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Use of calibration chamber as a large triaxial apparatus

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A segment of the gravel column, 1 m high and 0,53 m in diameter, was modeled in the calibration chamber. The reconstituted sample was consolidated at given confining pressure and than subjected to axial load exerted by the upper and lower membranes. Volumetric changes in both membranes and in the internal chamber were measured. Up to 2 % of vertical strain was reached and internal friction angle was evaluated. Secant modulus of deformation was determined at large strains and at intermediate strain level in the unloading – reloading cycle. For the latter several times higher modulus was found.

Keywords: calibration chamber, triaxial test, friction angle, deformation modulus, gravel

1. Introduction

Laboratory derermination of the shear strength and deformation characteristics of the gravely soils or composite materials needs a large scale apparatus to accommodate grain size. Large size direct shear box was constructed to study the shear strength of railway ballast, Bolt (1991) or of gravelly surface layers in slope stability analysis, Fannin et al. (2005). The tests performed at small vertical stress applied to the box give internal friction angle of gravelly soils even higher than 50 degrees. A new in-situ direct shear test was constructed and applied to study the resistance to translation forces the block samples of coarse grained material, Matsuoka et al. (2001) and Fannin et al. (2005). Here, the shear strength of the undisturbed material in its natural state can be determined.

In order to evaluate deformation characteristics of gravels at small strain a large triaxial cell equipped with local strain measurements was used, Flora et al. (1994). The needs for local strain measurements in gravel specimen is even more important than for the tests on sand. Here, some LDT based system are used, Flavigny et al. (1991), Tatsuoka et al. (1994), Da Re et al. (2001) or seismic wave propagation methods with bender elements, Brignoli et al. (1997), Fioravante et al. (2001), within the small strain elastic region. Stiffness of gravely soils to small strains was also studied in calibration chamber using compression and shear waves propagation, Brignoli et al. (1997).

Gravel columns are often used to reinforce soft subsoil and improve its drainage characteristics, Gryczmański (1993). A 1 m segment of a gravel column was modeled in the calibration chamber at Gdańsk University of Technology (GUT). Laboratory determination of the shear strength and deformation characteristics of gravel columns material at large and intermediate strains is the objective of this study.

2. Test description

2.1 Calibration chamber device

The calibration chamber built at GUT enables large size soil samples (Fig.1) to be tested in well defined boundary conditions. It is double-wall chamber with independent pressure control in internal and external chambers, which permits complex boundary conditions to be applied. The massif of the soil is confined in the rubber membrane. Vertical stress to the specimen is applied by the top and the bottom membranes, inflated with water. The water pressure in internal chamber is transmitted to the sample as a lateral stress. In this way some kind of triaxial system is realised. Due to important size of the specimen the vertical pressures in the upper and lower membranes are different and the lateral stress changes on its height. While at high confining stress this increase can be considered negligible, it is quite important in case of the physical modeling of gravel column, executed at small depths. A section of a gravel column, with a length of 1,0 m and 0,53 m in diameter, is modeled in the calibration chamber. The behaviour of the column section at given depth can be analysed using different horizontal stress applied in the chamber.

