Research Project:
"Evaluation of the Self-Boring Pressuremeter in Sand"

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1. PRESENT RESEARCH STATUS

During the period covered by this report the writers performed the following work:

a. No. 20 SBPT's in dry Ticino (TS) and Hokksund (HS) sands.
   A summary of the results of these tests is given in Table 1. These tests were performed using the so-called "ideal installation" meaning that the SBP probe was installed in the calibration chamber before the specimen was formed by pluviation.
   These tests complete the programme of tests in dry sand using ideal installation.

b. Starting from test No. 225 the Camkometer probe with the modified strain arms was used with the aim of detecting more reliably the lift-off pressure $p_0$ that under ideal conditions should correspond to the horizontal stress $q_h$ applied at the external boundary of the CC specimen.
   The modifications of the strain arms consisted in:
   - substitution of the original arms made of brass with new re-designed arms of steel, having a larger rigidity.
   - attempting to reduce the mechanical clearance seated in the original pivot-bush system by the insertion of a miniature roller bearing instead of the original bushing.
   - improving the planarity and reciprocal alignment of the pivot and arms seating.

Successively more rigid springs pushing the arms into their zero position were introduced and further improvements in the planarity and the reciprocal alignment of both pivot and arms seating were made.

All this was accomplished with the aim of reducing the observed mechanical compliance of the strain arms that obliterates the true value of the measured $p_0$.

Tests No. 201 to No. 224 were performed using a probe equipped with the original arms, see examples in Figs. 1 and 2.
Tests No. 225 to No. 228 were performed using the probe with the re-designed strain arms, see examples in Figs. 3 and 4.

Starting from test No. 233 the probe equipped with the last version of the modified and improved strain arms was used; see examples in Figs. 5 and 6.

The comparison of the initial part of the expansion curves shown in a very enlarged scale indicates that while the mechanical compliance of the strain arms has been reduced, their performance is still not completely satisfactory.

c. In order to ascertain that during the 1-D straining performed with the SBP already embedded in the CC there is no stress concentration around it, a test has been performed using the rigid Cambridge In-Situ $K_0$-cell. The results of this test are summarized in Fig. 7 and show that apart from some non-linearity and hysteresis of the device, the measured horizontal stress on the surface of the $K_0$-cell substantially equals the horizontal stress applied at the boundary of the CC specimen.
2. **RESEARCH PLANS**

a. Further improvements of the strain arms will be tried with the aim of achieving a better reliability of the $p_0$ assessment. This will require the execution of a limited number of additional SBPT's in dry sand.

b. The modification of the top of the CC in order to allow for the testing of the self-boring process, is in advanced state of design.

c. A preliminary series of CC tests will start with the SBP probe inserted by means of the self-boring process using the same techniques as used in the field. This will require performing the tests on saturated specimens thus slowing down the progress of the present research.

d. Analysis of the tests already available performed in dry sand with the aim of:

- determining the influence of the finite dimensions of the CC on the results of the SBPT's;
- working out the criteria that will allow to relate the different pressuremeter shear moduli $G$ to the relevant design problems. This will bring up questions like the influence of stress and strain levels on measuring models and consideration due to the problem of sand anisotropy;
- critical examination of the reliability of the usual assumption that $p_0$ equals $\sigma'_h$ also in sand;
- comparison of measured values of $G$ against other laboratory moduli obtained on pluvially deposited specimens of the test sands;
- evaluation of the reliability of the plane strain angle of shearing resistance $\phi'_p$ that may be obtained from expansion tests in sands using Rowe's stress dilatory theory.
3. MISCELLANEA

The writers co-operating with other European research centers using the CC for the validation of in-situ devices, have organized in Milan a second informal seminar on the progress made in this type of research. The meeting will take place at ENEL C.R.I.S. Laboratories in Milan on March 18 and 19, 1986.

