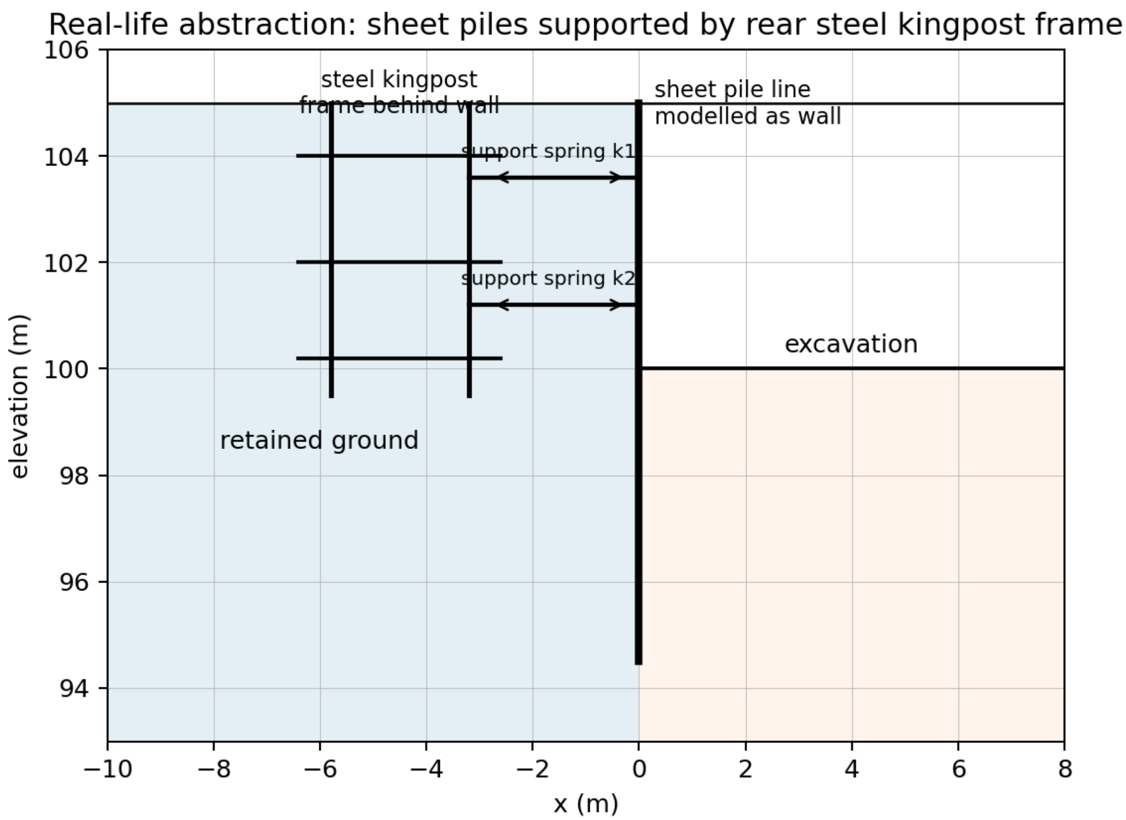
FEMSoilCalc v3

Junior Engineer Training Manual

Operation, modelling workflow and core geotechnical FEM theory



Sheet pile wall supported by a rear steel kingpost frame - model abstraction used in this guide.

Document item	Detail
App version	FEMSoilCalc v3
Intended reader	Graduate/junior structural or geotechnical engineer under supervision
Purpose	Teach safe operation, model building, interpretation and limitations
Status	Training guide for a prototype browser-based FEM app, not a certified design manual
Date	29 June 2026

Important engineering caveat

FEMSoilCalc is a transparent browser-based 2D plane-strain geotechnical FEM prototype. It is useful for learning, preliminary sensitivity studies and comparison checks, but it is not a replacement for a validated commercial package such as PLAXIS 2D, ADONIS, RS2, FLAC, or a project-specific numerical model reviewed by a competent geotechnical engineer.