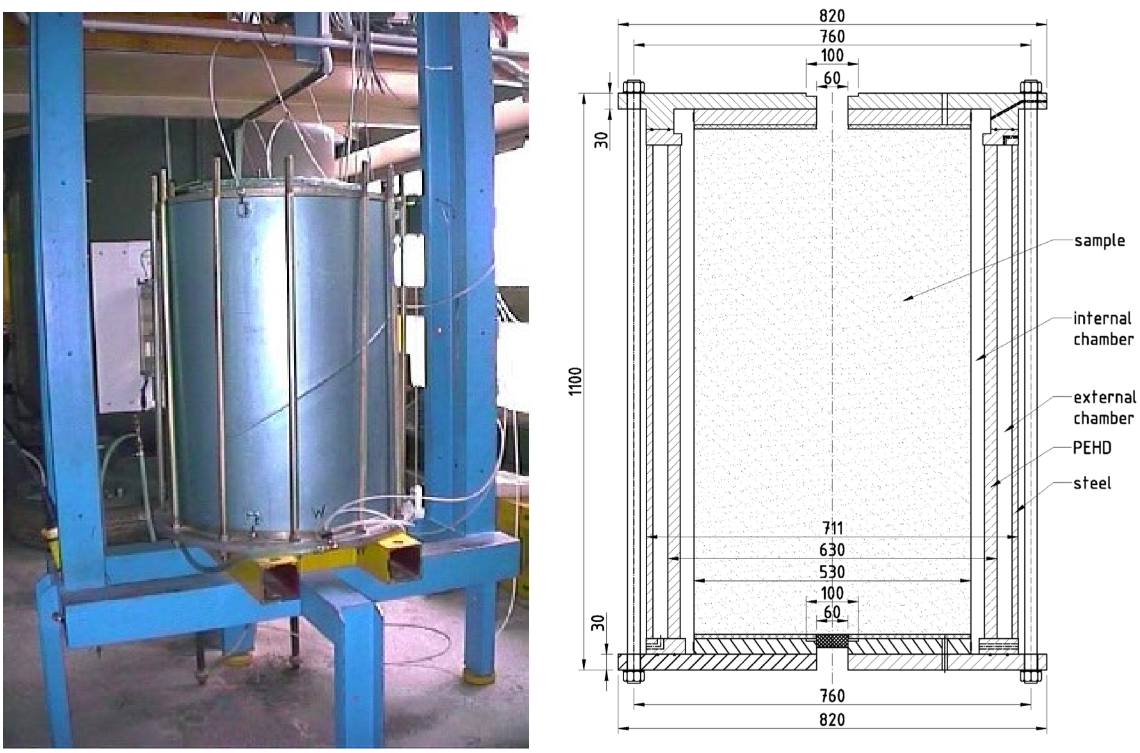

Figure 1. View and cross-section of the calibration chamber at Gdańsk UT, Bałachowski and Dembicki, 2003

Volumetric changes of the specimen are measured in air-water columns mounted on the control panel (Fig.2) and equipped with micropulse transducers BTL2. The position of the floating element in the column is used to determine the water volume expulsed or injected into the soil specimen. Level monitoring with floating element is characterized with high precision and linearity. Deformations of the air-water column itself are compensated with double wall construction.

Figure 2. Air-water column with level monitoring with micropulse transducers

2.2 Sample preparation

Well-graded (U=11,1) sandstone material with angular grains was used with d_{10} = 1,8 mm, d_{50} = 9,5 mm and d_{90} = 21,0 mm. The gravel specimen was reconstituted with five layers, each of them was mechanically compacted at natural water content of 3%. Special care was paid to avoid the membrane cut during compaction. The sample was consolidated at given confining pressure. Three confining pressures σ_3 applied in the mid-hight of the sample were used : 30 kPa, 50 kPa and 70 kPa. Volumetric changes and water pressure in the upper and lower membranes and within internal chamber were measured during consolidation and the loading phase.

3. Test results

Vertical stress (membrane pressure) applied to the specimen was steadily increased with horizontal stress kept constant in the internal and external chambers. Vertical strain ε_1 was calculated on the sum of volumetric changes in the upper and lower membranes (Fig.3). Larger volumetric changes are recorded in the upper membrane than in the lower one.

With equal stress applied in the internal and external chambers, the measuring (internal) chamber does not deform laterally. As vertical deformations of the chamber are also restricted, the volumetric changes within the specimen can be precisely determined with the measurements in the internal chamber. After initial contractancy some dilatancy of the specimen is obtained at larger strains (see volumetric changes recorded in the inner chamber).

