CUSTOMER SUPPORT NOTE

Geotechnical Capabilities

Note Number:	**CSN/LUSAS/1010**

This support note is issued as a guideline only.

LUSAS
Forge House, 66 High Street, Kingston upon Thames, Surrey, KT1 1HN, UK
Tel: +44 (0)20 8541 1999 Fax: +44 (0)20 8549 9399
Email: info@lusas.com www.lusas.com

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1. Introduction

LUSAS offers a variety of facilities and options for modelling complex geotechnical problems and soil–structure interaction. This support note provides an overview of the geotechnical capabilities available in LUSAS. LUSAS supports both 2D and 3D modelling, allowing soil to be represented explicitly using 2D or 3D elements and geotechnical material models. These models can be employed in a wide range of applications, including settlement, slope stability, and foundation analyses, as well as for modelling tunnels, embankments, and deep excavations. In addition, LUSAS provides an extensive range of joints, both linear and nonlinear, which can be employed to represent soil using springs.

Readers are also encouraged to consult the LUSAS Online Help system and the available geotechnical worked examples for further information.

2. Material models

Table 1 summarises the geotechnical models available in LUSAS, the types of soils for which they are suitable, and their practical applications. It is important to emphasise that selecting an appropriate material model requires sound engineering judgement. The suitability of a model depends on multiple factors, including specific soil properties, loading conditions, drainage characteristics, and project requirements, as soil behaviour is inherently complex and site-specific. The information presented in the table is intended for **general guidance only**.

LUSAS Geotechnical model	Suitable for soil type(s)	Practical applications	Notes
Tresca	Undrained clay analysis	Not commonly used	Simple model for undrained shear strength. The variation of shear strength with depth can be modelled using the variation facility
Duncan-Chang	Sands, gravels, clays	Settlement analysis, earth dams, embankments, foundations	Nonlinear incremental elastic model used for stress-dependent soil behaviour. It is not ideal for failure analysis or strength prediction but provides a rapid solution for problems in which stresses are increasing rather than decreasing (unloading), such as during embankment construction
Drucker-Prager	Sands, clays, general soils	Foundation analysis, underground structures	Smooth pressure-dependent, yield surface. Used as an alternative to the Mohr-Coulomb model
Mohr–Coulomb	Sands, gravels, stiff clays, general soils	Simple slope stability, retaining walls, bearing capacity of shallow foundations	Simplified model, elastic–perfectly plastic model
Modified Mohr-Coulomb	Sands, gravels, stiff clays, general soils	Simple slope stability, retaining walls, bearing capacity of shallow foundations	Enhanced version of the Mohr-Coulomb model with tension and compression cut-offs
Hardening Soil Modified	Sands, silts, stiff and soft clays	Settlement analysis of foundations, tunnels, deep excavations	Includes both shear hardening and compression hardening, making it more realistic for deep foundation analysis

LUSAS Geotechnical model	Suitable for soil type(s)	Practical applications	Notes
Barcelona Basic (BBM)	Unsaturated soils (clayey and silty soils with suction effects)	Collapsible/expansive soils, embankments on unsaturated ground	This model is particularly useful for unsaturated soil mechanics where suction influences strength and stiffness
Modified Cam-Clay	Normally consolidated to lightly over consolidated clays	Consolidation and settlement of clay deposits	Based on critical state soil mechanics
Hoek–Brown (rock model)	Rock masses	Tunnel stability, rock slopes, caverns, underground openings	Suited for intact and fractured rock masses

Table 1 – LUSAS material models (Geotechnics).

3. Facilities useful in geotechnical problems

This section provides an overview of a range of facilities that can assist in modelling geotechnical problems. For more detailed information, go to Help > Help Topics > Contents tab > Overview of LUSAS Geotechnical Facilities.