Do not use the output as a sole basis for construction-stage temporary works design. Always compare against independent hand calculations, limit-equilibrium checks, serviceability limits, structural checks of the wall and frame, and project-specific ground investigation information.

Learning outcomes

- Understand the coordinate system, stage definitions and sign conventions used by the app.
- Build a basic braced excavation model from scratch and run a mesh-sensitive check.
- Interpret displacement, wall bending moment, prop reaction, interface slip and mobilisation results.
- Understand the theory behind CST soil elements, K0 initial stresses, wall beam stiffness, interface springs and phi-c strength reduction diagnostics.
- Model a realistic sheet pile wall supported by a steel kingpost frame behind the wall using equivalent horizontal support springs.
- Recognise the limitations of the current v3 solver and know which results require independent verification.

1. What FEMSoilCalc is modelling

The app represents a vertical retaining wall in a 2D plane-strain soil domain. The retained side is negative x, the excavation side is positive x, and y is elevation. Soil is represented by constant-strain triangular continuum elements. The wall is represented by a vertical structural beam chain connected to the soil through interface springs. Props, anchors or a rear steel frame are represented as horizontal springs acting at selected wall elevations.

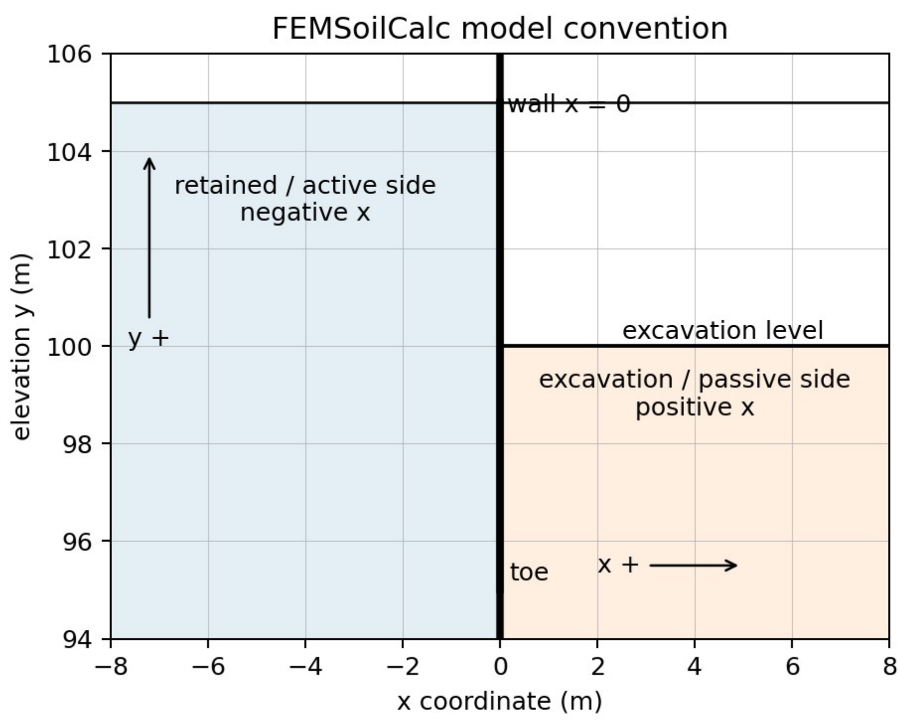


Figure 1 - Default coordinate convention. The wall line is usually x = 0.

The app should be thought of as a staged numerical section through a retaining wall. It is not a 3D model. Anything discrete out of plane, such as kingposts at centres, walers, struts, tie rods or frames, must be converted into equivalent stiffness and load per metre run of wall.

