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A parametric study on behavior of plastic concrete material in earth dams

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Abstract

In the current research, the mechanical behavior of plastic concrete in cut-off walls of embankment dams has been investigated. To do so, several triaxial compression tests have been carried out on the specimens with various mix designs under different confining pressures. It has been observed that the compressive strength of such a material increases dramatically with the confining pressures applied on the samples. Moreover, the material behavior is substantially dependent on the confining pressure values; so that, as the confining pressure increases, the material behavior intends to be more ductile. Furthermore, a parametric study has been done to investigate the influence of mix design on these materials. The results showed that the strength and elasticity modulus of plastic concrete increase with the increase of cement factor and decrease of bentonite content. However, the rate of increase is apparently dependent on the mix design changes.

Keywords: Plastic concrete; Mechanical behavior; Cut-off walls; Elastic modulus

1. Introduction

The seepage of water through the earth body of rock-fill and embankment dams as well as their foundations has been one of the most significant issues being regarded as an important factor involved in designing these huge constructions. One of the most common methods utilized to control and minimize the seepage is making use of a plastic concrete cut-off wall constructed in weak foundations of earth dams. Using such a material for construction of cut-off walls is vital especially for those located on weak foundations in seismic regions as assessed by Pashang Pisheh et al.[1]. They conducted an extensive series of numerical analyses to provide the critical depth of liquefiable soils beneath it the influence of seismic excitation of the ground could be neglected. Plastic concrete comprises of sand-gravel aggregates, cement, Na-bentonite and water. This type of concrete has widespread applications in the structure of cut-off walls of the earth dams. This material, due to lower rigidity than normal concrete and its appropriate impermeability, can suitably meet the intended requirements for designing cut-off walls of dams [2]. In literatures, it is recommended that the deformability modulus of this type of material and the adjacent soil be in the same order to have the deformation compatibility [3]. As a guideline, ICOLD recommends that the elastic modulus of plastic concrete should be between 4 to 5 times of the elastic modulus of the surrounding soil [3].

The walls constructed using this type of material, in addition to their characteristics of flexibility and low permeability, have a desirable shear strength and as such, their application to the construction of cut-off walls of rock-fill and earth dams is often more economical than other methods. Besides, this material covers a sufficient physical, chemical, and mechanical durability for the structure's lifetime and shows resistible characteristics against hydraulic fracturing during the impoundment and operation period. Due to the considerable loads applied on the foundation and the cut-off wall, the mechanical properties and behavior of materials used in the construction of such walls are of great significance. Moreover, since there are confining pressures applied on these types of walls in the real condition, there will be an urgent requirement for exact investigation of the possible impacts of triaxial pressures on the mechanical behavior of plastic concrete materials.

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Several researches have been carried out on the mechanical behavior of plastic concrete in unconfined and triaxial compression tests through which the experimental investigations conducted by Pashang Pisheh et al. [4-6] and Mahboubi et al. [7] assessed an extensive range of various mechanical characteristics of such a main material required for construction of cut-off walls of embankment dams. It must be noted that in the current research, the mix proportions of materials suggested by Pashang Pisheh et al. [4-6] were used with some minor revisions to perform the laboratory experiments of the study. Moreover, other researchers performed laboratory tests to evaluate the hydraulic and mechanical behavior of this material [8, 9]. So, the current research aims to study the behavior of plastic concrete materials under triaxial pressures as well as to investigate the impact of different parameters, i.e., the cement and bentonite content and the age of the specimens, on the mechanical behavior of plastic concrete materials. In other words, the primary objective of this paper is to describe the effect of the confining pressures on the triaxial strength of plastic concrete as well as characterize the effects of the time on the response of plastic concrete specimens. The results of this study are considered to be of interest for geotechnical and dam engineers.

