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PLASTIC AND INFLUENCE ZONE NUMERICAL EVALUATION FOR DILATOMETRIC BACK ANALYSIS

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Summary: *For last 30 years was dilatometer used for evaluation of deformation characteristics of rock massif. Dilatometric measurement is frequently used for very deep boreholes, where together with stress measurements using hydraulic fracturing plays key role in assessment of the environment. New formula for interpretation of data obtained from dilatometer was recently introduced, following the idea of influence zone. This paper focus on numerical back analysis of data from deep borehole from Brenner base tunnel. And the aim is to compare results from numerical modelling and from results obtained by analytically derived formulas. The conclusions underline the necessity of inclusion of the influence zone to the formulas for evaluation of massif characteristics.*

1. Introduction

Determination of geomechanical properties of rock massif presents difficulties due to the problems arising in sampling, specimen preparation and testing. Questionable is also the accuracy of the results for more complex formations since the tests are usually conducted on small specimens that cannot depict the structure. One of the methods used to directly evaluate the actual geomechanical properties of the rock mass is a dilatometer analysis.

The improvement of the standard dilatometer back analysis has been done recently by Kuklík and Záleský (2008). The newly developed formula presents new boundary condition and also incorporates the thickness of plastic zone layer as a new parameter.

The aim of the presented work is to focus on numerical back analysis of standard dilatometer test using FEM and verify the accepted assumptions of the new formula numerically.

2. Standard dilatometer test

The dilatometer determination of the rock mass mechanical properties is based on real time measurement of the applied pressure and change of the borehole diameter. The

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deformation is directly measured by three transducers installed in the metal body of the dilatometer probe.

A dilatometer test is usually performed in two, three or four cycles. The first testing cycle is preceded by, so called, base pressure inflation of the probe. The first cycle should guarantee a good contact between the probe and the borehole wall. The base pressure is typically a hydrostatic pressure plus 0,15 – 0,5 MPa.

While the first cycle consist of loading and subsequent unloading to the base pressure, in case of all other cycles the loading path consist of two parts. At first, the maximum pressure of the previous cycle is reached and then the loading continues to a higher level followed by unloading.

3. Analytical back analysis of the test

The common test evaluation is derived from three boundary conditions. Namely they are the zero displacement in the radial direction in infinity distance, the measured displacement on the probe-borehole interface and the known pressure in the same place.

The new formula introduced two new aspects. Firstly, it was the plastic zone around the borehole wall and secondly it was the phenomenon of influence zone presenting the assumption of zero displacement in the final distance from the borehole. The newly introduced formula is consistent with the common one and it can be shown that in limit case, where thickness of plastic zone is zero and influence zone is infinite, both formulas are equal.

$$E = \frac{\Delta p.(1+\nu)}{\frac{1}{2}\Delta d.\frac{\overline{R}_1}{R_2^2-\overline{R}_1^2}\left(\frac{R_2^2}{\overline{R}_1^2}+\frac{1}{1-2\nu}\right)} \tag{1}$$

where Δp = pressure difference; Δd = change of borehole diameter; ν = Poisson's ratio; $\overline{R}_1$ = thickness of plastic zone; R_2 = thickness of influence zone.

4. Numerical analysis

For numerical analysis the ADINA code was used. Due to the nature of the problem, the axisymmetric analysis was found to be most suitable. Using the appropriate time function, and with help of death element time it was possible to simulate the entire process of consolidation, material excavation and, finally, the dilatometer test.

4.1. Tested example

As an example was used dilatometer test from 986.5m deep borehole in chlorite schist. The test was a part of a Brenner base tunnel geotechnical investigation project. Label of the tested borehole is Va-B-03/04. All necessary data were obtained from Kuklík et al. (2008) and from Zalesky et al. (2006).

For the analysis purposes it was assumed that the borehole along the dilatometer packer sleeve and in close surroundings has constant diameter d = 92mm.

The total average displacement of the borehole wall was $\Delta d_t = 80.10^{-6}$m, while the unloading /elastic path reaches $\Delta d_e = 30.10^{-6}$m. The entire test log can be seen on Fig. 1.