2. Quick app tour

Area / tab	What the junior engineer should enter or review
Project	Project metadata only. It does not affect the calculation but helps identify saved files.
Geometry	Top elevation, formation level, toe level, domain widths, bottom boundary and mesh size.
Materials	Unit weight, stiffness, Poisson ratio, phi, cohesion, dilation and K0 for each soil layer.
Wall / Interfaces	Wall EI and EA per metre run, interface normal/shear penalty stiffness, wall friction delta, and support springs.
Loads	Water unit weight, water tables, solver settings, load steps and optional strength reduction diagnostic.
Stages	Construction sequence: initial state, excavation levels, water levels and which stages are analysed.
Summary	Maximum movements, wall moments, prop reactions, mobilisation, interface yield count and solver diagnostics.
Wall Results	Wall node elevations, horizontal/vertical displacement, rotation, moment and shear.
FEM Results	Element stress/mobilisation table and interface slip/yield table.
Canvas views	Mesh, deformed mesh, Ux, Uy, mobilisation and wall moment views.

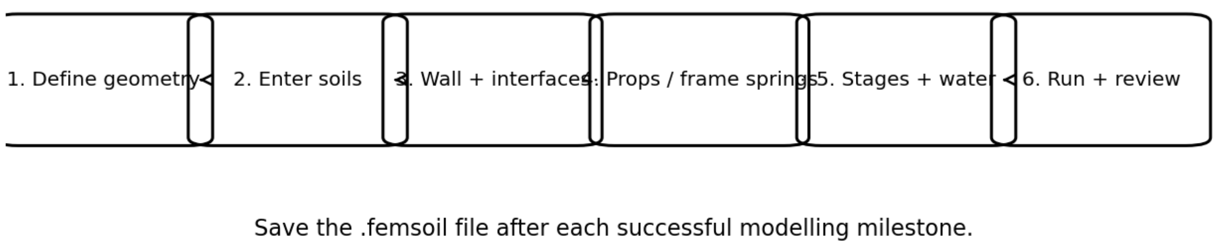


Figure 2 - Recommended modelling workflow.

3. Key theory in plain engineering language

3.1 Plane strain

A retaining wall section is normally analysed as a long wall where the out-of-plane strain is assumed to be zero. This is the plane-strain idealisation. It is appropriate when wall length is large compared with excavation depth and when end effects are not dominant. Discrete supports, kingposts or frames must be averaged into per-metre properties.

3.2 Soil continuum elements

The soil mesh uses CST triangular elements. A CST element has constant strain and constant stress inside each triangle. This is robust and simple, but it needs a reasonably fine mesh near stress gradients such as the wall, toe, prop levels and excavation corner.

For a linear elastic plane-strain element the element stiffness is assembled from:

$$k_e = \int B^T D B \, t \, dA = B^T D B A \quad \text{for unit thickness}$$

where B relates nodal displacement to strain, D is the plane-strain elastic matrix, and A is triangle area. Because strain is constant, the element can be too stiff in bending if the mesh is coarse. Mesh sensitivity is therefore essential.

3.3 Effective stress, unit weight and K0

The initial geostatic condition should not start from a stress-free soil block. The vertical stress comes mainly from self-weight, and the horizontal in-situ stress is approximated by K0 times vertical effective stress. For normally consolidated granular soils a common first estimate is K0 = 1 - sin(phi). For overconsolidated clays, K0 may be higher and should come from geotechnical advice.

In v3, K0 equivalent loading is included as an initial-stress body-force style contribution. This improves the first-stage displacement and lateral wall loading compared with treating lateral soil pressure only as a wall boundary pressure.

3.4 Wall beam and support springs

The wall is a vertical beam chain with axial stiffness EA and bending stiffness EI per metre run. The wall is connected to soil through interface springs. A steel kingpost frame, strut, waler, anchor or prop is represented by a horizontal spring at a wall node elevation. The spring stiffness entered in the app must be per metre run of wall.

For a discrete frame at spacing s, convert a frame support stiffness K_frame to a per-metre stiffness:

k_per_m = K_frame / s

Example: if one bay of steel frame provides 120000 kN/m horizontal stiffness at 2.5 m centres, enter 48000 kN/m per metre run as the prop stiffness. If the frame stiffness is uncertain, run sensitivity checks at perhaps 0.5x, 1.0x and 2.0x.

