8 Displacements near the Face of an Advancing Shaft

8.1 Problem Statement

A circular shaft is excavated in chalk and lined with monolithic precast concrete segments. The aim of this exercise is to determine the displacements that take place before the lining is installed. This type of information can then be used to enable a two-dimensional plane-strain analysis to include the effect of shaft or tunnel advancement on relaxation of shaft or tunnel loads (see Section 11).

For this example, the shaft's diameter is 5.44 m, and the thickness of the lining is 22 cm. The excavation increments are 1 m long, and after each round a 1 m precast concrete segment is placed right up to the face. Figure 8.1 shows a cross-section view of the process.

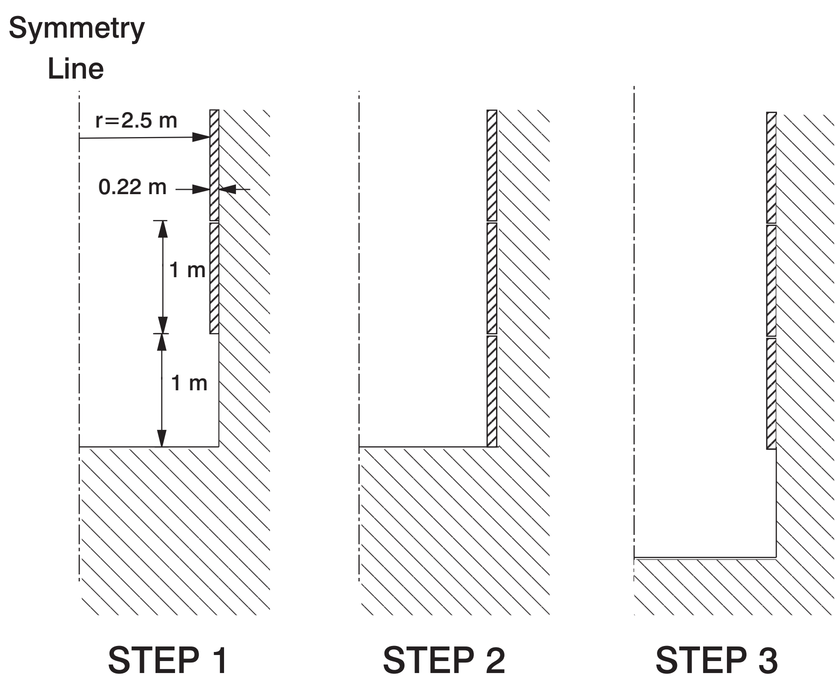

Figure 8.1 Problem geometry and excavation steps

In reality, the chalk exhibits time-dependent behavior associated with creep. The analysis presented here is limited to the elastic response, which accounts for the closure near the face. The following properties are used.

Chalk		
	density	2350 kg/m^3
	bulk modulus	600 MPa
	shear modulus	360 MPa
Concrete Liner		
	density	2500 kg/m^3
	bulk modulus	14 GPa
	shear modulus	8.4 GPa

The in-situ stress state is considered to be hydrostatic, with $\sigma_{xx} = \sigma_{yy} = \sigma_{zz} = 1.5$ MPa.

Panet (1979) published an expression relating shaft closure of an unsupported shaft to the distance to the shaft face. The expression provides a starting point for this example. The solution calculates radial displacements, u_r, at the shaft circumference:

$$u_r = c_0 + c_1\left[1 - \exp\left(-\frac{|y|}{0.7R}\right)\right] \quad y \geq 0 \tag{8.1}$$

$$u_r = c_0 - c_1\left[1 - \exp\left(-\frac{|y|}{0.7R}\right)\right] \quad y \leq 0$$

with

$$c_0 = -\frac{\sigma_o R}{2G}\, h_o \tag{8.2}$$

$$c_1 = -\frac{\sigma_o R}{2G}\, (1 - h_o)$$

where

R = unlined shaft radius;
$h_o \cong 1/3$;
σ_o = in-situ pressure;
G = shear modulus; and

$|y|$ = distance to the face (positive in the direction of the advancing face).