The Norwegian Geotechnical Institute and the Universities of Oxford, Chalmers (Göteborg, Sweden), British Columbia (Vancouver, Canada), Sydney (Australia), Grenoble (France), Louisiana (Baton Rouge, USA) are scheduled to attend the seminar.
SYMBOLS APPEARING IN TABLE 1

BC = Boundary conditions applied to the CC specimens
B-I = BC with constant boundary stresses \( \sigma'_h = \text{CONST.}, \sigma'_v = \text{CONST.} \)
\( y \) = Dry bulk density
\( D_R \) = Relative density
OCR = Overconsolidation ratio
\( \sigma'_v \) = Vertical stress \( \{ \) Applied to CC specimens
\( \sigma'_h \) = Horizontal stress \( \} \)
\( K_o \) = Coefficient of earth pressure at rest
\( P_{lim} \) = Ultimate cavity pressure from \( \log p \) vs. \( \log \frac{\Delta v}{v} \) plot
\( G_{ur} \) = Unloading-reloading shear modulus \((*)\)
\( P_B \) = Corrected cavity stress at which unload-reload loop starts
\( \Delta y \) = Shear strain amplitude of the loop
\( M \) = Constrained modulus \((**)\) measured during the 1-D straining of the CC specimen

\((*)\) Numerals indicate the number of the loop

\((***)\) Tangent modulus for NC specimens and secant modulus representing the whole unloading loop for OC specimens
| TEST | B/C | T/L | D | G | O/C | G/C | R | P | G | P | G | P | G | P | G | P | G | P | G | P | G | P | G | P | W | SAND |
|------|-----|-----|---|---|----|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|----|
| 201  | B+1 | 16.07| 67.0| 2.8| 113| 75 | 0.66| 76.1| 0.47| 47.68| 259 | 0.25| 50.72| 421 | 0.24| 187.2| HS |
| 207  | 15.33| 43.9 | 3.3| 110 | 65 | 0.59| 65.0 | 0.88| 36.18| 251 | 0.21| 36.21| 306 | 0.26| 176.9| HS |
| 208  | 14.81| 43.2 | 1.0| 113 | 45 | 0.40| 28.1 | 0.52| 25.16| 119 | 0.21| 27.33| 148 | 0.20| 36.1 | TS |
| 209  | 14.99| 49.7 | 1.0| 117 | 51 | 0.44| 46.0 | 0.69| 34.47| 136 | 0.24| 36.93| 169 | 0.12| 40.84| 224 | 0.14| 43.6 | TS |
| 210  | 15.11| 53.3 | 1.0| 511 | 245| 0.48| 81.2 | 2.65| 75.75| 537 | 0.13| 79.32| 650 | 0.12| 79.40| 763 | 0.13| 100.1| TS |
| 211  | 15.56| 67.4 | 1.0| 512 | 242| 0.47| 58.1 | 2.84| 72.42| 496 | 0.13| 79.04| 653 | 0.13| 81.56| 811 | 0.13| 114.9| TS |
| 212  | 15.47| 64.6 | 2.9| 111 | 83 | 0.75| 104.3| 1.40| 47.99| 273 | 0.14| 50.60| 367 | 0.14| 52.30| 478 | 0.15| 180.0| TS |
| 213  | 14.87| 47.5 | 2.8| 113 | 84 | 0.74| 102.3| 1.30| 47.91| 263 | 0.15| 48.66| 348 | 0.13| 51.45| 407 | 0.14| 168.8| TS |
| 214  | 14.73| 42.4 | 1.0| 112 | 54 | 0.48| 49.2 | 0.20| 49.20| 140 | 0.16| 34.69| 186 | 0.16| 36.84| 235 | 0.16| 508.0| TS |
| 215  | 16.32| 92.3 | 1.0| 515 | 227| 0.44| 254.4| 3.68| 93.70| 549 | 0.078| 93.90| 722 | 0.14| 105.88| 884 | 0.13| 143.7| TS |
| 216  | 14.81| 46.1 | 7.7| 61 | 57 | 0.93| 73.3 | 0.73| 40.96| 307 | 0.14| 42.04| 354 | 0.13| 40.89| 304 | 0.13| 136.8| TS |
| 218  | 15.43| 65.4 | 7.7| 72 | 71 | 0.99| 80.2 | 0.78| 45.89| 259 | 0.18| 46.08| 313 | 0.14| 47.16| 367 | 0.063| 149.6| TS |
| 219  | 15.51| 65.9 | 5.4| 113 | 101| 0.90| 131.4| 1.60| 61.62| 348 | 0.14| 61.38| 434 | 0.15| 65.05| 537 | 0.16| 207.5| TS |
| 220  | 14.93| 47.2 | 1.0| 313 | 148| 0.47| 139.1| 1.24| 51.44| 329 | 0.13| 50.89| 388 | 0.12| 54.20| 455 | 0.13| 80.1 | TS |
| 221  | 14.85| 44.6 | 2.9| 109 | 82 | 0.76| 68.3 | 1.06| 45.69| 265 | 0.13| 44.13| 317 | 0.12| 48.63| 372 | 0.12| 173.4| TS |
| 222  | 14.90| 46.2 | 5.5| 112 | 96 | 0.66| 141.4| 1.21| 52.04| 315 | 0.13| 51.61| 395 | 0.12| 51.62| 469 | 0.13| 199.0| TS |
| 224  | 15.79| 74.6 | 5.4| 114 | 93 | 0.82| 124.9| 1.72| 61.61| 317 | 0.13| 62.47| 412 | 0.13| 58.67| 490 | 0.23| 227.4| TS |
| 225  | 15.79| 74.6 | 5.5| 113 | 88 | 0.79| 96.4 | 1.58| 48.64| 319 | 0.19| 52.36| 416 | 0.14| 54.36| 499 | 0.14| 218.3| TS |
| 228  | 15.82| 75.7 | 1.0| 518 | 215| 0.42| 208.0| 2.99| 67.30| 443 | 0.13| 70.83| 537 | 0.13| 77.83| 630 | 0.12| 120.3| TS |
| 233  | 15.83| 75.7 | 1.0| 518 | 216| 0.44| 219.0| 2.94| 66.09| 434 | 0.14| 75.5 | 541 | 0.13| 78.7 | 654 | 0.14| 121.3| TS |
Fig. 1