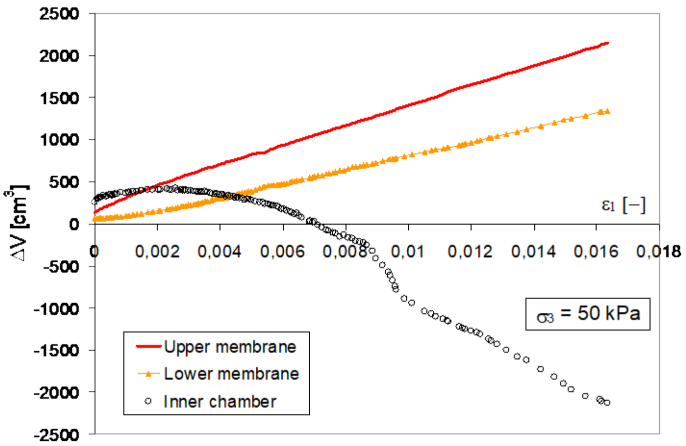

Figure 3. Volumetric changes recorded during consolidation and shearing at confining pressure of 50 kPa

The sample section during the shearing was corrected according to formula:

$$A_i = A_0(1-\varepsilon_1) \tag{1}$$

where:

A_0 - sample section after consolidation

The compression test was realised up to relative stabilisation of the deviator stress, observed for ε_1 close to 2% (see Fig.4). Any peak stress was reached within this strain range. Further membrane inflation could induce, however, non-uniform stress distribution on the lower and upper surface of the soil mass. Moreover, large volumetric changes observed in the membranes and internal chamber could not be accommodated by the measuring system designed for smaller volume variation during typical calibration chamber test on sand specimen. During the loading test the measuring chambers (Fig.2) were filled up with water a few times. These experimental difficulties induced some irregularities (Fig.4 and Fig.5) to the recorded values of volumetric changes. While a gravel column is steadily contractant for the horizontal stress of 70 kPa (Fig.5), some dilatancy is observed at lower confining pressures.

At the load beginning the membrane adjustment is observed due to grain rearrangement and grain penetration. This initial part of stress-strain curve is omitted in the calculation of deformation modulus. The tangent deformation modulus E_t (Table 1) is calculated :

$$E_t = \frac{\dot{\sigma}_1 - \sigma_3}{\dot{\varepsilon}_1} \tag{2}$$

where:

$\dot{\sigma}_1$ - increment of vertical stress,

$\dot{\varepsilon}_1$ - increment of vertical strain.

