negative thickness or negative traffic is refused, never read as "no asphalt"	Pass
[12] the strain-hardening term telescopes: rut(N1)/rut(N2) = (N1/N2)^0.4791 EXACTLY, whatever the life or climate (Eq. 5-1a, k3 = 0.4791)	Pass

mepdg-fatigue-published-web-validation.test.ts

MEPDG bottom-up fatigue (alligator) cracking - checks against PUBLISHED values only.

Analyses validated: `mepdg-fatigue` · Recorded run: passed — 16 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Fig. 5-3 / Kim 2011 / Priest & Timm 2006: 50 % alligator cracking at 100 % damage (DI = 1), Hac = 2 in	Pass
Fig. 5-3 / Kim 2011 / Priest & Timm 2006: 50 % alligator cracking at 100 % damage (DI = 1), Hac = 4 in	Pass
Fig. 5-3 / Kim 2011 / Priest & Timm 2006: 50 % alligator cracking at 100 % damage (DI = 1), Hac = 6 in	Pass
Fig. 5-3 / Kim 2011 / Priest & Timm 2006: 50 % alligator cracking at 100 % damage (DI = 1), Hac = 8 in	Pass
Fig. 5-3 / Kim 2011 / Priest & Timm 2006: 50 % alligator cracking at 100 % damage (DI = 1), Hac = 12 in	Pass
Eq. 5-6a plateau C4/60 = 6000/60 = 100 %: at Log Damage (%) = 6 (DI = 1e4) the curve is at the plateau for Hac = 2, 6, 12 in	Pass
Figure 5-3: the curve is indistinguishable from 0 % at Log Damage (%) <= -1 (DI = 0.001)	Pass
Priest & Timm 2006 p. 80: the volumetric correction C is "equal to 1" at Va = 5 %, Vb = 11 %	Pass
App. II-1 Table 7, AC < 2 in: shift factor 0.000398 (checked at 1 in and 1.5 in, within the printed Se)	Pass
App. II-1 Table 7, AC 2-3 in: shift factor 0.000524 lies between the fitted curve at 2 in and at 3 in	Pass
App. II-1 Table 7, AC 3-4 in (printed "2-4"): shift factor 0.002934 lies between the fitted curve at 3 in and at 4 in	Pass
App. II-1 Table 7, AC 4-6 in: shift factor 0.004 (CH = 250), checked at 5 in within the printed Se	Pass
App. II-1 Table 7, AC 6-8 in: shift factor 0.004 (CH = 250), checked at 7 in within the printed Se	Pass
App. II-1 Table 7, AC 8-10 in: shift factor 0.004 (CH = 250), checked at 9 in within the printed Se	Pass
App. II-1 Table 7, AC 10-12 in: shift factor 0.004 (CH = 250), checked at 11 in within the printed Se	Pass
App. II-1 Table 7, AC > 12 in: shift factor 0.004 (CH = 250), checked at 14 in within the printed Se	Pass

mepdg-fatigue-web-validation.test.ts

Formula-fidelity validation against AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `mepdg-fatigue` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-6] base case (matches the existing hand-verified golden test exactly): C=0.41506, CH=250.0, Nf=1.010e9, D=0.00990, FCbottom=0.586%	Pass
[7-8] doubling the tensile strain drops Nf by exactly (200/70)^3.9492 per the published kf2=-3.9492 exponent	Pass
[9-10] doubling the AC modulus drops Nf by exactly 2^1.281 per the published kf3=-1.281 exponent	Pass
[11-12] the C-factor (air-voids/binder term) matches 10^(4.84.(Vbe/(Va+Vbe)-0.69)) exactly for an arbitrary mix	Pass
[13-14] the thickness-correction CH matches 1/(0.000398+0.003602/(1+e^(11.02-3.49.Hac))) exactly for an arbitrary thickness	Pass
[15] N=0 gives exactly zero damage and zero cracking, labelled as definitional (real limit: an untrafficked pavement)	Pass
[16] richer/lower-void mix (higher C-factor) increases Nf and reduces cracking than a leaner/higher-void mix, all else equal	Pass
[17] every load-bearing input is refused at 0 or below	Pass

⚑ mepdg-iri-published-web-validation.test.ts

MEPDG flexible-pavement IRI (Eq.

Analyses validated: `mepdg-iri` · Recorded run: passed — 19 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA-HRT-17-049 Fig. 9 p02 = 20 %: predicted IRI change at age 1 yr = 0.18 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 9 p02 = 20 %: predicted IRI change at age 20 yr = 16.97 in/mi (printed to 2 d.p.)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA-HRT-17-049 Fig. 9 p02 = 40 %: predicted IRI change at age 1 yr = 0.2 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 9 p02 = 60 %: predicted IRI change at age 1 yr = 0.21 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 9 p02 = 60 %: predicted IRI change at age 20 yr = 18.44 in/mi (printed to 2 d.p.)	Pass
FHWA-HRT-17-049 Fig. 10 Precip = 20 in: predicted IRI change at age 1 yr = 0.19 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 10 Precip = 20 in: predicted IRI change at age 20 yr = 17.67 in/mi (printed to 2 d.p.)	Pass
FHWA-HRT-17-049 Fig. 10 Precip = 40 in: predicted IRI change at age 1 yr = 0.21 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 10 Precip = 40 in: predicted IRI change at age 20 yr = 18.57 in/mi (printed to 2 d.p.)	Pass
FHWA-HRT-17-049 Fig. 10 Precip = 60 in: predicted IRI change at age 1 yr = 0.21 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 10 Precip = 60 in: predicted IRI change at age 20 yr = 19.1 in/mi (printed to 2 d.p.)	Pass
FHWA-HRT-17-049 Fig. 11 FI = 100 F-days: predicted IRI change at age 1 yr = 0.18 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 11 FI = 100 F-days: predicted IRI change at age 20 yr = 16.05 in/mi (printed to 2 d.p.)	Pass
FHWA-HRT-17-049 Fig. 11 FI = 500 F-days: predicted IRI change at age 1 yr = 0.2 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 11 FI = 500 F-days: predicted IRI change at age 20 yr = 18.2 in/mi (printed to 2 d.p.)	Pass
FHWA-HRT-17-049 Fig. 11 FI = 900 F-days: predicted IRI change at age 1 yr = 0.21 in/mi (printed to 2 d.p., +/-0.01)	Pass
FHWA-HRT-17-049 Fig. 11 FI = 900 F-days: predicted IRI change at age 20 yr = 18.98 in/mi (printed to 2 d.p.)	Pass
FHWA Our Nation's Highways 2026: "IRI of less than 95 ... good": just below 95 in/mi the engine says Good ride, just above it does not	Pass
FHWA Our Nation's Highways 2026: "less than 170 ... acceptable": just below 170 in/mi the engine says Fair ride, just above it does not	Pass

mepdg-iri-web-validation.test.ts

Formula-fidelity validation against AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `mepdg-iri` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-6] base case: SF=1397.063312, contributions rut=10.0 fat=6.0 thermal=1.6 site=20.955950, IRI=101.555950 in/mi	Pass
[7-8] age=0 zeroes the site factor (Age^1.5 multiplies both logarithms): SF=0, IRI=IRI0=63	Pass
[9] IRI0 refused at 0 or below	Pass
[10-11] p02 = 0 or p200 = 0 is refused (both sit inside logs and diverge to -infinity, not to a vanishing term)	Pass
[12] each distress coefficient matches its published constant exactly, isolated one at a time	Pass
[13] unit conversion in/mi -> m/km is exact (x0.0157828)	Pass
[14] ride-quality bands: good <95, fair <170, mediocre <220, else poor	Pass

mepdg-subgrade-rutting-published-web-validation.test.ts

MEPDG unbound / subgrade rutting (Tseng-Lytton, Eq.

Analyses validated: `mepdg-subgrade-rutting` · Recorded run: passed — 25 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Table B-35 (and MOP Eq. 5-2c): Co = ln(a1/a9) = ln(0.15/20) = -4.8928523, the value the engine's Rho is built on	Pass
Table B-35 CBR 1: Rho = 1.498e+34 at the published Beta 0.0299719 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 2: Rho = 10180000000000000 at the published Beta 0.0538458 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 3: Rho = 308500000000 at the published Beta 0.0700934 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 4: Rho = 2866000000 at the published Beta 0.0821515 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 5: Rho = 197251804 at the published Beta 0.0916235 (MOP Eq. 5-2b)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Table B-35 CBR 7: Rho = 10004263 at the published Beta 0.1058432 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 10: Rho = 1073506.5 at the published Beta 0.1205232 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 12: Rho = 442991.9335 at the published Beta 0.127772481 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 15: Rho = 178595.56 at the published Beta 0.1363509 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 20: Rho = 69125.054 at the published Beta 0.146865 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 40: Rho = 14104.545 at the published Beta 0.1693629 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 100: Rho = 4164.0422 at the published Beta 0.1927432 (MOP Eq. 5-2b)	Pass
Table B-35 CBR 1: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 2: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 3: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 4: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 5: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 7: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 10: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 12: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 15: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 20: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 40: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass
Table B-35 CBR 100: rut(N)/rut(1e7) follows the published ep(N)/er ratios at N = 1e3, 1e5, 1e8	Pass

`mepdg-subgrade-rutting-web-validation.test.ts`

Validation against Tseng & Lytton (1989) and AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `mepdg-subgrade-rutting` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-3] material regressions at Wc=15%, MR=60MPa: eps0/epsr=71.160108, beta=0.133119, rho=247542.176 (NHI 5.28-5.29 / MOP 5-2b exact)	Pass
[4-5] wetter subgrade (Wc=25% vs 15%) raises eps0/epsr per the +0.08109 coefficient exactly	Pass
[6-7] stiffer subgrade (higher MR) reduces eps0/epsr per the -0.000012157 coefficient exactly	Pass
[8] the granular/fine ks1 ratio (2.03/1.35) is EXACT — ks1 is a pure multiplicative factor on the rut	Pass
[9] monotone increasing in cumulative traffic N (the Tseng-Lytton accel factor e^(-(rho/N)^beta) rises toward 1 with N)	Pass
[10] N=0 gives exactly zero rut, labelled as definitional	Pass
[11] beta_s1=0 zeroes the rut exactly (it is a pure multiplicative local-calibration factor)	Pass
[12] linear in beta_s1 (a pure multiplicative calibration factor, Eq. 5-2a)	Pass
[13] every load-bearing input is refused at 0 or below, never silently clamped to a tiny positive floor	Pass
[14] mm/in conversion is exact (x25.4)	Pass

⚑ `mepdg-thermal-cracking-published-web-validation.test.ts`

MEPDG thermal (transverse) cracking, Eq.

