GEM4D DOCUMENTATION

BEM Stress Analysis

User Manual

PRODUCT	GEM4D
DOCUMENT	BEM Stress Analysis — User Manual
VERSION	1.9.0.0
DATE	14 June 2026
STATUS	First issue

basrock.net

Contents

1. What this tool does

The **BEM ribbon tab** runs a three-dimensional, linear-elastic stress analysis around your underground excavations using the **Boundary Element Method (BEM)** — the same family of methods as Map3D and Examine3D.

You give it three things:

1. the **excavation geometry** — closed triangulated meshes already loaded in the GEM4D scene,
2. the **rock properties** — Young's modulus and Poisson's ratio of the rock mass, and
3. the **in-situ stress field** — the stress state in the ground before anything was mined.

It then computes, at any points you choose in the surrounding rock, the **total stress** (in-situ plus mining-induced) and the **elastic displacement**. Results come out as principal stresses (σ_1, σ_2, σ_3 in MPa), displacement (mm), and optionally the full six-component stress tensor — written to CSV files or appended directly to a point table inside GEM4D, where they can be colour-mapped, filtered, contoured as iso-surfaces, and exported like any other data.

Typical questions it answers:

- *Where does mining concentrate stress, and how high does it get?* (abutments, pillars, intersections)
- *Where does the rock destress?* (stope backs and walls, shadowed regions)
- *How will stresses at a planned excavation change because of the existing voids nearby?*

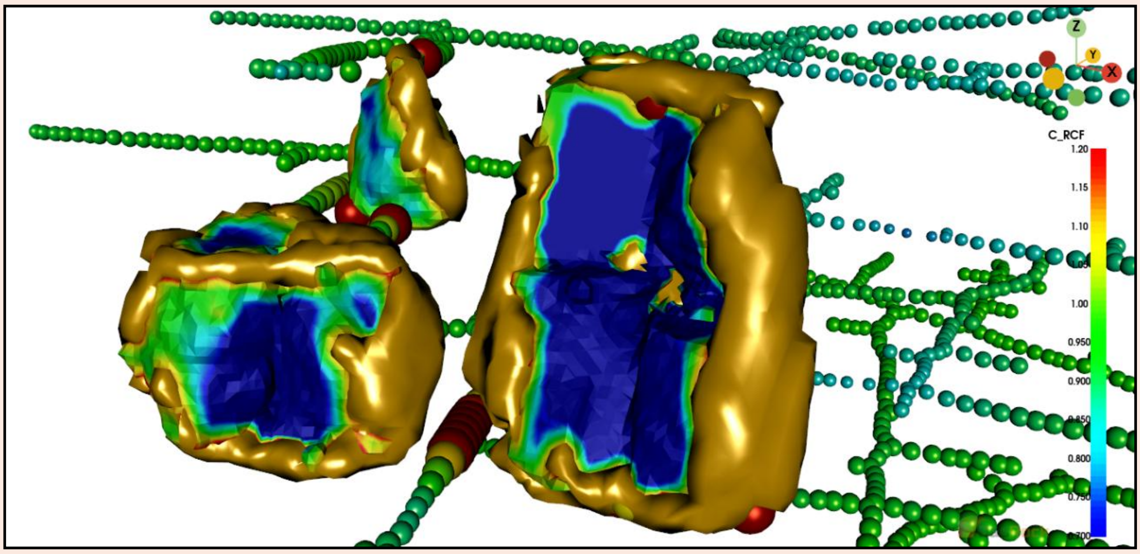

Figure 1: The Major Principal Stress (Sigma1) was used to colour the stopes and create the iso-surfaces, and the development is represented by Minodes coloured and scaled on the Rockmass Condition Factor (RCF).

2. Background theory

This section is written for users who have not run numerical stress models before. If you have used Map3D or Examine3D you can skip to §2.5, which covers the conventions specific to GEM4D.

2.1 In-situ stress and induced stress

Rock at depth is already stressed before mining: the weight of the overlying rock produces a **vertical stress** that grows with depth, and tectonic history produces **horizontal stresses** that are commonly expressed as ratios of the vertical ($k_H = \sigma_H/\sigma_v$ for the major horizontal direction, $k_h = \sigma_h/\sigma_v$ for the minor). When an excavation is made, the rock that used to carry load is removed and the stress must flow around the opening — concentrating in some places (abutments, pillars) and relaxing in others (backs, walls). The BEM computes this redistribution. Every stress it reports is the **total** stress: in-situ plus the mining-induced change.

2.2 Why BEM (and not FEM/FDM)?

Most stress programs (FLAC3D, RS3, Abaqus) discretise the entire volume of rock into millions of 3D cells. The Boundary Element Method only discretises the **excavation surfaces** — the triangles of your mesh become the model. The infinite rock mass around them is represented exactly by the mathematics of elasticity, so:

- model building is trivial: your existing GEM4D meshes *are* the model;
- the far-field boundary condition is exact — no artificial outer box;
- model sizes are tiny by comparison (thousands to hundreds of thousands of triangles, not millions of cells).