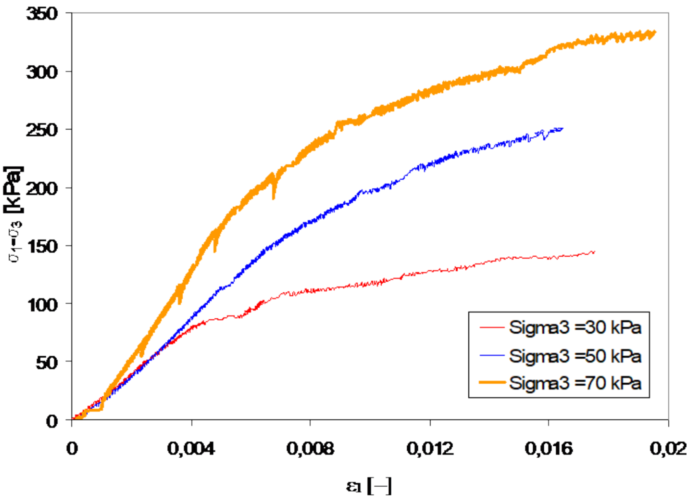

Figure 4. Deviator stress for different confining pressures

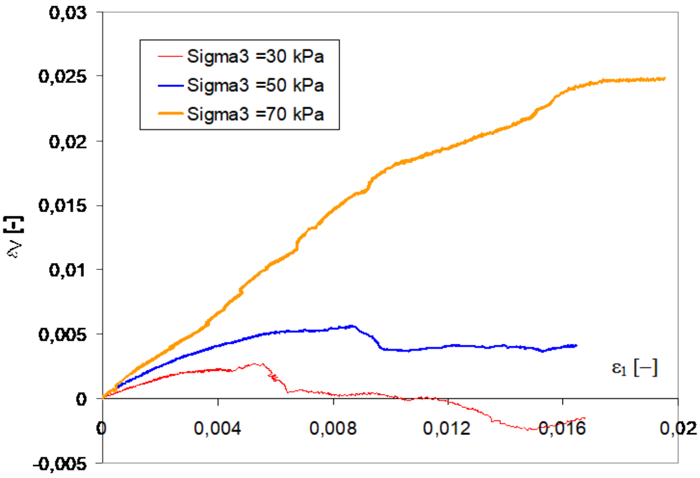

Figure 5. Volumetric strain for different confining pressures

Large strain tangent modulus is determined for the vertical strain increase of about 0,2 %. Deformation modulus increases generally with confining pressure (Table 1). During some compression tests small unload-reload loops, with a amplitude of 20 kPa, were also realised (Fig.6). The unloading-reloading secant modulus at lateral stress of 70 kPa corresponds to the vertical strain increase of about 0,01 %. Higher unload-reload modulus is found in each following loop due to soil densification, grain rearrangement and vertical stress increase during the loading. This intermediate strain modulus is several times higher than the corresponding large strain modulus.

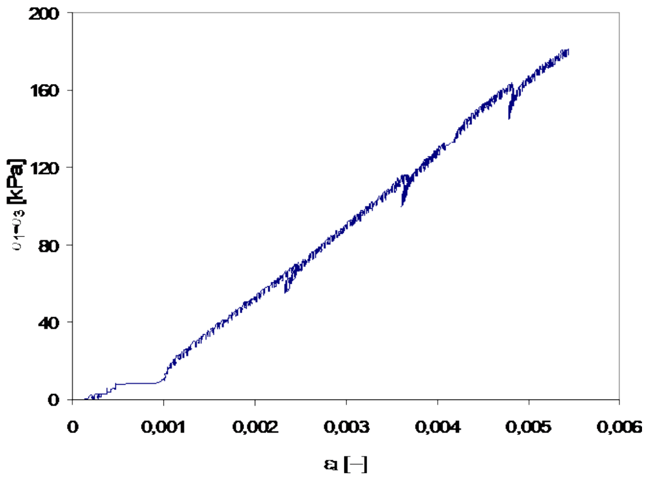

Figure 6. Deviator stress with unloading-reloading loops at confining pressure of 70 kPa

Table 1. Deformation moduli of the gravel column

σ_3 [kPa]	Modulus of deformation	
	tangent $E_{0,2\%}$ [MPa]	secant $E_{0,01\%}$ [MPa]
30	21,6	-
50	26,5	-
70	38,5	85,6 at ε_1 = 0,24% 109,8 at ε_1 = 0,37% 136,0 at ε_1 = 0,48%

The angle of internal friction was evaluated (Table 2) at the maximum vertical strain according to formula:

$$\phi = \arcsin \frac{\sigma_{1\max} - \sigma_3}{\sigma_{1\max} + \sigma_3} \tag{3}$$

where:

σ_3 – confining pressure,

σ_{1max} – maximum vertical stress applied to the sample.

Table 2. Values of internal friction angle

σ_3 [kPa]	30	50	70
ϕ [°]	44,4	45,6	44,6

4. Discussion

Quite low values of tangent deformation modulus of the gravel column are estimated in the calibration chamber. Embedment conditions on the upper and lower surface of the specimen play here an important role. Flavigny et al. (1991) studied the effect of friction conditions and sample elongation on the shear strength mobilisation and volumetric changes in triaxial tests on fine Hostun sand. For friction top and bottom plates and elongated samples the deformation modulus was from 1,2 to 1,35 times higher than for the specimen with height-diameter ratio equal 1 and lubricated ends. Larger difference was observed for tangent modulus than for the secant one. An intermediate condition – between the rough and lubricated ends - is present on the top and bottom surface of the specimen in the calibration chamber. More uniform stress distribution over the upper and lower surface of the sample should be expected for the membrane filled with water than in case of rigid end plates.

The membranes were additionally protected against grain penetration, however some penetration can still occur. This phenomena will increase the calculated vertical strain and it will diminish the estimated deformation modulus. Quasi-elastic deformation modulus determined in the unloading-reloading cycle is practically uninfluenced by the grain penetration.