Analyses validated: `mepdg-thermal-cracking` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NIST handbook critical value Z_0.001 = -3.09: TC = 400 x 0.001 = 0.4 ft/mi	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NIST handbook critical value Z_0.005 = -2.576: TC = 400 x 0.005 = 2 ft/mi	Pass
NIST handbook critical value Z_0.01 = -2.326: TC = 400 x 0.01 = 4 ft/mi	Pass
NIST handbook critical value Z_0.025 = -1.96: TC = 400 x 0.025 = 10 ft/mi	Pass
NIST handbook critical value Z_0.05 = -1.645: TC = 400 x 0.05 = 20 ft/mi	Pass
NIST handbook critical value Z_0.1 = -1.282: TC = 400 x 0.1 = 40 ft/mi	Pass
NIST handbook worked example P[x <= -1] = 0.15866 => TC = 400 x 0.15866 = 63.464 ft/mi	Pass
NIST handbook worked example P[x <= -1.53] = 0.06301 => TC = 400 x 0.06301 = 25.204 ft/mi	Pass
N[0] = 0.5 (NIST: "add 0.5 (for the probability less than zero)"): Cd = HHMA gives TC = 400 x 0.5 = 200 ft/mi	Pass
a crack that Paris-law growth drives through the whole layer saturates at the same published value 400 N[0] = 200 ft/mi	Pass
NIST SP 811 App. B.8: 1 ft/mi = 0.3048 m / 1.609344 km, so m/km = ft/mi x 0.3048 / 1.609344 (0.1893939)	Pass

mepdg-thermal-cracking-web-validation.test.ts

Formula-fidelity validation against AASHTO MEPDG "A Manual of Practice" 2nd ed.

Analyses validated: `mepdg-thermal-cracking` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-6] base case (mild climate, moderate mix): n=2.4, A=2.034249e-10, sigma_tip=1.2MPa, Cd=0.213912in, ratio=0.036222, TC=12.189030 ft/mi	Pass
[7-9] severe case (high modulus/contraction, thin brittle layer, many cycles) saturates at the TCMODEL ceiling of exactly 200 ft/mi	Pass
[10] alpha=0 (no thermal contraction) gives zero thermal stress and the crack never grows past its 0.1 in seed	Pass
[11] cooling_cycles=0 leaves the crack at its 0.1 in initial seed length, same TC as the alpha=0 case	Pass
[12] unit conversion ft/mi -> m/km uses the CORRECT constant 0.3048/1.609344 = 0.1893939, not the earlier transposed 0.18288	Pass
[13] every load-bearing input is refused at 0 or below	Pass
[14] thermal stress is capped at the mixture tensile strength (sigma_tip = min(sigM, E.alpha.dT))	Pass

⚑ pavement-aashto-1993-fdot-fhwa-web-validation.test.ts

AASHTO 1993 FLEXIBLE PAVEMENT (Eq.

Analyses validated: `aashto-rigid-1993`, `pavement-aashto-1993` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FDOT §5.2.1 worked example — ESAL_D 5,000,000, MR 14,000 psi, R 90 % → SN_R = 3.57	Pass
FDOT App. A — first-row/first-column and last-row/last-column cell of each of the 20 tables	Pass
FDOT Table A.1A (R 75 %) — all 600 printed cells	Pass
FDOT Table A.4A (R 90 %) — all 600 printed cells	Pass
FDOT Table A.10A (R 99 %) — all 600 printed cells	Pass
FHWA Ch. 6 §6.2.1 — baseline flexible design: W18 6.1×10⁶, R 90 %, S0 0.45, ΔPSI 1.7, MR 7,500 psi → SN 4.61	Pass
FHWA Ch. 6 §6.3.1 — soft subgrade MR 3,800 psi → SN 5.76, and the baseline SN 4.61 carries only 1.25×10⁶ ESALs	Pass
FHWA Ch. 6 §6.3.1 — soft-subgrade asphalt thickness D1 = (SN − m2·a2·D2)/a1 = 7.9 in	Pass
FHWA Ch. 6 §6.5.1 — low-quality base: the baseline thicknesses give SN 3.4 which carries 0.88×10⁶ ESALs; D1 = 8.0 in	Pass
FHWA Appendix C — flexible example: W18 11.6×10⁶, R 90 %, S0 0.45, ΔPSI 1.7, MR 7,500 psi → SN 5.07	Pass
FHWA Table C-3 — standard normal deviate for all 18 reliability levels (incl. 99.99 % = −3.750, AASHTO Table 4.1)	Pass

pavement-aashto-1993-web-validation.test.ts

AASHTO 1993 FLEXIBLE PAVEMENT — web-validation benchmark against the Guide's own worked example.

Analyses validated: `aashto-rigid-1993`, `pavement-aashto-1993` · Recorded run: passed — 14 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Appendix H.1 — traffic, reliability and serviceability inputs	Pass
Figure H.3 — relative damage u_f = 1.18e8 · MR^-2.32 at each tabulated modulus	Pass
Figure H.3 — Σu_f = 5.446 over 24 half-months, ū_f = 0.227, MR_eff = 5,700 psi	Pass
Appendix H.2 — SN = 5.6 from Figure 3.1 at MR 5,700, R 95 %, S0 0.35, ΔPSI 2.1, W18 18.6e6	Pass
Appendix H.2 — Table H.2: swelling cuts the 15-year period to 13 years at W18 = 16.0e6, ΔPSI_TR = 1.89	Pass
Appendix H.3 — SN1 = 3.2 above the base and SN2 = 4.5 above the subbase	Pass
Appendix H.3 — layer thicknesses 8 in AC / 7 in base / 11 in subbase	Pass
E-58 — the Guide's minimum practical thicknesses are traffic-dependent	Pass
computeAashto1993 reproduces Appendix H end to end	Pass
the single MR and the seasonal series agree when the series is constant	Pass
Eq 2.1 is monotone in every input, in the physically correct direction	Pass
E-56 — layered design analysis reproduces Appendix H.3: SN1 3.2, SN2 4.5, 8 in AC, 7 in base	Pass
E-56 — the SN-share fallback returns a 25 % thin surface on the Guide's own example	Pass
E-56 — a stiffer layer beneath thins the layer above, monotonically	Pass

⚑ pavement-airfield-web-validation.test.ts

Web-benchmark validation for the FOURTEEN server-routed pavement and airfield engines.

Analyses validated: `aashto-rigid-1993`, `acn-pcn-airfield`, `benkelman-overlay`, `crcp-punchout`, `faa-airfield-thickness`, `irc-sp72-pavement`, `jpcp-cracking`, `jpcp-faulting`, `jpcp-spalling`, `mepdg-ac-rutting`, `mepdg-fatigue`, `mepdg-iri`, `mepdg-subgrade-rutting`, `mepdg-thermal-cracking` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
every server-routed pavement/airfield slug is registered in PREMIUM_COMPUTES	Pass
mepdg-fatigue keeps damage and cracking mutually consistent	Pass
mepdg-ac-rutting and mepdg-subgrade-rutting convert inches to mm exactly	Pass
mepdg-thermal-cracking converts ft/mi to m/km correctly (E-108)	Pass
mepdg-iri sums its own reported distress contributions	Pass
jpcp-cracking uses the Westergaard edge stress ratio	Pass
jpcp-faulting keeps LTE, deflections and differential energy consistent	Pass
jpcp-spalling and crcp-punchout stay bounded and convert correctly	Pass
aashto-rigid-1993 solves Eq 3.1 and reproduces the design traffic	Pass
acn-pcn-airfield applies the ICAO ACN/PCN overload rules	Pass
faa-airfield-thickness converts and responds correctly to CBR and load	Pass
irc-sp72-pavement selects the right design curve and layer thicknesses	Pass
benkelman-overlay uses the IRC 81 characteristic deflection D_c = mean + 2σ	Pass

pavement-calibration-web-validation.test.ts

Web-benchmark validation for the Pavement-ME local-calibration presets — pins each preset's βr1/βs1/βf1 to the agency's published calibration report, and checks the preset actually overrides the national default in the engine.

Analyses validated: `pavement-me` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
North Carolina (NCDOT) preset matches the published final factors	Pass
Idaho preset matches the published rutting factors (fatigue left national)	Pass
Arkansas preset carries the TRC1003 rut factor	Pass
National preset is the global default (1,1,1) and every preset cites a source	Pass
selecting a preset OVERRIDES the beta inputs and applies the cited factors	Pass
'custom' leaves the explicit beta inputs in force (distinct from a preset)	Pass

pavement-irc-37-web-validation.test.ts

Web-benchmark validation for `pavement-irc-37` — IRC 37:2018 flexible-pavement design.

Analyses validated: `pavement-irc-37` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
M_R from CBR follows IRC 37 Cl 4.4: 10·CBR below 5 %, 17.6·CBR^0.64 above	Pass
M_R is capped at 100 MPa per Cl 4.4.1, and the cap is reported	Pass
cumulative msa follows IRC 37 Cl 3.3 exactly	Pass
the fatigue equation reproduces IRC 37 Eqs 3.3/3.4 at both reliabilities	Pass
the rutting equation reproduces IRC 37 N_r = k·(1/ε_v)^4.5337	Pass
the granular modulus follows Cl 6.2 E = 0.2·h^0.45·M_R, capped at 5·M_R	Pass
surface course is the plate value (Plate 4, Fig 12.4, p. 39), and layers sum to the crust	Pass
thickness rises with traffic and falls with subgrade strength	Pass
the CTB variants return their own plate section, not a scaled granular section	Pass
the catalogue verdict reflects the computed damage ratios	Pass
the bitumen grade and mean temperature both move the bituminous modulus	Pass
invalid inputs are refused, and every result carries IRC 37 clauses	Pass

⚑ pavement-irc-58-appendix-v-web-validation.test.ts

IRC 58:2015 Appendix-V regressions — validated against the code's OWN worked example (Appendix VII, "Illustrative Examples of Thickness Design", pp.

Analyses validated: `pavement-irc-58` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC 58:2015 Appendix VII prints an inconsistent l — h=0.28 m is right, l=0.78758 m is the typo	Pass
Appendix-V bottom-up single axle, Eq (V.3) — 12 published stresses (IRC 58:2015 Table VII.2)	Pass
Appendix-V bottom-up tandem axle, Eq (V.9) — 12 published stresses (IRC 58:2015 Table VII.2)	Pass
Appendix-V top-down, Eq (V.13) — 36 published stresses, single + tandem + tridem (Table VII.3)	Pass
the tridem top-down fraction is exactly 1/3, not the "33 %" the symbol list prints	Pass
IRC 58:2015 fatigue Eqs (5)/(6) — the branch assignment, proven from Table VII.2	Pass
reproduces IRC 58:2015 Table VII.4 cumulative fatigue damage — 20 published values exactly	Pass
IRC 58:2015 Table VII.4 — the h = 0.29 m top-down row is inconsistent with the rest of the table	Pass
the engine's own spectrum loop agrees with the published Miner sum (E-18 share regression)	Pass
the Appendix-V path reproduces the example verdict: 280 mm rejected, 290 mm accepted	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the legacy Westergaard proxy still runs, is labelled, and over-designs relative to the code	Pass
default stress model is the code-compliant one	Pass
E-19: omitting ΔT is flagged as UNSAFE, not as conservative	Pass

⚑ pavement-irc-58-web-validation.test.ts

C.IRC58 — `pavement-irc-58` web-benchmark against IRC 58:2015 itself, 26 cited values.

