SSLP105 - Excavation of a circular tunnel in a Summarized linear elastic

solid mass:

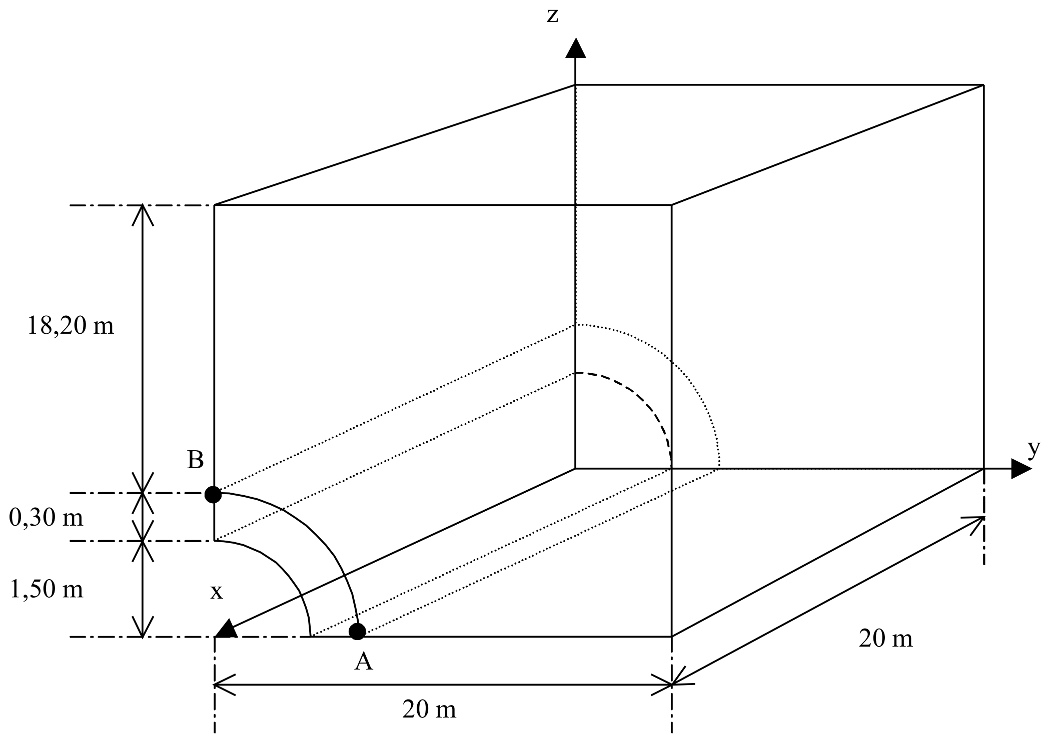
This test constitutes an example of implementation of a total methodology for the two-dimensional simulation of the digging and the supporting of a circular gallery in an underground solid mass with *Code_Aster*.

To validate the approach on the basis of simple analytical solution, one is brought to make restrictive assumptions on the geometry of the problem, the behavior of the materials (elastic linear) and the initial stress field (isotropic). The reference solution is given by the method known as "convergence-containment", classic for this kind of modelization 2D. For more detail on methodologies employed one will refer to documentation [U2.04.06].

1 Problem of reference

1.1 Geometry

It acts of a circular tunnel of section, covered by a concrete ring, which one excavates in a solid mass of soil. The two materials are supposed to be elastic linear.



1.2 Properties of the material

the materials are elastic linear.

1.2.1 Soil

$E_s = 4\,GPa$

$\nu_s = 0{,}3$

1.2.2 Concrete

$E_b = 20\,GPa$

$\nu_b = 0{,}2$

1.3 Initial conditions, boundary conditions and loadings

the stresses in the solid mass are supposed initially isotropic $(\sigma_{xx}=\sigma_{yy}=\sigma_{zz}=\sigma_0)$. The method used to simulate the excavation and the installation of supporting is the method known as “convergence-containment” presented for example in [bib1] and [bib2].

