Elaboration of thick shells theory for the application of convergence confinement method, for dimensioning of deep and shallow tunnels in anisotropic stress field

Etablissement de la théorie des coques épaisses pour le calcul des tunnels profonds et superficiels en contraintes anisotropes selon la méthode convergence-confinement

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ABSTRACT: Convergence Confinement Method (CCM), as it is easy to use, is frequently used for tunnel design because this method is able to simulate 3D effects at the tunnel face in a 2D problem. This is possible thanks to three curves: Ground Reaction Curve (GRC), Longitudinal Deformation Profile (LDP), and Support Confinement Curve (SCC).
To switch from isotropic in situ stress case, where the support is loaded only radially, to anisotropic case, shell theory and a contact condition between ground and support are needed. However, the range of application of Thin Shell Theory of Flügge, which is very often used, doesn't match with a lot of common cases for tunnels. It raises to ask question about the approximations induced by this theory for thickness/radius ratio over 1/20.
The purpose of this work is to determine stresses, forces and displacements in a thick shell. Then, these results are introduced in the global framework of CCM (SCC, LDP & GRC), for an anisotropic stress field with a random orientation with respect to the principal stresses orientation. This improvement allows to increase the range of application of CCM, which is based on simple concepts.

1 INTRODUCTION

CCM is an articulation between three curves (SCC, LDP & GRC), allowing to solve in 2D a 3D problem for tunnel dimensioning.

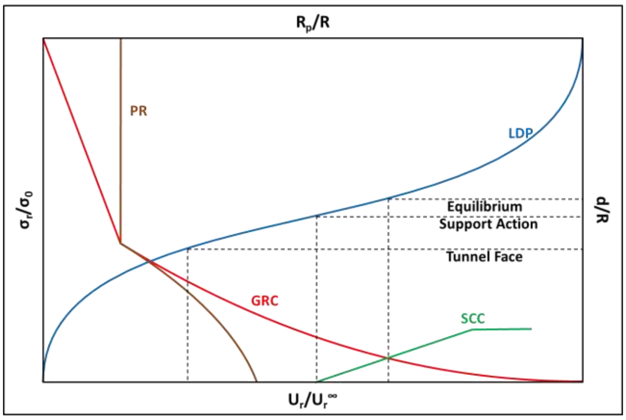

Figure 1. Curves of CCM

Although many researches are concentrated on GRC with complex behaviour laws, or on LDP with implicit interaction methods, the author is focusing on SCC.

In hydrostatic in situ stresses, the modeling of SCC can be quite simple (normal rigidity and stress limit), the modeling of SCC is much more complex in a non-hydrostatic case.

The first resolution of ground/support interaction in anisotropic conditions was achieved by (Einstein & Schwartz, 1979), using thin shell theory of (Flügge, 1960). Then, (Panet, 1986) used the same theory to introduce it explicitly in CCM. Finally, (Carranza Torres, Rysdhal, & Kasim, 2013) tried to extend the range of applicability of the results of Einstein & Schwartz, but still using Flügge's theory. All these results were obtained for elastic behaviour for both support and ground.

Among Flügge himself, its theory is valid for thickness/radius ratio less than 1/20. The approximation induced on a large scale of usual lining is studied in the next paragraphs.

2 METHODOLY USED TO ELABORATE THICK SHELL THEORY

The thick shell theory is developped by extension of the thick tube problem, using Airy's functions. It allows to give a quite simplified link between forces, stresses and strains, without taking into account any ground/support interaction.

Then, we use the methodology of (Panet, 1986 & 1995) to introduce rigorously the just established thick shell theory in CCM.

3 COMPARISON BETWEEN THICK SHELL THEORY AND THIN SHELL

We assume the tunnel is submitted to principal stress with lateral earth coefficient K0 = 0.5, such as:

$$\sigma_2^0 = K_0 \sigma_1^0 \qquad (1)$$

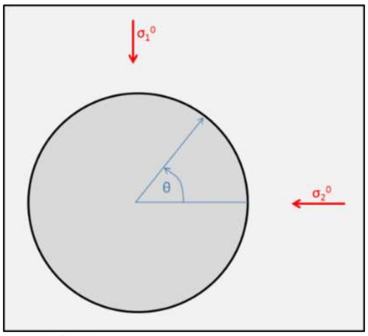

Figure 2. Problem definition

Then for a classical example, we obtain a comparison for a large scale of relative rigidity E/Es (Young's modulus of ground / support).

