Proceedings of the 24th European Young Geotechnical Engineers Conference (EYGEC), Durham, UK
Osman, A.S. & Toll, D.G. (Eds.) 2015
ISBN 978-0-9933836-01

Testing behaviour of sand in a triaxial apparatus

Jure Ofak, M.C.E.

Geotehnicki studio Ltd., Nikole Pavića 11, 10000 Zagreb, Croatia

ABSTRACT The paper presents investigation into the behaviour of a sand from Jerovec borrow pit in a triaxial apparatus. Triaxial tests were performed in drained and undrained conditions with the aim to determine the effect of initial state of compacted sand and isotropic compression on shear stress-strain curve, and generally on mechanical properties - stiffness and strength of Jerovec sand.

1 INTRODUCTION

It has been established that initially denser sand specimens in shearing loosen, and loose specimens get denser due to the redistribution of grains in shear zone and phenomenon named *dilatancy*. If dense sand is subjected to large deformation in drained conditions, shear stresses decrease (*material flow*), and the final strength is reached that almost does not depend on the initial density of the specimen. Additionally, sand reaches the final density that also almost does not depend on the initial density of the test specimen, but mostly on average effective stress at failure. Such state is named *critical state*, and the strength that the sand reaches in that state is called *critical state strength*. In diagram which connects void ratio, e, and average effective stress, p', at the *critical state*, final results approach a curve named *critical state line* (*CSL*). The same state is reached, and same line is approached in undrained shearing, due to changes in pore water pressure and resulting changes in effective stresses. (Jeffries and Been, 2006, Zlatović, 2006, Kvasnička and Domitrović 2007, Sokolić, 2010)

2 MATERIAL PROPERTIES OF THE SAND

Sand tested is named Jerovec after its place of origin. The following table shows basic data on the selected sand (Table 1), in comparison with some sands for which numerous test results have been published.

Table 1. The comparison of obtained parameters of JEROVEC sand 100-0,1/1 Smm with parameters of Toyoura, Ticino, Erksak, Boštanj, Portaway that are used for comparing results of a critical state line analysis.

Sand	D_{50} [mm]	FG [%]	G	e_{min}	e_{max}
Jerovec	0,42	0,35	2,59	0,844	0,497
Toyoura	0.16	0	2.65	0.987	0.608
Ticino	0.53	0	2.67	0.890	0.600
Erksak	0.70	0.7	2.66	0.747	0.521
Boštanj	0.12	30	2.75	0.742	0.500
Portaway	0.40	1.5	2.65	0.790	0.460
FG – fine grains < 0,06 mm [%]					

2.1 Grain-size distribution

Four particle size analyses were carried out according to the *ASTM D 422 – 63 (2007)e2 Standard Test Method for Particle-Size Analysis of Soils*, two by *dry sieving* and two by *wet sieving* and results are given in Figure 2-1.

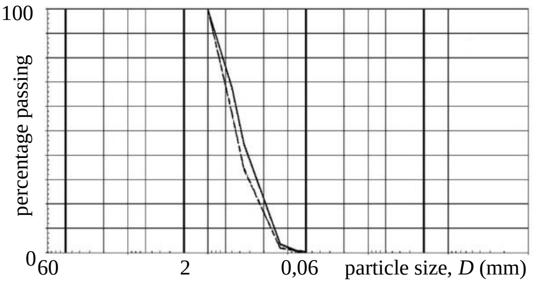

Figure 2-1 Grain-size distribution of Jerovec sand

2.2 Relative density

Relative density, and specific gravity of solid particles were tested according to the *ASTM D854-14 Standard Test Method for Specific Gravity of Soil Solids by Water Pycnometer.* Relative density of soil solids was found to be $\boldsymbol{\rho}_{\mathbf{s20°C}}$ = 2,59 g/cm^3

2.3 Minimum and maximum void ratio

Minimum void ratio, e_{min}, was tested according to the *ASTM Designation: D 4253-00 (2006) Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table*. Figure 2-1 shows the vibrating table with a mould filled with sand.

Maximum void ratio, e_{max}, was tested according to the *ASTM Designation: D 4254-00 (2006) Standard Test Method for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density*. It was also determined using another method. A standardized funnel is used to fill a glass graduated cylinder up to 50% of its capacity with dry sand, and the mass of soil is measured; the volume of sand in the graduate cylinder is then calculated. In another method, dry specimen is poured into a dry graduate cylinder. Third method consists of pouring dry sample in a graduate cylinder with water (a graduate cylinder is filled up to 50% of its capacity with water, so that the sample is completely covered with water).

Figure 2-3 illustrates all three methods of the test, and results are given in Table 1.