The trade-off is that the method is restricted to **linear elasticity in a homogeneous rock mass** — see the assumptions in §12. For mine-scale stress screening this is a standard, accepted approach.

2.3 Fictitious-force elements

GEM4D uses the **indirect BEM with fictitious-force (FF) triangular elements**. Each triangle of your excavation mesh carries an unknown "fictitious" force density. The solver finds the set of force densities that makes the excavation surfaces **traction-free** — i.e. exactly what a real open void does to the stress field. Once solved, the stress and displacement at *any* point in the rock follows by summing each element's analytic influence. The set of solved force densities is the "solution" that the **Save solution** button stores.

2.4 Two kernels: Kelvin (full-space) and Mindlin (half-space)

The "kernel" is the elasticity solution the elements are built from:

Kernel	Domain	Use when
Kelvin	Infinite rock in all directions	Deep excavations — depth more than a few excavation-spans below surface. The default.
Mindlin	Half-space with a stress-free ground surface at the configured RL	Shallow workings, open-pit interaction, anything where the free surface matters.

Mindlin runs are somewhat slower per element (the free-surface correction is extra work) but scale the same way. If your workings are deep, Kelvin is simpler and slightly more accurate near the excavation walls (§5.5).

2.5 Conventions used by GEM4D

- **Compression is positive** (rock-mechanics convention), and $\sigma_1 \geq \sigma_2 \geq \sigma_3$, so σ_1 is the major (most compressive) principal stress.
- **Coordinates are mine coordinates** in metres (Easting, Northing, RL) — the same frame as everything else in GEM4D.
- **Stress in MPa, displacement in mm** in all tables and CSV files.
- **Stress trend** in the Setup dialog is degrees clockwise from North, matching the usual mine-survey convention.
- Field points **inside** an excavation are physically meaningless (there is no rock there); GEM4D detects them and reports them as `Interior` (§9.4).

3. What you need before running

Requirement	Notes	Mandatory?
Closed ("watertight") triangulated meshes of every excavation to include	Stope shapes, development drives, voids — loaded and **visible** in the scene. Open surfaces (clipped fragments, unclosed CAD shells) cannot form a valid BEM model. GEM4D checks this for you (§6.3).	**Yes**
Rock-mass elastic properties	Young's modulus E (GPa) and Poisson's ratio ν for the rock mass (not intact-core values — use rock-mass-scale estimates).	**Yes**
In-situ stress knowledge	Either a σ_v + k-ratio description at the mining depth, or unit weight + k-ratios for a depth-varying field. From stress measurements or regional databases.	**Yes**
A sensible element count	Each triangle becomes one element. A few thousand to a few tens of thousands is the comfortable range; the solver can handle 250 000+ but runs then take hours (§7.3). Use **Mesh menu** → **Mesh reducer** to decimate over-detailed triangulations first.	Strongly advised

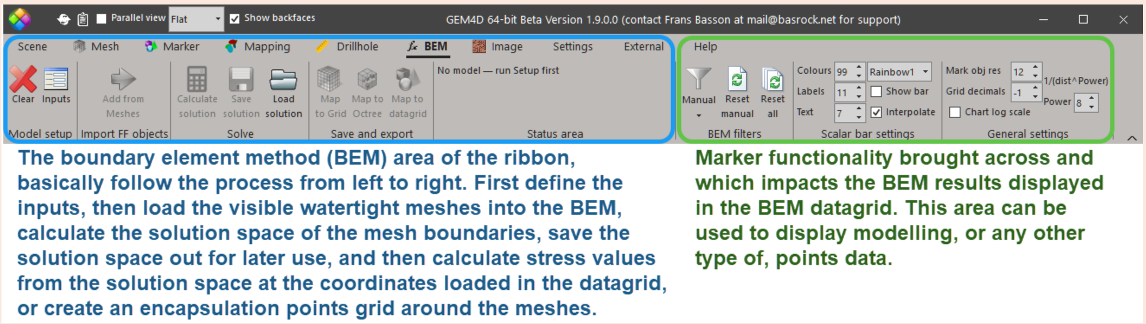

Figure 2: The BEM ribbon tab with its labelled groups - Model setup, Import FF objects, Solve, Save and export, Status area, BEM filters, Scalar bar settings, General settings.