The basic principle rests on a reduction in the nodal reactions generated at the edge of the future gallery by the initial stress state. This operation is indicated by name “déconfinement”. When déconfinement the value reached which corresponds to the conditions of building site that one wishes to model, one carries out the simulation of the installation of concrete supporting at the edge of the gallery.

The boundary conditions and the loading are summarized in the following table. The phases correspond to those of the diagram above, the edges are composed with the nodes identified on the diagram of the paragraph [§3.1] and between brackets the name of the groups of mesh or node of the file .comm).

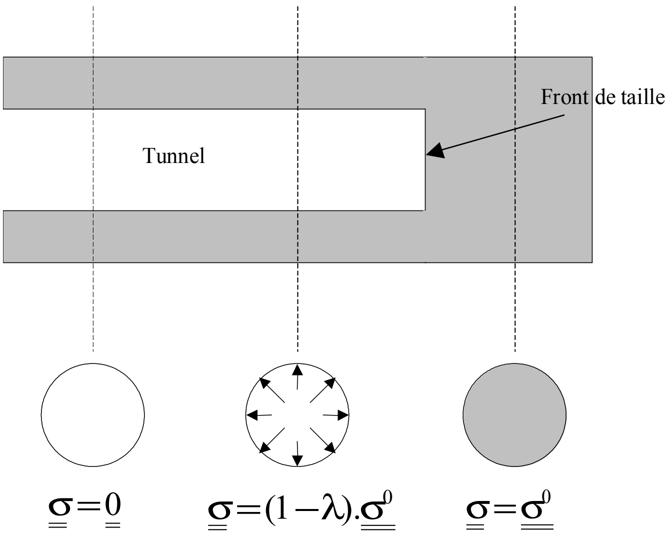
Edges	Phase 1	Phase 2	Phase 3	Phase 4
$N0N1$ (no_bas1)	$DY=0$	$DY=0$	-	-
$N1N2$ (bas_bet)	$DY=0$	$DY=0$	-	$DY=0$
$N2N3$ (no_bas2)	$DY=0$	$DY=0$	$DY=0$	$DY=0$
$N3N4$ (no_droit)	$DX=0$	$DX=0$	$DX=0$	$DX=0$
$N4N5$ (ma_haut)	$\sigma_{yy}=-5\,MPa$	$\sigma_{yy}=-5\,MPa$	$\sigma_{yy}=-5\,MPa$	$\sigma_{yy}=-5\,MPa$
$N5N6$ (no_left2)	$DX=0$	$DX=0$	$DX=0$	$DX=0$
$N6N7$ (no_left_bet)	$DX=0$	$DX=0$	-	$DX=0$
$N7N0$ (no_left1)	$DX=0$	$DX=0$	-	-
$N6N2$ (edge)	-	-	nodal Reactions corresponding to déconfinement	-
$N7N1$	-	-	-	Free

2 Reference solution

2.1 Method of calculating

2.1.1 Behavior of the solid mass

Either λ the rate of déconfinement, which represents the relative position of the section of tunnel considered compared to the coal face. In the method "convergence - containment", one replaces the future ground excavated by a tensor of the stress are equivalent, which one cause a drop in the intensity via λ to simulate the digging and the distance of the coal face.



The solution of the problem is thus similar to that of the infinitely thick tube charged by an internal pressure with intensity $(1-\lambda)\sigma_0$ and an external pressure with intensity σ_0 (see [bib3] for the detail of computations).

The stresses radial, orthoradiale as well as radial displacement with the wall of the tunnel in springy medium subjected toa rate of déconfinement λ are following

$$\begin{cases} \sigma_R = \left(1 - \frac{\lambda \cdot R^2}{r^2}\right)\sigma^0 \\ \sigma_\theta = \left(1 + \frac{\lambda \cdot R^2}{r^2}\right)\sigma^0 \\ U_R = \lambda \frac{R^2}{r} \cdot \frac{\sigma^0}{2G} \end{cases}$$

G is the shear modulus given by the following relation: $G = \frac{E}{2(1+\nu)}$.

2.1.2 Behavior supporting

supporting will be opposed to the natural motion of convergence of the tunnel and will thus apply an artificial containment to the rock.