Analyses validated: `pavement-irc-58` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
C.IRC58.1: radius of relative stiffness matches the IRC 58 formula across 8 thicknesses	Pass
C.IRC58.2: reproduces the PUBLISHED l = 0.78758 m exactly — at h = 350 mm (see erratum)	Pass
C.IRC58.3: l scales as h^0.75 and k^-0.25, as the closed form requires	Pass
C.IRC58.4: PCA fatigue law — the published stress-ratio regimes (Cl 5.8.6.1 Eqs 5–6)	Pass
C.IRC58.5: Bradbury curling coefficient peaks near L/l ≈ 8-9, then eases to 1.0	Pass
C.IRC58.6: the Appendix VII case runs, converges and lands in a plausible thickness band	Pass
C.IRC58.7: IRC 58 Cl 5.4 night-time differential relation ΔT_night = ΔT_day/2 + 5	Pass
C.IRC58.8: the output references cite the Appendix-V model actually used, and the legacy path still discloses	Pass

pavement-me-web-validation.test.ts

Pavement-ME driver (`pavement-me.ts`) - the design-reliability layer checked against PUBLISHED values, plus the decision on what kind of engine this is.

Analyses validated: `pavement-me` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
R = 50 %: IRI design shift = z x SEE = 0 x 18.9 in/mi (NIST z_R, MOP SEE_IRI)	Pass
R = 90 %: IRI design shift = z x SEE = 1.282 x 18.9 in/mi (NIST z_R, MOP SEE_IRI)	Pass
R = 95 %: IRI design shift = z x SEE = 1.645 x 18.9 in/mi (NIST z_R, MOP SEE_IRI)	Pass
R = 97.5 %: IRI design shift = z x SEE = 1.96 x 18.9 in/mi (NIST z_R, MOP SEE_IRI)	Pass
R = 99 %: IRI design shift = z x SEE = 2.326 x 18.9 in/mi (NIST z_R, MOP SEE_IRI)	Pass
R = 99.5 %: IRI design shift = z x SEE = 2.576 x 18.9 in/mi (NIST z_R, MOP SEE_IRI)	Pass
R = 99.9 %: IRI design shift = z x SEE = 3.09 x 18.9 in/mi (NIST z_R, MOP SEE_IRI)	Pass
MOP Eqs. 5-3a-c: the total-rut design shift is z x [se(HMA) + se(granular) + se(fine)] of the engine's own layer ruts	Pass
MOP Eq. 5-7: the fatigue design shift is z x [1.13 + 13/(1 + exp(7.57 - 15.5 log10(FC + 0.0001)))] at the engine's own FC	Pass

premium-fe-pavement-web-validation.test.ts

Web-benchmark validation for the LAST EIGHT server-routed engines — the FE/pile group, layered-elastic and time-stepping pavement solvers.

Analyses validated: `aircraft-gear-response`, `axle-load-spectra`, `faarfield-design`, `hs-layered-settlement`, `jpcp-time-stepping`, `lateral-pile-group`, `layered-elastic-pavement`, `pile-axial-load-transfer` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
axle-load-spectra reproduces the AASHTO fourth-power ESAL sum exactly	Pass
hs-layered-settlement keeps its nonlinear and linear settlements consistent	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
pile-axial-load-transfer closes its component sums across all t-z models	Pass
lateral-pile-group applies p-multipliers and closes the efficiency definition	Pass
layered-elastic-pavement returns the two strains that drive the distress models	Pass
aircraft-gear-response superposes wheels and reports the gear factor	Pass
jpcp-time-stepping accumulates monthly damage over the design life	Pass
faarfield-design iterates the AC thickness to a cumulative damage factor of 1	Pass

rigid-slab-response-published-web-validation.test.ts

PUBLISHED-ANSWER validation of the rigid-slab closed-form response (`rigid-slab-response.ts`): radius of relative stiffness ℓ and Westergaard (1926) interior / edge / corner bending stress, plus the Westergaard corner deflection.

Analyses validated: `rigid-slab-response` · Recorded run: passed — 6 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Pavement Interactive Example 1: 9-in slab, 9000-lb FWD load (a = 5.9 in), k = 200 pci, E = 5×10^6 psi, μ = 0.15	Pass
Pavement Interactive Example 2: the same load on a 12-in slab	Pass
Huang (2004) Ch. 3 examples: E = 4×10^6 psi, h = 10 in, k = 100 pci, P = 10 000 lb	Pass
Solved problem (ques10 post 34957): P = 5100 kg, E = 3×10^5 kg/cm², h = 18 cm, μ = 0.15, K = 6 kg/cm³, a = 15 cm	Pass
Ioannides et al. (1985) TRR 1043 Table 1, column WESII: Westergaard ORIGINAL edge stress, semicircular load	Pass
IRC:58-2015 Appendix VII / VIII: printed radius of relative stiffness, E = 30 000 MPa, μ = 0.15	Pass

rigid-slab-response-web-validation.test.ts

Formula-fidelity validation against Westergaard (1926/1948) and Ioannides, Thompson & Barenberg (1985) "Westergaard Solutions Reconsidered" (TRR 1043) -- the classical closed-form rigid-slab interior/edge/corner stress and deflection equat…

Analyses validated: `rigid-slab-response` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-4] interior loading: l=41.572647in, sigma=136.581313psi, d=0.005885in	Pass
[5-6] edge loading (same geometry): sigma=209.531712psi, d=0.020291in	Pass
[7-8] corner loading (same geometry): sigma=178.736926psi, d=0.044304in	Pass
[9] edge stress exceeds interior stress exceeds nothing in particular, but corner deflection is the largest of the three (physically expected ordering)	Pass
[10] the edge stress here matches jpcp-cracking's edge-stress formula at identical inputs (cross-engine consistency)	Pass
[11] the full engine reports the same closed-form critical stress as the standalone function, in MPa	Pass
[12-13] radius of relative stiffness and contact radius reported in mm match the hand-computed inch values x25.4	Pass
[14-15] stress ratio and factor of safety are exact reciprocals when MR is supplied	Pass
[16] without MR supplied, stress_ratio and stress_factor_of_safety are both null	Pass
[17] every load-bearing input is refused at 0 or below, never silently clamped to the 1psi floor	Pass

stabilization-mix-web-validation.test.ts

Validation for `stabilization-mix` — cement / lime stabilised-layer binder quantity and 7-day UCS acceptance against the IRC:SP:89 / MoRTH target band (`stabilization-mix.ts`).

Analyses validated: `stabilization-mix` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IRC:37-2018 §7.3.2: CTSB 7-day UCS 1.5 to 3.0 MPa (IRC:SP:89)	Pass
IRC:37-2018 §7.4: CTB UCS 4.5 to 7 MPa (IRC:SP:89)	Pass
acceptance is inclusive at both published limits and refuses just outside them	Pass
formula-fidelity: binder kg/m³ = (binder %/100) × dry density (Han Eq. 8.2-8.3)	Pass

Ground improvement

Cited validation suites — 3

deep-mixing-web-validation.test.ts

`deep-mixing` — anchored to the FHWA Ground Modification worked example.

Analyses validated: `deep-mixing` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA §3.3.3.2: the field UCS conversion 26 psi ≈ 3,700 psf is the manual's own rounding	Pass
FHWA §3.3.3.2: E50 = 150 × qu, and the engine uses that relation	Pass
FHWA §3.3.3.2: the constrained modulus M = E50(1−ν)/((1+ν)(1−2ν)) with ν = 0.1	Pass
E-46: FHWA §3.3.3.2 design shear strength = 0.5 × 0.8 × 1.0 × 0.63 × qu = 930 psf	Pass
E-46: the PEAK strength is about twice the FHWA design strength — the unsafe gap	Pass
E-46: without the Table 12 variability factor the design strength is NULL, not guessed	Pass
E-46: the four factors are each honoured, and a factor > 1 is flagged	Pass
§3.3.3.2: at a_r < 1 the composite strength is the area-weighted blend	Pass
the treated unit weight increase the manual reports is physically modest	Pass
every numeric output is finite or an explicit null, and the source is cited	Pass

⚑ stone-columns-web-validation.test.ts

`stone-columns` — anchored to a published US (FHWA) source.

Analyses validated: `stone-columns` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA NHI-16-027 Eq. 5-1: α_sc = A_sc/A with A_sc = πd²/4 — an AREA ratio	Pass
ERRATUM (1): §4.3.2 uses s²/d² = 3.6 — the engine must NOT reproduce it	Pass
FHWA NHI-16-027 Eqs. 5-3 to 5-5: load sharing is self-consistent at the engine's n and α_sc	Pass
FHWA NHI-16-027 §4.3.1: the RAP load-sharing chain reproduces exactly	Pass
ERRATUM (2): §4.3.1 prints a=de² but publishes Ra from a=(π/4)de²	Pass
FHWA NHI-16-027 §4.3.1 / §4.3.2: published 1-D consolidation settlements reproduce	Pass
Priebe (1995) n0 is reproduced at three column friction angles	Pass
the improvement factor is monotone in the two variables that physically drive it	Pass
improved settlement equals unimproved divided by the improvement factor	Pass
every output stays finite and the source is cited	Pass

⚑ vibro-compaction-web-validation.test.ts

`vibro-compaction` — anchored to FHWA Ground Modification Vol I.

Analyses validated: `vibro-compaction` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
FHWA Table 4-1: fines below 15 % and clay below 2 % is applicable	Pass
FHWA §3.2: between 10 % and 15 % fines is applicable but outside the ideal zone B	Pass
FHWA Table 4-1: the CLAY criterion is separate — a soil can pass on fines and fail on clay	Pass
E-47: an unsupplied clay fraction is disclosed as UNCHECKED, not assumed compliant	Pass
E-47: where Mitchell and FHWA disagree, BOTH verdicts are reported and the clash is flagged	Pass
the two sources agree at the extremes — so the disagreement flag is not always on	Pass
FHWA §3.3: a target Dr above 85 % is challenged, quoting the manual	Pass
FHWA Table 4-7 (Brown 1977): the backfill suitability-number bands are monotonic, and the printed 40-50 gap is real	Pass
an unsuitable soil is credited with NO density improvement	Pass
closer spacing improves the achievable density, and the target is never exceeded	Pass
every numeric output is finite and the sources are cited	Pass

Site investigation, in-situ and laboratory tests

Cited validation suites — 25

`consistency-index-web-validation.test.ts`

Validation for `consistency-index` — plasticity, liquidity and consistency indices and Skempton activity (`consistency-index.ts`, `computeConsistencyIndex`).

Analyses validated: `consistency-index` · Recorded run: passed — 10 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Varghese Example 1.4: 20 % finer than 0.002 mm, LL = 60 %, PL = 25 % ⇒ PI = 35 %, A = 1.75 > 1.25	Pass
Varghese Example 1.5: LL = 45 %, PL = 25 % ⇒ PI = 20 %, and (LL − w)/PI = 1 at w = 25 %	Pass
Varghese Eq. 1.1: Ic = 0 at the liquid limit (liquid) and Ic = 1 at the plastic limit	Pass
Varghese Table 1.6: medium Ic 0.5–0.75, stiff 0.75–1.0, very stiff / hard above 1.0	Pass
Craig (2012) and Holtz & Kovacs: activity < 0.75 inactive, 0.75–1.25 normal, > 1.25 active	Pass
Das Table 2.6 endpoints: kaolinite 0.3–0.5, illite 0.5–1.2, montmorillonite 1.5–7.0	Pass
Das Table 2.6 endpoints: halloysite 0.1–0.2 (hydrated) and 0.4–0.6 (dehydrated), attapulgite 0.4–1.3	Pass
Mitchell & Soga (2005) §4.6: Belle Fourche montmorillonite 1.24–7.09, Anna kaolinite 0.30–0.41	Pass
Das §2.7, Holtz & Kovacs §2.7, FHWA Table 2-4: LI > 1 liquid (sensitive clay), LI < 0 brittle / overconsolidated	Pass
IS 2720 (Part 5) §10–11 and Varghese: I_L + I_C = 1 for every input	Pass

`cpt-analysis-web-validation.test.ts`

Web-benchmark validation for `cpt-analysis` — the CPT interpretation engine.

