Measurement of K_o in the Triaxial Apparatus

Mésure du K_o dans l'Appareil Triaxial

L. PRUŠKA Asoc. Prof., Chief Research Worker, Czechoslovak Academy of Sciences, Institute of Theoretical and Applied Mechanics, Praha, Czechoslovakia

SYNOPSIS The pressure at rest of fully saturated dense Vltava river sand was determined by a special procedure. The samples were loaded in a triaxial test apparatus monotonously along seven different loading paths, with the measurements of the vertical force, cell pressure, vertical strain and the quantity of water expelled from the sample. Horizontal strain was calculated. From the assumption that the function $\varepsilon_r = F\ (\Delta\sigma'_3 : \Delta\sigma'_1)$ between the minimum positive and the minimum negative measured horizontal strain is linear (Fig. 1, 3, 4) the loading paths for zero lateral strain were calculated. It has been confirmed that the assumption of linearity was correct and that the coefficient of the pressure at rest was practically constant within the whole region of measurements. It has been measured that the value of the coefficient K_o is influenced by the initial stress (Fig.6) and that it is necessary to differentiate three practically used definitions of the coefficient of pressure at rest (Fig. 8). The extreme K_o-line corresponds with the equation published by Pruška (1972).

INTRODUCTION

The necessary prerequisite of the pressure at rest is zero strain in all planes perpendicular to control /primary/ stress. It is tacitly assumed that the control stress is the principal stress and that its direction is constant /Bishop, 1958/. In the measurements of the pressure at rest in the triaxial apparatus it holds that the vertical stress is the control stress and the cell pressure is the coercive stress. The conditions of zero lateral strain are carried out using the lateral strain indicator. This additional features complicates the test procedure. Moreover, the commonly used type of indicator with a mercury control, as described by Bishop and Henkel /1962/, requires special hygienic regulations and does not suit the tests with initial stress different from zero. The author used a special procedure for the determination of the pressure at rest in the triaxial apparatus, utilizing the property of compressed soil specimen that the lateral strain at loading paths was negative, when $K = \Delta\sigma'_3 : \Delta\sigma'_1 < K_o$, and positive when $K > K_o$ /Fig. 1/. The coefficient of pressure at rest K_o means the ratio of pressure increments $\Delta\sigma'_3 : \Delta\sigma'_1$ at zero lateral strain.

MATERIAL

Sand from the Vltava River of Zbraslav locality was used. The grains retained on sieve No 10 and passing the sieve with 0,125 mm openings were removed. 91.5% of grains were angular or subangular quartz particles with unit weight of solid particles 26,75 kN/m^3. The min. and max. porosity determined by the standard test were 33,1% resp. 42,1%. The standard box shear test begun with the porosity of n = 32,4% and terminated with n = 35,5%. It resulted in: ϕ' peak = 49.2°, ϕ' res. = 33.2° and c=0,00 - see Fig.2.

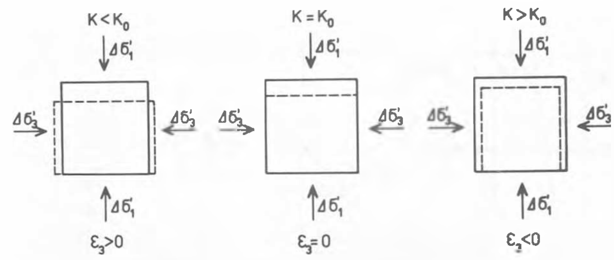


Fig.1 Deformation of an elementary cube at different ratios of pressure increments $K = \Delta\sigma'_3 : \Delta\sigma'_1$

SAMPLES

The samples were 10 cm in diameter and 18.5 cm in height. Boiled sand was poured into distilled water in a mould placed on a vibration table under action. When the sample was prepared, a negative pore pressure of 5 kPa was applied. Then the sample was transferred into the cell of the triaxial apparatus, where it was loaded by an all round pressure of 170 kPa. The pore pressure was then annuled and the vertical pressure σ'_1 was increased to 183 kPa /approx. hydrostatic initial pressure/ in the first series of tests, and to 425 kPa /pressure near the expected conditions of the pressure at rest/ in the second series.