3.1 Solution process

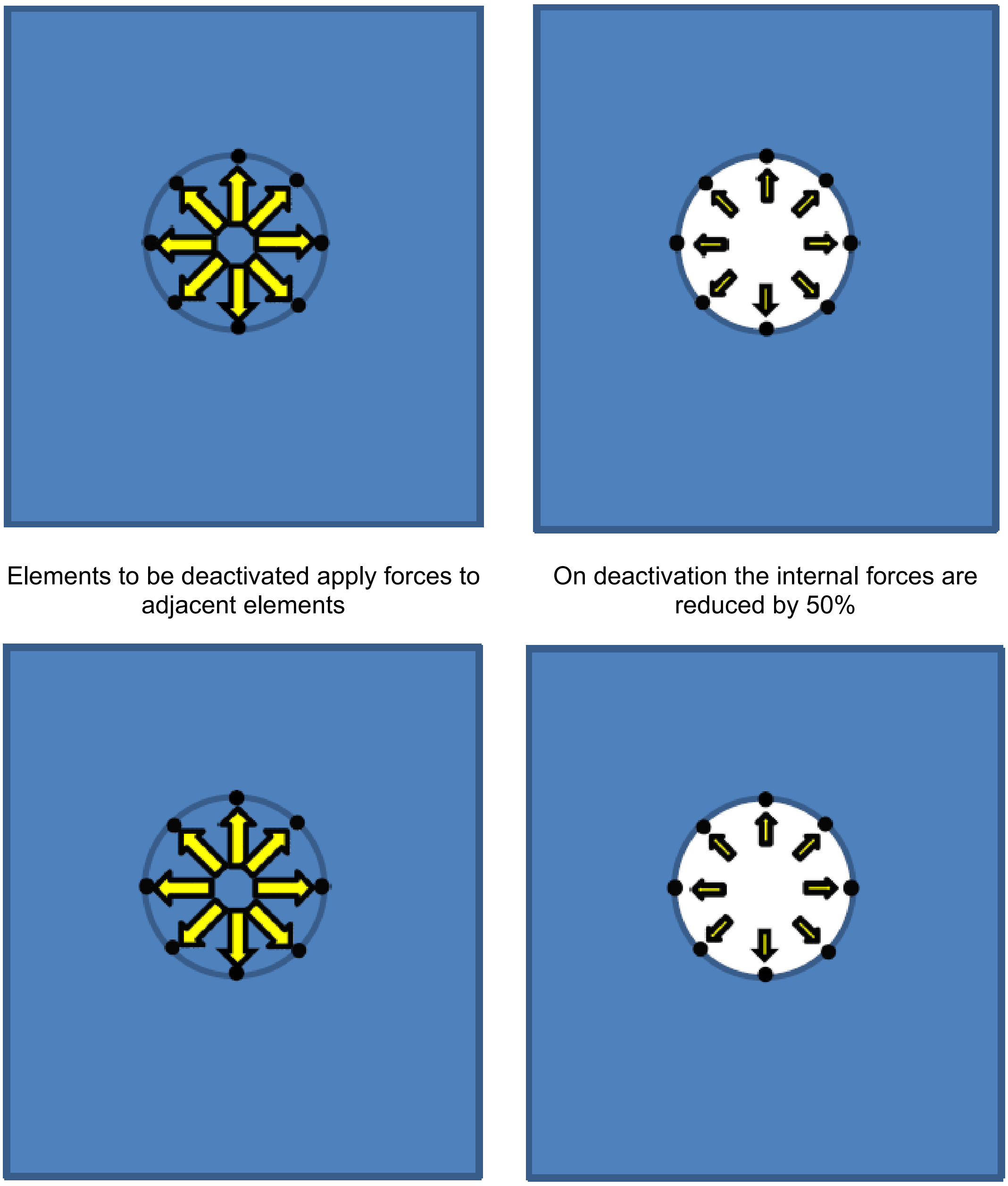
Geotechnical problems are handled in the nonlinear solution flow of Modeller. A problem is divided into a series of natural stages, such as excavating X metres of soil or lowering the water level by an amount Y. A stage can consist of a single action, such as applying a load of X in one go (*Nonlinear and Transient* dialog – *Manual incrementation* option), or it may be broken down into a series of steps, applying a load of X in multiple increments (*Nonlinear and Transient* dialog – *Automatic incrementation* option). Applying the load gradually helps convergence and allows the rate of loading to be increased or decreased depending on progress measured by the rate of convergence.

Two possibilities exist for the variation of load. The first is automatic loading, which is independent of time and uses a scaling parameter λ that runs from a start to a finish value over the stage, with all loads defined in the stage scaled by λ. At the end of the stage, a further “lock-in” stage is required to lock-in the loads to-date before starting the next stage with new loads to be scaled by λ. The second approach uses time to describe the variation of load in the form of a load curve (Analyses > Load Curve), explicitly defining the load at a given time over the full duration of the stage.

3.2 Activation and deactivation of elements

Elements can be activated or deactivated (Attributes > Activate and Deactivate) during the analysis to simulate processes such as embankment construction or soil excavation. By default, all elements are active at the start of the analysis, so any elements intended to appear later must first be deactivated. Deactivated elements remain in the analysis but have significantly reduced stiffness and do not carry any load.

Active elements are normally stressed, and these stresses are transferred to adjacent elements via internal nodal forces at shared nodes. Upon deactivation, the internal forces can be removed either in a single increment or gradually over the stage, which can aid convergence when the internal forces are large. The internal forces can be reduced by a given proportion initially, with a further reduction applied later. This approach is particularly useful in tunnel lining construction, where the surrounding soil may not have fully relaxed following the excavation and before the lining is installed (Figure 1).



Elements to be deactivated apply forces to adjacent elements

On deactivation the internal forces are reduced by 50%

Install tunnel lining

Remove remaining internal forces

Figure 1 – Deactivation of soil during the installation of a tunnel lining.