2. Material and methods

In the current research, several mixtures of plastic concrete have been proportioned and the significance of various parameters such as cement factor and bentonite content on the properties of plastic concrete has been studied. Plastic concrete specimens were prepared from five different mix designs (T1 to T5) and then were cured until desired ages. In the next stage, the specimens were compressed to failure at confining pressures ranging from 0 to 200, 350, and 500 kPa. The mixture designs and material proportions for the plastic concrete specimens are illustrated in Table 1, where, B is Na-bentonite by mass per cubic meter, C is cement by mass per cubic meter, W is water volume per cubic meter, S and G are sand and gravel aggregates by mass per cubic meter of plastic concrete. It is worth noting that the plastic concrete material prepared for the triaxial compression tests were compacted in cylindrical steel molds with 10 cm in diameter and 20 cm in height and then kept under water for curing in saturated conditions to the required age, at least 28 days. The particle size distribution curve (PSD) of the mixture of sand and gravel aggregates incorporated in the plastic concrete specimens is shown in Fig. 1.

Table 1 Mix proportions of the plastic concrete samples

Mix ID.	C (kg/m ³)	B (kg/m ³)	W (lit/m ³)	W/C	S (kg/m ³)	G (kg/m ³)
T1	160	35	252	1.58	765	875
T2	160	45	252	1.58	765	875
T3	160	25	252	1.58	765	875
T4	140	35	198	1.41	765	875
T5	180	35	306	1.70	765	875

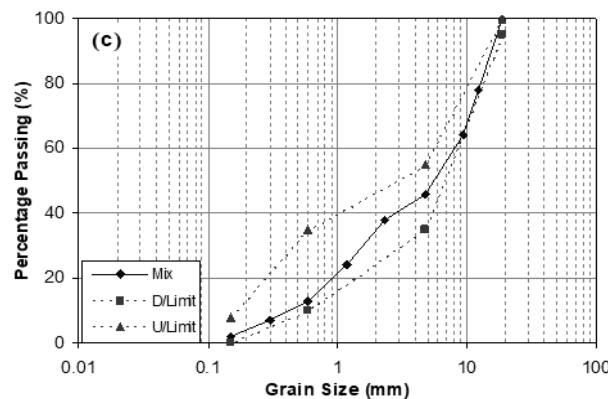


Figure 1 Particle size distribution curves for the mixture of aggregates

It must be noted that the cement used in the mix designs was Type I-425 from Tehran Cement Company and the Na-bentonite was acquired from Salafchegan. The liquid limit and plastic limit of the Na-bentonite used in the current investigation are 293% and 64%, respectively. Owing to the very low permeability and very high water absorption of

bentonite material, this material was mixed with 90% of the water determined for the mix design 24 hours prior to sample preparation. The remaining water content, i.e. 10%, was introduced upon the mixture preparation and adding of cement and aggregates. This scheme ensured that the bentonite particles are uniformly distributed and finally a homogenous mixture is derived.

3. Testing and procedures

To carry out the tests, an automated closed-loop servo controlled triaxial apparatus was incorporated. So, the specimens prepared in the laboratory were insulated by a latex membrane and then were placed in the computer-controlled triaxial system which allowed constant rate of strain (CRS) loading in compression. In such an apparatus, strain controlled loading is applied under various confining pressures. Axial displacement is monitored and controlled by a LVDT with the range and accuracy of 254 mm and 0.02 mm, respectively. The air pressure control system and regulator can provide a cell pressure up to 1000 kPa. As mentioned above, the triaxial tests were performed with the constant confining pressures of 0, 200, 350, and 500 kPa. A photograph of the apparatus during testing is illustrated in Fig. 2.



Figure 2 Plastic concrete specimen during testing

In spite of some researches on the effect of the rate of strain, there is a relatively lack of accepted guidelines for suitable rate of strain for plastic concrete. So, the standard of the soil mechanics should be used which were modified for plastic concrete material. According to the ASTM D2850 [10], brittle soil is one kind of soil that attains maximum axial stress in the range of 3-6%. However, as it is mentioned in the ICOLD bulletin No.51 [3], plastic concrete reaches its stress diversion trend in the range of 0.5-3% of axial strains. Normally, brittle soils are tested in the rate of the strain loading less than 3% per min. Whereas, plastic concrete attain its maximum axial stress in 5 times less than brittle soils. Therefore, for a cylindrical specimen with the height of 200 mm, the loading rate was determined as 0.1 mm/min to minimize the damping effects of loading and to provide the static condition requirements throughout the experiments [11].

