Numerical Study on the Effect of Grout Properties On the Results of Borehole Extensometers in Earth Dams

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Abstract

Measurements of surface and deep soil displacements are among the best approaches for monitoring and controlling the behavior of geotechnical structures such as dams, which can be conducted by using magnetic borehole extensometers. This type of instrumentation is installed into the boreholes and the space inside the borehole is filled with a mixture of Bentonite-cement grout. Studies have shown that the mechanism of borehole extensometer measurement, the effect of the mixing design of Bentonite-cement grout to fill the gap between the borehole and the extensometer and the effect of grout properties on the measurement have not been carefully studied. In this paper, a number of laboratory tests with different grout mixing designs were performed to determine mechanical properties and geo-mechanical parameters for numerical analysis. The results of numerical analysis show that compressive strength and hardness of the sample of grout will decrease as Bentonite to cement ratio increases. Furthermore, as the hardness of the grout and soil converge, the measurement error will decrease accordingly.

Keywords: Instrumentation, Magnetic extensometer, Bentonite-Cement Mixing, Numerical Modeling.

1. INTRODUCTION

Due to the uncertainty in assumptions of the design process, problems and constraints of the construction of dams, it seems necessary to pay closer attention to the assessment of the behavior of the dams and to study the results of the analysis of the actual behavior of the dam from the start of construction to the impoundment and within the operation period.

Engineering monitoring in geotechnical projects are part of the design process. Instrumentation is a way to control the stability of structures during the time of construction and operation. [1].

One of the important steps during installation of extensometers, is filling the gap between tube and borehole internal wall. The filling material is in direct contact with rock and instrument and thus can have significant impact on the accuracy of the measurements. If the filling material does not have the proper features it will not be able to provide the proper contact and thus the stability between the extensometer tube and borehole wall will be compromised. Materials commonly used to fill the gaps include cement, granular materials such as sand and Bentonite pallets. Experience has shown that cement - Bentonite grout is the best option for a filler material in the borehole and has been widely used in many applications. In cases where grout stiffness reduction is required, fly ash can be used instead of cement [2].

The ideal type of grout should be consistent with the ground stiffness. A weaker blend of the grout does not reflect the behavior of the surrounding soil, even if the grout is properly injected into the borehole. Also, a stronger mixture may exhibit a behavior which is independent of the surrounding ground. [3]

Burland et al (1972) described the grout around access tube of the magnetic extensometer as a soft flexible material that could prevent the collapse of borehole. Also, in order to inject in soft ground after installing extensometers a thick Bentonite grout was suggested [4]. Sonebi et al (2012) performed experiments on properties of Bentonite grout for geotechnical applications and the results showed significant effect of Bentonite on fluidity, the properties of the deformation and the compressive strength of the grout. The increase in the amount of Bentonite, unlike the water / Bentonite ratio (W / B), leads to an increase in the amount of flow time, plate adhesion, plastic viscosity and yield tension, and decreases water deflation and compressive strength in 3 days, 7 days and 28 days [5].

Also, Salehi (2008) carried out experiments on different mix designs with cement, Bentonite, and fly ash. The results of these experiments show that the increase of Bentonite has the greatest impact on reducing drainage water followed by decreasing water. In the meantime, the increase in the fly ash has the least impact. The dry density of the grout samples increases with increase in the amount of fly ash, comparing that with shear stress of interface between the grout and tube show a specific trend. It was also shown that the phenomenon of bleeding and, as a result, detachment causes significant errors in measuring the shear strength of the interface between the grout and the tube and the unaxial compressive strength. [1]

2. GROUT MIXING DESIGN

A review of past studies shows that the mechanism of measurement in extensometers, effect of Cement-Bentonite mixing design and the effect of grout properties have not been addressed. In this study, a number of laboratory tests with grout mixing design were used to determine mechanical properties. Mikkelsen (2002) [2], Kuisi et al. (2005) [6], as well as Slope Indicator Co. [7] and Soil Instruments Ltd. [3], introduced a grout mixing design for Cement-Bentonite in the installation of soil inclinometers (Table 1).