4. The BEM ribbon tab at a glance

The workflow runs left to right across the ribbon:

Group	Button	What it does	Section
Model setup	**Inputs**	Opens the *BEM Analysis — Setup* dialog: material, in-situ stress, solver options.	§5
Model setup	**Clear**	Resets the BEM model, mesh, and results (your Setup values are kept). Also, the way to **cancel** a running solve.	§7.4
Import FF objects	**Add from Meshes**	Builds the BEM model from all currently **visible** scene meshes.	§6
Solve	**Calculate solution**	Assembles and solves the system on a background thread.	§7
Solve	**Save solution / Load solution**	Stores / restores a solved model as a `.bem4d` file — reloading skips the solve entirely.	§8

Group	Button	What it does	Section
Save and export	**Map to Grid**	Evaluates results on a regular 3D grid and saves to CSV.	§9.1
Save and export	**Map to Octree**	Evaluates on an adaptive grid — dense near excavations, coarse far away — and saves to CSV.	§9.2
Save and export	**Map to datagrid**	Evaluates at the points already loaded in the **BEMResult** table and appends result columns in place.	§9.3
Status area	*(read-only)*	Live status: current phase, element count, iteration progress, elapsed time.	§7.2
BEM filters	*(several)*	Row filters for the BEMResult table — by mesh bounds, position relative to meshes, picked box/sphere, rubber-band selection.	§10.4
Scalar bar settings / General settings	*(several)*	Legend colours/labels, LUT choice, log scale, glyph resolution, grid decimals.	§10.5

The display side (point clouds, iso-surfaces, colour mapping) lives in the **BEMResult panel** — a data table and settings panel parallel to the Markers panel — described in §10.

5. Step 1 — Inputs (the Setup dialog)

BEM tab → **Inputs** opens *BEM Analysis — Setup*. Nothing here modifies an existing model until you press **Add from Meshes** again — the dialog just records your choices (§6.4 explains the "stale Setup" warning that protects you if you forget).

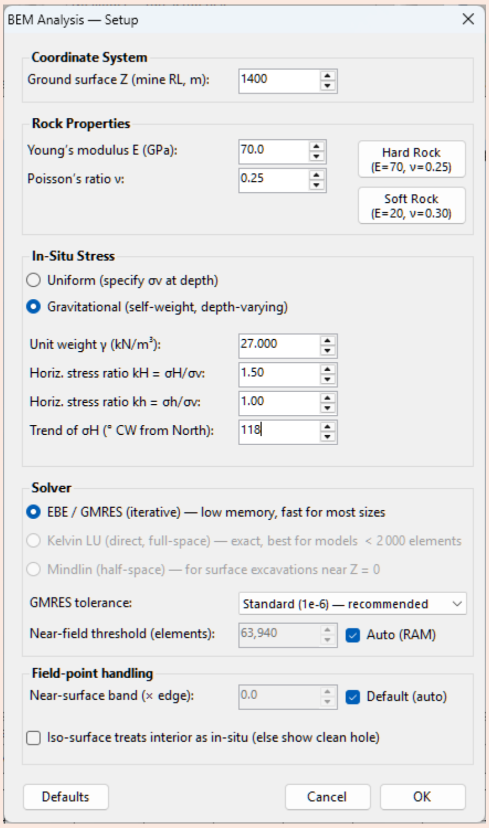

Figure 3: The BEM Analysis Setup dialog form.

5.1 Coordinate System

Field	Meaning	Default
Ground surface Z (mine RL, m)	The RL of the natural ground surface. Used by the Mindlin kernel as the free surface, and by the Gravitational stress option as the depth datum.	0

For deep mines with RL-style grids (e.g. surface at RL 5000), set this to the actual surface RL — depth is measured downward from this value.

5.2 Rock Properties

Field	Meaning	Range	Default
Young's modulus E (GPa)	Rock-mass stiffness.	0.001–1000	70
Poisson's ratio ν	Lateral strain ratio.	0–0.5	0.25

Two preset buttons fill typical values: **Hard Rock** (E = 70, ν = 0.25) and **Soft Rock** (E = 20, ν = 0.30). Note that in a homogeneous elastic model the *stresses* depend only weakly on E (they are driven by geometry and the in-situ field); E mainly scales the *displacements*.

5.3 In-Situ Stress

Choose one of two descriptions:

Uniform (specify σ_v at depth) — one constant stress tensor everywhere:

Field	Meaning	Default
Vertical stress σ_v (MPa)	The vertical stress at your mining horizon.	10
Horiz. stress ratio $k_H = \sigma_H/\sigma_v$	Major horizontal / vertical.	1.5
Horiz. stress ratio $k_h = \sigma_h/\sigma_v$	Minor horizontal / vertical.	1.0
Trend of σ_H (° CW from North)	Azimuth of the major horizontal stress.	0

Use this when your excavations span a limited depth range — it is the simplest and most common choice.

Gravitational (self-weight, depth-varying) — stress grows linearly with depth below the ground surface:

Field	Meaning	Default
Unit weight γ (kN/m³)	Overburden unit weight; σv(depth) = γ × depth.	27
k_H, k_h, Trend	As above, applied at every depth.	1.5 / 1.0 / 0

Use this when the model spans a large vertical range (e.g. an entire mine) or for shallow workings where the near-surface stress gradient matters. **Note:** with this option (or the Mindlin kernel) no excavation may extend above the ground surface Z — GEM4D checks and refuses the mesh if one does (§6.5).