Three analyses are performed for the advancing shaft:

(1) the unlined shaft is modeled and the results compared to Panet's (1979) solution;

(2) the effect of the lining is studied using zones to represent the lining; and

(3) the effect of the lining is studied using axisymmetric shell elements to represent the lining.

8.2 Modeling Procedure

Because the axis of the shaft is an axis of radial symmetry, an axisymmetric elastic model is used in this example. The *FLAC* model has dimensions 30 m by 60 m, and contains approximately 3800 zones. In order to limit the effect of the boundary condition, 30 meters of shaft have been modeled (6 diameters).

For the unlined case, the excavation of the 30 meters is modeled in only one step.

For the two lined cases, the excavation sequence is followed. For the case in which zones represent the concrete liner, the *FISH* function **excav** simulates the excavation sequence. (See "EXCAV.FIS".) For each round, rows **jj1** to **jj2** are excavated, and one-zone thick concrete liner zones are placed in rows **jj3** to **jj4**. Figures 8.2 and 8.3 show the geometry at the end of the run with a one-zone thick liner.

For the lined case in which axisymmetric shell elements represent the liner, the *FISH* function **excav_shell** simulates the excavation sequence. (See "EXCAV_SHELL.FIS".) For each round, rows **jj1** to **jj2** are excavated, and shell elements are connected to the grid from node **ns1** to **ns4**. Figures 8.4 and 8.5 show the geometry at the end of the run with an axisymmetric shell liner.