Table-1 Mixing design for Cement-Bentonite grout

Row	(W/C)	(B/C)
1	3	0.3
2	3	0.4
3	3	0.5

Mickelsen (2002) believed that the water-to-cement ratio should be controlled to perform field experiments [2]. For this purpose, in this mixing design, the cement was first mixed with water, which makes the ratio of water to cement constant. Furthermore, the strength and grout modulus will be more controllable. Finally, after 5 minutes, Bentonite was added to the mixture and, according to Will (1997) [8], and it took 30 minutes to hydrate Bentonite and better mixing. From each mixing design in Table (1), some examples are made in Nx standard dimensions, as shown in Fig.1

Fig. 1 - Materials and steps to prepare the sample

After performing uniaxial compressive test with self-controlling loading device in Shahrood university of Technology Laboratory on the provided samples presented in Fig.2 , the extracted results are presented in Table(2).

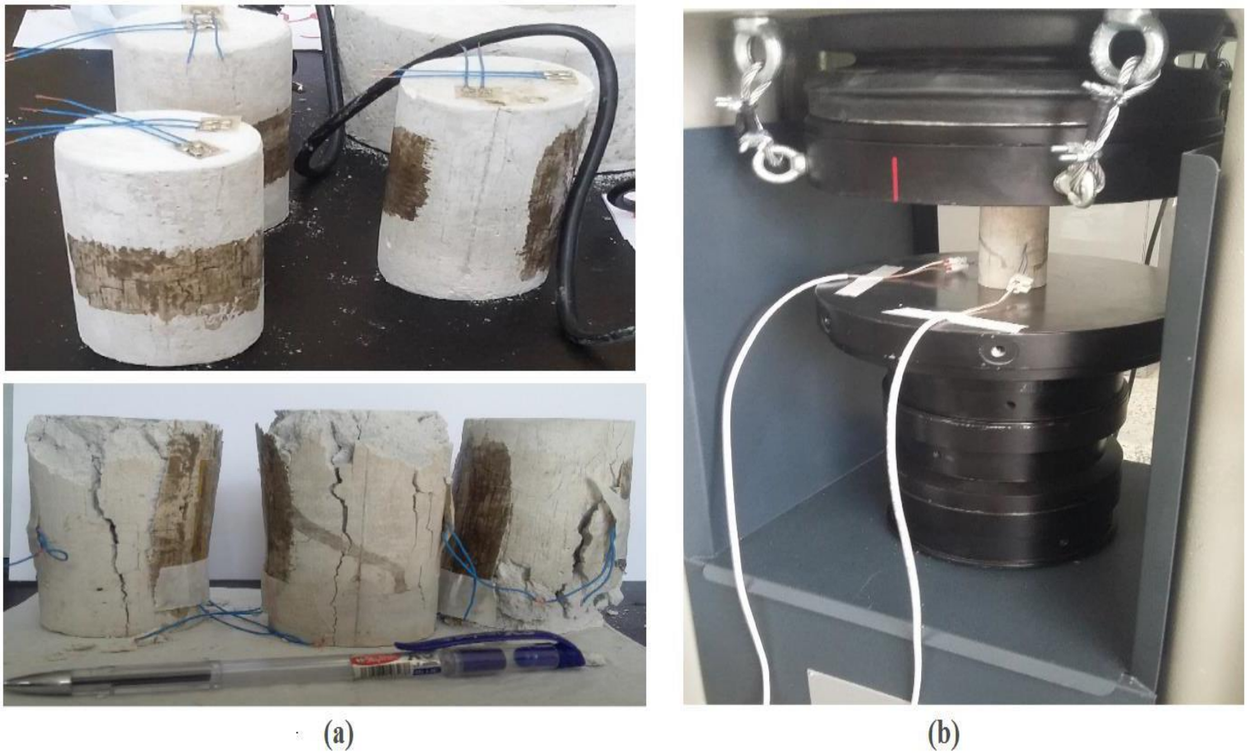


Fig.2 a) Sample before and after loading, b) Sample with strain gauge under the self-controlling loading unit