Figure 2-2 A mould with a sample and an accelerometer for controlling given parameters for the function of the table with a surcharge weight.

Figure 2-3 Three methods of test for determination of the maximum index density.

3 SPECIMEN PREPARATION METHOD

Wet tamping method was selected in order to obtain desired densities. Sand was dried to a constant mass and defined quantity of water is added to achieve the desired water content of 5%, left overnight to homogenize and tamped into mould. The desired density was obtained with good precision.

4 TRIAXIAL APPARATUS

Triaxial apparatus was constructed in order to test the behaviour of soil during homogenous change of effective stresses and homogenous deformation – primarily to test deformability and strength, but allowing also measurements following wide variety of stress paths. Standard triaxial apparatuses provide axially symmetrical load and deformation.

In this investigation, equipment produced by Controls was used, at the Geotehnicki studio in Zagreb, as shown Figure 4-1.

Figure 4-1 Triaxial apparatus at the Geotehnicki studio Ltd

5 PHASES IN CONSOLIDATED DRAINED AND UNDRAINED TESTS

5.1 The proper installation of a test specimen

The proper installation of the specimen is the first important step in every test. Since the behaviour of soil is highly dependable on the structure of the soil, it is essential to preserve the original structure, even if the specimens are prepared in a laboratory, as it is presented in this paper.

Closing of the cell and similar procedures must be performed with great care not to cause disturbances of the specimen.

5.2 Saturation of a specimen

Degree of saturation, S_r, is the ratio of water volume and pore volume in the soil specimen.

$$S_r = \frac{V_w}{V_p}$$

This paper presents drained and undrained triaxial shear tests on fully saturated sand specimens.

Degree of saturation equal to 1 or 100% corresponds to the value of *pore pressure coefficient B*, equal B=1.

$$B = \frac{\Delta u}{\Delta \sigma_3}$$

In order to check the degree of saturation or the value of parameter B, the specimen in the triaxial test is loaded only with a small and slow enough increase in the cell pressure that affects the sample isotropically (vents have to be closed). A pore pressure transducer measures the value (increase) of pore pressure in the sample which is compared to the increase of cell pressure. If the values are equal, parameter B is B=1, i.e. the sample is fully saturated.

In order to provide full saturation of a specimen, *back pressure* was imposed, in parallel to the increase of cell pressure for the same amount, in order to avoid the change of effective stress. This was repeated until a specimen was fully saturated.

5.3 Consolidation of a specimen

Loading the sample must be sufficiently slow in order not to disturb soil structure, and in consolidation phase drains are open, i.e. the volume of soil can change. Specimens are most frequently loaded isotropically, although in general better results can be obtained with K_0 conditions when isotropic and axial load are increased alternately and gradually so that the permanent horizontal deformation remains close enough to zero. The tests in which the change of volume is not permitted are often carried out, and those are unconsolidated undrained tests. In this investigation, all the tests were consolidated isotropically.

5.4 Specimen shearing

Specimen shearing is in general an increase of axial load or imposing axial deformation. In this investigation, monotonic tests up to failure were carried out.

There are two main types of tests:

(a) *drained* tests during which drains are open, i.e. water can flow in or out of the specimen (*Consolidated Drained*, *Consolidated Isotropically Drained – CID* if the test sample is isotropically loaded in the consolidation phase) and

(b) *undrained* tests during which drains are closed during shearing, i.e. if the test sample is saturated, the volume of the specimen does not change (*Consolidated Undrained, Consolidated Isotropically Undrained – CIU* if the test specimens isotropically loaded in the consolidation phase).

Both groups of tests were performed in this investigation.

6 TEST RESULTS

A total of nine triaxial shear tests were carried out: four consolidated drained tests (CID) and five consolidated undrained tests (CIU).

Test results are presented in five diagrams:

1. diagram of *deviatoric stress*, *q*, versus *average effective stress*, *p'*,
2. diagram of *void radio*, *e*, *versus average effective stress*, *p'*,
3. diagram of *deviatoric stress*, *q* versus *relative longitudinal deformation*, ε_q,
4. diagram of *change of volume*, ε_v versus *relative longitudinal deformation*, ε_q,
5. diagram of *change of pore pressure*, *Δu* versus *relative longitudinal deformation*, ε_q.

Table 6-1 shows main parameters of tests: initial void ratios and initial average effective stresses, as well as data at the end of each test.