5.4 Solver

Choice	Meaning
EBE / GMRES (iterative) — low memory, fast for most sizes	The default and recommended path. Scales to 250 000+ elements.
Kelvin LU (direct, full-space) — exact, best for models < 2 000 elements	Direct dense solve. Only available up to 6 700 elements — above that GEM4D switches to EBE/GMRES automatically and tells you.
Mindlin (half-space) — for surface excavations near the surface	Selects the half-space kernel (§2.4). Uses LU or EBE automatically by size.

Field	Meaning	Default
GMRES tolerance	Iterative-solver convergence target: 1e-4 (Coarse) / 1e-6 (Standard) / 1e-8 (Fine). Standard is right for production work; Coarse is useful for quick scoping runs on very large models.	1e-6
Near-field threshold (elements)	Above this element count the solver stops caching near-field terms in RAM and recomputes them on the fly (slower per iteration but cannot run out of memory). **Auto (RAM)** sizes it to your machine — e.g. ~62 k on a 32 GB workstation, ~88 k on 64 GB. Leave on Auto unless you know why you're changing it.	Auto

You do not need to manage any of the other solver machinery — GEM4D automatically switches to memory-safe modes at the documented size thresholds and reports what it picked in the status area (§7.2).

5.5 Field-point handling

Field	Meaning	Default
Near-surface band (× edge)	Within this many mean-element-edge-lengths of an excavation wall, evaluated stresses are flagged `NearSurface` and, for iso-surface rendering only, smoothed toward in-situ. With the Kelvin kernel the integrator is exact right up to the wall, so the auto band is **0** (no flagging); with Mindlin it is **2.0**.	Default (auto)
Iso-surface treats interior as in-situ (else show clean hole)	What iso-surfaces do *inside* excavations: unchecked (default) the interior is masked out and iso-surfaces show a clean hole at the void; checked, the interior is back-filled with the in-situ tensor so iso-surfaces close smoothly across it. Affects rendering only — tables and CSV always mark interior points explicitly.	Unchecked

Defaults restores every field; **OK** stores the setup; **Cancel** discards changes.

6. Step 2 — Add from Meshes

BEM tab → Add from Meshes builds the BEM model from **all currently visible mesh objects** — the same visibility scope as every other GEM4D mesh action. Hide anything you don't want in the model first (use the object list panel), then press the button.

6.1 What it does to your triangles

For each visible mesh, GEM4D automatically:

1. **Triangulates** any quads/strips and drops stray line/point geometry;
2. **Merges near-duplicate vertices** (common in DXF round-trips) to restore shared edges;
3. **Orients all triangle normals consistently outward** — you do *not* need to fix windings yourself; the inward-facing convention the solver needs is applied internally;
4. **Skips degenerate (zero-area) sliver triangles** and tells you how many were dropped;
5. Adds every surviving triangle as one FF element, in mine coordinates.

The scene shows a light overlay of the imported BEM mesh so you can confirm what went in.

6.2 Replacing an existing model

If a model already exists, you are asked *"BEM already contains N elements. Replace with the currently visible meshes?"* — Add from Meshes always rebuilds from scratch (it never appends silently), and the rebuild always uses the **current** Setup values, so this is also the way to apply a Setup change to the model.

6.3 The watertightness check

After import, GEM4D checks whether the combined surface is closed and reports one of three outcomes in the summary dialog:

Outcome	Meaning	What to do
No watertight note	The mesh is fully closed.	Nothing — ideal.
"minor non-watertight defects (informational)"	A handful of open/non-manifold edges at floating-point-noise scale (typically leftover slivers). Solver accuracy is unaffected; classification can only be wrong within microns of the defects.	Safe to continue.
"WARNING: Mesh is not watertight"	Real geometric holes or non-manifold junctions. The solve will still run, but points near the defects may be misclassified as inside/outside the excavation, affecting iso-surfaces and CSVs.	Repair the source mesh — **Create 1 → mesh repair / RemeshBEM** tools, or fix it in your CAD package — and re-add.

6.4 The "stale Setup" guard

The model is built with the Setup values current *at Add-from-Meshes time*. If you later change Setup (different kernel, stress field, surface elevation, …) and press Solve or a Map button, GEM4D warns that the model is stale and tells you to re-run Add from Meshes. Solve offers a Yes/No override (for when you only changed something cosmetic); the Map buttons require the rebuild.

6.5 Geometry prechecks

- **Clipping mode is exited automatically.** Clipped fragments are open surfaces and would fail watertightness; BEM always operates on the full closed meshes.
- **Elevation check (Mindlin or Gravitational only).** Every visible mesh must lie entirely at or below the configured ground surface Z. Offending meshes are listed by name with their max Z so you can move, hide, or trim them — or raise the surface elevation.