Table-2. Parameters obtained from uniaxial test

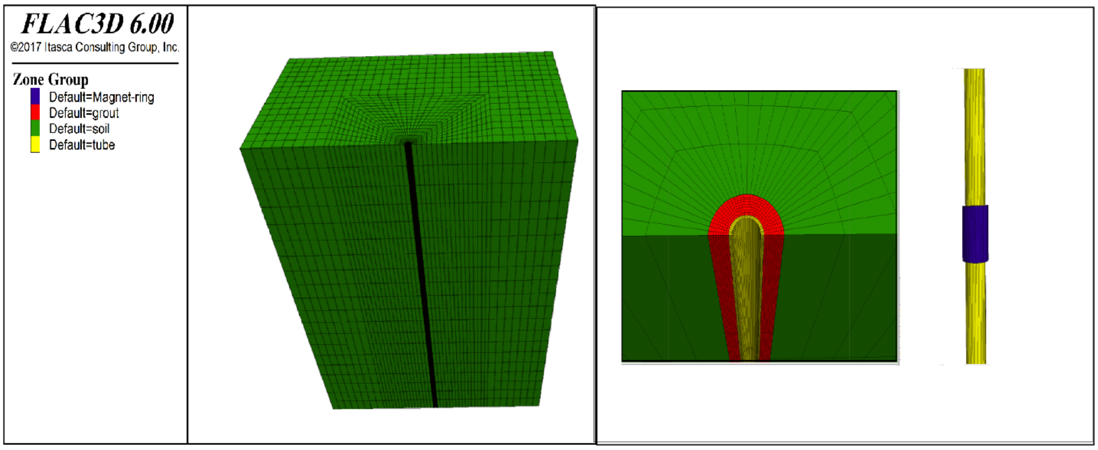
row	Ratio of (B/C) in constant ratio of (W/C=3)	Density (Kg/m^3)	Peak of strength (MPa)	Modulus of elasticity (MPa)	Poisson's ratio
1	0.3	1268	1.18	91	0.26
2	0.4	1166	0.9	79	0.27
3	0.5	1012	0.7	62	0.25

3. NUMERICAL MODELING

In order to investigate the effect of slurry properties on the results of measuring the borehole extensometer, a block was created in FLAC3D. The dimensions of the block is 8 m in length, 4 m in width and 10 m in height. Then a borehole with 0.15 m diameter was generated in the block.

A tube with 70 mm in diameter and 5 mm in thickness was modeled inside the borehole and the magnetic/spider ring is considered as a loop connected to the tube at measuring points 2 and 5 m from the surface of the model. As shown in Fig. 3, the space between the tube and borehole is filled with grout. Due to axisymmetric property of the model, half of model has been used for analysis. The surroundings of the borehole have been considered dry, and no change in volume or creep has been made in the grout.

Constitutive models provide a qualitative description of the materials behavior and other parameters of the material to determine this behavior [9]. A good constitutive model is able to predict the soil response under critical loading constituents, taking into account the actual properties under these critical loads [10]. The FLAC 3D software provides various constitutive models for the user. Among existing models, the Mohr Coulomb model is used to simulate plastic deformations and to show shear failure in soil [11]. The used soil parameters are shown in Table (3).