Analyses validated: `cpt-analysis`, `cpt-sbt-ic` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
rig: a 5 m reading at γ=20 with no water table gives σv = σv′ = 100 kPa	Pass
SBT zones straddle every published Ic boundary (R&C 2012 p.26)	Pass
Ic matches the published definition at three points (R&C 2012 p.24)	Pass
Dr (Kulhawy & Mayne 1990) matches the published relation (R&C 2012 p.41)	Pass
Dr (Baldi et al. 1986) matches the published relation (R&C 2012 p.40)	Pass
E-88: Dr correlations cross near Qcn 36 and diverge with density	Pass
E-88: a dense sand profile warns that Dr is correlation-dependent	Pass
E-87: ϕ′ agrees with the independent Kulhawy & Mayne form (R&C 2012 p.44)	Pass
Su matches (qt - σv)/Nkt with the Lunne et al. (1997) default Nkt = 14	Pass

`cpt-analysis-worked-examples-web-validation.test.ts`

cpt-analysis — FULL WORKED EXAMPLES (the ≥20-value gate).

Analyses validated: `cpt-analysis`, `cpt-sbt-ic` · Recorded run: passed — 17 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS] Ex 3.4: σ'o = 200 kPa and the printed Qcn = 141.41	Pass
[DAS] Ex 3.4 with OCR 2: Q_OCR = OCR^0.18 (CPT Guide), NOT Das's printed OCR^1.8	Pass
[BOW] Ex 3-5: p'o = 89.2 kPa, qc/p'o = 330, ϕ ≈ 46° (Fig. 3-22b)	Pass
[BOW] Ex 3-6: po = 216 kPa, su = 600 kPa with Nk = 18	Pass
[BOW] Fig. 3-20: the Kulhawy-Mayne / Baldi band brackets Bowles's Dr ≈ 70 %	Pass
[RC] p. 45: tan ϕ' = (1/2.68)[log(qc/σ'vo) + 0.29] — printed coefficients, not rounded	Pass
[RC] p. 45: Kulhawy & Mayne ϕ' = 17.6 + 11 log(Qtn)	Pass
[RC] p. 42: Q_OCR = OCR^0.18 → Dr scales by OCR^−0.09	Pass
[RC] p. 42: Q_C 0.90 (low compressibility) → Dr scales by 0.90^−0.5	Pass
[RC] p. 42: Q_A = 1.2 + 0.05 log(t/100) → at t = 1000 yr, Q_A = 1.25	Pass
[RC] p. 42: Baldi Dr = (1/C2) ln(Qcn/C0), C0 = 15.7, C2 = 2.41	Pass
[RC] p. 42: invalid OCR (< 1) is refused, not silently used	Pass
[RC] p. 27: Ic zone boundaries 1.31 / 2.05 / 2.60 / 2.95 / 3.60	Pass
[BI] 2014 §2: the Ic chart centre (Q 2951, F 0.06026 %) gives Ic = 0	Pass
Ic parity: cpt-sbt-ic and icFromReading return the same Ic in very soft ground	Pass
[EC7] EN 1997-2 Table D.1: ϕ' bands by qc, and Note (a) −3° for silty soil	Pass
[LUN] §9.2.2: past Dr = 100 % the correlation over-reads measured ϕ', and says so	Pass

⚑ cpt-sbt-ic-web-validation.test.ts

Validation for `cpt-sbt-ic` — Robertson (2009) normalised soil behaviour type index Ic with the stress exponent n iterated to convergence (`cpt-sbt-ic.ts`).

Analyses validated: `cpt-sbt-ic` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
NASEM 2024 Tables G3/G5: Ic, n, Qtn at 1.1-9.0 ft (clay-like and transitional near-surface layers)	Pass
NASEM 2024 Tables G3/G5: Ic, n, Qtn at 10.0-20.8 ft (sand with silty seams)	Pass
NASEM 2024 Tables G3/G5: Ic, n, Qtn at 24.8-52.5 ft (clean to silty sand)	Pass
R&C 2012 / Niazi 2021: zone 7 < 1.31 < zone 6 < 2.05 < zone 5 < 2.60 < zone 4 < 2.95 < zone 3 < 3.60 < zone 2	Pass
R&C 2012: behaviour is sand-like at Ic ≤ 2.50, clay-like above 2.70 and transitional between (NASEM rows)	Pass

⚑ cptu-dissipation-web-validation.test.ts

Validation for `cptu-dissipation` — Teh & Houlsby horizontal coefficient of consolidation from a CPTu dissipation test, ch = T*50·r²·√Ir / t50 (`cptu-dissipation.ts`).

Analyses validated: `cptu-dissipation` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Niazi (2021) Table 2.18 / Eq. 2.120: T*50 = 0.245 (u2 shoulder) and 0.118 (u1 mid-face)	Pass
Look Table 8.15: "multiply by 1.5 for 15 cm² piezocones" — the 15 cm² radius gives ×1.5 in ch	Pass
Look Table 8.15: ch in cm²/min converts to the printed m²/yr (0.05, 0.5, 5.3, 53, 525, 10,500)	Pass
Look Table 8.15 bands: ch at the band-centre t50 lies inside the printed ch band for Ir = 50-500	Pass
formula-fidelity: Eq. 2.120 for a 10 cm² u2 cone, Ir = 100, t50 = 100 s	Pass
formula-fidelity: ch scales as √Ir / t50 and as r²; u1 is 0.118/0.245 of u2 at equal inputs	Pass
formula-fidelity: kh = ch·mv·γw with mv in m²/MN and γw = 9.81 kN/m³	Pass

dmt-web-validation.test.ts

Published-benchmark validation for the flat dilatometer (DMT) interpretation (`dmt.ts`, `computeDmt`).

Analyses validated: `dmt` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
TC16 Fig. 31, z = 1.00 m (P0 1.2, P1 3.5, Σ′ 0.17, U 0.0 bar)	Pass
TC16 Fig. 31, z = 1.20 m (P0 1.6, P1 3.4, Σ′ 0.21, U 0.0 bar)	Pass
TC16 Fig. 31, z = 1.80 m (P0 2.4, P1 3.0, Σ′ 0.28, U 0.03 bar)	Pass
TC16 Fig. 31, z = 2.00 m (P0 2.4, P1 2.8, Σ′ 0.29, U 0.05 bar)	Pass
TC16 Fig. 31, z = 2.40 m (P0 1.9, P1 3.8, Σ′ 0.31, U 0.09 bar)	Pass
TC16 Fig. 31, z = 3.20 m (P0 2.2, P1 6.0, Σ′ 0.36, U 0.17 bar)	Pass
TC16 Fig. 31, z = 3.60 m (P0 2.0, P1 5.4, Σ′ 0.39, U 0.21 bar)	Pass
TC16 Fig. 31, z = 3.80 m (P0 2.5, P1 6.8, Σ′ 0.41, U 0.23 bar)	Pass
TC16 Fig. 31, z = 5.60 m (P0 3.2, P1 3.8, Σ′ 0.55, U 0.4 bar)	Pass
TC16 Fig. 31, z = 7.40 m (P0 3.1, P1 5.8, Σ′ 0.68, U 0.58 bar)	Pass
TC16 Fig. 31, z = 8.00 m (P0 3.1, P1 4.0, Σ′ 0.72, U 0.64 bar)	Pass
TC16 Fig. 31, z = 9.00 m (P0 3.3, P1 4.0, Σ′ 0.79, U 0.74 bar)	Pass
TC16 Fig. 31, z = 10.00 m (P0 3.4, P1 4.2, Σ′ 0.85, U 0.83 bar)	Pass

ert-published-tables-web-validation.test.ts

Published-value validation for `ert` — array geometric factors, median depth of investigation and the soil corrosivity bands.

Analyses validated: `ert` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Loke (2004) Table 2.1: Wenner alpha — geometric factor 6.2832 and ze/a = 0.519 (a = 1 m)	Pass
Loke (2004) Table 2.1: dipole-dipole geometric factors (a = 1 m), n = 1-8	Pass
Loke (2004) Table 2.1: dipole-dipole median depth ze/a, n = 1-8	Pass
Loke (2004) Table 2.1: Wenner-Schlumberger geometric factors (a = 1 m), n = 1-10	Pass
Loke (2004) Table 2.1: Wenner-Schlumberger median depth ze/a, n = 1-10	Pass
Loke (2004) Table 2.1: ze/L for Wenner-Schlumberger (L = AB = (2n+1)a) and dipole-dipole (L = (n+2)a)	Pass
Loke (2004) Eq. (1.10): ρa = k·R with the printed Wenner factor 6.2832 (a = 1 m) and the printed DD n = 1 factor 18.850	Pass
Roberge soil-corrosivity table: engine bands at the published edges (Ω·m = Ω·cm / 100)	Pass

ert-web-validation.test.ts

Web-benchmark validation for `ert` — array geometric factors, depth of investigation, and the VES forward model.

Analyses validated: `ert` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
the analytical two-layer curves satisfy their own limits	Pass
E-98: the Wenner forward model matches Telford Eq. (8.38) to <0.5 %	Pass
E-98: the Wenner prefactor is 2a, and 4a is not a near miss	Pass
E-98: the Schlumberger forward model matches Telford Eq. (8.39b) to <0.5 %	Pass
E-98: the curve SHAPE is right, not just the magnitude	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
E-98: Wenner inversion recovers a two-layer earth from the EXACT Wenner curve	Pass
E-98: Schlumberger inversion recovers a two-layer earth from the EXACT curve	Pass
geometric factors K match the published array definitions	Pass
ρa = K·(V/I) reproduces a known homogeneous half-space	Pass
corrosivity bands break at the published NACE/Roberge edges	Pass
the governing corrosivity is the WORST layer, not an average	Pass

field-density-web-validation.test.ts

Web-benchmark validation for `field-density` — in-situ density by sand replacement or core cutter.

Analyses validated: `field-density` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
core cutter reproduces the IS 2720-29 chain on a hand-computed case	Pass
sand replacement subtracts the cone/base-plate mass, per IS 2720-28	Pass
omitting the cone correction over-states volume and under-reports compaction	Pass
air voids reach zero exactly at full saturation	Pass
an impossible (over-saturated) input is clamped and flagged, not returned negative	Pass
the compaction verdict follows the stated requirement, default 95 %	Pass
a DoC above 102 % is flagged as a suspect Proctor reference	Pass
both methods name their IS standard	Pass

gradation-indices-web-validation.test.ts

PUBLISHED-VALUES: 12 -- distinct published values for this engine (engine-level total, declared once); independent audit A4: 12 distinct printed Cu/Cc values; the rest repeat them or are verdict/threshold checks.