Table 6-1 Parameters of CID and CIU tests performed

TEST	MARK	e_0	p'_0 [kPa]	e_{cs}	p_{cs} [kPa]
CID	CID_01	0,776	100	0,870	156
	CID_02	0,762	250	0,790	431
	CID_03	0,747	750	0,710	1234
	CID_04	0,801	250	0,790	424
CIU	CIU_01	0,772	100	0,770	495
	CIU_02	0,755	250	0,750	510
	CIU_03	0,721	750	0,720	849
	CIU_04	0,801	250	0,800	343
	CIU_05	0,765	750	0,765	648

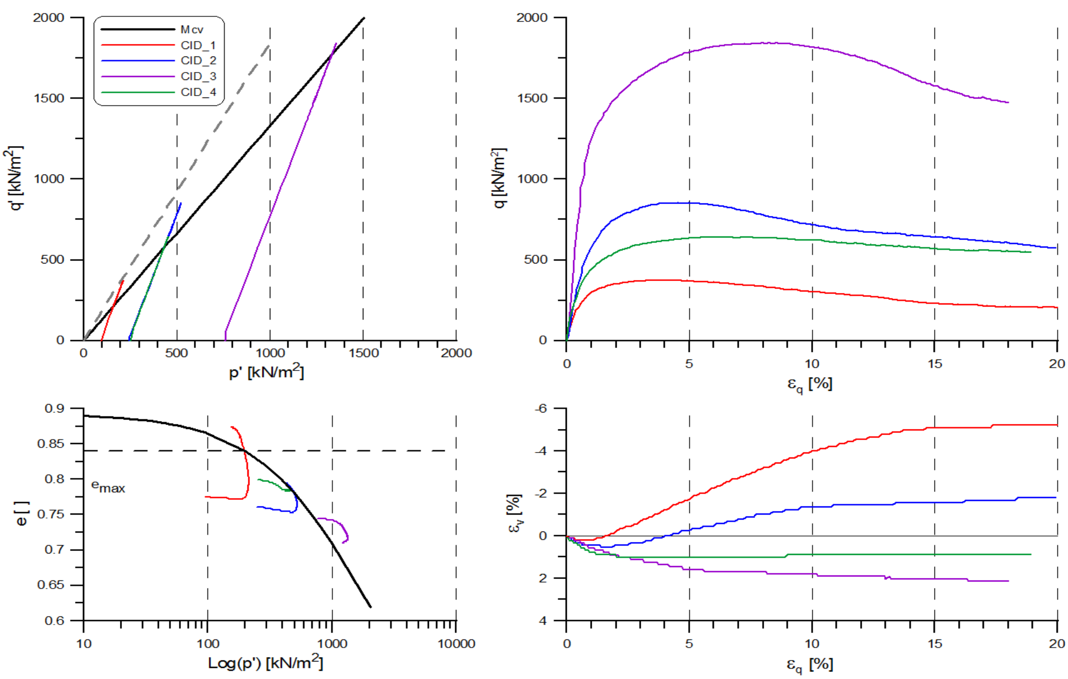

Figure 6-1 The results of CID tests on Jerovec sand

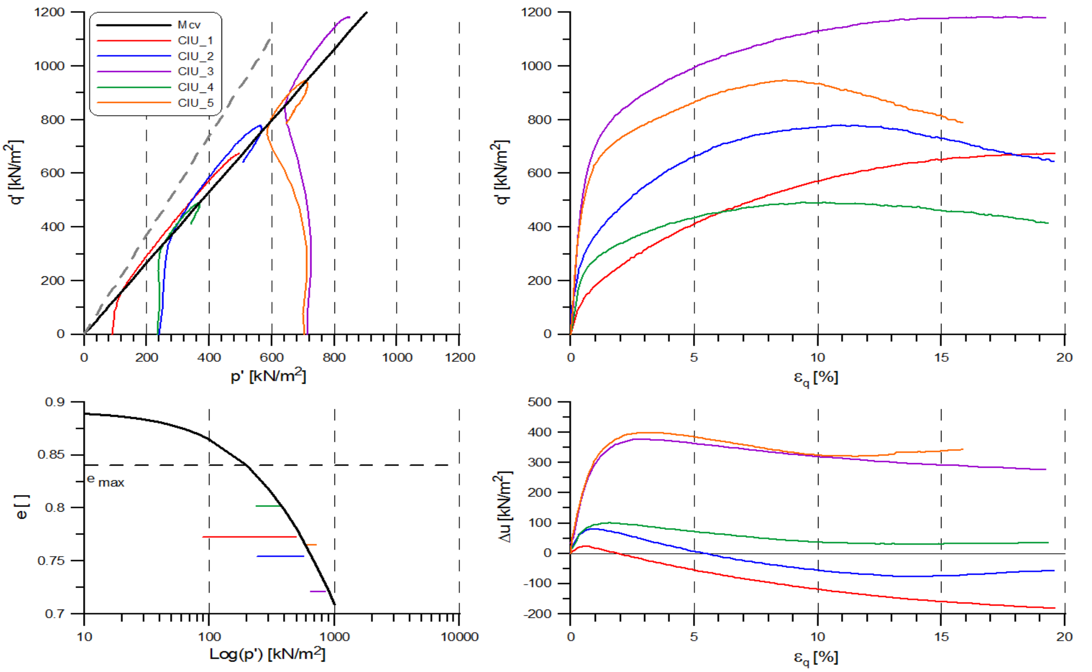

Figure 6-2 The results of CIU tests on Jerovec sand

Figures 6-1 and Figure 6-2 show the collective results for four CID and five CIU tests respectively. The analysis of these results is in accordance with the known behaviour of sand, as it is described in the introduction.

Stiffnesses ($\delta q/\delta\varepsilon_1$ or q/ε_1) in drained and undrained tests is not equal.

If the volume of a specimen decreases, stiffness in undrained tests is higher than stiffness in drained conditions. If the volume of a specimen increases in drained conditions it is the opposite.

All the specimens in all test show tendency towards the unique line in the diagram connecting *void radio, e, versus average effective stress, p'*, shown in lower left part of both Figure 6-1 and 6-2, being the critical state line of the Jerovec sand.

Figure 6-3 shows the data corresponding to the ends of tests on Jerovec sand and the resulting critical state line of Jerovec sand compared with the critical state lines of some well known sands.

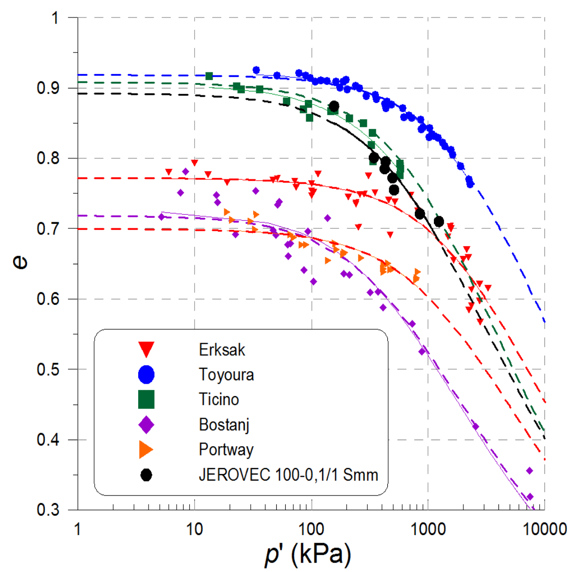

Figure 6-3 The critical state line of Jerovec sand in comparison with the critical state lines of some other well known sands

7 CONCLUSION