3.3 Displacement reset

A displacement reset (Attributes > Reset Deformation) is used to restore some or all of the model to its original position. It can be applied at any point in the analysis but is strictly valid only for models with linear geometry. After establishing the initial ground conditions, a displacement reset can be used to restore the starting geometry (Figure 2). During the construction of embankments, it can also be employed to reset the level of a new layer after it has been initialised and before the next layer is placed on top (Figure 2).

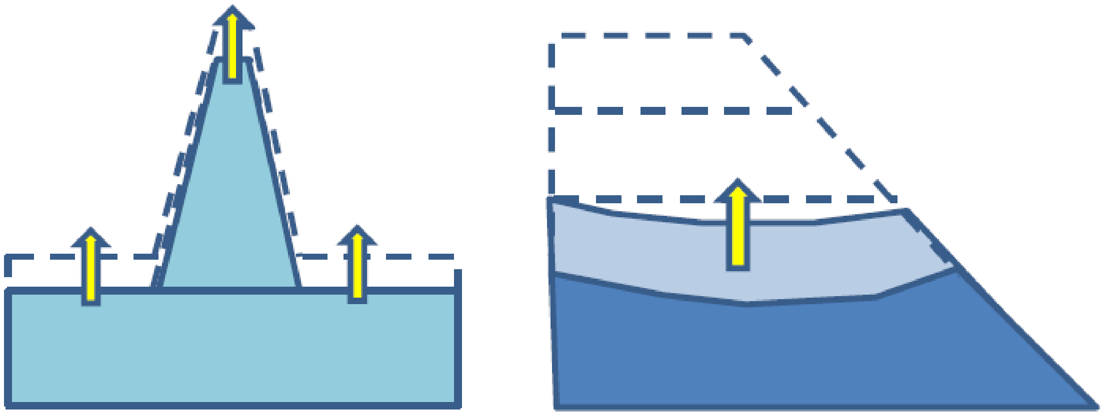


Figure 2 – Displacements resets can be applied to all or part of the model.

3.4 Spatial variations

Arbitrary spatial variations in material properties, such as Young's modulus, can be defined using the *Profile Variation* facility (Utilities > Variation > Profile Variation). The profile can be discontinuous at the boundaries between layers (Figure 3). Individual profiles can be defined at multiple locations within the domain, with material properties interpolated between them. A common application of profiles is to describe the variation of the over-consolidation ratio (OCR) with depth below the ground surface.

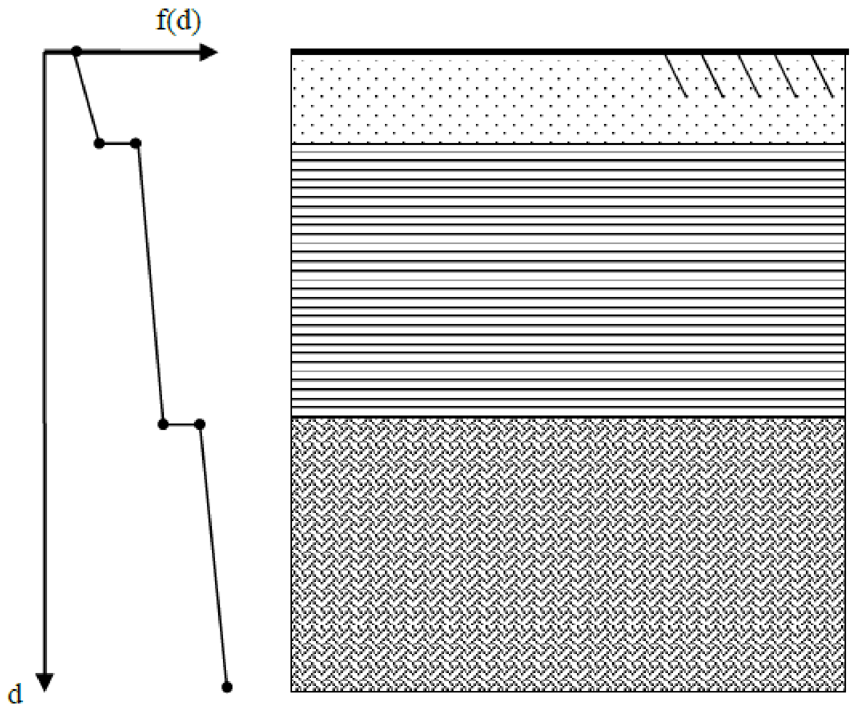


Figure 3 – Variation through depth – the profile can be discontinuous at the boundary between layers.

3.5 Modelling of partially saturated soil

Above the phreatic surface, the soil is partially saturated. Within the capillary zone, capillary forces increase the cohesion between soil particles. Above this lies the two-phase zone, and beyond that, the dry zone. As the distance above the phreatic surface increases, the suction effect of the capillary forces gradually diminishes. This behaviour is represented using Soil Water Characteristic Curves (SWCCs). LUSAS employs a two-phase model that relates the porewater pressure above the phreatic surface to both effective saturation and relative hydraulic conductivity.