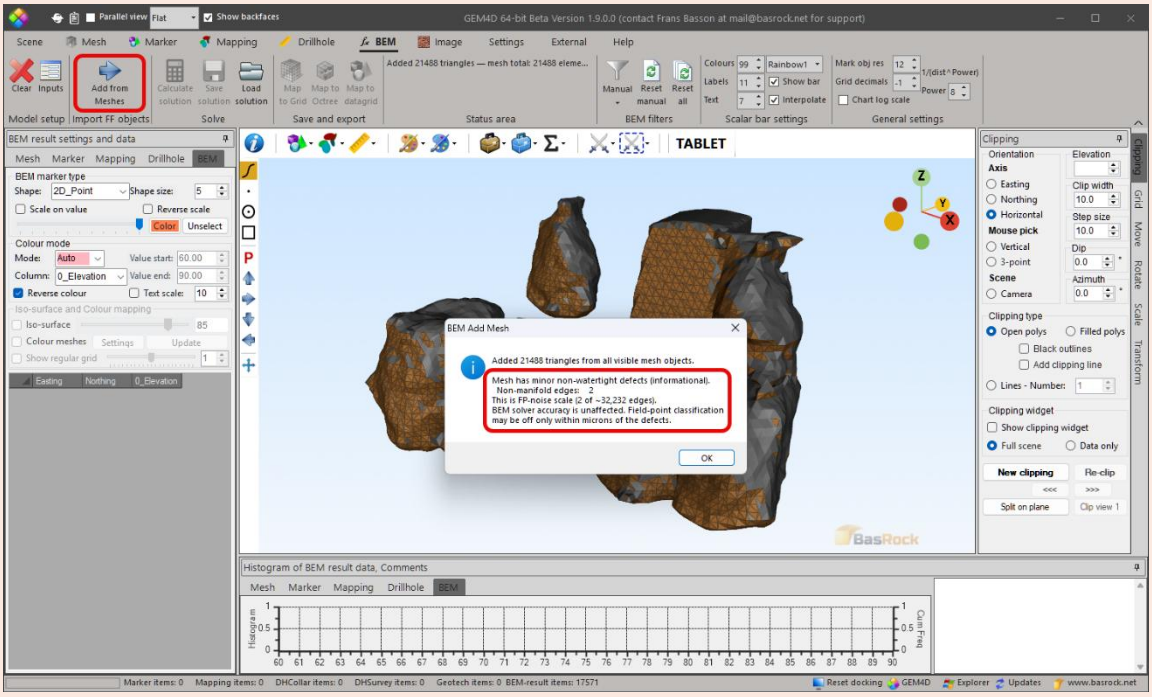

Figure 4: When the visible meshes are loaded into the BEM engine, the "Add from Meshes" summary dialog shows with a watertight warning if there are openings in the mesh. The BEM shapes are shown in transparent orange to indicate when a BEM model is loaded in the scene.

7. Step 3 — Calculate solution

BEM tab → **Calculate solution** assembles the influence system and solves it. The solve runs on a **background thread** — the rest of GEM4D stays responsive, and the Status area animates with elapsed time.

7.1 Which solver actually runs

GEM4D picks the safe path automatically, based on element count N:

Elements	Path	Notes
≤ 6 700 (and LU selected)	Dense LU (direct)	Exact; fastest below ~2 000 elements.
> 6 700	EBE / GMRES (iterative)	Forced automatically — a dialog explains the switch if you had asked for LU (the dense matrix would exceed memory and array limits).
≥ near-field threshold (Auto: RAM-dependent, ~62 k at 32 GB)	+ matrix-free near-field	Slower per iteration, immune to RAM exhaustion.
≥ 250 000	+ matrix-free far-field	The status label appends "(MF far-field)" so you know why each iteration takes longer. Runs of this size complete in hours, not minutes.

7.2 Reading the status area

During a solve you will see, in order:

- `BEM · <phase>…` — the major phases (build right-hand side, octree, preconditioner, H-matrix build, GMRES);
- `BEM · Building H-matrix: x / y blocks (%)` — the assembly progress;
- `BEM · GMRES iter n ‖r‖/‖b‖ = …` — the iterative solver converging; the residual should fall steadily toward your GMRES tolerance;
- `Solved — N el · t ms · k iter` on success.

7.3 How long will it take?

Rough guidance on a modern workstation: hundreds of elements solve in seconds; ~10 000 in tens of seconds to minutes; ~100 000 in tens of minutes; ~300 000 in 1–2 hours. Field-point mapping afterwards (§9) is separate and depends on how many points you evaluate. If a scoping answer is enough, decimate the meshes (Mesh reducer) and/or use the Coarse GMRES tolerance.

7.4 Cancelling

Press **Clear** to cancel a running solve (it also resets the model, so you will need Add from Meshes again). The Map buttons warn you rather than letting you accidentally interrupt a solve in progress.