3.5 Interfaces

The interface values kn and ks are numerical penalty spring stiffnesses between wall and soil. High values force the soil and wall to move together; low values allow more slip or separation. The wall friction delta and roughness parameter limit the shear transfer. Interface behaviour is approximate in v3, so treat yielded interface counts and slip as warning indicators rather than a final design proof.

3.6 Staged excavation

Excavation is simulated by deactivating soil on the excavation side above the stage excavation level. v3 carries previous displacement/load state forward between stages, so a later excavation is not solved as a completely independent fresh model. However, it remains a simplified incremental procedure, not a full elastoplastic stress-history engine.

Staged construction concept

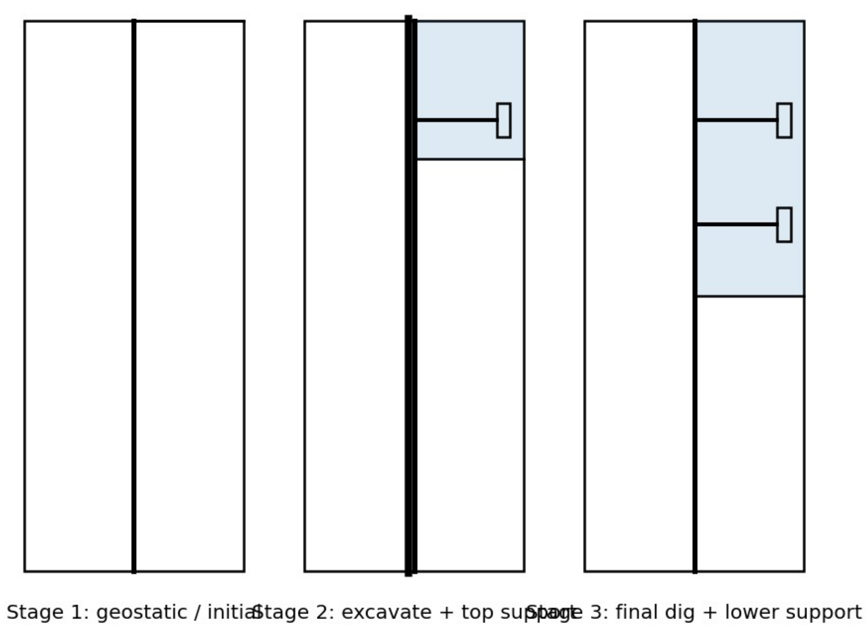


Figure 3 - Staged construction should match the physical temporary works sequence.

3.7 Solvers: direct, PCG and auto

The direct solver is usually more robust for small and medium models. PCG/CSR is intended for larger models but can struggle if the matrix is poorly conditioned, the mesh is distorted, or penalty stiffness values are excessive. Auto mode selects a route based on model size. If a PCG run fails, retry with direct solver and a coarser mesh. If direct fails with a singular matrix warning, check supports, inactive regions, wall/interface stiffness and geometry.

3.8 Mobilisation and phi-c strength reduction

The mobilisation plot compares stress demand against an approximate Mohr-Coulomb strength measure. Values close to or above 1.0 indicate zones where the elastic stress state is beyond or near the assumed shear strength. The phi-c strength reduction option reduces tan(phi) and c by a factor and reports the first factor associated with high mobilisation or solver difficulty. This is a diagnostic, not a certified factor of safety.

4. Getting started tutorial - run the built-in braced excavation example

1. Open FEMSoilCalc v3 in the browser.
2. Use the drop-down marked "Load verification example" and select "Braced excavation - dense sand".
3. Click "Run FEM". Wait for the status bar to say the run is complete.
4. On the right-hand canvas, switch between Mesh, Deformed, Ux, Uy, Mobilisation and Wall M.
5. Open the Summary tab and record maximum horizontal displacement, maximum wall moment, maximum prop reaction, maximum mobilisation and solver method.
6. Open Wall Results and identify the elevation of maximum moment and approximate shear reversal.
7. Open FEM Results and review the highest mobilisation zones. These should generally concentrate near the wall, toe or excavation corner.
8. Save the file as a .femsoil file before changing inputs.