The test programme was made to investigate the basic elements of mechanical behaviour of sand Jerovec. A total of nine triaxial tests (four CID and five CIU) were carried out. Tests were performed for different densities of sand ($I_d = 0 \div 0{,}25$) and for different isotropic consolidation pressures ($\sigma'_c = 100 \div 750$ kPa). Specific properties of the behaviour of this sand are described and presented in diagrams q-p'; e-p'; q-ε_q; ε_v-ε_q in Figure 6-1 for CID tests, and in diagrams q-p', e-p', q-ε_q, Δu- ε_q in Figure 6-2 for CIU tests. It can be believed that the critical state was almost reached, and the values of the pairs e, p' at the end of the tests together with the critical state line of Jerovec sand is presented and compared with the critical state lines for some well known sands in Figure 6-3.

A relatively low dispersion of test results shows that the test programme was carried out in a proper way, and the obtained values fit in the expected range of results of sand testing well known to the international geotechnical community.

ACKNOWLEDGEMENTS

Laboratory tests presented in this paper were performed in the Geotechnical laboratory of Geotehnicki studio Ltd. and results are part of the Diploma thesis of the author. Author wishes to express his gratitude to Professor Sonja Zlatović, PhD (Polytechnic of Zagreb, Croatia) and Igor Sokolić, PhD (Geotehnicki studio Ltd., Zagreb, Croatia).

REFERENCES

Jefferies, M., Been, K., 2006. *Soil Liquefaction - A critical state approach,* CRC Press

Kvasnička, P., Domitrović, D., 2007. *Soil Mechanics,* University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Zagreb (in Croatian)

Sokolić, I., 2010. *A sand model embedded into the generalized Iwan system,* PhD thesis, University of Zagreb, Faculty of Civil Engineering, Zagreb (in Croatian)

Zlatović, S., 2006. *Introduction to Soil Mechanics,* The Polytechnic of Zagreb, Zagreb (in Croatian)