8. Saving and reloading solutions (`.bem4d`)

The expensive part of a BEM run is the solve. Once `Solved` appears:

- **Save solution** writes a `.bem4d` file containing the element mesh (in mine coordinates), the solved per-element force densities, and all your Setup inputs.
- **Load solution** restores all of it and rebuilds the post-processor **without re-solving** — you are immediately ready to Map results. Loading into an empty scene also frames the camera on the BEM mesh overlay; loading over existing data leaves your view alone.

Because the mesh is stored in mine coordinates, a `.bem4d` is portable across sessions and machines. Typical use: solve the big model once (or overnight), save, then come back any number of times to extract grids, octrees, and datagrid mappings from the saved solution.

9. Step 4 — Getting results out (the three Map buttons)

All three buttons require a solved (or loaded) model. Each ask whether to include the **full stress tensor** components (Sxx … Sxz) in addition to the always-included principal stresses and displacement. Evaluations beyond 1 000 000 points ask for confirmation first — they can take several minutes (progress and cancel via the status area / Clear).

9.1 Map to Grid

Evaluates on a **regular 3D grid** and saves straight to CSV (default name `BEM_FieldPoints.csv`).

The standard Grid3D dialog opens **pre-filled with the model extents plus 15 % padding** and a default cell size of roughly 8 % of the model's largest dimension — adjust the min/max/spacing per axis to suit. Keep an eye on the total point count: spacing halves → point count ×8.

CSV columns: `X_m, Y_m, Z_m, S1_MPa, S2_MPa, S3_MPa, U_mm` (+ `Sxx_MPa … Sxz_MPa` if requested) `, Status, DistToSurface_m` (§9.4).

9.2 Map to Octree

Same output as Map to Grid (default name `BEM_OctreePoints.csv`), but the points come from an **adaptive octree**: dense close to the excavation surfaces, coarse far away. This concentrates the evaluation budget where the stress gradients are and is usually the best choice for iso-surface source data.

One input: **max refinement depth** — 3 = coarse, 5 = balanced (default), 7 = fine. Each extra level up to doubles the resolution near the excavations.

9.3 Map to datagrid

Evaluates at the **points already loaded in the BEMResult table** (§10.1) — your own grid, Minode points, instrument locations, whatever you load — and **appends the result columns to the table in place**, where they are immediately available for colour-mapping and filtering. Only **visible** (unfiltered) rows are evaluated.

Columns appended: `BEM_S1_MPa, BEM_S2_MPa, BEM_S3_MPa, BEM_U_mm` (+ tensor columns if requested) and `BEM_Status`. Points inside an excavation get blank cells.

Optional Kirsch tangential stress (offered only when you include the tensor): adds `BEM_Tang_MPa` = $3\cdot\sigma_1(ip) - \sigma_3(ip)$ projected in each point's wall plane — an estimate of the in-plane (ip) tangential boundary stress at the excavation skin. **Only say Yes if the loaded points are development Minodes** whose Dip/DipDir columns describe the local wall orientation; for ordinary point data the result is meaningless.

9.4 The `Status` column

Every evaluated point is classified:

Status	Meaning	Values reported
`Far`	In the elastic rock, away from any wall.	Evaluated stress/displacement, as-is.
`NearSurface`	Within the near-surface band of a wall (Mindlin only, by default — §5.5). Values are kept in tables/CSV; only iso-surface *rendering* smooths them.	Evaluated values, flagged.
`Interior`	Inside an excavation (or above the free surface in half-space mode). No rock exists here — the numbers would be meaningless.	NaN / blank cells.

`DistToSurface_m` gives the signed distance to the nearest excavation wall (negative = inside), which is handy for filtering and QA.

10. Step 5 — Displaying results (the BEMResult panel)

The **BEMResult panel** is a point-data table and display panel that works exactly like the familiar Markers panel but is owned by the BEM workflow so your survey/marker data is never touched.

10.1 Loading data into the table

Right-click the BEMResult grid → **Load data from CSV-file** (or paste from clipboard). The first three columns must be X, Y, Z in mine coordinates — which is exactly what the Map to Grid / Map to Octree CSVs contain, so the normal loop is:

1. **Map to Octree** → save CSV;
2. right-click the BEMResult grid → **Load data from CSV-file** → pick that CSV;

3. colour and contour (below).

Alternatively load any point CSV first and use **Map to datagrid** to append results in place (§9.3).

10.2 Points: shape, size, colour

The *BEM marker type* group sets the glyph (**2D_Point**, cone, sphere, cube, vector), its size, opacity and base colour; *Colour mode* selects which column drives the colour map (e.g. `S1_MPa`), the value range, and reverse/scale options. Very large tables automatically fall back to 2D points — volumetric glyphs are capped for performance.