TEST N° 211, TICINO SAND
DR = 674.4; OCR = 1; \( \sigma_0' = 521 \text{kPa} \)
ORIGINAL ARMS; 1mV = 0.02074 mm

CORRECTED CAVITY STRESS \( p \) [kPa]

STRAIN [mV]

APPLIED BOUNDARY STRESS \( p_0 = 247 \text{kPa} \)

TOTAL STRAIN

ARM 2

ARM 1

ARM 3

235

219

209

240

400

320

160
TEST N° 224, TICINO SAND

DR = 74.6% ; OCR = 5.4 ; 0'Y = 116 kPa

ORIGINAL ARMS ; 1 mV = 0.02134 mm

CORRECTED CAVITY STRESS p [kPa]

APPLIED BOUNDARY STRESS \( \sigma_0 = 93 \) kPa

STRAIN [mV]
TEST N°228, TICINO SAND
DR 75.7 %; OCR = 1; $\sigma_0^1 = 512 \text{kPa}$
MODIFIED ARMS; 1ST PHASE; $1\text{mV} = 0.02134 \text{mm}$

CORRECTED CAVITY STRESS $p [\text{kPa}]$

APPLIED BOUNDARY STRESS
$\sigma_h = 215 \text{kPa}$

STRAIN [mV]
Fig. 4

Test No.225, Ticino Sand

$\text{DR} = 74.6\%$; $\text{OCR} = 5.5$; $d_v = 115$ kPa

Modified Aris; 1st Phase; $1\text{mV} = 0.02143\text{mm}$

$P_0 = 93$ kPa

$\sigma_h = 90$ kPa

Total Strain

ARM 1

ARM 2

ARM 3

Corrected Cavity Stress $P (\text{kPa})$
TEST N° 233, TICINO SAND

\[ D_R = 79.6\% ; \ OCR = 1 ; \sigma^I_v = 522\, \text{kPa} \]

MODIFIED ARMS ; 2\textsuperscript{ND} PHASE ; \( 1\, \text{mV} = 0.01978\, \text{mm} \)

**Diagram:**
- X-axis: STRAIN [mV]
- Y-axis: CORRECTED CAVITY STRESS \( p \) [kPa]
- Graph shows stress-strain relationship with various data points and labels.
TEST N°234, TICINO SAND

$D_R = 77.0\% ; O_C R = 5.3 ; \sigma^I_v = 118\text{kPa}$

MODIFIED ARMS ; 2ND PHASE ; $1\text{mV} = 0.01978\text{mm}$

- CORRECTED CAVITY STRESS $p [\text{kPa}]$
- STRAIN [mV]
1-D STRESSING OF THE CAMBRIDGE $K_0$-CELL IN CC

![Graph showing the stress-strain relationship for Ticino Sand, DR = 60%, Test No. 226. The graph plots $P_h$ (kg/cm²) against $\sigma_f$ (kg/cm²) with points indicating BC-3 loading and BC-3 unloading.](image-url)
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