4. Results and discussion

4.1. Effect of confining pressure

Fig. 3 summarizes the effect of the confining pressure on the mechanical strength of plastic concrete for specimens from the mix T1. Referring to this figure, when confining pressure increases from 0 to 500 kPa, the values of the deviatoric stress of the material obviously increase. These results are well comparable to those of reported by other researchers [4, 5 and 7]. Fig. 4 shows the response of specimens which were prepared of mix designs T1, T2, and T3 with different bentonite contents. It can be observed that the increase of confining pressure not only causes an increase in the compressive strength but also increases the elastic modulus of plastic concrete specimens.

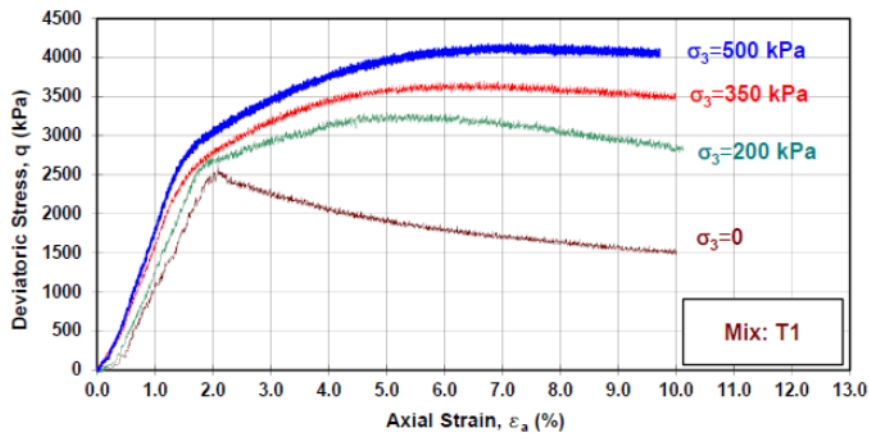


Figure 3 Effect of confining pressure on the deviatoric stress of the material

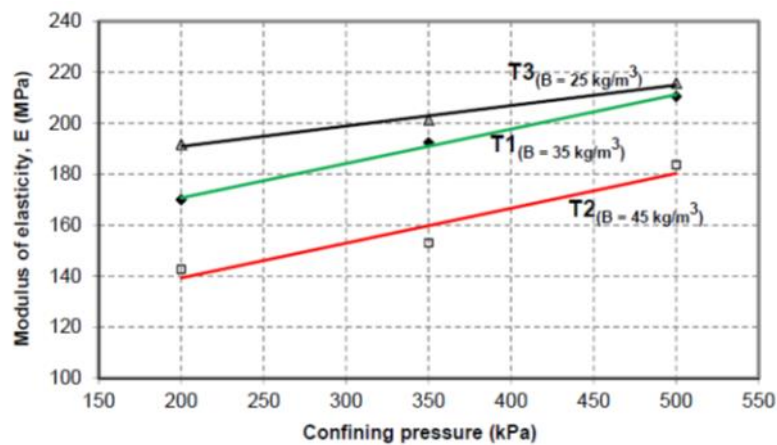


Figure 4 Effect of confining pressure on the elastic modulus

In addition to the above-mentioned results, figure 3 shows that the failure mode of the samples is substantially affected by the changes in the confining pressure. So that, at zero or low amounts of confining pressure, the mode of failure is the same as brittle materials, and the samples fail with an obvious peak strength point followed by strain-softening behavior. For higher values of confining pressure, the specimens behave more likely ductile materials, and the corresponding response exhibits strain-hardening behavior. The above-mentioned behavior has been concluded for very hard cemented materials by previous researchers [4, 5, and 7]. The reason of the difference in this behavior is the fact that, the failure mechanism in low values of confining pressure is governed by the progressive deterioration of the cement bonds between the aggregates, but in high value ones, the shear strength will be mainly governed by the frictional properties of the material [11].

