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ABOUT THE STRESS-STATE MEASUREMENTS IN SOIL MODELS

LES MESURES DES CONTRAINTES DANS LES MODELES DU SOL

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SYNOPSIS. This paper reports about a research which deals with the construction and the calibration of different types of pressure cells to be used in measuring the state of stress induced at the interior of a soil model.
The knowledge of the stress-state distributions is in effect of great relevance in such instances as the Soil-Foundation Interaction Analyses or the interpretation of Calibration Chambers tests.
Five different types of cells have been designed and tested. Their overall dimensions have been limited at minimum values yet maintaining the ability of the cell to provide readings integrated from a reasonable sensing surface with respect to the sand grains' mean size.
All of the pressure cells were calibrated either in a fluid then in the same soil which will be used later to build the laboratory models.
Numerical simulations have then been executed using a FEM modeler in order to check the basic hypothesis and some of the soil-cells interaction phenomena stood out.

INTRODUCTION

The major problems in the soil-structure interaction field result from factors that can be grouped in two main categories:

- phenomena developing during interaction (strictly related to stress and strain states), which can be difficulty separated;
- uncertainties on the soil characteristics and behaviour.

Such studies are thus performed following different approaches among which the most usual are:

- theoretical analyses and numerical modeling;
- experimental analyses and physical modeling;
- observation and monitoring of full scale models: e.g. the "real" interaction structure.

The experimental approach, as is well known (Jamiolkowski et al., 1985), allows us to have or better, to assign specific conditions to be respected during the course of a designed test; moreover, the relevant data can be measured in easier and more accurate ways.
Some of the before mentioned problems are consequently simplified by using this technique.
This paper reports about a research which deals with the construction and the calibration of different types of pressure cells to be used in measuring the state of stress induced at the interior of a soil model.

PRELIMINARY CONSIDERATIONS

The knowledge of the stress build-up distributions, in addition to the soil-foundation interaction analyses, is of great relevance in other instances such as the interpretation of calibration chamber tests (Ghionna et al., 1991).
As far as physical model testing is concerned, Berardi et al. (1991) and Berardi (1992) report the results of experimental tests performed using circular plates on a large model built with pluvially deposited sand.
In those tests induced vertical stresses were measured by means of particular pressure cells, in order to evaluate, at least qualitatively, factors such as, stress concentrations, stiffening decay and stress distributions, with the goal of analyzing which kind of soil model could best be used to forecast settlements.
It is therefore obvious the importance and the usefulness of accurate experimental measurements.
The main purpose of this research is, then, to identify the principal distinctive features, with respect to the biasing ones (Weiler et al., 1982), in order that the response of pressure transducers can be totally reliable and accurate.
It must be pointed out that any stress cell will never have the same stress-strain-time characteristics as those of the soil, and that the stress registered by any transducer will never, in general, be the stress at that point if the transducer itself was not present.
The fact that the free-field soil stress does not equal the value registered by a cell implies that calibration factors have to be methodically applied to all of the soundings of every test performed.
The usual procedure to achieve correction factors is to calibrate the transducer in a fluid and in the soil where the transducer has to be used.

DESCRIPTION OF THE PRESSURE CELLS

Owing to the fact that modeling, if performed inside a laboratory, usually has to be scaled to limited space availability, a lot of care has been used to determine the size of the pressure cells.
Five different types of cells have been purposely set up, all within the category of diaphragm pressure cells, filled either with gas or fluid.
The problems arising from, and to be faced when choosing the proper transducer, range from geometrical/dimensional aspects (overall sizes and shape ratios) to cell-soil interaction (Dunnicliff et al., 1988).