3.6 Phreatic surfaces

Free water levels are modelled using one or more phreatic surface elements. A phreatic surface element defines the position of the free water surface, with all points below it assumed to be under hydrostatic pressure (Figure 4). The water level can be raised or lowered by applying a prescribed displacement to the phreatic surface element, thereby modifying the hydrostatic pressure distribution. The weight of the fluid can be adjusted using automatic loading or load curves, which alters the applied pressure without changing the hydrostatic pressure distribution.

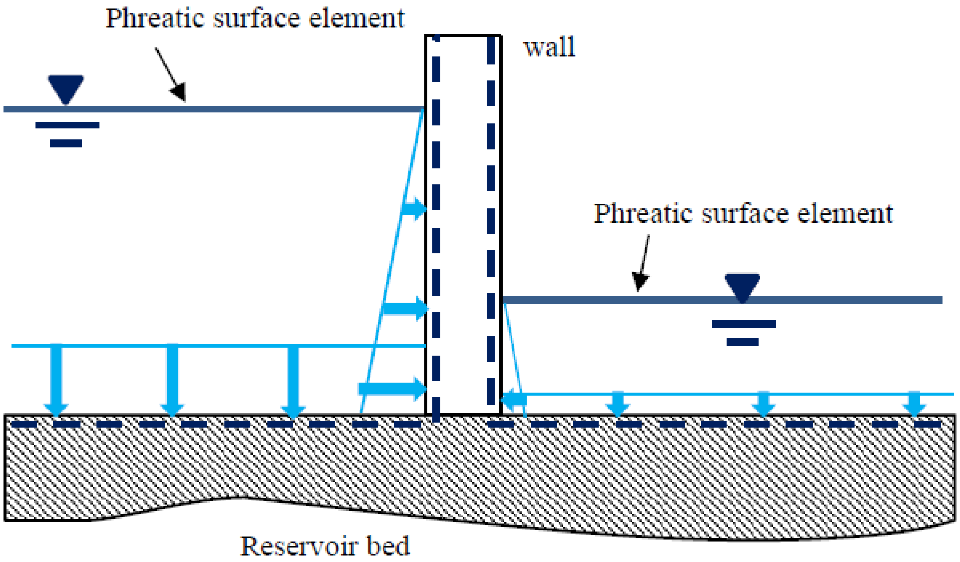


Figure 4 – Use of phreatic surfaces.

3.7 Arbitrary groundwater distribution

A groundwater distribution can be defined using the *Profile Variation* facility (Utilities > Variation > Profile Variation). Individual profiles can be defined through the depth, and the porewater pressures between these profiles are linearly interpolated (Figure 5). The porewater pressures defined in this way remain constant during the analysis; however, excess porewater pressures can develop under undrained loading. On consolidation, the excess porewater pressures are drained and the underlying groundwater distribution recovered.

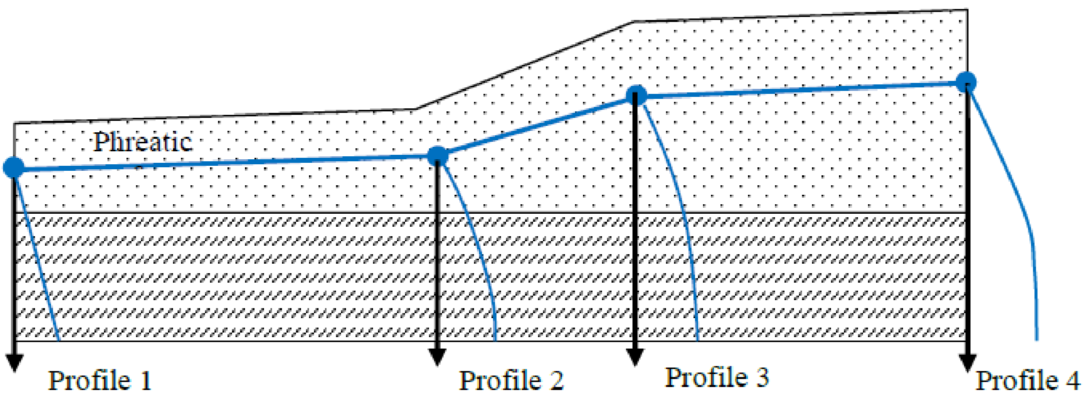


Figure 5 – Profiles defining known groundwater variation.

3.8 Boundary conditions

Several types of fluid flow boundary conditions (Attributes > Support) can be assigned to individual nodes (Figure 6).