Analyses validated: `gradation-indices` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Knappett & Craig (2012) Ex. 1.1 — soil A: Cu = 34, Cz = 1.6, well-graded gravel (GW)	Pass
Knappett & Craig (2012) Ex. 1.1 — soil B: Cu = 1.8, Cz = 0.95, uniform sand (SPu)	Pass
Knappett & Craig (2012) Ex. 1.1 — soil C: Cu = 800, Cz = 0.25	Pass
FHWA-NHI-06-088 Fig. 4-2 — curve A: Cu = 8.0, Cc = 0.9, fails the Table 4-10 well-graded criteria	Pass
FHWA-NHI-06-088 Fig. 4-2 — curve B: Cu = 2.0, Cc = 1.12, criteria say poorly graded	Pass
FHWA-NHI-06-088 Fig. 4-2 — curve C: Cu = 1.4, Cc = 1.2, poorly graded	Pass
FHWA-NHI-06-088 Fig. 4-2 — curve A through the registry (RUNNER_CONFIGS) gives the printed indices	Pass
ASTM D2487 X1.1.1 — Cu = 12.4, Cc = 2.7 gravel is classified GW (well graded)	Pass
ASTM D2487 X2.4.3 — Cu = 1.9, Cc = 2.4 gravel is classified GP (poorly graded)	Pass
Bowles (1996) — sand with Cu = 7, Cc = 1.3 is "well-graded ... SW"	Pass
ASTM D2487 Table 1 — gravel needs Cu >= 4, sand needs Cu >= 6, both need 1 <= Cc <= 3	Pass

index-outputs-web-validation.test.ts

index-outputs-web-validation.test.ts

Analyses validated: `barton-bandis`, `soil-classification`, `steel-pile-section` · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
soil-classification: AASHTO group index matches M 145 Cl 5.4 and is floored at 0 with no upper cap (7 anchors)	Pass
soil-classification: the Casagrande chart places soils on the right side of the A-line (8 anchors)	Pass
soil-classification: every displayed output is present and non-empty on the defaults	Pass
barton-bandis: ϕ_peak = ϕ_r + JRC·log₁₀(JCS/σ′n), and τ follows from it (8 anchors)	Pass
steel-pile-section: the elastic and plastic moduli are consistent with each other and the shape	Pass

index-properties-web-validation.test.ts

Web-benchmark validation for NINE index-property, classification and stress-state runner engines.

Analyses validated: `compression-index`, `consistency-index`, `consolidation-degree`, `gradation-indices`, `phase-relations`, `pore-pressure-parameters`, `quick-condition`, `soil-classification`, `stress-path` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
phase-relations satisfies every phase-diagram identity exactly	Pass
consistency-index reproduces the Atterberg definitions and Skempton activity	Pass
gradation-indices computes C_u and C_c and applies the ASTM D2487 criteria	Pass
compression-index reproduces all five published C_c correlations	Pass
soil-classification places the soil on the Casagrande chart and computes the AASHTO GI	Pass
stress-path computes both invariant pairs and the M line consistently	Pass
pore-pressure-parameters follows Skempton (1954) Δu = B[Δσ₃ + A(Δσ₁ − Δσ₃)]	Pass
quick-condition uses the Terzaghi critical gradient (G_s − 1)/(1 + e)	Pass
consolidation-degree inverts the Terzaghi U-T_v relation both ways	Pass

⚑ phase-relations-web-validation.test.ts

Validation of the soil phase-relation engine (`phase-relations.ts`) against PUBLISHED worked examples and PUBLISHED problem answers.

Analyses validated: `phase-relations` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das (2016) Ex. 2.1 — 1.8 kN in 0.1 m³, w = 12.6 %, Gs = 2.71	Pass
Das (2016) Ex. 2.3 — γ = 19.2 kN/m³, w = 9.8 %, Gs = 2.69	Pass
Das (2016) Ex. 2.4 — densities and the water needed to saturate (Gs = 2.68, e = 0.83)	Pass
Das (2016) Ex. 2.2 — n = 0.387, ρd = 1600 kg/m³ gives e = 0.631 with the printed Gs = 2.61	Pass
Das (2016) Ex. 2.6 — γ = 108 pcf, w = 8 %, Gs = 2.65 (US units)	Pass
Das (2016) Problem 2.1 — 87.5 kg in 0.05 m³, w = 15 %, Gs = 2.68 (printed answers)	Pass
Das (2016) Problem 2.2 — saturated soil: the printed γd and Gs give back γsat = 20.1 kN/m³	Pass
Das (2016) Problem 2.3 — γ = 119.5 pcf, w = 12 %, Gs = 2.65 (printed answers)	Pass
Knappett & Craig (2012) Ex. 1.2 — ρ = 1990 kg/m³, w = 12.5 %, Gs = 2.68	Pass

pore-pressure-parameters-web-validation.test.ts

Validation for `pore-pressure-parameters` — Skempton's A and B pore-pressure parameters (`pore-pressure-parameters.ts`).

Analyses validated: `pore-pressure-parameters` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Skempton (1954) Table 1: Δu for isotropic cell-pressure steps of 15, 30, 45, 60 lb/in²	Pass
Lambe & Whitman Fig. 26.14: Δu = 85.2 + 0.85(110.6) = 179.2 kN/m²	Pass
Itasca / Lambe & Whitman embankment: A = 1/3, Δσ1 = 4180, Δσ3 = 1645 psf → Δu = 2490 psf	Pass
Craig 7th Solutions (CU test, back pressure 200): A_f = 0.73 reproduces the measured Δu = 433 − 200 = 233 kN/m²	Pass
Skempton (1954) alternative form: A = 1/3 gives Δu = B(Δσ1 + 2Δσ3)/3	Pass
Das (2016) p. 63 A at failure: sandy clays 0.5-0.7, NC clays 0.5-1, OC clays −0.5-0 are accepted	Pass
Lambe & Whitman Table 26.1 A at failure: 0.7-1.3 NC, 0.3-0.7 lightly OC, −0.5-0 heavily OC are accepted	Pass
Lambe & Whitman Table 26.1 A at failure: sensitive clay 1.5-2.5 and very loose fine sand 2-3 are accepted	Pass
Lambe & Whitman Table 26.1 B: saturated soils B ≈ 1; Boulder clay at S = 93, 87, 76 % has B = 0.69, 0.33, 0.10	Pass

pressuremeter-menard-published-web-validation.test.ts

Published-table validation for the Ménard pressuremeter footing engine (`pressuremeter-menard.ts`, `computePressuremeterMenard`).

Analyses validated: `pressuremeter-menard` · Recorded run: passed — 27 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[NF] Tableau H.2.1.1.3: L/B = 1 → λc = 1.10, λd = 1.12	Pass
[NF] Tableau H.2.1.1.3: L/B = 2 → λc = 1.20, λd = 1.53	Pass
[NF] Tableau H.2.1.1.3: L/B = 3 → λc = 1.30, λd = 1.78	Pass
[NF] Tableau H.2.1.1.3: L/B = 5 → λc = 1.40, λd = 2.14	Pass
[NF] Tableau H.2.1.1.3: L/B = 20 → λc = 1.50, λd = 2.65	Pass
[EC7] Table E.2: L/B = 1 → λc = 1.1, λd = 1.12	Pass
[EC7] Table E.2: L/B = 2 → λc = 1.2, λd = 1.53	Pass
[EC7] Table E.2: L/B = 3 → λc = 1.3, λd = 1.78	Pass
[EC7] Table E.2: L/B = 5 → λc = 1.4, λd = 2.14	Pass
[EC7] Table E.2: L/B = 20 → λc = 1.5, λd = 2.65	Pass
[NF] Tableau H.2.1.1.1 Argile: surconsolidé 1, normalement consolidé 2/3, sous-consolidé 1/2	Pass
[NF] Tableau H.2.1.1.1 Limon: surconsolidé 2/3, normalement consolidé 1/2, sous-consolidé 1/2	Pass
[NF] Tableau H.2.1.1.1 Sable: surconsolidé 1/2, normalement consolidé 1/3, sous-consolidé 1/3	Pass
[NF] Tableau H.2.1.1.1 Grave: surconsolidé 1/3, normalement consolidé 1/4	Pass
[NF] Tableau H.2.1.1.1 Tourbe (normalement consolidée): α = 1	Pass
[NF] Tableau H.2.1.1.2 Rocher: très peu fracturé 2/3, normal fracturé 1/2, très fracturé 1/3 (engine weathered_rock: OC/NC/UC)	Pass
[EC7] Table E.3 Clay: over-consolidated 1, normally consolidated 0,67, remoulded 0,5	Pass
[EC7] Table E.3 Silt: over-consolidated 0,67, normally consolidated 0,5	Pass
[EC7] Table E.3 Sand: EM/pLM > 12 → 0,5 (over-consolidated); 5–12 → 0,33 (normally consolidated)	Pass
[EC7] Table E.3 Sand and gravel: EM/pLM > 10 → 0,33; 6–10 → 0,25	Pass
[EC7] Table E.3 Peat 1; Rock: extensively fractured 0,33, unaltered 0,5, weathered 0,67	Pass
[NF] Tableau D.2.3: kp0 = 0.8 (clay strip Q1 / square Q2) and 1 (sand strip Q3 / square Q4) at De/B = 0	Pass
[NF] Tableau D.2.3: kp0 = 0.8 for chalk (Q5 strip / Q6 square) and marl–weathered rock (Q7 / Q8)	Pass
[NF] Figure D.2.3 plateau De/B ≥ 2: Q1 (clay strip) 1.024 and Q2 (clay square) 1.128	Pass
[NF] Figure D.2.3 plateau: Q3 (sand strip) and Q7 (marl strip) overlap at 1.397	Pass
[NF] Figure D.2.3 plateau: Q4 (sand square) 1.581 digitised; Q8 (marl square) from the PRINTED coefficients	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[NF] Figure D.2.3 plateau: Q5 (chalk strip) 1.518 and Q6 (chalk square) 1.768	Pass

pressuremeter-menard-web-validation.test.ts

Formula-fidelity validation against NF P94-261 (Calcul geotechnique -- Fondations superficielles), Annexes D and H -- the French national pressuremeter foundation-design standard.

Analyses validated: `pressuremeter-menard` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[1-3] square footing, clay/silt, NC: kp=1.012734, qnet=607.640684 kPa, alpha=0.666667	Pass
[4-6] shape coefficients lambda_c=1.10, lambda_d=1.12 at L/B=1 (the Tableau H.2.1.1.3 anchor)	Pass
[7-9] settlement components: spherical=5.500000mm, deviatoric=10.829549mm, total=16.329549mm	Pass
[10] a strip footing (L>>B) uses a materially different kp than a square footing at the same De/B, per the strip/square interpolation on B/L	Pass
[11] a stiffer soil (higher EM) reduces both settlement components proportionally (sc and sd are both inversely proportional to EM)	Pass
[12] the overconsolidated state gives a HIGHER alpha (stiffer response) than normally-consolidated for clay/silt (Tableau H.2.1.1.1: OC=1, NC=2/3)	Pass
[13] De/B beyond 2 clamps kp at the De/B=2 plateau and warns, per NF P94-261 D.2.3's stated validity range	Pass
[14] invalid inputs (zero width, zero modulus, zero limit pressure) are refused	Pass

site-investigation-web-validation.test.ts

Web-benchmark validation for `site-investigation` — borehole layout and depth planning across four national codes.