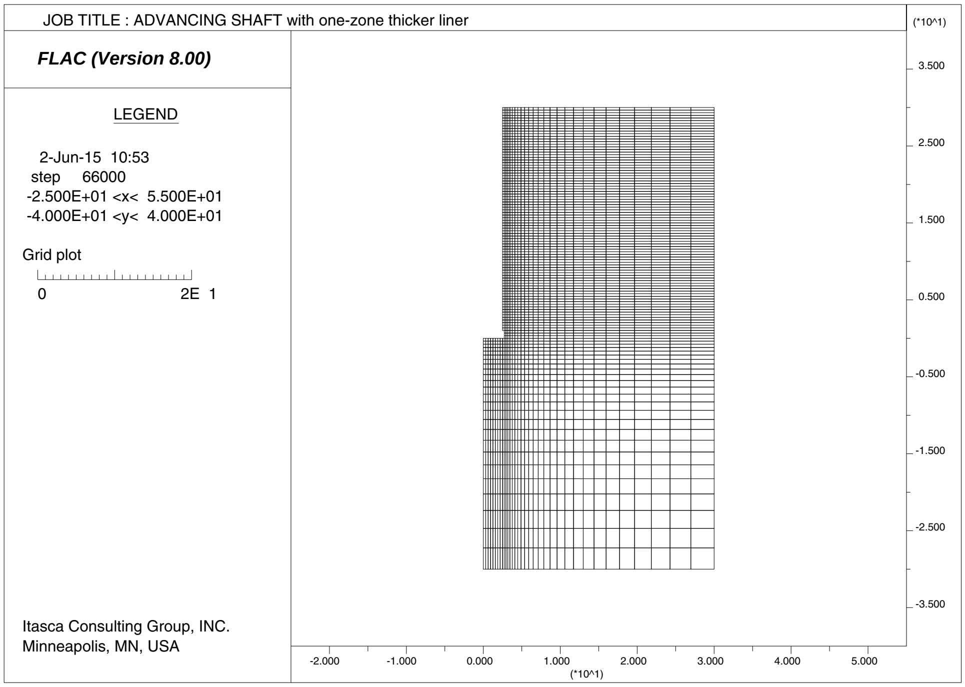

Figure 8.2 Zone geometry

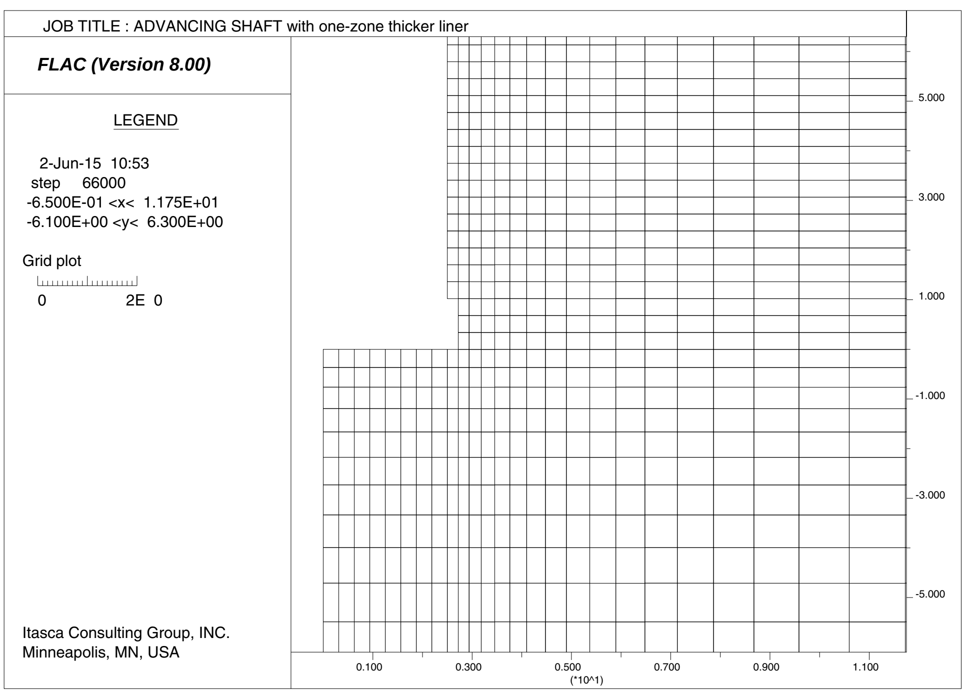

Figure 8.3 Zone geometry (detail)