(a) (b)

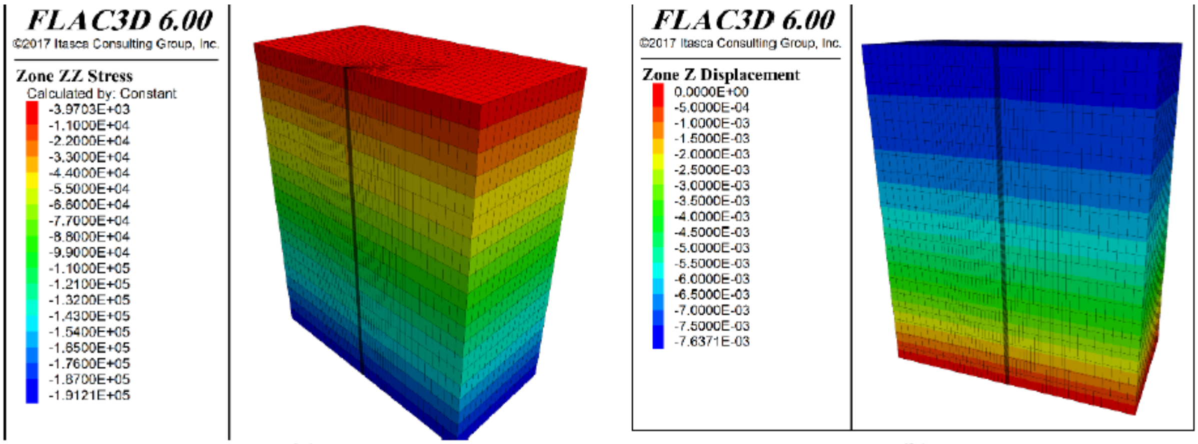
Fig 3-a) Model geometry and its meshing, b) Components of the model include grout, tube and magnetic ring

Table 3. Geomechanical Properties of Soil Types

Row	Parameter	Unit	Soft soil	Medium soil	Stiff soil
1	Density	Kg/m^3	1750	1800	2000
2	Modulus of elasticity	MPa	10	40	80
3	Poisson's ratio	-	0.35	0.3	0.35
4	Internal friction angle	Degree	25	17	38
5	Dilation angle	Degree	0	0	15
6	Cohesion	KPa	3	30	0
7	Interface friction angle	Degree	22	18	28

After applying the boundary conditions, the stress and vertical displacement contour are presented in this study for numerical model verification (Fig. 4).

To determine the error percentage of the extensometer measurement according to Fig. 4, the model is placed under an additional 10 kPa load and the points are located within the grout at a distance of 2.5 m from the borehole axis in the soil environment.



(a) (b)

Fig 4- a) Stress contour, b) Displacement contour

The measured points are indicated by distance (d) from the model surface and the difference between the displacement obtained within the grout (y_c) and its corresponding soil (y_r) is the measurement error. In this study, the percentage of the measurement error of the settlement is obtained from equation (1).

$$\text{Measurement error (\%)} = \frac{y_c - y_r}{y_r} \times 100 \qquad (1)$$

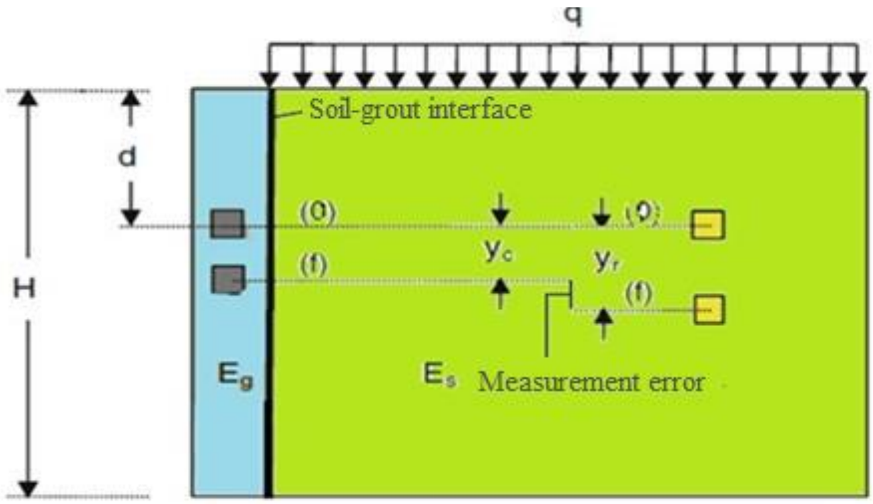


Fig 5- Determination of measurement error

Using the parameters obtained from the uniaxial compressive test presented in Table (2), for all types of soil including soft, medium, and stiff soils, the results are shown in Fig 6.