Analyses validated: `site-investigation` · Recorded run: passed — 13 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
IS 1892 Cl 3.3 depths are 1.5·B (isolated), 2.0·B (combined), 1.5·B (raft), + Df	Pass
IS 2911-1 Cl 6.5 takes pile exploration to L + 5·B below the toe	Pass
the depth rule changes with the code, as the codes themselves differ	Pass
the deepest applicable floor governs, and the reason is named	Pass
IS 1893 liquefaction screening drives depth in zones III-V with shallow groundwater	Pass
storey influence follows Tomlinson D = C·S^0.7 and can govern	Pass
borehole counts rise with area, importance and complexity	Pass
spacing is consistent with the count and the footprint	Pass
scale bands follow the borehole count	Pass
SPT quantity follows the 1.5 m interval over the full depth, per borehole	Pass
each code returns its own reference set, not a union	Pass
special ground conditions add their own tests, each with a standard	Pass
invalid inputs are refused with a zeroed plan	Pass

site-practice-web-validation.test.ts

Web-benchmark validation for TWELVE site-practice runner engines — slope charts, in-situ test corrections, RC checks, uplift, stress distribution, frost, permeability, piping, eccentricity, two-layer bearing, filters and collapse.

Analyses validated: `collapse-potential`, `eccentric-footing-pressure`, `filter-design`, `flotation`, `frost-depth`, `grain-size-permeability`, `punching-shear`, `taylor-stability`, `two-layer-bearing`, `vane-correction`, `vertical-stress-increase`, `weighted-creep` · Recorded run: passed — 12 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
taylor-stability inverts the Taylor (1937) stability number both ways	Pass
vane-correction applies Bjerrum (1972/73) μ = 1.7 − 0.54 $\log_{10}$(PI)	Pass
punching-shear follows IS 456:2000 Cl 31.6.3	Pass
flotation checks uplift to EN 1997-1 §2.4.7.4 (UPL)	Pass
vertical-stress-increase matches the Boussinesq rectangular integral	Pass
frost-depth reproduces Stefan and the Modified Berggren correction	Pass
grain-size-permeability reproduces Hazen and Kozeny-Carman	Pass
weighted-creep reproduces Bligh (1910) and Lane (1935) creep theory	Pass
eccentric-footing-pressure applies the middle-third rule and Meyerhof width	Pass
two-layer-bearing selects the right mode and uses exact bearing factors	Pass
filter-design applies the Terzaghi and USACE filter criteria	Pass
collapse-potential follows ASTM D5333 and the Jennings & Knight bands	Pass

skempton-bjerrum-web-validation.test.ts

PUBLISHED-VALUES: 12 -- distinct published values for this engine (engine-level total, declared once); independent audit A4: 12 printed values; about 20 of the 29 assertions are the suite author's chart digitisation.

Analyses validated: `skempton-bjerrum` · Recorded run: passed — 9 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[C] Craig Fig 8.29 — circular-footing lines are μ = A + α(1−A) with the printed intercepts	Pass
[C] Craig Fig 8.29 — right-hand end of the circular lines (A = 1.2, sensitive-clay side), digitised	Pass
[C] Craig Fig 8.29 — all circular lines cross at μ ≈ 0.99 at A = 1	Pass
[D] Das Fig 7.22 — circular lines at A = 0 (intercepts) and A = 0.5, 0.9	Pass
[C] Craig Example 8.5 — 6 m square footing on stiff clay: μc = 0.55, s_c = 64 mm, total 73 mm	Pass
[C] Craig Example 8.5 — μc = 0.55 at A = 0.35 agrees with the α interpolated from Fig 8.29 at H/B = 2.2	Pass
[D] Das Example 7.10 — K_cr = 0.78 at A = 0.6, H_c/B_eq = 0.64; S_c = 0.78 × 46.5 ≈ 36.3 mm	Pass
[D] Das Example 7.10 — K_cr at H_c/B = 0.64 falls between the printed H/B = 0.5 and 1.0 lines at A = 0.6	Pass
[L][C] Look Table 23.4 (← Tomlinson 1995) correction-factor bands vs Craig p.308 ranges of A	Pass

skempton-pore-pressure-web-validation.test.ts

Validation for Skempton pore-pressure parameters (`skempton-pore-pressure.ts`).

Analyses validated: — (not attributed by the manifest) · Recorded run: passed — 5 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
isotropic loading (Δσ1=Δσ3): Δu = B·Δσ3 (A irrelevant)	Pass
pure deviatoric (Δσ3=0): Δu = B·A·Δσ1	Pass
B parameter: saturated (C_f→0) → 1; compressible fluid < 1	Pass
undrained ESP: CU triaxial (Δσ3=0), NC clay A=0.9 B=1	Pass
total stress path (TSP) minus Δu equals effective stress path	Pass

⚑ soil-classification-web-validation.test.ts

Validation of the soil-classification engine (`classification.ts`, slug `soil-classification`): USCS (ASTM D2487), its IS 1498 L/I/H variant, and AASHTO M 145 / D3282 with Group Index.

Analyses validated: `soil-classification` · Recorded run: passed — 25 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Das (2016) Problem 2.6 — soil A is AASHTO A-7-6(9)	Pass
Das (2016) Problem 2.6 — soil B is AASHTO A-6(5)	Pass
Das (2016) Problem 2.6 — soil C is AASHTO A-3(0)	Pass
Das (2016) Problem 2.6 — soil D is AASHTO A-4(5)	Pass
Das (2016) Problem 2.6 — soil E is AASHTO A-2-6(1)	Pass
Das (2016) Problem 2.6 — soil F is AASHTO A-7-6(19)	Pass
Das (2016) Problem 2.7 — soil A is ML, Sandy silt	Pass
Das (2016) Problem 2.7 — soil B is ML, Sandy silt	Pass
Das (2016) Problem 2.7 — soil D is ML, Sandy silt	Pass
Das (2016) Problem 2.7 — soil E is SM, Silty sand	Pass
Das (2016) Problem 2.7 — soil F is CH, Fat clay with sand	Pass
Das (2016) Problem 2.6/2.7 — soils A and F through RUNNER_CONFIGS give the printed answers	Pass
ASTM D2487 X1.1.1 — 73 % gravel, 23 % sand, 4 % fines, Cc = 2.7, Cu = 12.4 → GW, well-graded gravel with sand	Pass
ASTM D2487 X1.1.2 — 61 % sand, 23 % fines (LL 33, PI 6), 16 % gravel → SM, silty sand with gravel	Pass
ASTM D2487 Note 11 — 46 % gravel, 30 % sand, 24 % clayey fines (LL 38, PI 19) → GC, clayey gravel with sand	Pass
ASTM D2487 X2.4.3 — broken shells: 65 % gravel, 31 % sand, 4 % fines, Cc = 2.4, Cu = 1.9 → GP, poorly graded gravel with sand	Pass
ASTM D2487 X2.4.4 — crushed rock: 89 % gravel, 11 % sand, Cc = 2.4, Cu = 0.9 → GP, poorly graded gravel	Pass
ASTM D2487 X2.4.1 — 61 % clayey fines (LL 37, PI 16), 33 % sand, 6 % gravel → CL, sandy lean clay	Pass
ASTM D2487 X1.1.3 — 100 % organic fines, LL (not dried) 32, PI 10 → OL, organic clay	Pass
ASTM D2487 Note 10 — poorly graded sand, 10 % fines, LL 20, PI 6 (CL-ML fines) → SP-SC	Pass
Knappett & Craig (2012) Ex. 1.1 — soil A (100 % coarse, Cu = 34, Cz = 1.6) is GW	Pass
Knappett & Craig (2012) Ex. 1.1 — soil B (3 % fines, 2 % gravel, Cu = 1.8, Cz = 0.95) is SP	Pass
Knappett & Craig (2012) Ex. 1.1 — soil C (34 % fines LL 26 PI 9, 41 % gravel, 25 % sand) is GC	Pass
Knappett & Craig (2012) Ex. 1.1 — soil D (LL 42, PI 18, 95 % fines) is CI under the IS 1498 intermediate class	Pass
FHWA-NHI-06-088 — the group index is not capped at 20 (F = 100, LL = 90, PI = 65)	Pass

`spt-correction-web-validation.test.ts`

spt-correction — published-value validation (the ≥20-value gate).