TESTS

Every series consisted of 7 tests. The loading paths were constant at every test and were defined as a ratio of the cell pressure increments

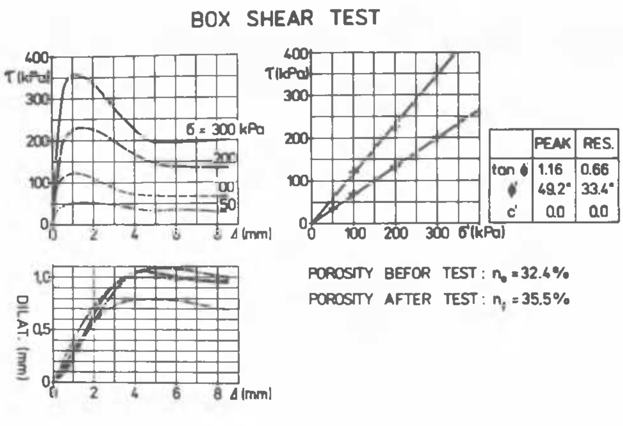


Fig.2 Box shear test results

to the vertical pressure increments. The samples were tested at the following seven loading paths: K = 1.0 - 0.7 - 0.4 - 0.2 - 0.1 - 0.05 and 0.00 /Fig.3/. In the tests of every series the vertical pressure increments $\Delta \sigma'_1$ were identical. The cell pressure increments were calculated individually for each stress path.

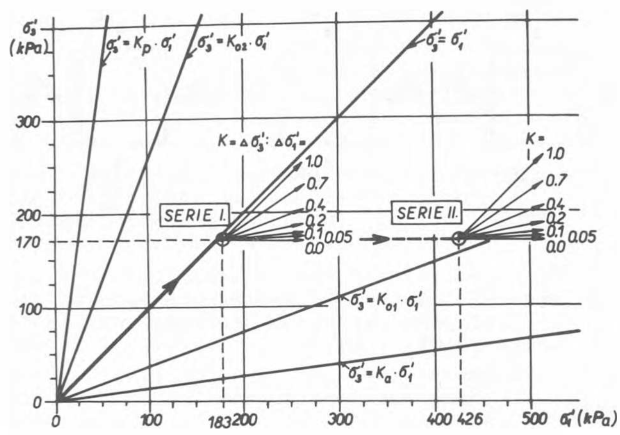


Fig.3 Starts of tests and directions of loading paths

The last test of every series corresponded with the standard triaxial test. Measurements of vertical force, cell pressure, vertical strain of the sample with an accuracy of 0.005 mm, and the quantity of water expelled from the sample with an accuracy of 0.1 ccm were parts of the test procedure. The tests were carried out by Hroch /1975/.

TEST RESULTS

The horizontal strain of the sample was calculated from the measured data by means of the equation

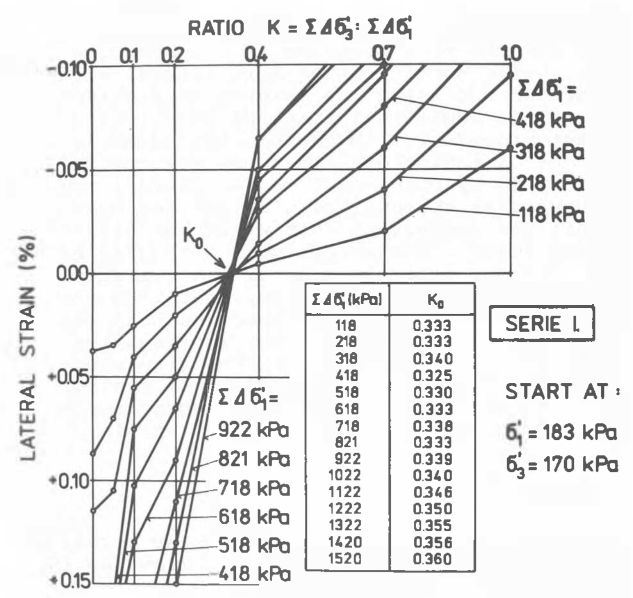
$$\varepsilon_r = 0.5 / \varepsilon_v - \varepsilon_1 /, \qquad /1/$$