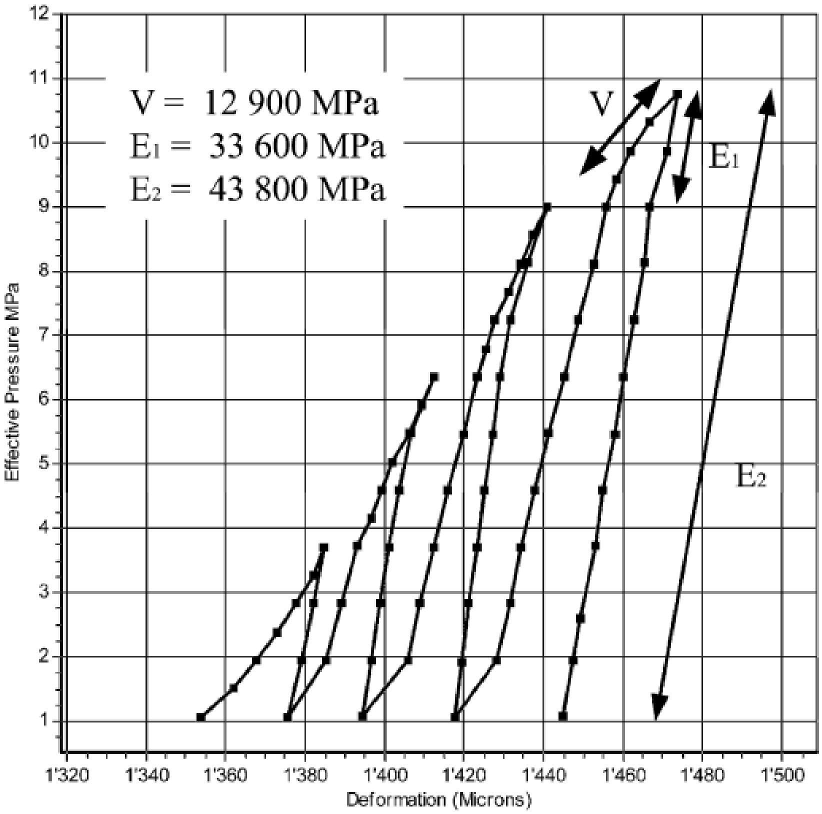

Fig. 1: Dilatometer test in borehole Va-B-03/04s, 986,5 m depth, chlorite schist. Graphical representation from the DilatoII software program: average from deformation measurements of all three extensometers (Zalesky et al., 2006).

Due to the lack of laboratory data Poisson ratio of the rock was assumed to be $v = 0,33$.

For the comparison purposes data from Kuklik et al (2008) were used. It focused on the same problem while employing newly developed formula. Results in the following table have been obtained for the same study case assuming $R_2 = 5.\ \bar{R}_1$.

Tab. 1: Values of E according to new formula (Kuklik et al. 2008)

$\bar{R}_1$	$1,1R_1$	$1,2R_1$	$1,3R_1$	$1,4R_1$	$1,5R_1$	$1,6R_1$	$1,7R_1$	$1,9R_1$	$1,9R_1$	Old formula
E (GPa)	41,6	45,4	49,2	53,0	56,8	60,4	64,3	68,1	71,9	43,8

4.2. Test results

Numerous calculations have been done to simulate the dilatometer test incorporating both elasticity and plasticity (Mohr – Coulomb) for rock and also various contact elements.

The initial stress state was either directly prescribed or reached by self-weight load with appropriate time function. It can be point out that both approaches lead to similar results. This can not be stated for the different modelling approaches on the contact, as they tend to give slightly more variable results.

The results indicated that plastic zone around borehole is small and can be nearly neglected. So in the new formula borehole radius can be used instead of plastic zone radius with negligible loss of accuracy. The main reason for this simplification is the depth of borehole. In case of shallow borehole analysis attention needs to be paid to the possible increase of plastic zone diameter.

The results also confirmed the improvement in accuracy when the influence zone theory is used for evaluation of rock mass parameters. When the characteristics evaluated from the original formula were used, the displacement (rock deformation) were either too small or the effective stress for the required deformation was nearly double than measured. Generally good results can be obtained for with of influence zone in range from $2.R_1$ to $5.R_1$, where R_1 is borehole radius.

Unfortunately this range will presumably vary for different rocks and also for different testing depth, so proper numerical back analysis has to be carried out in order to secure the accuracy of interpretation of measured results.

5. Conclusions

The numerical analysis presented some results that are in general agreement with the new formula. However, during the simulations of the dilatometer test in the deep borehole no significant plastic zone has been observed.

According to the simulations the influence zone is 2 to 5 times wider than the borehole and particular number is sensitive to testing depth, properties of the rock and loading pressure.

Neglecting the idea of influence zone and so calculating the deformation parameters of the rock mass with the original formula tends to give higher values of deformation modulus and Young’s modulus. If these values are used for numerical simulations of the following geotechnical work (ex. tunneling) the loss in accuracy can be very high. Usually these numbers are used as an upper limit and the scale effect is considered.

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