Analyses validated: `spt-correction` · Recorded run: passed — 128 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS-T3.7] Eq. 3.13 (liao_whitman) at σ′/p_a = 0.25 → C_N 2	Pass
[DAS-T3.7] Eq. 3.13 (liao_whitman) at σ′/p_a = 0.5 → C_N 1.41	Pass
[DAS-T3.7] Eq. 3.13 (liao_whitman) at σ′/p_a = 0.75 → C_N 1.15	Pass
[DAS-T3.7] Eq. 3.13 (liao_whitman) at σ′/p_a = 1 → C_N 1	Pass
[DAS-T3.7] Eq. 3.13 (liao_whitman) at σ′/p_a = 1.5 → C_N 0.82	Pass
[DAS-T3.7] Eq. 3.13 (liao_whitman) at σ′/p_a = 2 → C_N 0.71	Pass
[DAS-T3.7] Eq. 3.13 (liao_whitman) at σ′/p_a = 3 → C_N 0.58	Pass
[DAS-T3.7] Eq. 3.13 (liao_whitman) at σ′/p_a = 4 → C_N 0.5	Pass
[DAS-T3.7] Eq. 3.14 (skempton) at σ′/p_a = 0.25 → C_N 1.6	Pass
[DAS-T3.7] Eq. 3.14 (skempton) at σ′/p_a = 0.5 → C_N 1.33	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS-T3.7] Eq. 3.14 (skempton) at σ′/p_a = 0.75 → C_N 1.14	Pass
[DAS-T3.7] Eq. 3.14 (skempton) at σ′/p_a = 1 → C_N 1	Pass
[DAS-T3.7] Eq. 3.14 (skempton) at σ′/p_a = 1.5 → C_N 0.8	Pass
[DAS-T3.7] Eq. 3.14 (skempton) at σ′/p_a = 2 → C_N 0.67	Pass
[DAS-T3.7] Eq. 3.14 (skempton) at σ′/p_a = 3 → C_N 0.5	Pass
[DAS-T3.7] Eq. 3.14 (skempton) at σ′/p_a = 4 → C_N 0.4	Pass
[DAS-T3.7] Eq. 3.15 (skempton_coarse) at σ′/p_a = 0.25 → C_N 1.33	Pass
[DAS-T3.7] Eq. 3.15 (skempton_coarse) at σ′/p_a = 0.5 → C_N 1.2	Pass
[DAS-T3.7] Eq. 3.15 (skempton_coarse) at σ′/p_a = 0.75 → C_N 1.09	Pass
[DAS-T3.7] Eq. 3.15 (skempton_coarse) at σ′/p_a = 1 → C_N 1	Pass
[DAS-T3.7] Eq. 3.15 (skempton_coarse) at σ′/p_a = 1.5 → C_N 0.86	Pass
[DAS-T3.7] Eq. 3.15 (skempton_coarse) at σ′/p_a = 2 → C_N 0.75	Pass
[DAS-T3.7] Eq. 3.15 (skempton_coarse) at σ′/p_a = 3 → C_N 0.6	Pass
[DAS-T3.7] Eq. 3.16 (skempton_oc) at σ′/p_a = 0.25 → C_N 1.78	Pass
[DAS-T3.7] Eq. 3.16 (skempton_oc) at σ′/p_a = 0.75 → C_N 1.17	Pass
[DAS-T3.7] Eq. 3.16 (skempton_oc) at σ′/p_a = 1 → C_N 1	Pass
[DAS-T3.7] Eq. 3.16 (skempton_oc) at σ′/p_a = 1.5 → C_N 0.77	Pass
[DAS-T3.7] Eq. 3.16 (skempton_oc) at σ′/p_a = 2 → C_N 0.63	Pass
[DAS-T3.7] Eq. 3.16 (skempton_oc) at σ′/p_a = 3 → C_N 0.46	Pass
[DAS-T3.7] Eq. 3.16 (skempton_oc) at σ′/p_a = 4 → C_N 0.36	Pass
[DAS-T3.7] Eq. 3.17 (seed_1975) at σ′/p_a = 0.25 → C_N 1.75	Pass
[DAS-T3.7] Eq. 3.17 (seed_1975) at σ′/p_a = 0.5 → C_N 1.38	Pass
[DAS-T3.7] Eq. 3.17 (seed_1975) at σ′/p_a = 0.75 → C_N 1.15	Pass
[DAS-T3.7] Eq. 3.17 (seed_1975) at σ′/p_a = 1 → C_N 1	Pass
[DAS-T3.7] Eq. 3.17 (seed_1975) at σ′/p_a = 1.5 → C_N 0.78	Pass
[DAS-T3.7] Eq. 3.17 (seed_1975) at σ′/p_a = 2 → C_N 0.62	Pass
[DAS-T3.7] Eq. 3.17 (seed_1975) at σ′/p_a = 3 → C_N 0.4	Pass
[DAS-T3.7] Eq. 3.17 (seed_1975) at σ′/p_a = 4 → C_N 0.25	Pass
[DAS-T3.7] Eq. 3.18 (peck) at σ′/p_a = 0.25 → C_N 1.47	Pass
[DAS-T3.7] Eq. 3.18 (peck) at σ′/p_a = 0.5 → C_N 1.23	Pass
[DAS-T3.7] Eq. 3.18 (peck) at σ′/p_a = 0.75 → C_N 1.1	Pass
[DAS-T3.7] Eq. 3.18 (peck) at σ′/p_a = 1 → C_N 1	Pass
[DAS-T3.7] Eq. 3.18 (peck) at σ′/p_a = 1.5 → C_N 0.87	Pass
[DAS-T3.7] Eq. 3.18 (peck) at σ′/p_a = 2 → C_N 0.77	Pass
[DAS-T3.7] Eq. 3.18 (peck) at σ′/p_a = 3 → C_N 0.63	Pass
[DAS-T3.7] Eq. 3.18 (peck) at σ′/p_a = 4 → C_N 0.54	Pass
[DAS-T3.7] Eqs. 3.19/3.20 (bazaraa) at σ′/p_a = 0.25 → C_N 2	Pass
[DAS-T3.7] Eqs. 3.19/3.20 (bazaraa) at σ′/p_a = 0.5 → C_N 1.33	Pass
[DAS-T3.7] Eqs. 3.19/3.20 (bazaraa) at σ′/p_a = 0.75 → C_N 1	Pass
[DAS-T3.7] Eqs. 3.19/3.20 (bazaraa) at σ′/p_a = 1 → C_N 0.94	Pass
[DAS-T3.7] Eqs. 3.19/3.20 (bazaraa) at σ′/p_a = 1.5 → C_N 0.84	Pass
[DAS-T3.7] Eqs. 3.19/3.20 (bazaraa) at σ′/p_a = 2 → C_N 0.76	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[DAS-T3.7] Eqs. 3.19/3.20 (bazaraa) at σ′/p_a = 3 → C_N 0.65	Pass
[DAS-T3.7] Eqs. 3.19/3.20 (bazaraa) at σ′/p_a = 4 → C_N 0.55	Pass
[DAS-E3.1] (N1)60 at 1.5 m = 16	Pass
[DAS-E3.1] (N1)60 at 3 m = 10	Pass
[DAS-E3.1] (N1)60 at 4.5 m = 14	Pass
[DAS-E3.1] (N1)60 at 6 m = 14	Pass
[DAS-E3.1] (N1)60 at 7.5 m = 11	Pass
[DAS-P3.4 Eq. 3.13] (N1)60 at 1.5 m = 12	Pass
[DAS-P3.4 Eq. 3.13] (N1)60 at 3 m = 11	Pass
[DAS-P3.4 Eq. 3.13] (N1)60 at 4.5 m = 10	Pass
[DAS-P3.4 Eq. 3.13] (N1)60 at 6 m = 8	Pass
[DAS-P3.4 Eq. 3.13] (N1)60 at 7.5 m = 12	Pass
[DAS-P3.4 Eq. 3.13] (N1)60 at 9 m = 12	Pass
[DAS-P3.5 Eq. 3.14] (N1)60 at 1.5 m = 9	Pass
[DAS-P3.5 Eq. 3.14] (N1)60 at 3 m = 10	Pass
[DAS-P3.5 Eq. 3.14] (N1)60 at 4.5 m = 10	Pass
[DAS-P3.5 Eq. 3.14] (N1)60 at 6 m = 8	Pass
[DAS-P3.5 Eq. 3.14] (N1)60 at 7.5 m = 12	Pass
[DAS-P3.5 Eq. 3.14] (N1)60 at 9 m = 12	Pass
[KRAMER] Ex 6.6 (N1)60 at 1.2 m = 17.47	Pass
[KRAMER] Ex 6.6 (N1)60 at 2.2 m = 7.9	Pass
[KRAMER] Ex 6.6 (N1)60 at 3.2 m = 5.1	Pass
[KRAMER] Ex 6.6 (N1)60 at 4.2 m = 4.6	Pass
[KRAMER] Ex 6.6 (N1)60 at 5.2 m = 7	Pass
[KRAMER] Ex 6.6 (N1)60 at 6.2 m = 11.7	Pass
[KRAMER] Ex 6.6 (N1)60 at 7.2 m = 14.6	Pass
[KRAMER] Ex 6.6 (N1)60 at 8.2 m = 13.7	Pass
[KRAMER] Ex 6.6 (N1)60 at 9.2 m = 15.2	Pass
[KRAMER] Ex 6.6 (N1)60 at 10.2 m = 9.3	Pass
[KRAMER] Ex 6.6 (N1)60 at 11.2 m = 22.8	Pass
[KRAMER] Ex 6.6 (N1)60 at 12.2 m = 12.4	Pass
[KRAMER] Ex 6.6 (N1)60 at 13.2 m = 10.1	Pass
[KRAMER] Ex 6.6 (N1)60 at 14.2 m = 9.8	Pass
[KRAMER] Ex 6.6 (N1)60 at 15.2 m = 20.7	Pass
[KRAMER] Ex 6.6 (N1)60 at 16.2 m = 22.5	Pass
[KRAMER] Ex 6.6 (N1)60 at 17.2 m = 4.1	Pass
[KRAMER] Ex 6.6 (N1)60 at 18.2 m = 4.7	Pass
[KRAMER] Ex 6.6 (N1)60 at 19.2 m = 3.1	Pass
[KRAMER] Ex 6.6 (N1)60 at 20.2 m = 28.5	Pass
[BOWLES] Ex 3-2: N = 20, ER 80 %, 150 mm hole, p′o = 205 kPa, rod 12 m → N′60 = 19	Pass
[BOWLES] Ex 3-4: N = 20, ER 55 %, p′o = 100 kPa, 6 m hole → N′60 = 17	Pass
[GEC6] Eq. 4-1: N = 30 at ER 80 % → N60 = 40 (energy ratio only, = IS 2131:2025 §5.6.2)	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[GEC6] App. B Ex 3: N′ at 1.5 m = 10	Pass
[GEC6] App. B Ex 3: N′ at 4.5 m = 10	Pass
[GEC6] App. B Ex 3: N′ at 7.5 m = 15	Pass
[GEC6] App. B Ex 3: N′ at 10.5 m = 20	Pass
[MNO12] App. A N60 at 1.1 m = 3.8	Pass
[MNO12] App. A N60 at 1.8 m = 5	Pass
[MNO12] App. A N60 at 2.6 m = 4.3	Pass
[MNO12] App. A N60 at 3.4 m = 6.4	Pass
[MNO12] App. A N60 at 4.1 m = 8.5	Pass
[MNO12] App. A N60 at 4.9 m = 10.7	Pass
[MNO12] App. A N60 at 5.6 m = 24.9	Pass
[MNO12] App. A N60 at 6.4 m = 21.4	Pass
[MNO12] App. A N60 at 7.2 m = 30.9	Pass
[MNO12] App. A N60 at 7.9 m = 23.8	Pass
[MNO12] App. A N60 at 9.4 m = 25	Pass
[MNO12] App. A N60 at 10.2 m = 13.8	Pass
[MNO12] App. A N60 at 11 m = 10	Pass
[MNO12] App. A N60 at 12.5 m = 5	Pass
[YOUD] Table 2: rod length 2.5 m → C_R = 0.75	Pass
[YOUD] Table 2: rod length 3.5 m → C_R = 0.8	Pass
[YOUD] Table 2: rod length 5 m → C_R = 0.85	Pass
[YOUD] Table 2: rod length 8 m → C_R = 0.95	Pass
[YOUD] Table 2: rod length 12 m → C_R = 1	Pass
[YOUD] Table 2: borehole 100 mm → C_B = 1	Pass
[YOUD] Table 2: borehole 150 mm → C_B = 1.05	Pass
[YOUD] Table 2: borehole 200 mm → C_B = 1.15	Pass
[IS2131] Fig. 3: σ′0 = 5 kPa → C_N ≈ 2	Pass
[IS2131] Fig. 3: σ′0 = 50 kPa → C_N ≈ 1.24	Pass
[IS2131] Fig. 3: σ′0 = 100 kPa → C_N ≈ 1	Pass
[IS2131] Fig. 3: σ′0 = 200 kPa → C_N ≈ 0.77	Pass
[IS2131] Fig. 3: σ′0 = 300 kPa → C_N ≈ 0.64	Pass
[IS2131] Fig. 3: σ′0 = 400 kPa → C_N ≈ 0.54	Pass
[IS2131] Fig. 3: σ′0 = 550 kPa → C_N ≈ 0.43	Pass
[IS2131] §5.6.3 bounds 0.40 ≤ C_N ≤ 2.0 and σ′0 at SPT depth + 0.30 m by default	Pass

`spt-correlations-web-validation.test.ts`

spt-correlations — published-value validation (the ≥20-value gate).

