E3S Web of Conferences **363**, 02014 (2022) https://doi.org/10.1051/e3sconf/202236302014
INTERAGROMASH 2022

The comparative analysis of methods for determining the mechanical performance of macrofragmental soils

Armen Ter-Martirosyan[1*], *Georgiy* Angelo[1], and *Lyubov'* Yermoshina[1]

[1]Moscow State National Research University of Civil Engineering, 26, Yaroslavskoye Shosse, 129337, Moscow, Russia

Abstract. Many researchers, including Marachi, Frost, Varadarajan, Mojtaba, Gupta, Kuznetsov and others, have investigated the mechanical properties of coarse clastic soils. In this work, two methods were considered to determine the strength and deformation characteristics of coarse clastic soil.The first method is based on the determination of normative values for the mechanical properties of coarse clastic soils based on their physical characteristics (developed by the Far Eastern Research Institute for Structural Design and Technology (FERISDT)), and the second method is based on consolidated-drained (CD) tests in a triaxial compression device at five different values of hydrostatic pressure. According to the results of the study carried out in accordance with the two methods, a significant difference in the values of specific cohesion and deformation modulus of the coarse clastic soil was obtained.The values of specific adhesion obtained by FERISDT method are nearly two times lower than those obtained by triaxial tests. While the specific cohesion has been largely influenced by aggregate percentage, the values of in-ternal friction angle and the modulus of deformation changed only slightly.

1 Introduction

Many hydraulic engineering projects, such as earth dams, use as the material for the body of the dam macrofragmental soils with various aggregates. Where an earth dam has to be high, the underlying layers of macrofragmental soils can collapse under the load from overlying soils. The resultant destruction and fragmentation into smaller fragments can reduce the strength and increase deformability. In this context, correctly determined mechanical performance of the dam body soil it is of critical importance [1].

Given the large size of the inclusions in the macrofragmental soils and relevant prescriptions of the testing standards concerning their size, the laboratory testing of the soils is question requires special facilities, which may not be available to each and every testing lab, complicating the description of mechanical performance of macrofragmental soils.

---

* Corresponding author: lyubov.ermoshina1801@mail.ru

Marsal, who conducted a series of large-scale triaxial compression tests on coarse-grained soils (test samples diameter = 113 cm), has found that a factor critical to shear strength and compressibility is fragmentation of the granular material under compression and deviatory loading according to Marsal, R.J. 1967. Large scale testing of rock. In Journal of the Soil Mechanics and Foundations Division 93(2): 27-43.

Fumagalli describes laboratory testing of cohesionless materials of rock-fill dams. His paper outlines the main parameters affecting the compression – grain size distribution curve, shape factor, and initial consolidation degree according to Fumagalli, E. 1969. Tests on Cohesionless Materials for Rocfill Dams. In Journal of the Soil Mechanics and Foundations Division 95(1): 313-332.

Marachi, Chan and Seed explored the performance of dumped rock embankments. The results of their laboratory tests have revealed a certain degree of dependence of the soil internal friction angle on grain size, while the rock material consisting of well-sorted rounded inclusions was found to have better mechanical properties than materials consisting of angular rocks. It was further found that the strength and deformation capacity of the soil samples under testing were influenced also by the pre-stress degree according to Marachi, D.N., Chan, C.K. and Seed, H.B. 1972. Evaluation of properties of rockfill materials. In Journal of the Soil Mechanics and Foundations Division 98(1): 95-114.

Frost conducted a series of tests, in field and laboratory conditions, that sought to explore the performance of stone-and-gravel filling of Mangla and Tarbela earth dams in Pakistan according to Frost, R.J. 1973. Some testing experiences and characteristics of boulder-gravel fills in earth dam. American Society for Testing and Materials. STP 523: 207-233.

Miura and O-Hara conducted a series of triaxial compression tests to investigate the effect of particle fragmentation on the shear strength of granite, which revealed a clear relationship between the particle fragmentation rate and the degree of dilatancy according to Miura, N. & O-Hara, S. 1979. Particle crushing of decomposed granite soil under shear stresses. In Soils and Foundations 19(3): 1–14.

Sharma, Venkatachalam and Animesh Roy have described a method for predicting the behavior of a rock fill prototype exposed to excessive loads, that uses triaxial and uniaxial compression tests according to Sharma, V.M., Venkatachalam, K. & Animesh Roy. 1994. Strength and Deformation Characteristics of Rock-fill Materials. XIII ICSMFE, New Daihi.