Within the imposed conditions (scaled models interacting with pluvially deposited sand), one requirement is to shrink the overall dimensions as much as possible yet maintain the ability of the cell to return readings integrated from a reasonable sensing surface with respect to the sand grains' mean size; this conclusion leads to the exclusion of the piston-type cells.
Previous research (Berardi et al., 1991) helped us in tuning the cells' dimensions, assembling and in choosing the materials to be used, leading us to analyze three families of transducers.
The first one has been produced in the form of a small polythene reservoir, thermically sealed, filled with de-aired water and containing a miniaturized electrical pressure cell.
The shape is that of a square (max. edge 3 cm) with a thickness of a few millimeters (≤ 5); within this family two types (named as types "A" and "B") are differentiated only by some geometrical characteristics related to different ways of sealing.
To the second family of transducers belongs a cell, called type "C", formed by two small sensing disks made from polythene sheet which are hold against an aluminium circlet by two screwed flanges; perfect sealing is achieved by interposing O-rings between the two polythene disks and the aluminium circlet. The resulting cavity is filled again with de-aired water and contains the same miniaturized pressure sensor as in the first cell family, "A" and "B". The overall diameter, as can be seen from Fig. 1, is 4.2 cm.
Difficulties arise during the positioning of this pressure cell above the sand surface, due to a non-perfect contact between the bottom sensing face and the sand grains, so we were forced to modify it by substituting one of the two polythene disks with a flat aluminium plate; this resulted in a second type of transducer of this family that has only one sensible face as is shown in Fig. 1 (type "D").

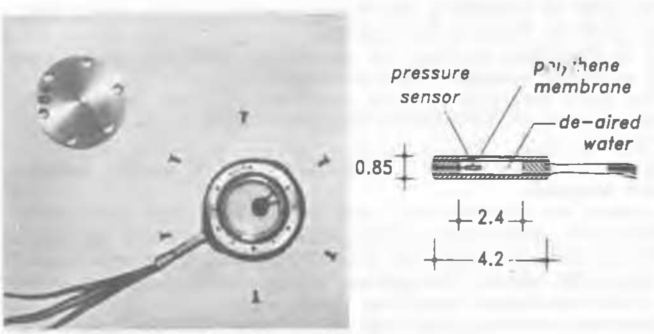

Fig. 1. Photograph of type "D" cell and schematic section

The last family of transducers, named type "E", belongs to the more classical type of pressure cells formed as a circular metallic (Beryllium Copper was actually used) case which contains a small cavity with simple air at atmospheric pressure sealed inside. One of its sides becomes the sensing face by gluing to it a single-foil strain gauge to monitor its diaphragm-like deflections when the cell is exposed to external actions.

EXPERIMENTAL TESTS' DESCRIPTION

All of these pressure cells were calibrated both in a fluid, than in the same soil which will be used later to build the laboratory models.
The Fluid-Calibration has been the starting step propaedeutical to the interpretation of the Soil-Calibration phase; moreover it allowed us to assess the linear and repeatable behaviour of the cells within their designed pressure range.
The second step has been performed using a Calibration-Chamber (referred to as CC in the following), see Fig. 2, specially designed for this very purpose which consists of a cylindrical perspex box, whose height versus radius ratio equals unity and is filled with sand.

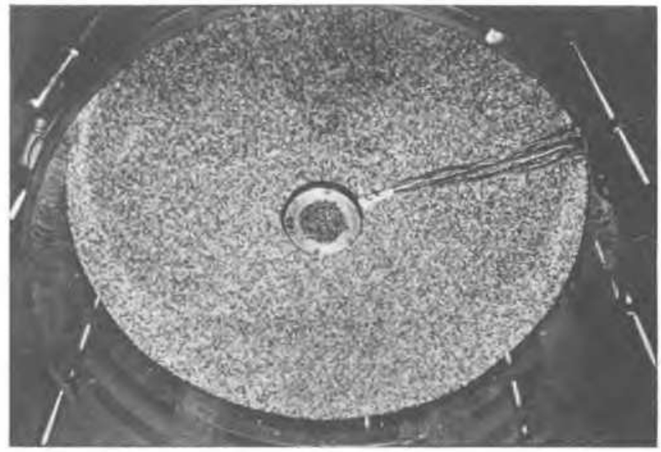

Fig. 2. Photograph of the CC during the arrangement of a type "D" calibration test