Suggested trainee questions

- Does the deformed shape make engineering sense? The wall should generally move towards the excavation after excavation.
- Does the prop reaction increase after the support stage is active?
- Does refining the mesh materially change maximum wall moment or displacement?
- Are interface slips small relative to the expected physical wall-soil movement?
- Do high mobilisation zones line up with an expected passive wedge, active wedge, wall toe or base heave mechanism?

Mesh sensitivity exercise

Run	dx	dy	Solver	What to compare
A - coarse	1.5 m	0.75 m	direct or auto	Fast sanity check. Record max Ux, wall M and prop R.
B - normal	1.0 m	0.50 m	auto	Default comparison.
C - refined near practical limit	0.75 m	0.375 m	auto/PCG	Check whether key results stabilise.

For a junior engineer, the target is not to find the finest mesh possible. The target is to show that the result used for design judgement is not a coarse-mesh artefact.

5. Build a simple model from scratch

The following small model is intentionally simple. It teaches the relationship between input elevations, soil stiffness, wall stiffness and results.

Input group	Value
Geometry	top 105.0, formation 100.0, toe 95.0, left 16, right 14, bottom 91, dx 1.0, dy 0.5, wallX 0

Soil 1	Sand: gamma 18 kN/m3, E 30000 kPa, nu 0.30, phi 32 deg, c 0, psi 0, K0 0.47
Wall	EI 45000 kNm2/m, EA 1.0E7 kN/m, kn 1.0E6, ks 1.0E5, delta 20 deg, roughness 0.67
Prop	Elevation 103.0, stiffness 50000 kN/m per metre, prestress 0, active stage 2
Water	activeWT 92, passiveWT 92, gammaW 10
Stages	Initial: excavation 105; Stage 2: excavation 102.5; Stage 3: excavation 100.0

9. Start with Clear All.
10. Enter the geometry first. Check that top > formation > toe > bottom.
11. Enter material values. For a single layer, the default layer assignment is adequate.
12. Enter wall and interface values. Avoid unrealistically high penalty values until the basic model is stable.
13. Add one prop at elevation 103 m and set it active from Stage 2.
14. Add three construction stages. Ensure each stage is ticked to analyse.
15. Run FEM using solver auto and loadSteps 3.
16. If the model fails, coarsen the mesh and use direct solver before changing soil or wall properties.

6. More realistic tutorial - sheet piles supported by a steel kingpost frame behind

6.1 Problem statement

A temporary excavation is required beside a retained platform. A line of sheet piles forms the excavation face. Behind the sheet piles, a steel kingpost frame with walers provides temporary lateral restraint. The frame is discrete out of plane, so the 2D FEM section will use equivalent horizontal springs at the wall support elevations.