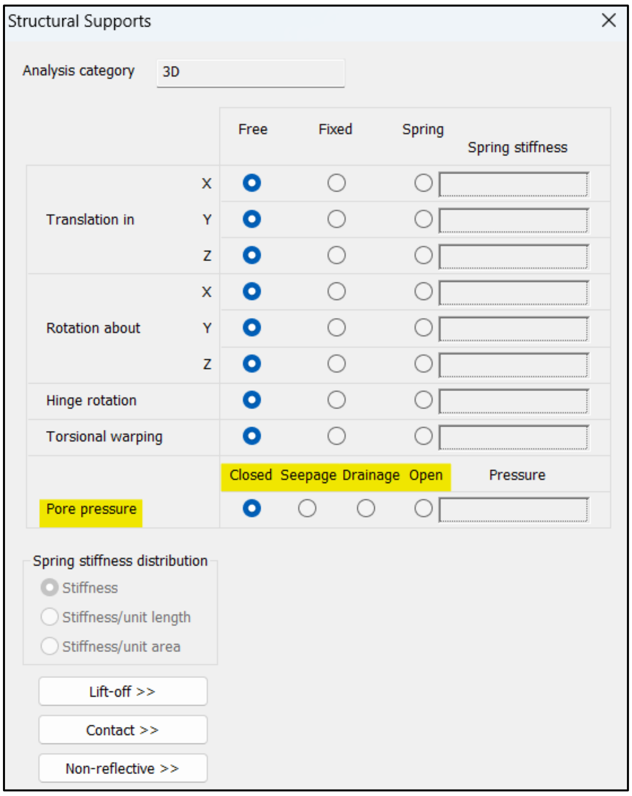


Figure 6 – Structural Supports dialog: Fluid flow boundary conditions.

Open

Porewater can flow into and out of the soil at the node. The porewater pressure is fixed.

Closed

At a closed node, porewater cannot flow into or out of the soil. The porewater pressure at the node is free to rise or fall. If a previously closed node is opened, the required pressure after opening should be set using a total prescribed displacement.

Seepage

Seepage boundary conditions are applied along a ground surface intersected by the phreatic surface. Nodes above the phreatic surface are closed, while nodes below it are open, with the porewater pressure set to zero.

Drainage

Consolidation boundary conditions are used to restore the steady state porewater pressure at the boundary immediately before undrained loading. This approach provides an alternative to reapplying the porewater pressure boundary conditions and is particularly useful for partially saturated soils.

Viscous/non-reflecting boundaries

In an analysis, the model domain represents a finite region of essentially unbounded rock and soil. For a static analysis, the model should be large enough that the influence of the boundaries is negligible. In dynamic analyses, waves propagate through the soil and are reflected back into the domain at the boundaries. In practice, it is often impractical to make the model large enough for the effects of reflected waves to be negligible. Viscous boundaries allow waves to exit the domain, minimising reflections. During the initialisation stage of the geotechnical model, the average bulk and shear moduli are determined at the boundaries and used to evaluate the damping properties of the viscous supports. Additional relaxation coefficients can be applied if necessary.

3.9 Interface elements

Interface elements (Attributes > Mesh > Surface > Element type > Interface elements) are typically placed between two dissimilar materials, such as soil and concrete. They define a discontinuity in the mesh, allowing the adjacent elements to slide relative to each other. A Mohr-Coulomb friction law is used to describe this behaviour. The stiffness of pressure-dependent soils varies with depth, and consequently, interface stiffnesses vary as well. These values can optionally be updated at the end of each step or even at each iteration to account for changes due to loading or excavation. Interface elements can also serve as a path for, or a barrier to, the flow of water.

3.10 Phi-c stability analysis

The phi-c stability analysis can be performed using either the Mohr-Coulomb or Hoek-Brown material models. During the analysis, the soil's shear resistance is gradually reduced until failure occurs. As the soil approaches failure, progressively smaller steps are required to accurately determine the critical condition.

Phi-c reduction attributes are defined using the Attributes > Phi-c Reduction menu item. Once the model is defined, a *Phi-c reduction* attribute can be assigned to all or some of the relevant features for a specified analysis or analysis branch. This allows the stability of a particular slope, for example, to be evaluated without affecting other parts of the model (Figure 7). The assignment is made to a specific loadcase or analysis stage.