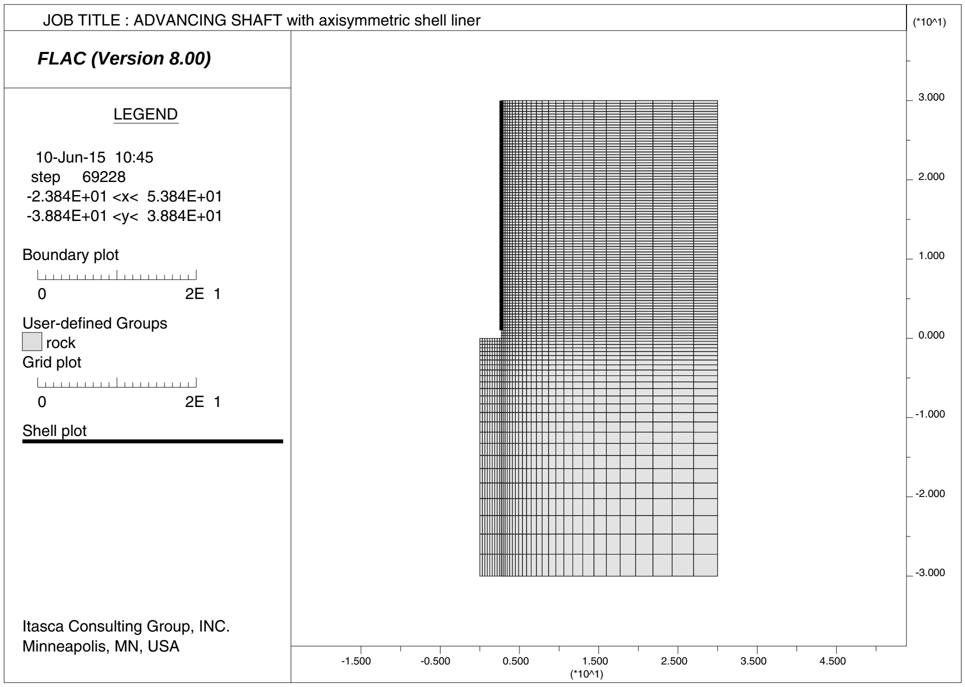

Figure 8.4 Zone geometry - shaft with axisymmetirc shells

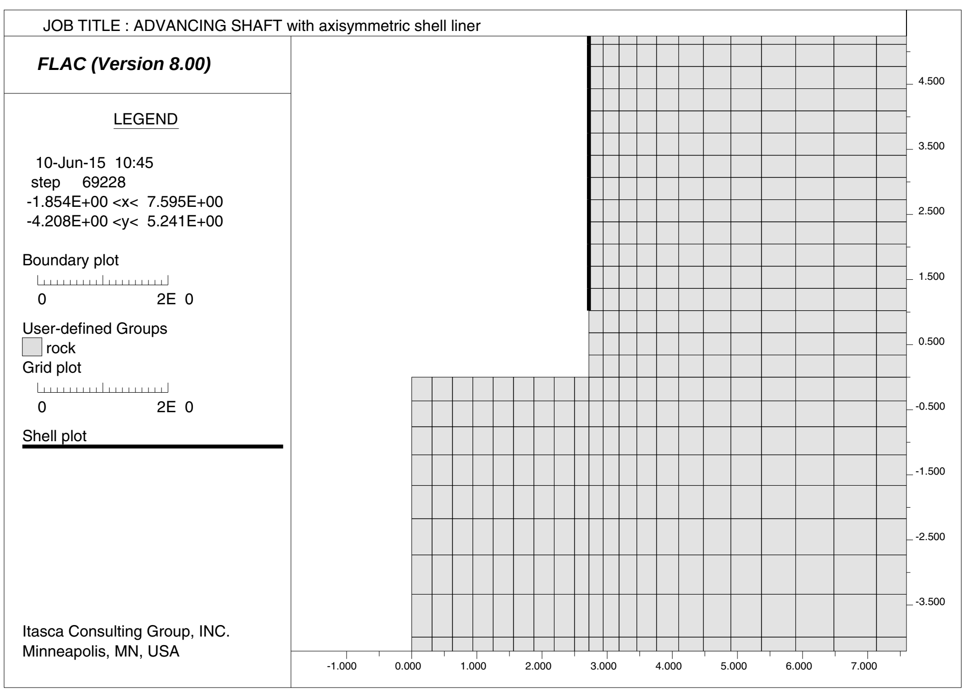

Figure 8.5 Zone geometry (detail) - shaft with axisymmetirc shells

8.3 Results

For the analysis of the unlined shaft, the radial displacements, u_r, calculated at the shaft circumference closely match Panet's solution (Eq. (8.1)). Figure 8.6 compares the radial displacements as a function of the distance to the face obtained from *FLAC* with Panet's solution.

For the lined shaft analysis, the radial displacements that take place at the shaft interface with the precast liner are plotted in Figure 8.7. The results using a one-zone thick liner closely match the results using an axisymmetric shell liner. The displacements for both liner cases are approximately 60% of those with no liner. The jagged shape is due to the uneven radial displacement of the unsupported span, which is partially confined at both ends (last ring of lining and shaft's face) and relatively free to move in the middle.

Figure 8.8 shows a magnified grid plot for the unlined shaft, while Figure 8.9 shows the same plot for the shaft with the one-zone thick liner. The jagged shape of the deformed liner is also evident in the second plot.