where ε_v - volumetric strain,
ε_1 - vertical strain. It was stated that the diameter of the samples decreased in both series for loading paths K = 1.0 - 0.7 and 0.4, and increased for loading paths K = 0.2 - 0.1 - 0.05 and 0.00. The results are illustrated in Fig.4 for the 1st series and in Fig.5 for the 2nd series. In Figs. 4 and 5 lateral strain is plotted against stress path. The measured values corresponding with identical vertical pressure increments $\Delta \sigma'_1$ are connected with straight lines instead of curves for the sake of simplicity. The sake of clarity not all measured values are illustrated. From the linear function $\varepsilon_r = f /K/$ within the interval of $0.2 < K < 0.4$ the states of zero lateral strain were calculated. These states were expressed by the coefficient of pressure at rest K_o and tabulated to supplement Figs. 4 and 5. The equation used for the calculation of the coefficient K_o was by these calculations

$$K_o = \Sigma \Delta \sigma'_3 : \Sigma \Delta \sigma'_1 \qquad /2/$$

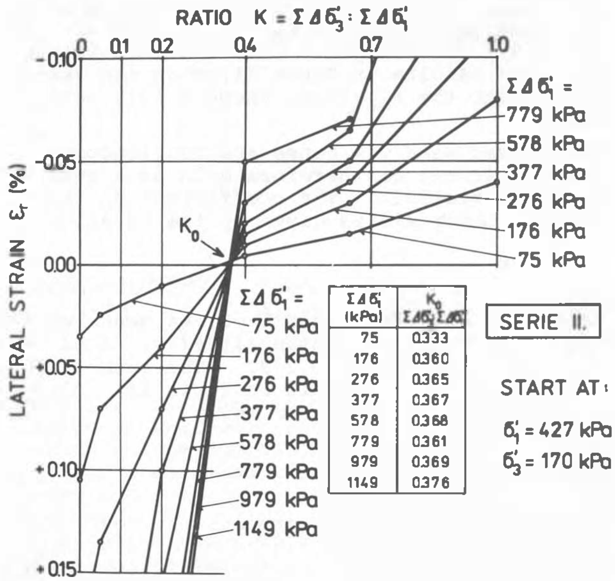
The sum means the pressure increment from the initial state /see Fig.3/.

The tables supplementing Fig.4 and 5 demonstrate that the coefficient of the pressure at rest varied within the limits of 0.325 and 0.340 for the vertical pressure increments up to 1027 kPa, and within the limits of 0.346 and 0.360 for higher increments in the first test series, and within the limits of 0.360 and 0.369 /neglecting both extreme values of 0.333 and 0.379/ in the second series.



ΣΔσ1' (kPa)	K_o
118	0.333
218	0.333
318	0.340
418	0.325
518	0.330
618	0.333
718	0.338
821	0.333
922	0.339
1022	0.340
1122	0.346
1222	0.350
1322	0.355
1420	0.356
1520	0.360

Fig.4 Test results - series I. Lateral strain versus ratio of pressure increment



Σ Δσ'1 (kPa)	K0 Σ Δσ'3 : Σ Δσ'1
75	0.333
176	0.360
276	0.365
377	0.367
578	0.368
779	0.361
979	0.369
1149	0.376

Fig.5 Test results - series II. Lateral strain versus ratio of pressure increment

DISCUSSION OF TEST RESULTS

- It is evident that the results of the second test series give higher values of the coefficient K_o than the results of the first series /Fig.6/. The dependence of both principal stresses is constant, even if the second series may show a slight bilinearity with the bend at the pressure about at σ'_1 = 950 kPa. In the first series bilinearity cannot be either excluded or confirmed.
- The coefficient K_o is generally calculated from total pressures

$$K_o = \sigma'_3 : \sigma'_1 \qquad /3/$$

The calculations according to Eq. /3/ are shown in Tables I and II, Col. 5, and presented graphically in Fig.7. It can be seen that the K_o-line of the second test series passes through the origin of coordinates, the maximum deviation being 8 to 15 kPa according to the method of assessment. On the other hand, the K_o-line of the first test series intersects the vertical axis at 110 kPa which makes it impossible to assume that it is a K_o-line of current type. This K_o-line incorporates also the effects of the sample stress before the beginning of the tests and excludes, consequently, the horizontal strains which took place before the test beginning.