4.2. Effect of cement factor

In the current study, to evaluate the effect of cement factor, several specimens with different values of cement content, i.e., mixes T1, T4, and T5 were triaxially loaded under various confining pressures. As an instance, the result of the tests under confining pressure of 500 kPa is demonstrated in Fig. 5. As predicted, with the increase in the employed cement factor, in a given confining pressure, the peak point of the stress-strain curve and corresponding elastic modulus increase. Moreover, the higher is cement factor, the less is the axial strain corresponding to the peak point of the compressive strength curve. Moreover, Fig. 6 illustrates the effect of cement factor and confining pressure on the elastic modulus parameter. Regarding this figure, the elastic modulus of plastic concrete rises with increasing the cement factor and confining pressure. Furthermore, the augmentation of this parameter with the increase in the cement factor is more evident in the higher values of cement magnitudes. Because in the higher values of cement factor, due to enhancement of the formed cement bonds, the samples behave more likely rigid materials.

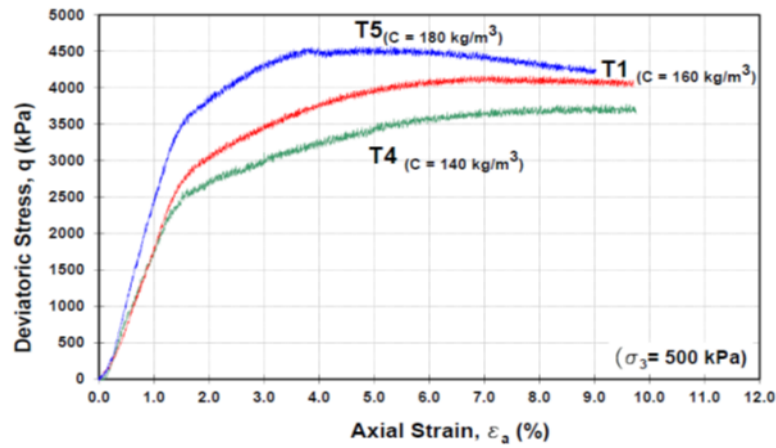


Figure 5 Effect of cement factor on the deviatoric stress of the material

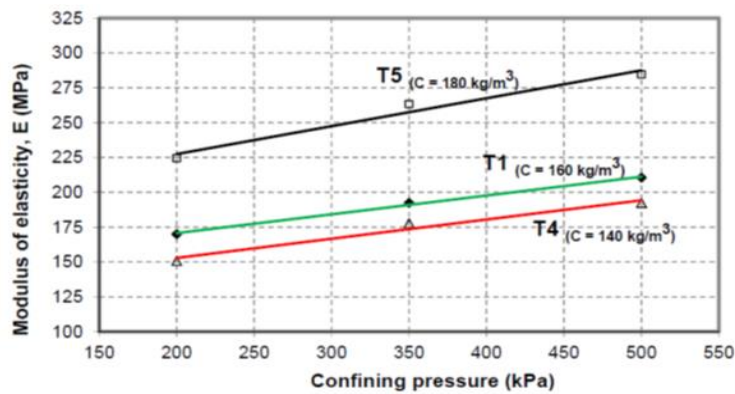


Figure 6 Effect of cement factor on the elastic modulus of the material

4.3. Effect of bentonite content

In this part, to evaluate the bentonite content influence on the plastic concrete behavior, triaxial tests were done on the samples with different values of bentonite content but constant the other mixture proportions. Fig. 7 illustrates, for instance, the results for mixes T1, T2, and T3 with bentonite content varied from 25 to 45 kg/m³ under 350 kPa of confining pressure. As shown in this figure, increasing the bentonite content, the peak point and slope of the linear part of the stress-strain curve presenting respectively the material compressive strength and elastic modulus clearly lessen. This outcome may be attributed to the weakening effect of bentonite particles in the bonds formed between cement material and aggregates and also decreasing the rate of cement hydration in the material.