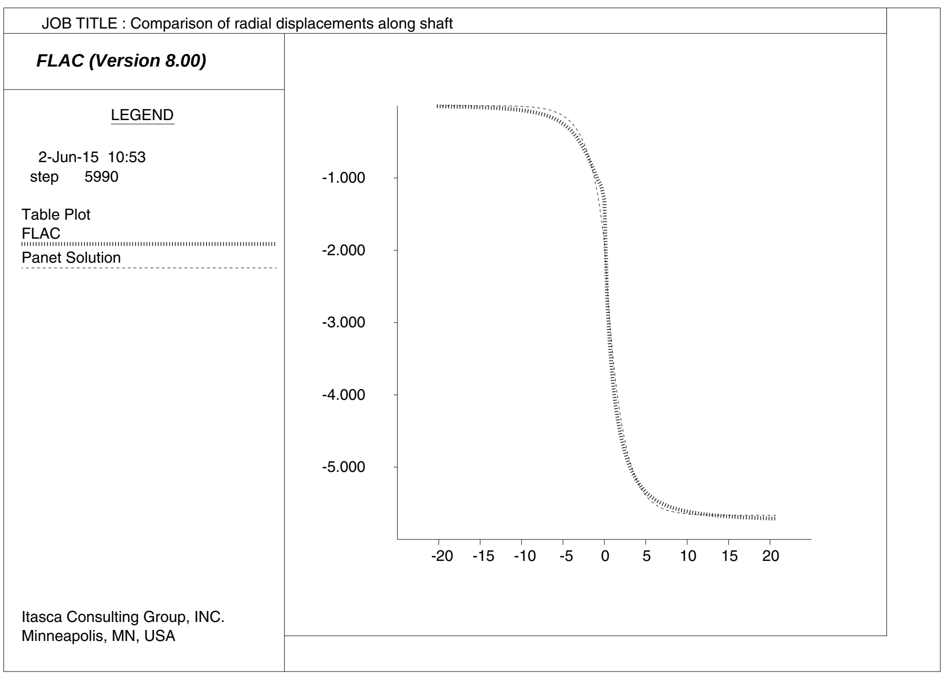

Figure 8.6 Comparison of radial displacements (mm) as a function of the distance to the face (m) for the unlined shaft

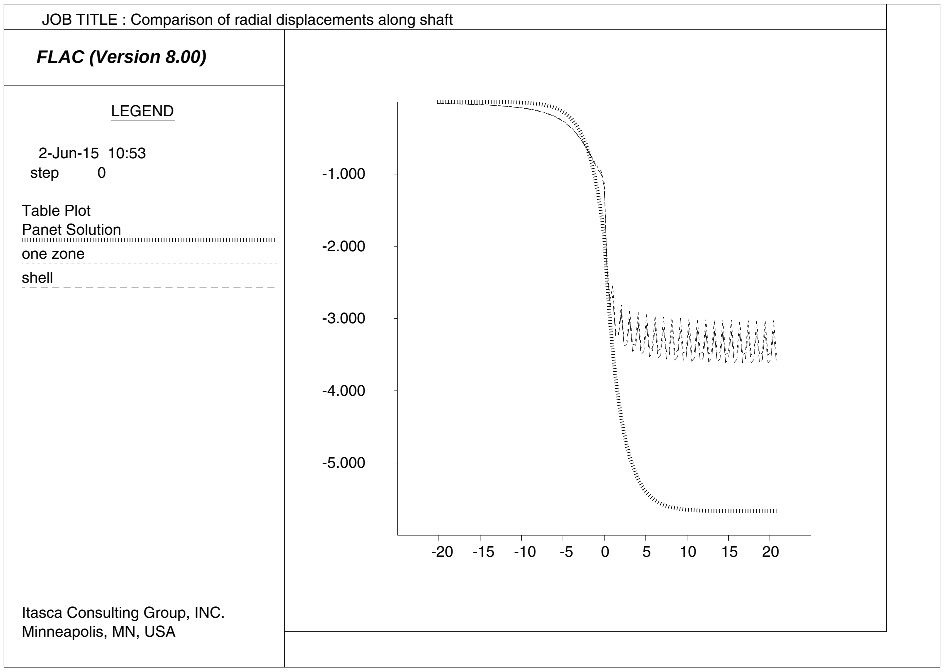

Figure 8.7 Comparison of radial displacements (mm) as a function of the distance to the face (m) for the lined shaft versus the unlined shaft