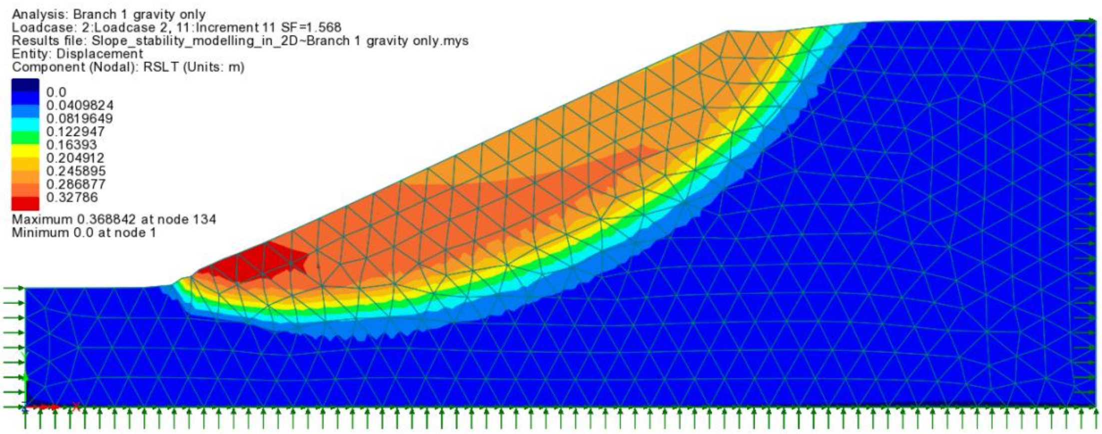


Figure 7 – Slope stability analysis.

4. Modelling soil using springs

When considered appropriate, engineers may model soil using springs. LUSAS supports this approach by offering a wide range of joint materials suitable for such applications. These materials can be accessed through Attributes > Material > Joint. The *Joint Material Attribute* dialog is shown in Figure 8.

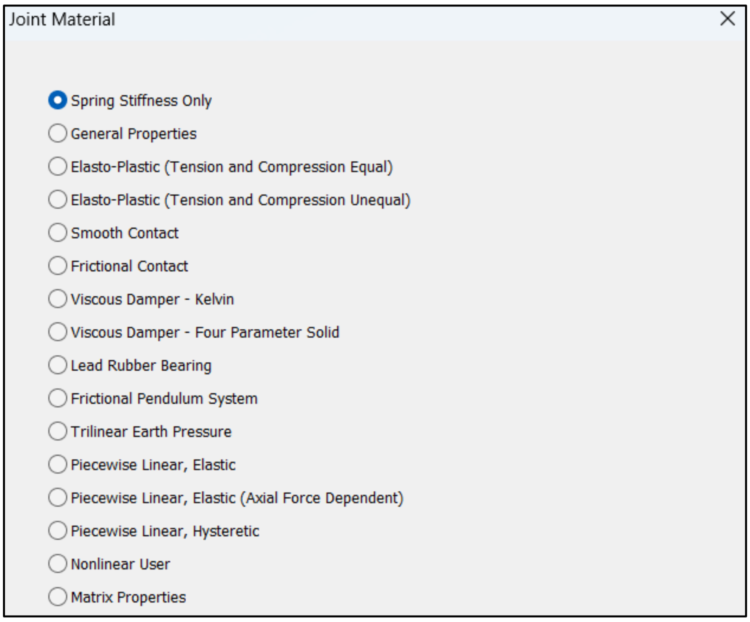


Figure 8 – Joint Material Attribute dialog.

The joint material names are self-explanatory. Additional details on the response curves of the joint materials are available in the LUSAS Help system. The following is a selection of joint materials that can be used for modelling soil.

4.1 Spring Stiffness Only

While linear elastic springs are generally unsuitable for modelling soil behaviour, they can be used in cases where a simplified approximation is acceptable. Appropriate stiffness values can be obtained from the literature or determined through field testing. In LUSAS, *Spring Stiffness Only* joints (linear, elastic springs) can be used without the need for nonlinear controls.

4.2 Smooth Contact

Smooth Contact joints are a more advanced type of joint that model lift-off. As their response curve is nonlinear (see Figure 9), models using *Smooth Contact* joints require nonlinear controls.

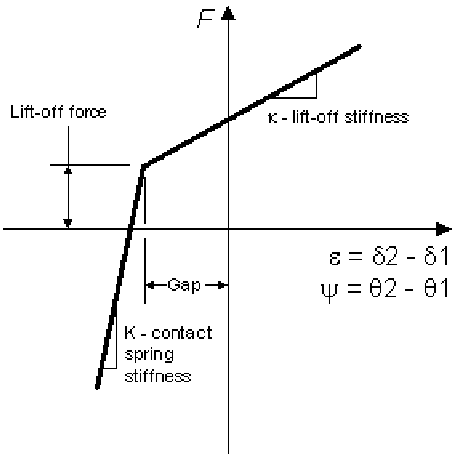


Figure 9 – Smooth Contact joint response curve.

4.3 Piecewise linear, elastic

Piecewise linear, elastic joints are specified by a single Force/Displacement curve defined in a piecewise linear way. As their load-deflection curve is nonlinear (see Figure 10), models using *Piecewise linear, elastic* joints require nonlinear controls.

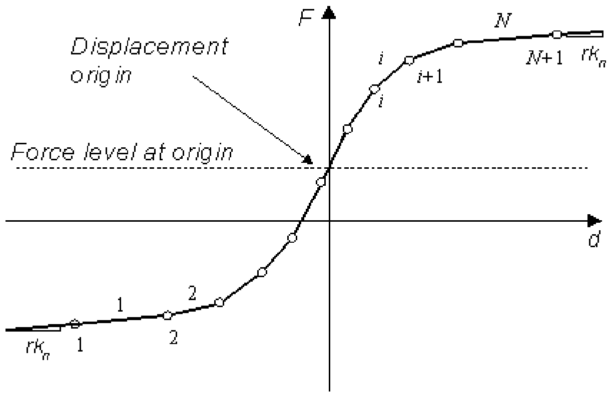


Figure 10 – Typical piecewise linear load-deflection curve with N linear segments.

