Construction of an arched culvert

For LUSAS version:	22.0
For software product(s):	LUSAS Bridge plus or LUSAS Civil&Structural plus
With product option(s):	Geotechnical, Nonlinear

Problem Description

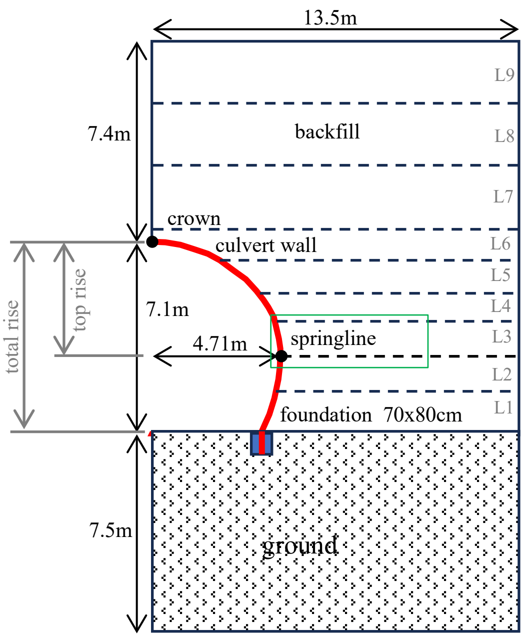


Figure 1: Problem geometry

This analysis considers the construction of a long-span arch culvert from curved corrugated metal with ends anchored in concrete footings. Backfill soil is compacted sequentially in a series of layer on each side of the culvert. During construction the crown of the arch first rises as soil is placed along its sides and compacted and then falls as it is fully covered. The example is based on the analysis by Katona [1] with the problem geometry shown in figure 1. It is analysed using plane strain and takes advantage of symmetry about the tunnel axis.

The backfill is placed in nine layers. Each layer is compacted by a pressure of 35kPa before the next layer is placed.

Keywords

2D continuum elements, manually assigned interface elements, activation of elements, compaction, change of friction.

Associated Files

Associated files can be downloaded from the user area of the LUSAS website.

- ❑ **Construction of an arched culvert.mdl** is the model file for this example.
- Use **File > Open** to open the file named above that was downloaded and placed in a folder of your choosing.

Discretisation

The 2D problem is meshed with quadrilateral plane strain elements (QPN8) and the culvert wall with quadratic plane strain beams (BMI3N). Interface elements (IPN6) are placed between the backfill and the culvert wall. The bottom of the model is fully restrained and the lateral sides are restrained in the x-direction only.

Figure 2 shows the mesh and boundary conditions. The culvert wall is given a thickness of 5cm.

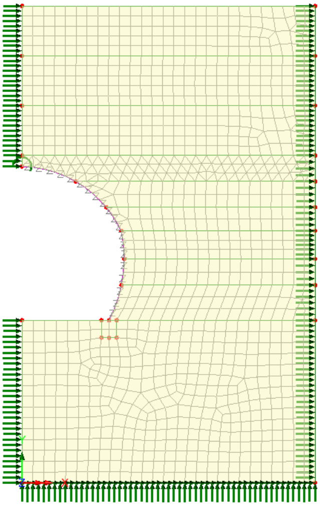


Figure 2: Mesh and boundary conditions

Material Properties

The material properties are listed in tables 1,2 and 3.

Table 1: Backfill - Modified Mohr-Coulomb properties

Young's modulus E (kPa)	Poisson's ratio ν	Density ρ (t/m^3)	Cohesion c (kPa)	Friction angle ϕ^o	Dilation angle ψ^o	Rankine yield stress (kPa)
13800	0.3	2.0	1.0	30	0	0

Table 2: linear elastic properties

Material	Young's modulus E (kPa)	Poisson's ratio ν	Density ρ (t/m^3)	K_0
Culvert wall	207x10^6	0.3	1.6	0
Footing	20.7x10^6	0.2	2.0	0
Ground	1x10^6	0.3	2.0	0.5

Table 3: Interface properties

Material	Normal stiffness factor	Shear stiffness factor	Cohesion	Angle of friction ⁰
No friction	10	0.15	0	0
Friction	10	0.15	0	20

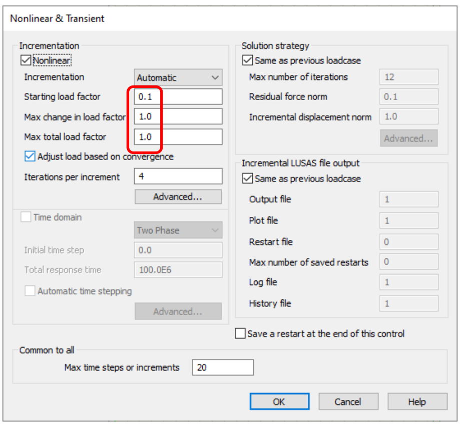
Loading Conditions

Gravity loading is applied.