One should notice that the deformation moduli of a real gravel column will be higher than determined in the calibration chamber due to :

- higher compaction of the executed column than that reconstituted in laboratory,
- more rigid conditions on the boundaries applied to the real column segment than to the soil mass in calibration chamber,
- the surrounding soft soil which will restrict to some extent the lateral deformations of the column. Intermediate conditions between constant lateral stress and no-volume changes test should be applied. The test with the imposed lateral stiffness will model the influence of the surrounding soil. This influence does not seem to be essential in the modeling of the gravel column.
- the transfer of vertical load not only on the column head but to the surrounding soft soil as well. This complex transfer mechanism, function of the column distribution, distance, relative stiffness of the soft soil and column, depends also on the consolidation of the soft soil, Gryczmański (1997). It can be thus time dependent.

Only global volumetric changes were recorded during the tests. Some local strain measurements would be however possible with displacement gauges or proximity transducers mounted on the membrane. Contrary to triaxial apparatus it is not possible to observe neither the failure mode nor deformation localisation within the specimen in the calibration chamber.

Calibration chamber could also be applied to study some composites like tire chips/shreds – sand mixtures, Gotteland et al. (2005). Some CPT/ DMT penetration tests could be performed in the composite mass which was not possible in the compacted gravel column. The deformation characteristics of the composite could be related to the deformation modulus from DMT and the internal friction angle to the cone resistance in the calibration chamber.

5. Conclusions

As the gravel characteristics are hardly studied in a typical triaxial test, they were determined during a loading test in the calibration chamber. A segment of the gravel column was modeled in the calibration chamber with constant lateral stress condition. The behaviour of the column segment at given depth was analysed using different horizontal stress applied in the chamber. Deformation moduli were determined at large and intermediate strains. A several times higher deformation modulus was determined at unloading-reloading cycle than at large strains. The angle of internal friction of the gravel was estimated at the maximum vertical strain of about 2 %. High values of internal friction angle close to 45 degrees are obtained.

The tests on gravel specimen in the calibration chamber are however time consuming and troublesome, with a possible membrane cut and large volumetric changes not accommodated by the measuring system. The application of the calibration chamber as a large size triaxial device is limited to relatively small, about 2 %, vertical strain imposed by the membranes inflated with water. Larger volumetric changes in the lower and upper membranes could induce non uniform stress and strain distribution on the column surface. Such a level of vertical strain is however not sufficient to approach failure for all specimen and especially for composite soils. Some data concerning deformation characteristics of soil mass can be still deduced. In certain materials, like sand-tire chips/ shreds mixtures, calibration chamber could be used to determine deformation characteristics of the composite. As an advantage, a penetration test in calibration chamber could be moreover performed on the same specimen.

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Komora kalibracyjna jako wielkowymiarowy aparat trójosiowego ściskania

Wycinek kolumny żwirowej o długości 1 m i średnicy 0,53 m modelowano w komorze kalibracyjnej. Uformowaną i zagęszczoną próbkę konsolidowano przy zadanym naprężeniu w komorze, a następnie zwiększano naprężenia pionowe mierząc zmiany objętościowe w membranach górnej i dolnej oraz komorze wewnętrznej aparatu. Badania prowadzono do uzyskania odkształcenia pionowego próbki około 2 %, przy której występuje względna stabilizacja dewiatora naprężenia. Określono wartości kąta tarcia wewnętrznego oraz moduły odkształcenia masywu gruntowego przy dużych odkształceniach (0,5 %) oraz w cyklu odciążenie – powtórne obciążenie. W ostatnim przypadku uzyskano wielokrotnie większe wartości modułu odkształcenia. Zastosowanie komory kalibracyjnej jako wielowymiarowego aparatu trójosiowego ściskania należy ograniczyć do zakresu odkształceń pionowych nie większych niż 2 %. Poza tym zakresem, naprężenia oraz przemieszczenia, przekazywane na grunt przez membrany wypełnione wodą, mogą być nierównomiernie rozłożone. W niektórych gruntach możliwe jest przeprowadzenie testu obciążenia masywu gruntowego w komorze z wykonaniem sondowania statycznego lub badania dylatometrycznego w komorze kalibracyjnej na tej samej próbce gruntu.