4.4 Trilinear Earth Pressure

The *Trilinear Earth Pressure* joint material simplifies the modelling of various soil–structure interaction problems. It defines a piecewise linear joint material that generates earth pressures based on structural deflections, with pressures increasing with depth along the vertical axis. Multiple attributes can be defined to represent soil layers or variations in properties due to the presence of water. The *Trilinear Earth Pressure* joint dialog is shown in Figure 11. **Worked example**: Embedded Retaining Wall.

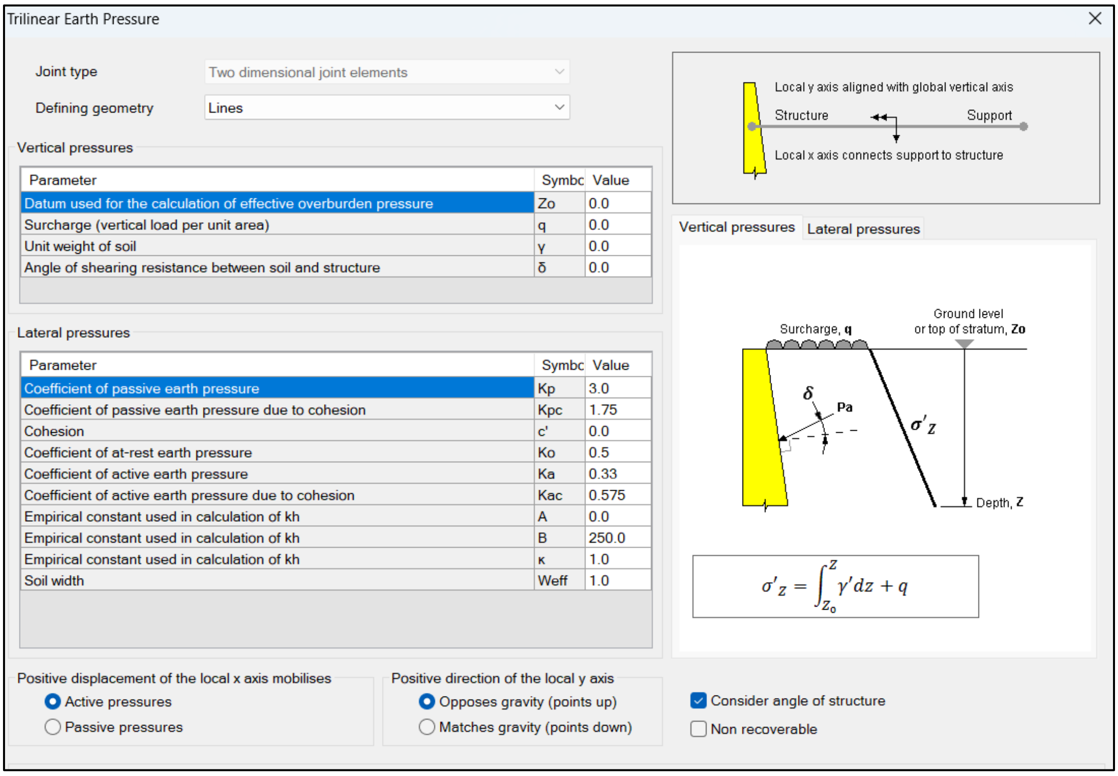


Figure 11 – Trilinear Earth Pressure joint dialog.

4.5 Embedded Pile Material Layup (p-y curves)

Embedded Pile Material Layup attributes (Attributes > Material > Embedded Pile Material Layup, see Figure 12), used in conjunction with P–y Curve utilities (Utilities > P–y Curve, see Figure 13), can be employed to model the soil surrounding an embedded pile. Once defined, joint material attributes (piecewise linear joints) are automatically added to the *Attributes* treeview. The *Embedded Pile Material Layup* attribute is intended exclusively for assignment to lines representing piles. **Worked example**: Defining P-y curves for a Piled Integral Bridge.