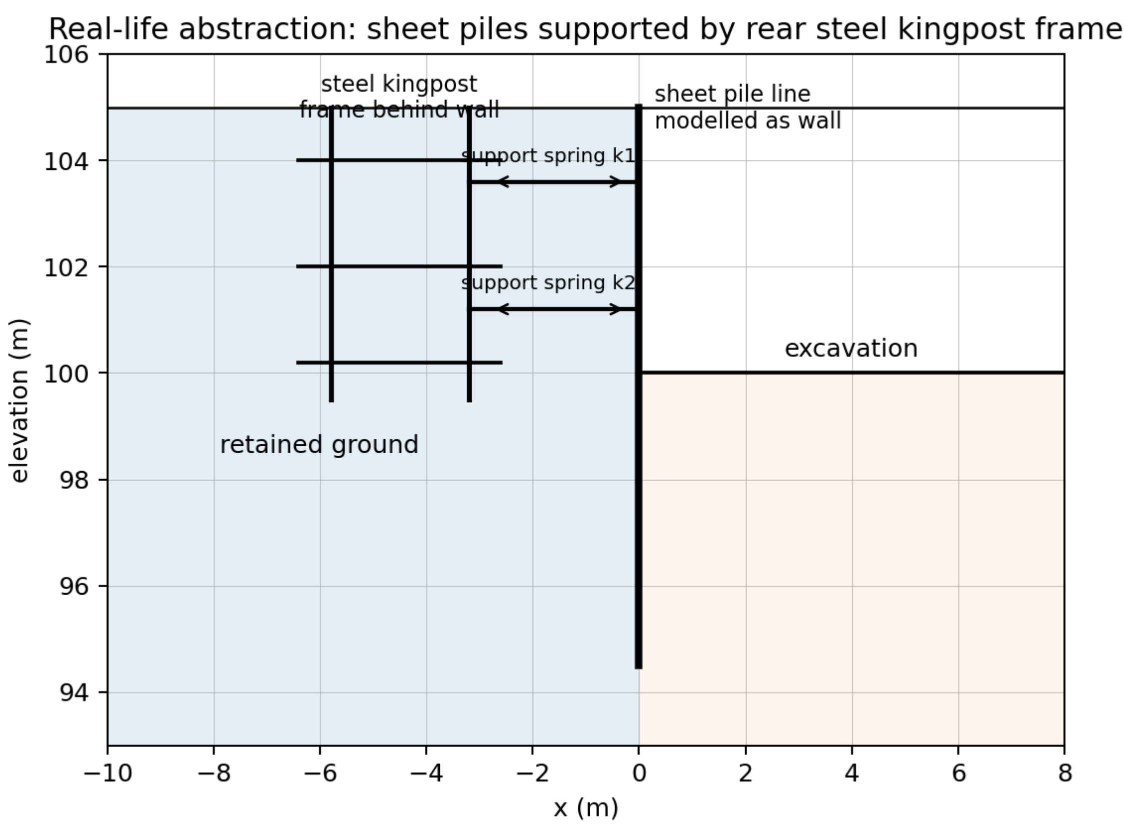


Figure 4 - Sheet pile and rear kingpost frame represented as wall plus support springs.

6.2 Assumed training data

Item	Assumed value for tutorial
Ground level	105.00 m
Final excavation level	100.00 m
Sheet pile toe	94.50 m
Model bottom boundary	90.00 m
Retained-side width	20 m
Excavation-side width	16 m
Mesh	dx 1.0 m, dy 0.5 m initially
Surcharge behind wall	10 kPa from x = -15 m to x = -1 m, active from Stage 1
Water	training case dry: water tables at 90 m; add water later as sensitivity
Sheet pile stiffness	EI 60000 kNm2/m, EA 1.0E7 kN/m
Interface	kn 1.0E6 kN/m3, ks 1.0E5 kN/m3, delta 20 deg, roughness 0.67

Soil profile for the training case

Layer	Elevation range	gamma	E prime	nu	phi prime	c prime	K0
Made ground	105 to 102 m	18	12000 kPa	0.32	28 deg	0	0.55
Medium dense sand	102 to 98 m	19	30000 kPa	0.30	33 deg	0	0.45
Dense sand/gravel	below 98 m	20	60000 kPa	0.28	38 deg	0	0.38

6.3 Convert the steel kingpost frame to app support springs

The frame should be analysed separately as a structural frame. For the FEMSoilCalc model, the frame contribution is idealised as horizontal restraint at the wall. Use serviceability stiffness, not ultimate capacity. Include the flexibility of walers, connection details, struts and kingposts where possible.

Support level	Frame bay stiffness from separate frame analysis	Frame spacing	App stiffness per metre
Upper waler at 103.6 m	150000 kN/m per frame line	2.5 m	60000 kN/m
Lower waler at 101.2 m	110000 kN/m per frame line	2.5 m	44000 kN/m

If the frame stiffness is unknown, run a sensitivity study. For example, repeat the analysis with both support stiffnesses multiplied by 0.5 and 2.0. A wall design that is extremely sensitive to frame stiffness needs closer structural modelling.