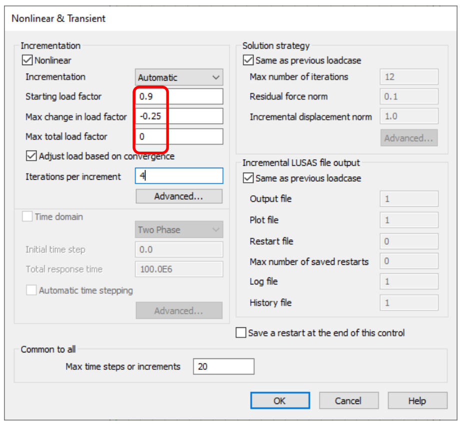
A compaction load is applied after each new layer has been placed.

Modelling Hints

The compaction load is applied using automatic loading. It is first ramped up and then, in the following load stage, ramped down. The required nonlinear controls are shown in figure 3. The **Starting load factor** is set to 0.1, the **Maximum total load factor** and the **Max change in load factor** are both set 1.0 for the ramping up stage. In the unloading stage, the **Starting load factor** is set to 0.9, ie less than the 1.0 used in the previous stage, the **Max change in load factor** to -0.25 and the **Max total load factor** is set to 0.



Load parameters for ramping up



Load parameters for ramping down

Figure 3: Loading parameters for application of compaction load

This problem is quite difficult to solve and to improve convergence the number of line searches using residuals is increased from 3 to 5.

Running the analysis

Setting initial conditions

The culvert wall, interface elements and backfill layer are deactivated. Gravity loading is then applied to generate the initial stresses in the soil (figure 4).

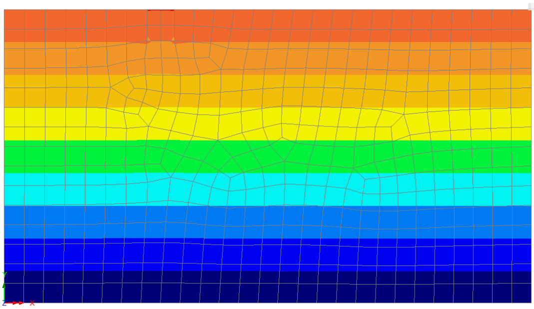


Figure 4: Initial vertical stress distribution in ground

Installation of culvert wall

The culvert wall is activated. Figure 5 shows the vertical stress contours and the bending moment distribution in the wall as it bends under self-weight.

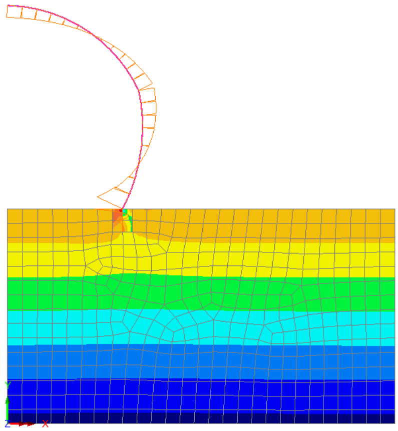


Figure 5: Installation of culvert wall

Activation of first layer of backfill

The first layer of the backfill and the adjacent interface elements are activated. Gravity is applied as an automatic load to the layer. The vertical stresses are shown in figure 6.

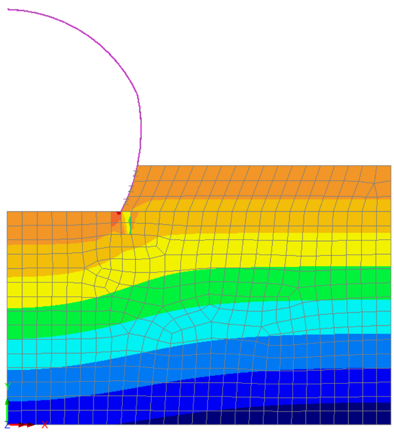


Figure 6: Vertical stresses after first backfill layer is activated

Compaction of first layer

The compaction load of 35kPa is applied to the top of the layer. The increased vertical stresses under compaction are shown in figure 7.

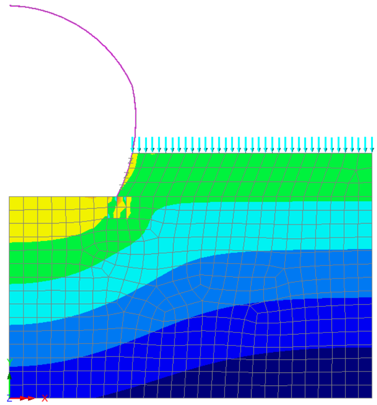


Figure 7: Vertical stresses after compaction of first layer

Removal of compaction load of first layer

The compaction load is reduced and the backfill rebounds. The vertical stress distribution is shown in figure 8.

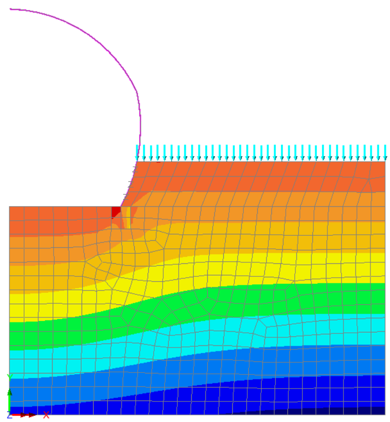


Figure 7: Vertical stresses after removal of compaction load

The process is repeated until all nine layers are placed.