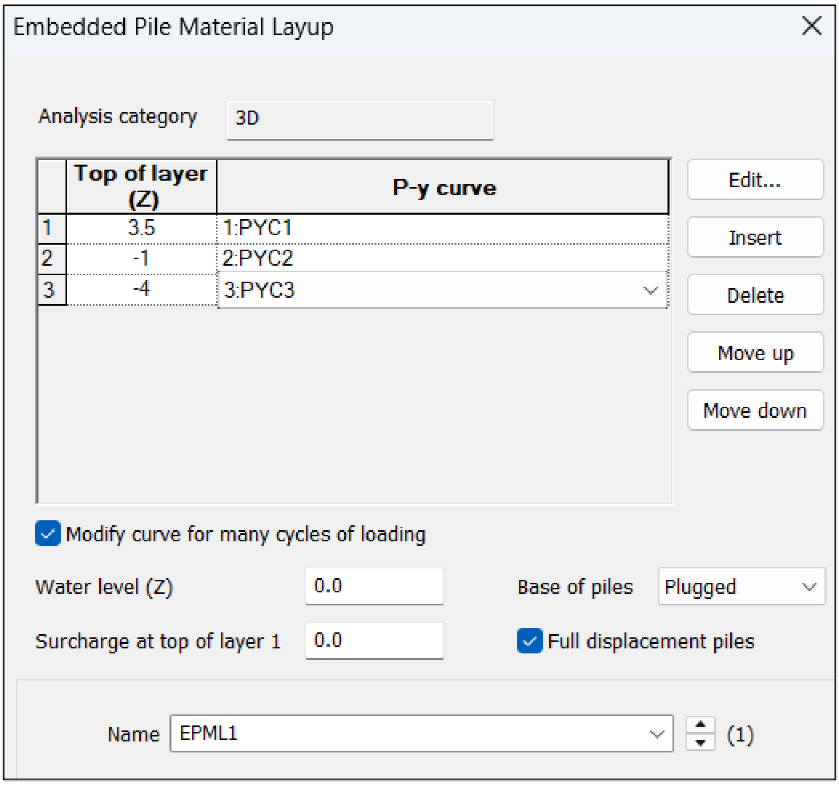


Figure 12 – Embedded Pile Material Layup dialog.

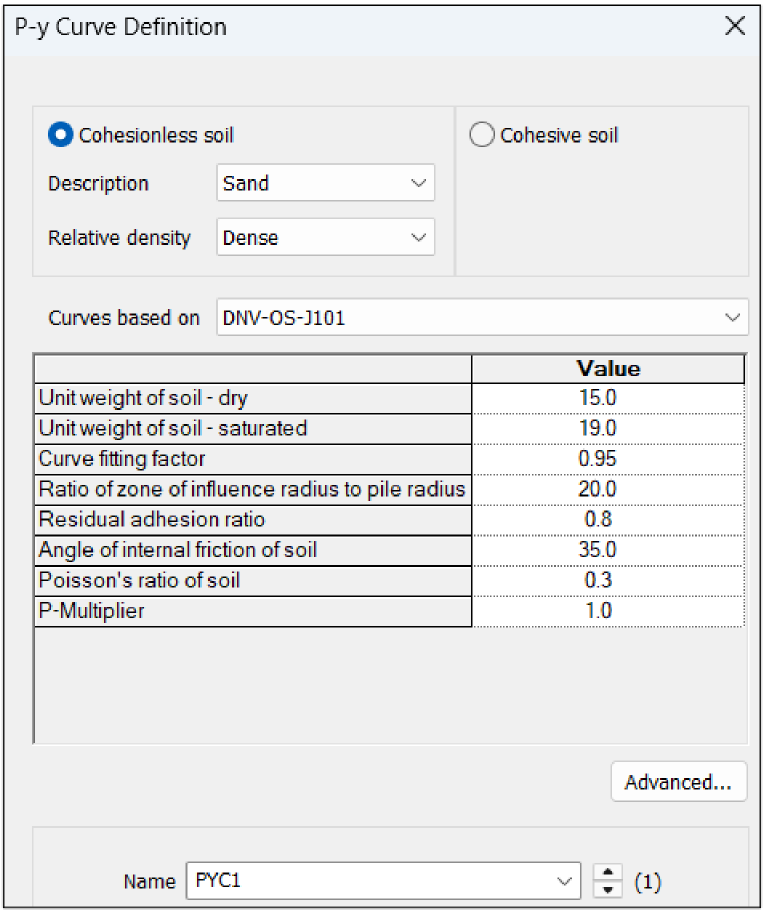


Figure 13 – P-y Curve Definition dialog.

5. Summary

LUSAS offers advanced geotechnical modelling capabilities, enabling the analysis of both simple and complex problems using a wide range of material models and modelling tools. It also provides a wide selection of joint materials for applications where soil behaviour can be represented using springs. Including the structure within the same model is particularly valuable for soil-structure interaction problems, enabling users to obtain results for both the soil and the structure without the need for additional software.

For more detailed information, readers are encouraged to refer to:
Help > Help Topics > Contents tab > Overview of LUSAS Geotechnical Facilities
Help > Help Topics > Contents tab > Worked Examples
Help > Help Topics > Contents tab > Theory Manual 1
Help > Help Topics > Contents tab > Theory Manual 2

If you have any doubts or require specific advice for your type of analysis, please contact the LUSAS Technical Support team at support@lusas.com.