6.4 Construction stages for the kingpost example

Stage	Excavation level	Support active	Purpose
1 - Initial K0	105.0	none	Generate initial stress state with surcharge and self-weight.
2 - Trim to upper waler	103.2	upper support active	Represents first dig and installation of upper waler/kingpost restraint.
3 - Intermediate dig	101.0	upper support active	Check movement before lower support is effective.
4 - Final dig	100.0	upper + lower active	Final temporary works condition.

6.5 Data entry steps

17. Create the project title: "Sheet pile with rear kingpost frame - training".
18. Enter the geometry values from the assumed data table.
19. Enter the three soil materials. If layer editing is not visible in the current UI, use the built-in example closest to the soil profile and adjust materials; otherwise assign layer tops at 105, 102 and 98 m.
20. Enter wall stiffness EI and EA. Confirm the units are per metre run of wall.
21. Enter interface values. Start with default penalty values; do not chase unrealistic zero slip by making penalties enormous.
22. Add an upper prop at 103.6 m with k = 60000 kN/m, active stage = 2.
23. Add a lower prop at 101.2 m with k = 44000 kN/m, active stage = 4.
24. Add retained-side surcharge from x = -15 to x = -1, q = 10 kPa, active from Stage 1.
25. Set dry water tables to 90 m for both active and passive sides in this first exercise.

26. Add the four construction stages exactly as shown above.
27. Run with solver auto, nonlinear = 1, loadSteps = 3, strengthReduction = 0.

6.6 What to review after running

Result	Engineering interpretation
Max Ux	Check wall serviceability. Excessive movement may indicate inadequate embedment, insufficient frame stiffness, soft soil or incorrect staging.
Wall M	Use as a guide for the sheet pile structural design envelope, but compare with independent limit-equilibrium or beam-on-spring checks.
Prop reactions	Convert kN/m back to frame or waler forces by multiplying by frame spacing or tributary width.
Mobilisation	High values near the toe or excavation base suggest passive resistance or base stability sensitivity.
Interface slip/yield	Indicates whether wall-soil shear transfer is being capped. High slip may mean interface parameters dominate the result.
Solver log	PCG iteration growth or direct solver conditioning problems can indicate excessive penalty stiffness, weak restraint or poor mesh.

6.7 Convert output back to steel frame actions

If the app reports an upper support reaction R_upper = 80 kN/m and the kingpost frame spacing is 2.5 m, the approximate frame line load is:

F_upper_frame = 80 x 2.5 = 200 kN per frame line

This force should be checked in the steel frame model, walers, connections, kingpost base/foundation and any temporary works bracing. Also check construction tolerances and eccentricity between sheet piles, walers and frame members.

6.8 Sensitivity matrix for the senior engineer to review

Case	Change	Reason
Base	Training values above	Reference result.
S1	Frame stiffness x 0.5	Checks if the wall relies too heavily on assumed frame stiffness.
S2	Frame stiffness x 2.0	Bounds a stiffer frame or accidental fixity.
S3	phi reduced by 2 degrees	Ground uncertainty.
S4	E reduced by 50 percent	Serviceability uncertainty.
S5	Water active side at 103 m, passive at 100 m	Dewatering or perched water sensitivity.
S6	Toe raised/lowered by 0.5 m	Embedment sensitivity.

7. Common mistakes and how to catch them

Mistake	Symptom	Correction
Wrong side of wall	Wall moves the wrong way or excavation void appears on wrong side	Use negative x for retained side and positive x for excavation side.
Formation/toe/bottom elevations inconsistent	Validation warnings or empty/odd mesh	Check top > formation > toe > bottom.
Frame stiffness entered as total rather than per metre	Prop reactions/displacements unrealistic	Divide discrete frame stiffness by spacing before entry.
Penalty stiffness too high	Ill-conditioned matrix, PCG non-convergence	Reduce kn/ks and test sensitivity.
Mesh too coarse	Moment peaks and mobilisation zones jump between runs	Refine dy near wall levels or reduce dx/dy globally.
Ignoring water	Wall movements and moments too low	Run water table sensitivity.
Using SRM as a certified FoS	Misleading safety statement	Call it a diagnostic only and verify separately.