4. ANALYSIS OF THE RESULTS

Obviously, if the stiffness of grout inside the borehole is equal to the stiffness of the surrounding environment, the displacement of the environment will be transferred to the extensometer more accurately. Therefore, if the stiffness of grout to the stiffness of soil is closer to one, then less error percentage is found. It can also be found from fig (1) that with increasing the percentage of Bentonite to cement, due to reduced stiffness of grout, the measurement error percentage decreases.

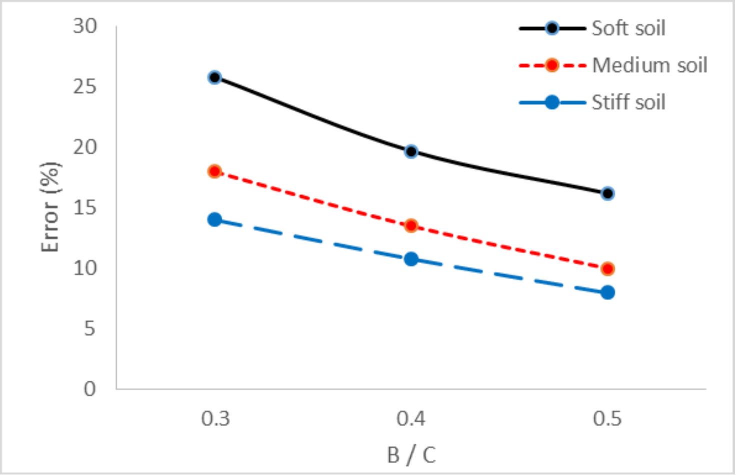


Fig 6- Error percentage of measurement for different ratios of (B / C)

Also a parametric study is carried out on different (Eg/Es) ratios for soft, medium and stiff soils, where Eg is the elastic modulus of the grout and Es is the elastic modulus of the soil. This study is also carried out in 3 states where the cohesion of the interface (between soil and grout) is a coefficient of the soil cohesion (1, 2/3,1/3) and the angle of friction of the various levels has been investigated, and the results are shown in Fig (7), (8) and (9).

According to the fig (2), (3), (4), it can be seen that, the higher the ratio of Eg / Es increases the error percentage of measurement, and if grout stiffness is less than the soil stiffness, the measurement error percentage will be lower, but there will be a borehole stability problem. Also, the closer the interface cohesion is to the soil cohesion, the lower the measurement error percentage and the internal friction angles of the interface also have no effect on the error of measurement.

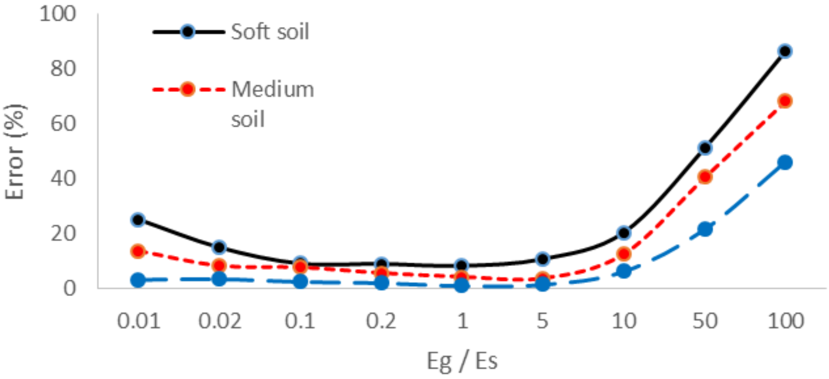
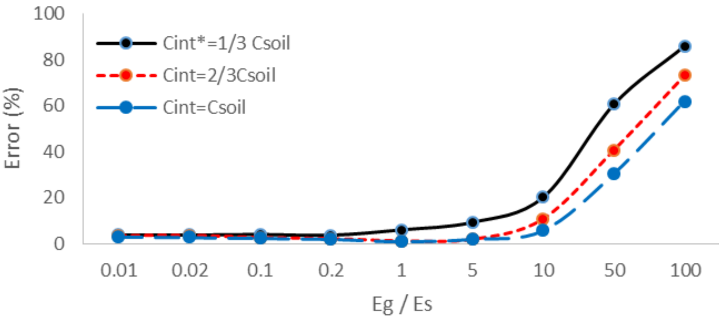