- To complete the assessment of test results let us calculate the coefficients K_o for the individual loading steps, i.e. from the equation

$$K_o = \Delta\sigma'_3 : \Delta\sigma'_1 \qquad /4/$$

The results are shown in Tables I and II, col. 6, and in Fig.8.

- If we calculate the limit K_o-line, which the author /1972/ denoted as K_{O1}-line and for which he deduced the equation

$$K_{O1} = \tan\ (45^o - \phi':2)\ , \qquad /5/$$

we ascertain that for the angle of internal friction ϕ' peak = 49.2° as measured at the box

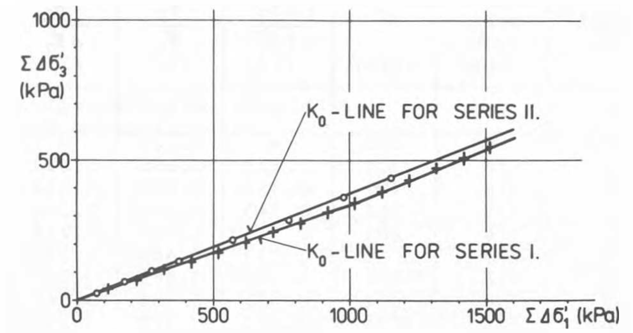


Fig.6 K_o-lines calculated from Eq. 2

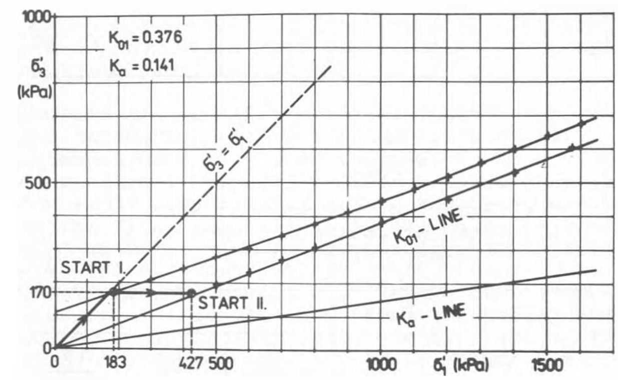


Fig.7 K_o-lines as calculated from Eq. 3

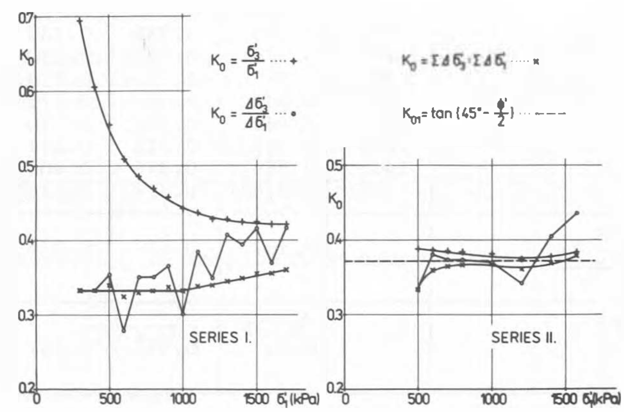


Fig.8 Coefficient of pressure at rest calculated from three different equations

TABLE I

Coefficient of Pressure at Rest
Calculated by Equation 1 or 2 or 3
Test Series I

Pressure Increment No	Pressure Increment $\Sigma \Delta \sigma_1'$ /kPa/	Pressure σ_1' /kPa/	K_o		
			$\frac{\Sigma \Delta \sigma_3'}{\Sigma \Delta \sigma_1'}$ /1/	$\frac{\sigma_3'}{\sigma_1'}$ /1/	$\frac{\Delta \sigma_3'}{\Delta \sigma_1'}$ /1/
1	2	3	4	5	6
0	0	183	-	0.929	-
1	118	301	0.333	0.695	0.333
2	218	401	0.333	0.605	0.334
3	318	501	0.340	0.555	0.354
4	418	601	0.325	0.509	0.278
5	518	701	0.330	0.486	0.350
6	618	801	0.333	0.469	0.351
7	718	901	0.338	0.458	0.367
8	821	1004	0.333	0.443	0.301
9	922	1105	0.339	0.437	0.385
10	1022	1205	0.340	0.429	0.349
11	1122	1305	0.346	0.428	0.407
12	1222	1405	0.350	0.425	0.395
13	1322	1505	0.355	0.425	0.416
14	1420	1603	0.356	0.421	0.369
15	1520	1703	0.360	0.421	0.417
$\frac{\sum_1^{10} K_o}{n}$			0.334		0.340

TABLE II

Coefficient of Pressure at Rest
Calculated by Equation 1 or 2 or 3
Test Series II

Pressure Increment No	Pressure Increment $\Sigma \Delta \sigma_1'$ /kPa/	Pressure σ_1' /kPa/	K_o		
			$\frac{\Sigma \Delta \sigma_3'}{\Sigma \Delta \sigma_1'}$ /1/	$\frac{\sigma_3'}{\sigma_1'}$ /1/	$\frac{\Delta \sigma_3'}{\Delta \sigma_1'}$ /1/
1	2	3	4	5	6
0	0	427	-	0.398	-
1	75	502	0.333	0.388	0.333
2	176	603	0.360	0.387	0.380
3	276	703	0.365	0.385	0.373