The gap between the two theories becomes very important for a relative rigidity over 5.10-3., reaching 40% for axial thrust, 15% for bending moment and 60% for shear force (particularly for the no slip contact condition, which is the most frequent condition).

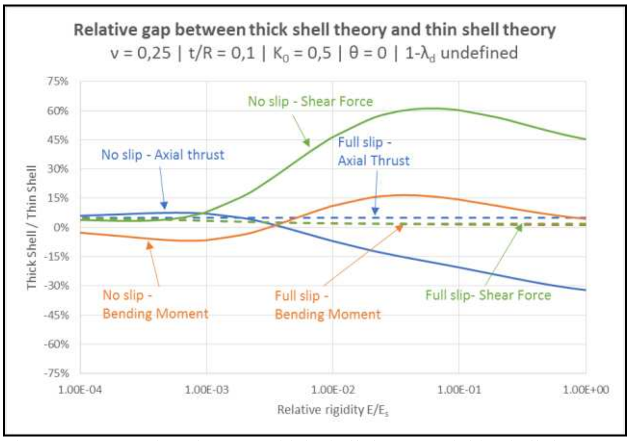

Figure 3. Comparison between thick shell theory and thin shell theory

Taking into account the true behaviour of a thick shell, using thick shell theory, seems essential.

4 INFLUENCE OF A NON-PRINCIPAL STRESS FIELD

Here, we analyze the influence of a progressive inclination ζ of the tunnel, from $\zeta = 0°$ (tunnel) to $\zeta = 90°$ (vertical shaft), in a non-hydrostatic stress field between the three principle stresses. We use the approach of (Jaeger & al, 2007) to rotate the in situ stress in 3D.

This implies to be able to take into account the initial shear stress in the ground. This has been another improvement for the thick shell theory, using one more time the methodology described in chapter 2.

The parameters given in table1 are used to obtain the results presented in figure 4.

e_1 is the vertical direction, e_2 & e_3 are the two horizontal directions. f_{cd} is the design compressive resistance of concrete.

Table 1. Parameters used for the non-principal stress field case

K0 between e_1 and e_2	0.8
K0 between e_1 and e_3	0.5
Fixed angle between e_2 and e_3	15°
Relative in situ stress f_{cd} / σ_1^0	5
Relative rigidity E / E_s	10^{-2}
Relative thickness t/R	1/10

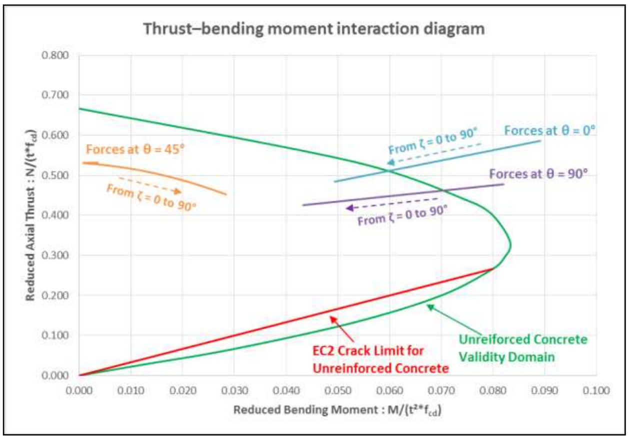

Figure 4. Thrust-Bending moment interaction diagram

In this example, the tunnel is under-dimensioned, but the shaft is well-dimensioned. We can also see the evolution of the thrust-bending moment interaction. This is the only analytical closed-form model which is able to show this kind of results, for such random in situ stress field.

5 CONCLUSION

As announced in abstract, we improved the range of CCM by rigourous approach to take into account the support behaviour for any thickness. This is a complete closed-form solution, for an elastic behaviour of the ground.

With these results, it creates new opportunities to solve new common problems. In particular, the assessment of approximation due to stress gauges in finite elements method, and three medium interaction (ground/grout/segmental lining, or ground/primary support/final lining).

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