Either K_s the stiffness of supporting, it is given by the following relation if it is considered that supporting is comparable to a thin tube (ν_b is the Poisson's ratio of the concrete):

$$K_s = \frac{E_b \cdot e}{(1-\nu_b^2) \cdot R}$$

If $k_s = \frac{K_s}{2 \cdot G}$ represents the stiffness relative of the concrete compared to the solid mass and λ_d the rate of déconfinement to the installation of supporting, then the radial stresses and orthoradiales as well as radial displacement out of wall are given by [bib1]:

$$\begin{cases} \sigma_R = \frac{k_s}{1+k_s}(1-\lambda_d)\sigma_0 \\ \sigma_\theta = \frac{k_s}{1+k_s}(1+\lambda_d)\sigma_0 \\ U_R = \frac{1+\lambda_d \cdot k_s}{1+k_s} \cdot \frac{\sigma_0}{2\mathrm{G}} \cdot R \end{cases}$$

2.2 Quantities and results of reference

One tests the following quantities on the level of the wall at the points A and B figure of paragraph 1.1, at time when déconfinement is total:

1) radial stress: σ_{yy} in A or σ_{zz} in B ;
2) stress orthoradiale: σ_{zz} in A or σ_{yy} in B ;
3) radial displacement: u_y in A or u_z in B .

2.3 Uncertainties on the solution

None. Result analytical exact.

2.4 Bibliographical references

[1] The computation of the tunnels by the method convergence-containment, Mr. Panet, Presses of the ENPC 1995

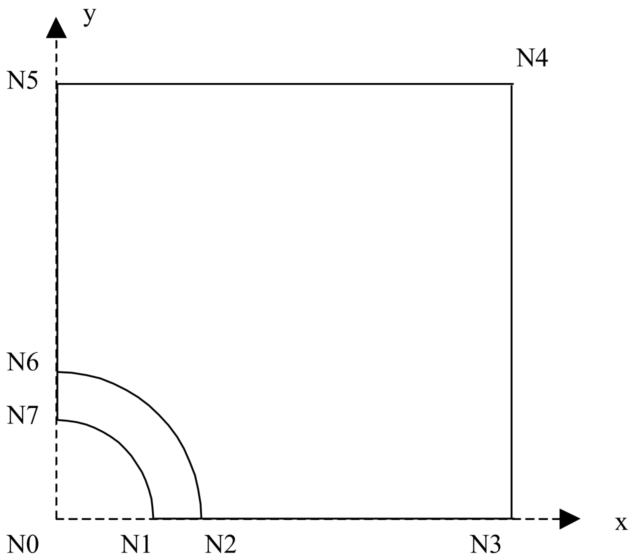
[2] How to simulate the digging of a tunnel with *Code_Aster* ? Principle of the method, implemented and validation, A. Courtois, R. Saidani, P. Sémété, note EDF HT 2/25/045 /A - 2002

[3] Mechanics of the continuums, volume 2, J. Salençon, ED. Ellipses - 1988

3 Modelization A

3.1 Characteristic of the modelization

Modelization 2D in plane strains. This modelization corresponds to methodology 3 of documentation [U2.04.06]: excavation with supporting with initialization of the stresses by call with CREA_CHAMP and déconfinement according to a method of sequence of models.



3.2 Characteristic of the mesh

Many nodes:	8477
Number of meshes:	3304 of type QUAD8

3.3 Course of computation

the purpose of this case test is to test a method. The following table presents the main steps which structure the command file.

Commands	Comments
CREA_CHAMP	Initialization of the stresses geostatics (here isotropic $5\,MPa$ in compression)
STAT_NON_LINE	Blocking of the nodes of the gallery for computation of the nodal reactions to inject to simulate déconfinement
the CREA_CHAMP	Recovery of nodal reactions
STAT_NON_LINE	Re-injection of nodal reactions
STAT_NON_LINE	intermediate Computation to pass from a model without mesh representing the segments concrete to a model with meshes representative (see [bib2])
STAT_NON_LINE	progressive Déconfinement of the solid mass

3.4 Quantities tested and results

After the installation of the coating (final moment), one tests the components σ_{xx} and σ_{yy} with the nodes $N2$ and $N6$ as well as radial displacement in these points (DX for $N2$, DY for $N6$).