4	377	804	0.367	0.384	0.373
5	578	1005	0.368	0.381	0.370
6	779	1206	0.361	0.374	0.341
7	979	1406	0.369	0.378	0.405
8	1149	1576	0.379	0.384	0.436
$\frac{\sum_1^8 K_o}{n}$			0.362	0.382	0.376
$\frac{\sum_2^8 K_o}{n}$			0.367	0.381	0.382

shear test by Hroch /1975/ the lover value of the coefficient K_o is K_{01} = tan /45°-24.6°/ = 0.372. A comparison of the calculation with the results in Table II, when the tests began near the K_{01}-line, shows a full agreement.

- The tested sand was dense and monotonously loaded. It may be therefore hold as a quasi-elastic material. The coefficient K_o for elastic materials is given by the Equation

$$K_o = \frac{\nu}{1 - \nu} \qquad /6/$$

Using the Poissons ratio $\nu = 0.264$ measured for the tested sand by Pruška /1979/ we found that the coefficient K_o = 0,359. The comparison with the measured result in Table II. Col.4 shows a full agreement as well.

CONCLUSION

- The coefficient of the pressure at rest of saturated dense sands can be calculated from special triaxial tests using different loading paths.
- The effect of initial stress influences the test results even in the case of non-preconsolidated sands.
- K_o-tests results in the K_o-line of the current type only if the stress at the beginning of the test is null or corresponds to the pressure at rest. The farther the initial stress from the K_o-line, the lower the value of the coefficient K_o.
- For dense sands monotonously loaded the Eqs. 5 and 6 may be used.

REFERENCES

Bishop, A.W. Discussion. Brussels Conference 58 on Earth Pressure Problems. Vol. III, p. 70.

Bishop, A.W., Henkel,D.J. /1962/. The Measurement of Soil Properties in the Triaxial Test. 2nd Ed., E.Arnold, Ltd, London.

Hroch, Z. /1975/. Deformation of sand loaded on straight paths by axially symetric loading /in Czech/. PhD Thesis, ÚTAM ČSAV Praha.

Pruška, L. /1972/. Basic Equations of Pressure at Rest of Granular Materials. Proc. 5th Europ. Conf. SMFE, Vol. 1, 69-76, Madrid.

Pruška,L. /1979/. Influence of Minor Principal Stress on the Compressibility of Compacted Sand. Proc. 7th ECSMFE, Vol. 2, 103-106, Brighton.