Fig 7- Error percentage of measurement for different (Eg / Es) ratios for different soils



* Interface

Fig.8 Error percentage of measurement with different interface cohesion for different (Eg / Es) ratios for medium soil

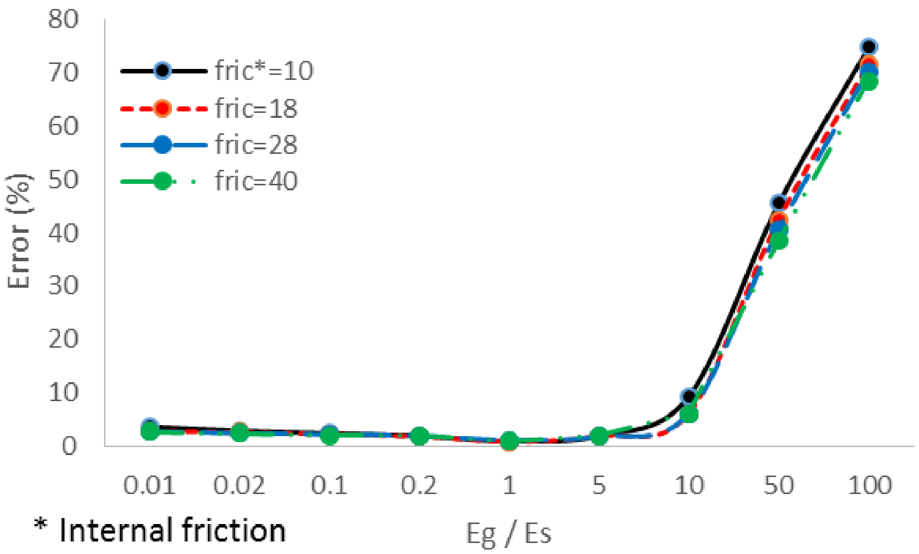


Fig.9 Percentage error of measurement with different friction angles in different ratios of Eg / Es for medium soil

5. CONCLUSIONS

The results of laboratory studies on grout samples show that as the amount of Bentonite to cement ratio increases, the strength and grout stiffness decreases. Also, according to the numerical study, the measurement of the displacement of the extensometer in the borehole is a function of grout stiffness surrounding it. The error percentage of measurement is reduced by increasing the ratio of Bentonite to cement. This reduction in error percentage of measurement is compared in three soft, medium and stiff soil types. Comparison of these results shows that stiff soil is less affected by grout properties and less error percentage will occur. Measurement errors have been increased by increasing the modulus ratio and was not significant for rates of the elastic modulus of (Eg / Es) more than 5% for the three different soil types (soft, medium, and stiff), and the higher error in the soft soil type Is found.

It has also been shown that the grout with less stiffness than the surrounding soil has lower measurement error. The interface cohesion in different ratios of Eg/Es less than 5, has no significant effects on the results, but when this ratio is more than 10 and the closer the interface cohesion to soil cohesion, the lower the measurement error rate, is. Also, the friction angle of the interface was studied, according to the results obtained, these angles do not affect the results of the error percentage.

6. REFERENCES

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