Indraratna and Salim have developed an analytical model describing the process of fragmentation of larger inclusions in triaxial loading conditions. Their large-scale triaxial tests allowed to quantify the degree of destruction (crushing) experienced by the larger inclusions during testing. The sample had a diameter of 300 mm and a height of 600 mm according to Indraratna, B. & Salim, W. 2002. Modeling of particle break-age of coarse aggregates incorporating strength and dilatancy. In Geotechnical Engineering 155(4): 243-252.

Varadarajan, Sharma, Venkatachalam, and Gupta have studied the behavior of soils sampled from two different dam sites, using a three-axial compression facility. The first series of samples consisted of rounded particles and the second one of angular particles. As noted by these authors, the two series of samples demonstrated two different behavior patterns: while the soil consisting of rounded particles showed continuous volumetric compression during the test, the soil consisting of compressed particles demonstrated dilatancy during primary compression according to 9. Varadarajan, A., Sharma, K.G., Venkatachalam, K. & Gupta, A.K. 2003. Testing and Modeling Two Rockfill Materials. In Journal of Geotechnical and Geoenvironmental Engineering 129 (3): 206-218.

Ghanbari, Sadeghpour, Mohamadzadeh and Mo-hamadzadeh have conducted two series of large-scale tests – triaxial compression tests and direct shear tests – on the rockfill materials used in the construction of four dams in Iran. According to the test results, the internal friction angle appeared to be 3 to 4 degrees higher during the direct shear test than during the three-axial compression tests, making the authors to conclude that the internal friction angle obtained by direct shear test should use higher safety coefficients [2].

Ashok Gupta investigated the performance of the rock material, sampled from two different sites (Ranjit Sagar Dam and Purulia Dam), by conducting triaxial tests [3].

Aghaei Araei, Soroush, and Rayhani investigated the behavior of rock with rounded and angular inclusions by conducting large-scale triaxial tests and numerical simulations in Plaxis, using an elastic-plastic model of hardening soil. The samples under testing had a diameter of 300 mm and a height of 600 mm. The rate of axial load application was 0.5 mm/min. The conducted studies have shown high reproducibility of numerical modeling and experimentally obtained results [4].

In their joint work, Mojtaba Atashbahar, Reza Jamshidi Chenari and Mir Ahmad Lasht e Neshaei describe the performance of the rock fill sampled from two different sites in Gilan Province, Iran. The large-scale triaxial compression tests, conducted at various compressive pressures, have covered well sorted and poorly sorted material. The authors conclude that the lower the compressive pressure, the more the material is able to expand. Moreover, as the compressive pressure increases, what causes the sample to break is its accumulated axial deformations [5].

Kuznetsov and Verkhozin conducted a comparative analysis of two methods for determining the strength of the macrofragmental soil of Nepsk-Botuobinsk anteclise. The first method involves large-scale direct shear tests according to GOST 20276. The second method uses the methodology developed by the Far Eastern Research Institute for Structural Design and Technology (FERISDT). The two methods have appeared to produce two different results for shear strength. The authors recommend that the strength calculation methods that rely of physical properties of soil should be used with caution [6].

The strength properties of coarse-grained soil have been explored also by Shi, Kai Liu and Jianhua Yin, who conducted a series of direct shear tests on smaller soil samples [7].

2 Materials and methods

For the purpose of determining the strength (c, φ) and deformation (E, ν) performance of macrofragmental soil, our study made use of two methods, one developed by the Far Eastern Research Institute for Structural Design and Technology (FERISDT) and the other involving consolidated-drained (CD) triaxial tests according to GOST 12248.

The FERISDT relies on determining the standard mechanical performance of coarse-grained soils based on physical characteristics. But, along with such basic physical characteristics of soil as density (ρ) and natural water content (W), it is still necessary to determine grain size composition, namely, the percentage of aggregate (P_1), plastic limit (W_P), liquid limit (W_L) and abrasion coefficient (k_e).

To determine the abrasion coefficient, the tests used the abrasion-resistant steel drum and 2 mm sieve.

The macrofragmental soil's strength and deformation testing involved a series of lab tests using the dedicated, certified facility by NPP Geotech (LLC).