	Reference	*Aster*	Difference (%)
Node $N2$			
σ_{xx}	-1,52821.106	-1,53154.106	0,218
σ_{yy}	-8,47179.106	-8.52772.106	0,660
DX	-1,6925.10-3	-1,6684.10-3	-1,422
Node $N6$			
σ_{xx}	-8,47179.106	-8,41147.106	-0,712
σ_{yy}	-1,52821.106	-1,52943.106	0,080
DY	-1,6925.10-3	-1.7184.10-3	1,529

4 Modelization B

4.1 Characteristic of the modelization

Modelization 2D in plane strains. This modelization corresponds to methodology 2 of U2.04.06 documentation: excavation with supporting with initialization of the stresses by call to `CREA_CHAMP` and déconfinement using only one model and materials "flexible" for the excavated zone.

The mesh is the same one as for modelization A.

4.2 Déroulement of computation

the purpose of this case test is to test a method. The following table presents the main steps which structure the command file.

Commands	**Comments**
`CREA_CHAMP`	Initialization of the stresses geostatics (here isotropic $5\,MPa$ in compression)
`STAT_NON_LINE`	Blocking of the nodes of the gallery for computation of the nodal reactions to inject to simulate déconfinement
`the CREA_CHAMP`	Recovery of nodal reactions
`STAT_NON_LINE`	Re-injection of nodal reactions
`STAT_NON_LINE`	progressive Déconfinement of the solid mass

4.3 Quantities tested and results

After the installation of the coating (final moment), one tests the components σ_{xx} and σ_{yy} with the nodes $N2$ and $N6$ as well as radial displacement in these points (DX for $N2$, DY for $N6$).

	Reference	***Aster***	**Difference (%)**
Node $N2$			
σ_{xx}	-1,52821.106	-1,53619.106	0.52
σ_{yy}	-8,47179.106	-8.53167.106	0.71
DX	-1,6925.10-3	-1,6687.10-3	-1.41
Node $N6$			
σ_{xx}	-8,47179.106	-8,41158.106	-0.71
σ_{yy}	-1,52821.106	-1,52967.106	0.1
DY	-1,6925.10-3	-1.7180.10-3	1.51

5 Modelization C

5.1 Characteristic of the modelization

Modelization 2D in plane strains. This modelization corresponds to case 1 of documentation [U2.04.06]: excavation without supporting with initialization of the stresses by call to CREA_CHAMP and déconfinement using only one model and a "flexible" material for the excavated zone. This modelization will thus give different results since there are no supportings. The analytical solution is provided here by the equation (1).

The mesh is the same one as for modelization A.

5.2 Déroulement of computation

the purpose of this case test is to test a method. The following table presents the main steps which structure the command file.

Commands	Comments
STAT_NON_LINE	Initialization of the stresses geostatics
CREA_CHAMP	Recovery of stresses initialized
STAT_NON_LINE	Blocking of the nodes of the gallery for computation of the nodal reactions to inject to simulate déconfinement
the CREA_CHAMP	Recovery of nodal reactions
STAT_NON_LINE	Re-injection of the nodal reactions

5.3 Quantities tested and results

After the installation of the coating (final moment), one tests the components σ_{xx} and σ_{yy} with the nodes $N2$ and $N6$ as well as radial displacement in these points (DX for $N2$, DY for $N6$).

	Reference	*Aster*	Difference (%)
Node $N2$			
σ_{yy}	-10.106	-1,013.106	1.13
DX	-2,4000.10-3	-2,4375.10-3	1.54
Node $N6$			
σ_{xx}	-10.106	-9,89.106	1.13
DY	-2,478.10-3	-2,4375.10-3	1.66

6 Summary of the results

the values obtained with *Code_Aster* are in agreement with the values of the analytical solution of reference.