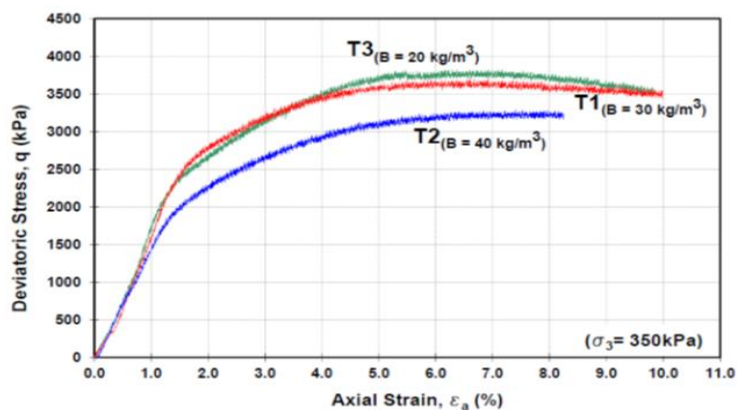


Figure 7 Effect of bentonite content on the deviatoric stress of the material

4.4. Effect of specimens' age

The hydration process of every cementitious material is completed when such a material is cured for a long time [11]. Therefore, for plastic concrete as one of the cementitious materials, the increase of compressive strength is expected due to accomplishment of the cement hydration as well. In the current research, the effect of the age of specimens on the mechanical behavior of the material was studied using triaxial compression tests performed on the samples at different ages of 28 days, 3 and 6 months, and 1 year under different confining pressures. Fig. 8 demonstrates the variation of the elastic modulus of the samples in different ages. As shown, increasing the age of the samples and therefore completion of cement paste hydration, the elastic modulus of the material increases. However, the results indicate that the rate of the increase is more rapid in the early ages of the specimens particularly at the ages lower than 3 months. The same trend in the compressive strength behavior as a function of the age was also previously reported [4 and 5].

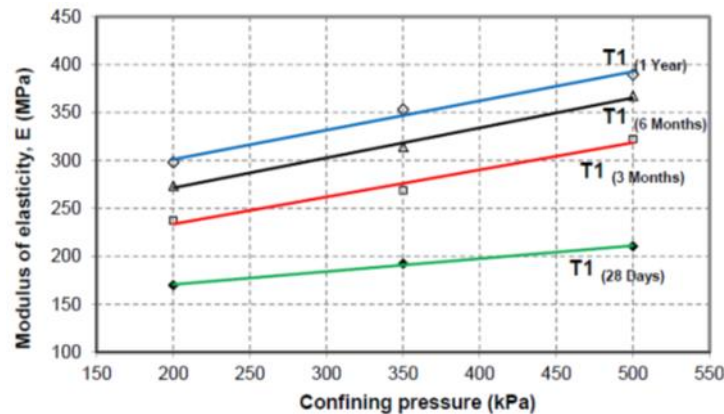


Figure 8 Effect of specimens' age on the elastic modulus of the material

5. Conclusion

The effect of mix design, confining pressure, and age of the plastic concrete specimens on the strength and deformability parameters as well as the failure modes of this type of material was investigated. Based on the findings of the current research, it is concluded that the confining pressure applied on the samples has significant effects on the compressive strength and mechanical behavior of plastic concrete. So that the strength of the material substantially increases with the confining pressure. Moreover, the change in the confining pressure applied on the samples results in variation of failure mode of the specimens and changing the behavior from strain-softening to hardening. It was shown that the strength and elasticity modulus of plastic concrete increase with the increase of cement factor and decrease of bentonite content. The rate of increase is apparently dependent on the mix design changes. So, the results of the current study can widely be used in the design and construction of cut-off walls of plastic concrete in embankment dams.

Compliance with ethical standards

Acknowledgments

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