This facility comprises a 500 kN kinematic load device, a 2 MPa supercharger, control units, a triaxial compression chamber of type "A" (for samples with a height of 600 mm and a diameter of 300 mm) and a computer installed with ASIS 4.1 software. The general configuration of the facility is shown in Figure 1.

Fig. 1. The triaxial compression test facility (for samples with a height of 600 mm and a diameter of 300 mm).

The macrofragmental soil was tested using disturbed samples with ρ=2.1 g/cm^3 and water content W=10%. Sample preparation involved removal of all particles larger than 50 mm. Figure 2 shows a sample of macrofragmental soil with disturbed structure.

The tests were carried out according to a consolidated-drained scheme at five different hydrostatic pressure levels (100, 400, 650, 800 and 1200 kPa) in a kinematic loading mode at a speed of 0.5 mm/min.

Fig. 2. Disturbed sample of macrofragmental soil.

3 Results

The study has produced the following results.

Prior to the use of FERISDT method, the macrofragmental soil samples were analyzed for physical characteristics; in two samples from one site, percentage of aggregate was determined (Figure 3). The percentage of d≤2 mm aggregate particles was needed for the purpose of calculations. Table 1 shows the macrofragmental soil sample (EGE-1) test results, obtained by FERISDT method.

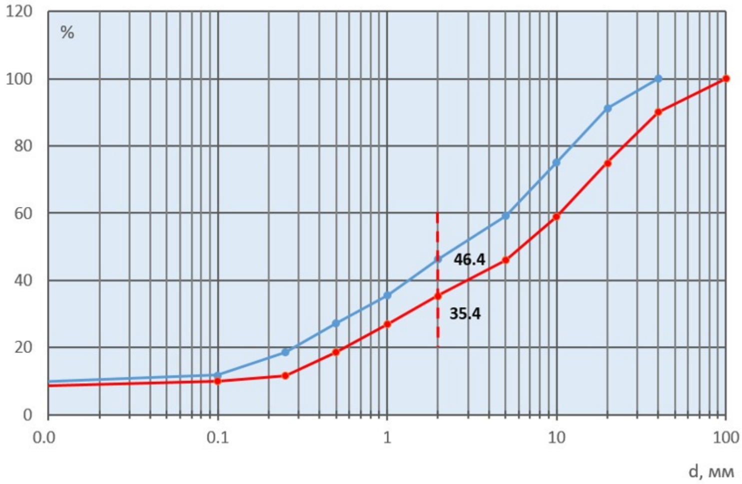

Fig. 3. Grain size composition of EGE-1.

Table 1. Macrofragmental soil tests results obtained by FERISDT method.

Soil sample	Aggregate percentage, P_1, %	Elasticity modulus, *E*, MPa	Specific cohesion, *c*, kPa	Internal friction angle, φ, °
EGE-1	35.4	44.5	28	35.2
	46.4	43.2	34	34.5

To determine the macrofragmental soil's mechanical characteristics, we conducted, in accordance with GOST 12248, a series of triaxial compression tests at five different hydrostatic pressure levels. Based on the results of these tests, Mohr circles were plotted to determine the macrofragmental soil's strength (Figure 4). Table 2 shows the results of tests performed in the triaxial compression device (EGE-1).

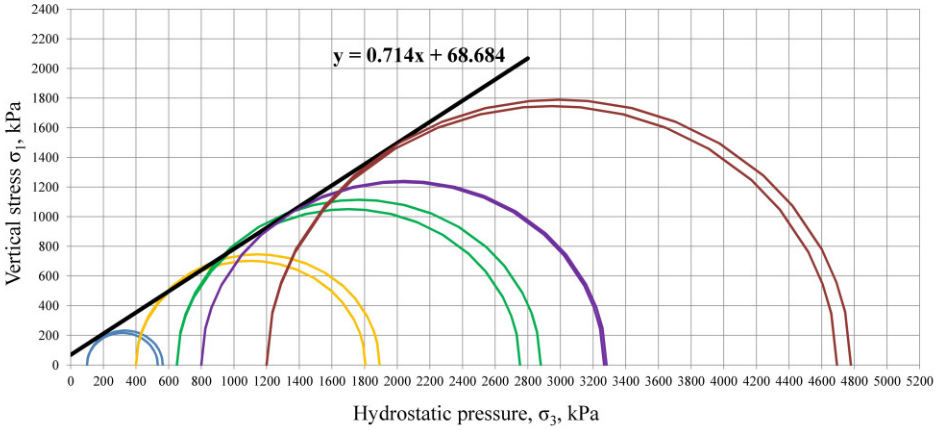

Fig. 4. Coulomb-Mohr diagram.