Results

Figure 8 shows the variation of the crown displacement for each of the loading stages. Three solutions are shown. In the first, NF, no friction is applied between the soil and the wall. In the second, NFPL, no friction is applied during the placement of the layer, but friction is introduced for the following compaction stage. The third solution, FPL, has friction during the placement of the layer as well as the compaction stage. The placement of the layers with or without friction makes negligible difference to the crown displacement whilst the displacements are largest when there is no friction.

The placement of the layers up to layer 5, L5, result in an upwards displacement of the crown which is exacerbated by the compaction load. At layer 6 the backfill covers the crown and the crown displacement starts to reverse. Prior to covering the crown, the compaction (see C1 in figure 8) leads to plastic straining with the crown remaining permanently higher after the removal of the compaction load. After burying the crown, the compaction load makes little permanent difference to the crown displacement (see C2 in figure 8).

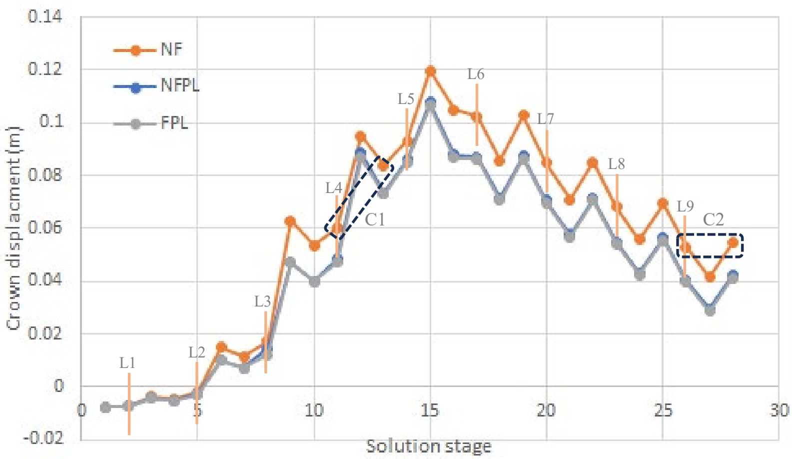


Figure 8: Variation of crown displacement with loading

In figure 9, the displacement of the crown is normalised by dividing by the height or total rise of the culvert whilst the increase in depth of the backfill measured from the springline is divided by the top rise. Averaged experimental results are shown by the yellow line [1]. The key characteristic to note is that the crown starts to fall once the backfill covers it with the actual percentage rise of the crown depending on many factors. The experimental data shows a more rapid reduction of the crown height as the backfill is increased. The reduction in the model is not as steep and is affected by the need to reverse the accumulated plastic strain between the culvert wall and the vertical boundary. The effective plastic strain at the end of loading is shown in figure 10.

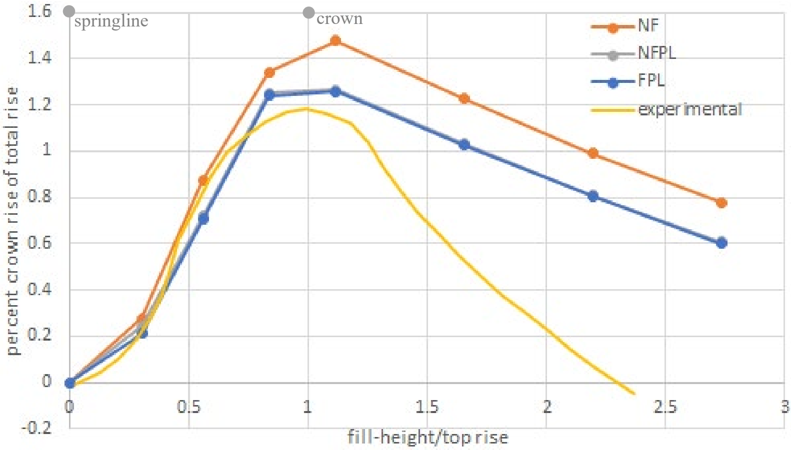


Figure 9: Displacement of crown with increasing backfill

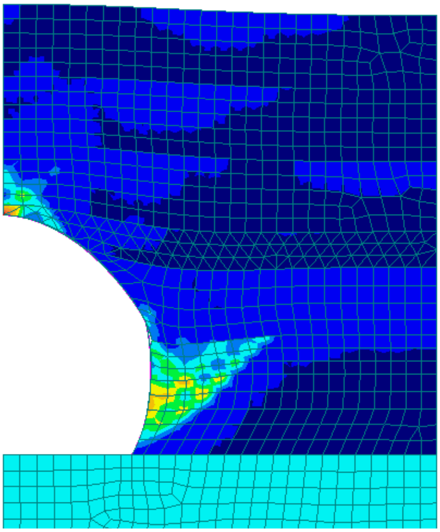


Figure 10: Effective plastic strain at end of loading

References

[1] Katona Michael G., A simple contact-friction interface element with applications to buried culverts, Int.J.Num. and A.Meths.Geomechanics, 1983.