10.3 Iso-surfaces

The *Iso-surface and Colour mapping* group contours the loaded point cloud in 3D:

- **Iso-surface** + the value slider/box — draws the 3D contour shell at your chosen value of the colour column (e.g. the σ1 = 60 MPa surface);
- **Colour meshes** — drapes the colour map onto the excavation meshes themselves;
- **Show regular grid** — overlays the source grid;
- **Update** rebuilds after edits; **Settings** opens the advanced options.

Whether iso-surfaces show a clean hole at the excavations or close smoothly across them is the Setup back-fill option (§5.5). Octree CSVs make the smoothest iso-surfaces for a given point budget.

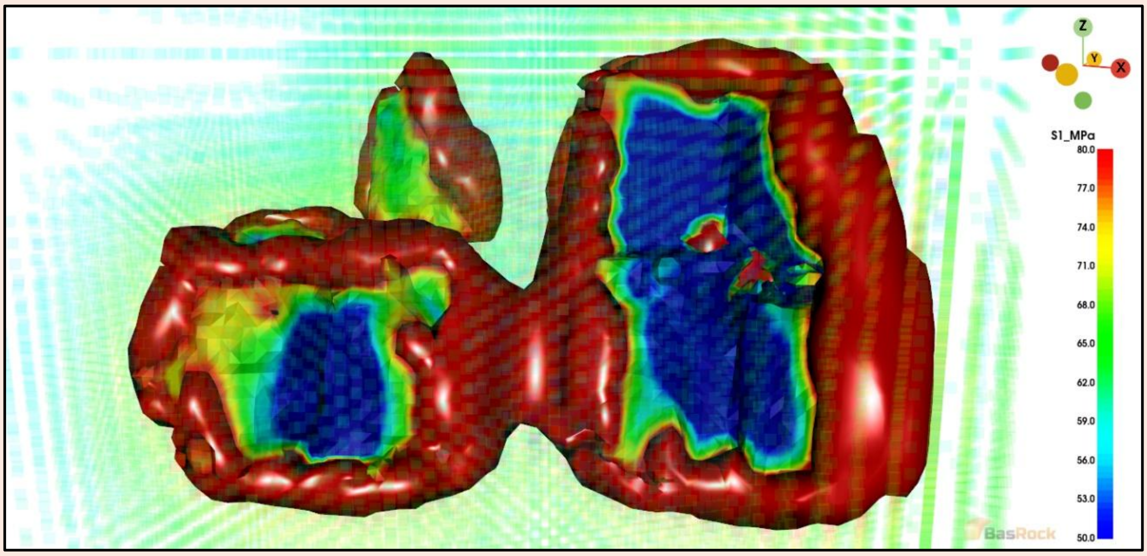

Figure 5: BEM results an octree CSV loaded and shown as large transparent points, the mesh coloured on “S1_MPa” and the iso-surface enabled, with the scalar bar on the left.

10.4 BEM filters (ribbon group)

Row filters for the BEMResult table, mirroring the Marker filters: **Mesh bounds** (keep points within visible-mesh bounding boxes), **Relative to meshes** (position relative to mesh surfaces), **Pick box / Pick sphere** (interactive region picks), **Remove inside/outside selection** (rubber-band), and **Reset manual / Reset all**. Filtered-out rows are excluded from the display *and* from Map to datagrid runs.

10.5 Scalar bar and general settings (ribbon groups)

Legend colour count, label count, text size, LUT choice (Rainbow1/Rainbow2/RedBlue/CoralTeal/Custom), bar visibility and interpolation; plus glyph resolution, grid decimal places, and **Chart log scale** for the histogram/scalar bar. These behave identically to their Marker-tab counterparts.

11. Suggested workflow (quick reference)

1. **Inputs** — set E, ν, in-situ stress, kernel, surface RL. *(§5)*
2. Make exactly the meshes you want modelled **visible**; decimate over-detailed ones first. *(§3, §6)*
3. **Add from Meshes** — read the watertightness verdict. *(§6.3)*
4. **Calculate solution** — watch the status area; save a `.bem4d` when done. *(§7–8)*
5. **Map to Octree** (depth 5) → CSV → load into the **BEMResult** grid. *(§9.2, §10.1)*
6. Colour by `S1_MPa`, turn on an iso-surface, set the scalar bar. *(§10)*
7. For specific points of interest (Minodes, instruments, planned development), load them into the BEMResult grid and **Map to datagrid**. *(§9.3)*

12. Assumptions and limitations

Be aware of what the current implementation does **not** model:

- **Linear elastic, homogeneous, isotropic rock** — one E and one ν everywhere. No plasticity, no joints/faults, no soft/stiff zones, no backfill stiffness.
- **One excavation state** — the model is "everything mined" as a single snapshot. There is no mining-step sequencing yet (each stage must be run as its own model with its own Add from Meshes).
- **Stress and elastic displacement only** — no strength factors or factor-of-safety output yet; compare σ_1/σ_3 against your strength criterion manually (calculated columns on the BEMResult grid are one convenient way).
- **Dry, static analysis** — no pore pressure, no dynamic/seismic loading.
- **Constant-stress elements** — values within roughly one element-edge of a wall are less accurate than in the body of the rock (this is what the `NearSurface` machinery manages). For wall-skin stresses on development, the Kirsch tangential option (§9.3) is the supported approach.
- **In-situ stress is vertical + two horizontals** — principal axes plunging at an angle cannot yet be specified.