Table 2. Macrofragmental soil test results obtained by triaxial compression device.

Soil sample	HYdrostatic pressure, σ_3, kPa	Elasticity modulus, *E*, MPa	Specific cohesio, *c*, kPa	Internal friction angle φ,°
EGE-1	100	21.79	68.7	35.5
	400	58.21		
	650	73.75		
	800	101.21		
	1200	140.33		

4 Conclusions

Our study of macrofragmental soil has enabled the following basic conclusions:

1. There is a wide discrepancy between the test results obtained with two different methods – for the specific cohesion and the elasticity modulus of macrofragmental soil. The values of specific adhesion obtained by FERISDT method are nearly two times lower than those obtained by triaxial tests. While the specific cohesion has been largely influenced by aggregate percentage, the values of internal friction angle and the modulus of deformation changed only slightly.

2. As shown by our experimental studies, the results obtained for macrofractural soil by FERISDT method have a number of limitations, which relate primarily to criticality level of

a construction project and the impossibility of determining the Poisson's ratio. FERISDT methodology provides for neither background assumptions, nor the general principle for determining mechanical parameters, which makes the results validation difficult.

3. The mechanical characteristics of macrofragmental soil obtained by FERISDT method must not be used in structural analysis of critical facilities. FERISDT method produces the strength and deformation values that are erroneously low and can increase a project's feasibility and construction costs. Further, the said method is mentioned nowhere in the core regulatory documents (Construction Regulations 22.13330, 23.13330, 39.13330 and 4513330), which, instead, prescribe the use of GOST standards obtained by field and laboratory tests.

4. All things considered, the issue requires further, more in-depth research. FERISDT methodology has potential solely as a method for preliminary estimation of design solutions.

References

1. A. Z. Ter-Martirosyan, A. Yu. Mirny, Integration, Partnership and Innovation in Construction Research (2017)
2. A. Ghanbari, A. H. Sadeghpour, H. Mohamadzadeh, M. Mohamadzadeh, Electronic Journal of Geotechnical Engineering **13** (2008). URL: https://www.mendeley.com/catalogue/adc40957-f5d0-30e5-a79c-9c660aeb6fe0/
3. A. Aghaei Araei, A. Soroush, M. Rayhan, Scientia Iranica **17(3)**, 169-183 (2010). URL: https://www.mendeley.com/catalogue/5c4f45f7-4ab3-362f-be59-6c9d13e468d2/
4. K. Ashok, Gupta, Electronic Journal of Geotechnical Engineering **14** (2009). URL: https://www.scopus.com/record/display.uri?eid=2-s2.0-67650617232&origin=resultslist&sort=plf-f&src=s&st1=Triaxial+behaviour+of+rockfill+materials&nlo=&nlr=&nls=&sid=116b62b3340b3d6d0382232eb3cdc887&sot=b&sdt=cl&cluster=scopubyr%2c%222009%22%2ct&sl=55&s=TITLE-ABS-KEY%28Triaxial+behaviour+of+rockfill+materials%29&relpos=2&citeCnt=22&searchTerm=
5. A. B. Mojtaba et al., *Evaluation of the behavior of rockfill material using large-scale triaxial tests*. In Proceedings of the 2nd International Conference on Geotechnical & Urban Earthquake Engineering, Tabriz, 7-9 September 2015 (2015). URL: https://www.researchgate.net/publication/312021003_Evaluation_of_the_Behavior_of_Rockfill_Material_Using_Large-Scale_Triaxial_Tests
6. N. L. Kuznetsov, I. I. Verhozin, Bulletin of Russian Academy of Natural Sciences' Siberian Office for Earth Sciences. Geology, Exploration and Development of Mineral Deposits **42(1)**, 41-54 (2019). DOI: 10.21285/2541-9455-2019-42-1-41-54
7. X. S. Shi, L. Kai, Y Jianhua, Acta Geotechnica **148** (2020). DOI: 10.1007/s11440-020-01107-3