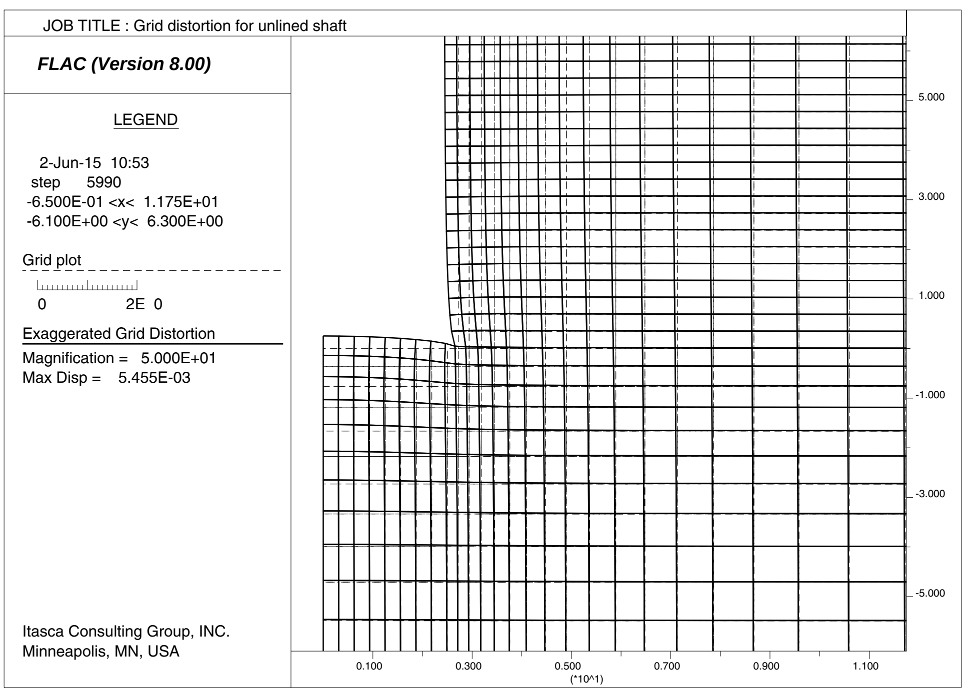

Figure 8.8 Deformed grid for the unlined shaft (magnification factor = 50)

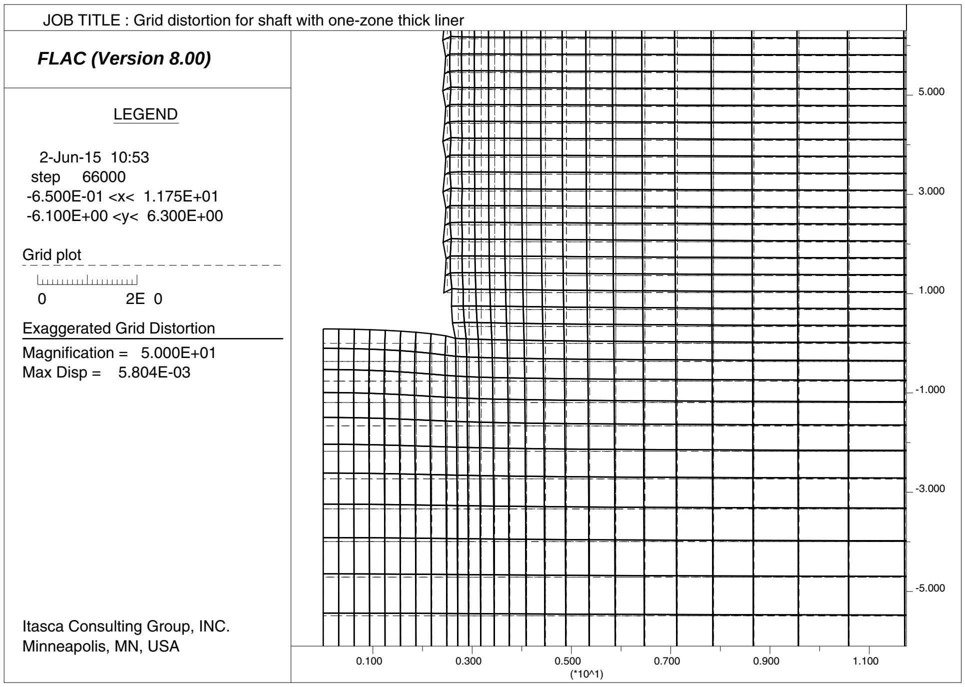

Figure 8.9 Deformed grid for the lined shaft (magnification factor = 50)

8.4 Reference

Panet, M. "Time-Dependent Deformations in Underground Works," in ***Proceedings of the 4th ISRM Congress (Montreux)***, Vol. 3, pp. 279-289. Rotterdam: A. A. Balkema and the Swiss Society for Soil and Rock Mechanics (1979).