The standard caveat applies: an elastic model tells you where stress *would* concentrate if the rock stayed elastic. Interpreting over-stress, yield, and support needs is the engineer's job.

13. Messages and troubleshooting

Message / symptom	Cause and fix
Status shows *"No model — run Setup first"* / buttons greyed out	The workflow is sequential: Inputs → Add from Meshes → Calculate solution → Map. Each button enables when its prerequisites exist.
"…requires all excavations to sit at or below Z = …" (Add from Meshes)	Mindlin kernel or Gravitational stress is selected and a visible mesh pokes above the ground surface RL. Move/hide/trim the listed meshes, or raise the surface Z in Setup.
"BEM already contains N elements. Replace…?"	Normal — Add from Meshes always rebuilds rather than appending. Yes = rebuild from the currently visible meshes with the current Setup.
"No triangles found in visible mesh objects."	Nothing visible contained polygon geometry (e.g. only points/lines visible, or everything hidden). Make the excavation meshes visible.

Message / symptom	Cause and fix
"Skipped N degenerate (zero-area) triangles"	Informational — sliver triangles in the source mesh were dropped. Harmless unless the count is a large fraction of the mesh, in which case repair the source.
"WARNING: Mesh is not watertight."	Real holes/non-manifold edges. Repair (RemeshBEM / mesh repair / CAD fix) and re-add, or accept possible point misclassification near the defects.
"Add at least one excavation before solving."	The model is empty — run Add from Meshes.
Stale-Setup warning at Solve / Map	Setup changed after the model was built. Re-run Add from Meshes so the model picks up the new values (Solve allows a deliberate override).
"…Switching automatically to the EBE / GMRES iterative solver…"	You selected LU but the model exceeds 6 700 elements. Informational — the run continues on the iterative path.
"This will evaluate N field points, which may take several minutes."	Your grid/octree exceeds 1 000 000 points. Coarsen the spacing or reduce the depth unless you really need the density.
"Load BEM datagrid data first." / "No visible BEM datagrid rows."	Map to datagrid needs points in the BEMResult table (and at least one row passing the filters). Load a CSV (§10.1) or relax the filters.
"BEM datagrid row count changed during evaluation."	The table was edited while the evaluation ran. Re-run Map to datagrid.
"A BEM operation is currently running…"	Solve/Map in progress — wait for it, or cancel with Clear.
Solve seems stuck on *"GMRES iter…"* with a slowly falling residual	Normal for large models — watch ‖r‖/‖b‖ trend toward the tolerance. If progress stalls for very long, consider the Coarse tolerance for scoping, or check the mesh for pathological slivers.
Iso-surface has a ragged hole at the excavation	That is the interior mask (default). If you prefer closed surfaces, tick *"Iso-surface treats interior as in-situ"* in Setup and re-map.
Results look rotated ~90° from expectation	Check the **Trend of σ_H** value — it is degrees clockwise from North for the *major horizontal* stress, and k_H vs k_h may be swapped relative to your data source.

14. References

- Crouch, S.L. & Starfield, A.M. (1983). *Boundary Element Methods in Solid Mechanics.* Allen & Unwin. (The fictitious-force / displacement-discontinuity BEM formulation.)
- Beer, G., Smith, I. & Duenser, C. (2008). *The Boundary Element Method with Programming.* Springer. (Modern BEM implementation, iterative solvers.)
- Brady, B.H.G. & Hoek, E. & Brown, E.T. — *Rock Mechanics for Underground Mining* (Brady & Brown, 3rd ed., 2004) and *Underground Excavations in Rock* (Hoek & Brown, 1980). (In-situ stress, induced stress around openings, k-ratios.)
- Mindlin, R.D. (1936). Force at a point in the interior of a semi-infinite solid. *Physics*, 7, 195–202. (The half-space kernel.)
- Kirsch, G. (1898). Die Theorie der Elastizität und die Bedürfnisse der Festigkeitslehre. (The classical tangential boundary-stress relation used by the Map-to-datagrid Kirsch option.)

Revision history

Date	GEM4D	Change
2026-06-12	1.9.0	First issue — covers the FF (fictitious-force) implementation: Kelvin/Mindlin kernels, uniform/gravitational in-situ stress, auto solver-path selection (LU / EBE-GMRES / matrix-free), `.bem4d` save-load, Map to Grid/Octree/datagrid, field-point classification, BEMResult display panel.