8. Minimum QA checklist before issuing results

- Model screenshot saved showing geometry, wall and stages.

- Inputs independently checked by another engineer: elevations, soil parameters, wall EI/EA, support stiffness and water levels.
- At least one coarser and one finer mesh run compared.
- Frame/prop reactions converted correctly from kN/m to discrete member forces.
- Wall moments compared with a separate limit-equilibrium, beam-on-springs or previous project benchmark.
- Mobilisation plot reviewed for plausible failure mechanisms.
- Water and soil strength sensitivity checked.
- Temporary works sequence in the model matches the intended site sequence.
- Limitations stated clearly in the calculation note.

9. Troubleshooting guide

Message / behaviour	Likely cause	First actions
Cannot run: red validation fields	Missing or impossible input values	Fix highlighted fields. Use numeric values only where expected.
Singular or ill-conditioned stiffness matrix	Unrestrained DOF, inactive zone, very weak/strong interface, bad geometry	Use direct solver, coarsen mesh, reduce penalty stiffness, check bottom/side boundaries.
PCG did not converge	Poor conditioning or excessive penalty stiffness	Try direct solver. Reduce kn/ks. Increase loadSteps.
Very large displacement	Inadequate embedment/support, soft soil, wrong units or wrong side of excavation	Check model convention, support stiffness per metre, soil E and toe level.
Mobilisation > 1 over large region	Elastic stress state exceeds approximate strength	Treat as a warning; run sensitivity and independent stability check.
Prop reaction sign seems wrong	Support active stage or direction misunderstood	Check stage number and wall movement direction.

10. What FEMSoilCalc v3 still does not do

- It does not implement a fully validated Mohr-Coulomb return-mapping plasticity algorithm.
- It does not perform coupled consolidation or seepage analysis.
- It does not automatically generate unstructured graded meshes around wall toes and excavation corners.
- It does not replace separate structural analysis of kingpost frames, walers, struts or connections.
- It does not certify a global factor of safety; SRM is a diagnostic only.
- It does not remove the need for independent hand checks and senior engineering review.

11. Appendix A - Useful modelling formulae

Quantity	Expression / note
Normally consolidated K0	K0 approximately 1 - sin(phi prime)
Discrete support to per metre stiffness	k_per_m = K_frame / spacing
Discrete support force from app reaction	F_frame = R_app x spacing
Hydrostatic pore pressure	u = gamma_w (water table elevation - y), for y below water table
Approximate active pressure coefficient	Ka = (1 - sin phi) / (1 + sin phi) for level Rankine soil
Phi-c reduction diagnostic	tan(phi_reduced) = tan(phi) / SRF; c_reduced = c / SRF

12. Appendix B - Suggested calculation note wording

The following text may be adapted into a project calculation note:

"A 2D plane-strain FEM sensitivity model was prepared using FEMSoilCalc v3 to review the staged behaviour of the temporary sheet pile wall. The model idealises soil as CST continuum elements, the sheet pile as a vertical beam chain per metre run, and the rear kingpost frame as equivalent horizontal support springs at the waler elevations. Results have been used for comparison and sensitivity only. Wall bending moments, support reactions, global stability and frame member forces require independent verification by established temporary works design methods and structural analysis."

13. Appendix C - Suggested external references for further learning

- Potts & Zdravkovic - Finite Element Analysis in Geotechnical Engineering.
- Brinkgreve et al. - PLAXIS manuals and validation examples.
- CIRIA guidance on embedded retaining walls and temporary works, as applicable to the project.
- Eurocode 7 and the UK National Annex for geotechnical design principles.
- SCI/steel design guidance for checking kingpost frames, walers, struts and connections.