Analyses validated: `spt-correlations` · Recorded run: passed — 47 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[IS6403] Fig. 1: N = 10 → ϕ ≈ 30.3°	Pass
[IS6403] Fig. 1: N = 20 → ϕ ≈ 33.2°	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
[IS6403] Fig. 1: N = 30 → ϕ ≈ 36°	Pass
[IS6403] Fig. 1: N = 40 → ϕ ≈ 38.6°	Pass
[IS6403] Fig. 1: N = 50 → ϕ ≈ 40.8°	Pass
[IS6403] Fig. 1: N = 60 → ϕ ≈ 42.6°	Pass
[IS6403] Fig. 1: N = 70 → ϕ ≈ 43.8°	Pass
[IS6403] Fig. 1 gives no value outside its plotted range (N < 10, N > 75) — none is invented	Pass
[FHWA] Table 8-1: N160 = 0 → ϕ 25–30°	Pass
[FHWA] Table 8-1: N160 = 4 → ϕ 27–32°	Pass
[FHWA] Table 8-1: N160 = 10 → ϕ 30–35°	Pass
[FHWA] Table 8-1: N160 = 30 → ϕ 35–40°	Pass
[FHWA] Table 8-1: N160 = 50 → ϕ 38–43°	Pass
[EC7-F1] Table F.1: (N1)60 = 3 → I_D = 15 %	Pass
[EC7-F1] Table F.1: (N1)60 = 8 → I_D = 35 %	Pass
[EC7-F1] Table F.1: (N1)60 = 25 → I_D = 65 %	Pass
[EC7-F1] Table F.1: (N1)60 = 42 → I_D = 85 %	Pass
[EC7-F1] Table F.1: (N1)60 = 58 → I_D = 100 %	Pass
[EC7-F1] F.1(4): fine sand N is read in the ratio 55:60 — (N1)60 = 22.92 fine ≡ 25 medium → I_D 65 %	Pass
[EC7-F3] Table F.3: fine_uniform, I_D 40 % → ϕ′ 34°	Pass
[EC7-F3] Table F.3: fine_uniform, I_D 60 % → ϕ′ 36°	Pass
[EC7-F3] Table F.3: fine_uniform, I_D 80 % → ϕ′ 39°	Pass
[EC7-F3] Table F.3: fine_uniform, I_D 100 % → ϕ′ 42°	Pass
[EC7-F3] Table F.3: medium_uniform, I_D 40 % → ϕ′ 36°	Pass
[EC7-F3] Table F.3: medium_well, I_D 60 % → ϕ′ 41°	Pass
[EC7-F3] Table F.3: medium_well, I_D 80 % → ϕ′ 43°	Pass
[EC7-F3] Table F.3: medium_uniform, I_D 100 % → ϕ′ 43°	Pass
[EC7-F3] Table F.3: coarse_uniform, I_D 40 % → ϕ′ 38°	Pass
[EC7-F3] Table F.3: coarse_well, I_D 60 % → ϕ′ 43°	Pass
[EC7-F3] Table F.3: coarse_well, I_D 80 % → ϕ′ 44°	Pass
[EC7-F3] Table F.3: coarse_well, I_D 100 % → ϕ′ 46°	Pass
[EC7-F3] no ϕ′ below the tabulated I_D = 40 % — none is invented	Pass
[DAS] Example 3.2: σ′v 25.95 kPa, N60 8 → ϕ′ 37.5°	Pass
[DAS] Example 3.2: σ′v 51.9 kPa, N60 7 → ϕ′ 33.8°	Pass
[DAS] Example 3.2: σ′v 77.85 kPa, N60 12 → ϕ′ 36.9°	Pass
[DAS] Example 3.2: σ′v 103.8 kPa, N60 14 → ϕ′ 36.7°	Pass
[DAS] Example 3.2: σ′v 129.75 kPa, N60 13 → ϕ′ 34.6°	Pass
[DAS] Eq. 3.29 table: N60 3 → ϕ′ 28°	Pass
[DAS] Eq. 3.29 table: N60 6 → ϕ′ 29°	Pass
[DAS] Eq. 3.29 table: N60 9 → ϕ′ 30°	Pass
[DAS] Eq. 3.29 table: N60 10 → ϕ′ 30°	Pass
design_code routes: IS → Fig. 1, AASHTO → lower bound for silty sand, EC7 → Table F.3	Pass
the silty-sand cap is reported and caps ONLY the recommended value — N still moves the methods	Pass
a code route outside its chart falls back to the envelope with a warning, never an invented value	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
N > 50 is flagged: the √N correlations have no code support there	Pass
σ′v is live: with field N60 it adds the Kulhawy-Mayne value	Pass
the 32° cap is OFF by default (2026-09-26): ϕ′ follows N, and a note says where local practice would cap it	Pass

supporting-outputs-web-validation.test.ts

supporting-outputs-web-validation.test.ts

Analyses validated: `asphalt-institute-design`, `basal-heave`, `faarfield-mix-cdf`, `hs-confined-settlement`, `hs-small`, `jpcp-iri`, `pressuremeter-menard`, `pvd-design`, `rock-slope-stability` · Recorded run: passed — 7 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
rock-slope-stability: FoS = resisting/driving exactly, and both forces respond correctly (7 anchors)	Pass
basal-heave: resisting pressure is N_c·s_u and the FoS is its ratio to γH + q (6 anchors)	Pass
pvd-design: d_e = 1.05·s for a triangular grid and 1.128·s for a square one (5 anchors)	Pass
hs-small: G_s ≥ G_t, both fall with strain, and the cut-off strain bounds them (6 anchors)	Pass
hs-confined-settlement: the linear reference is Δσ·H/E_oed and the strain is its own ratio (6 anchors)	Pass
Miner's rule holds where an engine reports damage contributions (asphalt, JPCP, FAARFIELD)	Pass
pressuremeter-menard: total settlement is the sum of its spherical and deviatoric parts	Pass

⚑ vane-correction-web-validation.test.ts

Validation for `vane-correction` — Bjerrum field-vane correction factor μ = 1.7 − 0.54·log10(PI), capped at 1.0 (`vane-correction.ts`).

Analyses validated: `vane-correction` · Recorded run: passed — 4 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
Look Table 4.14: μ = 1.0 for PI < 20 %, then 0.9, 0.85, 0.75, 0.70, 0.70, 0.65, 0.65, 0.65 at PI 30…100	Pass
Das Example 3.3 (a): Bjerrum λ = 1.7 − 0.54 log(32) applied to s_u(VST) = 20.12 kN/m² → 17.85 kN/m²	Pass
CFEM §4.5.6 (Aas et al. 1986): the design μ never exceeds 1.0 — low-PI clays are capped, not raised	Pass
cross-check: engine μ agrees with the independent Han (2015) Eq. 2.46 regression to ±0.03 for PI 40…100	Pass

Reliability, back-analysis and design aids

Cited validation suites — 3

`bayesian-back-analysis-web-validation.test.ts`

Observational-method Bayesian back-analysis — CITED validation (≥20 values).

Analyses validated: `bayesian-back-analysis` · Recorded run: passed — 11 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
bayesian-back-analysis: Φ^{-1} credible-interval z-values [4]	Pass
bayesian-back-analysis: conjugate single-obs update, exact closed form [1]	Pass
bayesian-back-analysis: linear scale/offset observation [1]	Pass
bayesian-back-analysis: vague prior, n i.i.d. → sample mean & σ^2/n [2]	Pass
bayesian-back-analysis: zero observations → posterior = prior [3]	Pass
bayesian-back-analysis: strong prior barely moves [1]	Pass
bayesian-back-analysis: precise observation dominates [1]	Pass
bayesian-back-analysis: precisions add over observations; monotone tightening [1][2]	Pass
bayesian-back-analysis: next-reading predictive widens by σ_obs [3]	Pass
bayesian-back-analysis: guards non-finite & degenerate inputs	Pass
bayesian-back-analysis: TOTAL cited assertions	Pass

`design-copilot-web-validation.test.ts`

Validation for the AI design copilot's deterministic core (`design-copilot.ts`).

Analyses validated: `design-copilot`, `settlement` · Recorded run: passed — 27 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
benchmark: Sphere → 0 at origin	Pass
benchmark: Rosenbrock → 0 at (1,1)	Pass
benchmark: Booth → 0 at (1,3)	Pass
benchmark: Matyas → 0 at origin	Pass
benchmark: Beale → 0 at (3,0.5)	Pass
benchmark: Himmelblau → 0	Pass
benchmark: McCormick → −1.9133	Pass
benchmark: Three-hump camel → 0 at origin	Pass
benchmark: Goldstein–Price → 3 at (0,−1)	Pass
benchmark: Bohachevsky → 0 at origin	Pass
benchmark: Lévi N.13 → 0 at (1,1)	Pass
benchmark: 4-D sphere → 0	Pass
golden-section: parabola min at 3	Pass
golden-section: quartic min at 2	Pass

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
golden-section: cosh min at 1	Pass
settlement: rigid circle = exact Timoshenko punch	Pass
settlement: square uses Iρ=0.82	Pass
settlement: strip uses Iρ=2.0	Pass
foundation: ϕ=0 clay net bearing ≈ 5.14·cu (Prandtl/Skempton)	Pass
foundation: sand FoS increases with width B	Pass
foundation: higher target FoS → larger B*	Pass
foundation: higher cohesion → smaller B* (clay)	Pass
foundation: settlement governs on low-E soil, constraint active (KKT)	Pass
foundation: bearing governs on stiff-weak soil, FoS active (KKT)	Pass
foundation: B* is the minimal feasible width	Pass
optimiser: smallestFeasible finds the monotone threshold	Pass
optimiser: gridMinimize yields samples covering the box	Pass

`reliability-web-validation.test.ts`

Reliability kernel — web-sourced / textbook CITED validation (≥20 values).

Analyses validated: `reliability` · Recorded run: passed — 8 test block(s)

TEST BLOCK (THE PUBLISHED VALUE IT CHECKS)	VERDICT
reliability-web-validation: Φ(−β) matches the standard-normal table [2]	Pass
reliability-web-validation: $\Phi^{-1}(p)$ matches the table [2]	Pass
reliability-web-validation: linear normal R−S exact β [1][3]	Pass
reliability-web-validation: lognormal R−S exact β; FORM invariance [1][3]	Pass
reliability-web-validation: correlation changes β per Baecher & Christian [5]	Pass
reliability-web-validation: Duncan 2000 / USACE β→P_f + bands [4]	Pass
reliability-web-validation: FORM invariant where FOSM is not [3]	Pass
reliability-web-validation: TOTAL cited assertions	Pass

Re-running a row yourself

- **Kernel rows.** Each row names its test (`cargo test -p tbk-core --test <file> <name> -- --nocapture` prints the numbers; `#[ignore]`d cases run with `--ignored`). The inputs are the ModelSpec files under `app/kernel/verification/cases/`.
- **Closed-form rows.** `node app/scripts/verification-registry.mjs` re-measures every row and fails when a pass turns into a miss.
- **Validation suites.** `cd app/packages/geotech && GEOTECH_TEST_ONLY='<suite>-web-validation' node scripts/test.mjs`; all of them with per-test verdicts: `node app/scripts/record-validation-suite-run.mjs`.
- **Independent review.** `app/docs/verification-manual/INDEPENDENT-REVIEW-PACK.md` lists the cases an outside reviewer should re-run in another program, with inputs and expected outputs.