Uniform pressures were applied equally to both of its circular sides, directly on the sand's surface, by two lattice membranes coupled with the top and bottom sealing caps of the CC.
A uniform quartzy and natural sand coming from the Ticino river bed, that has been well classified and investigated by others (A.G.I., 1985), was used for the Soil-Calibration tests.
The cylindrical sand samples were casted by the pluvial deposition technique using a sand spreader assembly (Passalacqua, 1991). The technique used to prepare the samples guarantees good repeatability and good quality in terms of relative density uniformity. In these particular tests the relative density ranged from 77% to 90%.
The whole set of Soil-Calibrations were made with 32 tests, within which the five types of pressure cells' behaviours have been analyzed. The following, reports about the results obtained from the second type of the second family and the last described cells, respectively named types "D" and "E".
This decision was made principally because of the fact that the first three types of transducers showed relevant underreadings and excessive influence from their positioning in situ, then also because type "E" cells are the most widely used in practice and at last for a lack of space.
During every test many loading-unloading cycles were performed in a pressure range with a maximum of 300 kPa.
As previously stated, the cell's presence inside the sand sample alters the free-field condition but in this laboratory controlled case, where the boundary conditions (K_0) and the applied uniform pressure have been imposed, proper simulations to predict the true stress field can be done, in order to backanalyze the cell's readings during the course of the calibration tests. The numerical simulations have been executed using an axialsymmetric, linearly elastic FEM modeler (DeSalvo et al., 1987) and, notwith-

standing the schematic formulation's limits of such a discrete approach, the basic hypothesis have been checked and some of the soil-cell interaction phenomena stood out.
The numerical phase dealt with the analysis of the sand-sample interaction with the surrounding box, taking into account that the frictional phenomena growing at this interface, even if the perspex' surface was really smooth, influenced the inner states of stress. Consequently this side of the boundary was simulated by frictional-gap elements and the problem became geometrically non-linear because of the introduction of this dependence upon relative displacements arising at the sand and the boundary interface.

RESULTS' ANALYSIS

As stated among the preliminary considerations, the main objective of this research was the setting up of the most effective pressure transducer in order to be able to measure the state of stress inside a soil model.
The analysis of the results obtained by the described tests led to identifying two types of cells ("D" and "E") which distinguish themselves for reliability and accuracy among all those that have been examined.
Remaining therefore, within these, and with regard to cells type "E", it can be said that all of them revealed a non linear behaviour, certainly related to their bending diaphragm because this very deflection triggers the developing of an arching effect just above its sensing surface: this effect, in turn, is responsible for the hysteretic behaviour observed during loading-unloading cycles.
This experimental evidence, shown in Fig. 3, has been confirmed by the FEM analyses too, both qualitatively and quantitatively.

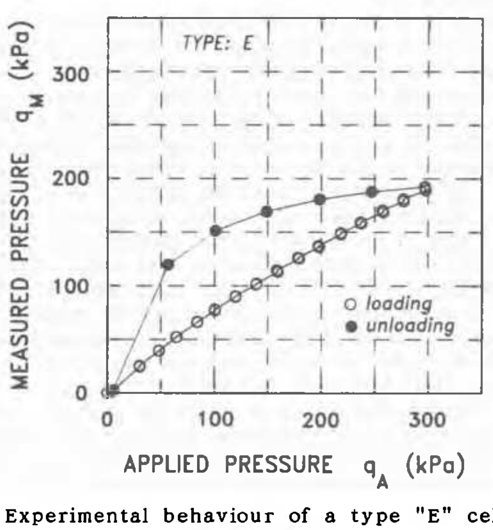

Fig 3. Experimental behaviour of a type "E" cell when embedded at a depth ≥ 0.5·D

It has been noted that the arching effects are already well developed when the cell lies embedded under a layer with height 0.5·D, with D being the outer diameter of the cell itself. On the contrary, when the cell is very close to the loading membrane, there is no arching at all and the cell performance is reliable, linear and not hysteretic.
Moreover, the readings of the "E" type cells are notably dependent upon the stress level existing inside the soil sample.
"D" type cells, on the contrary , don't exhibit such

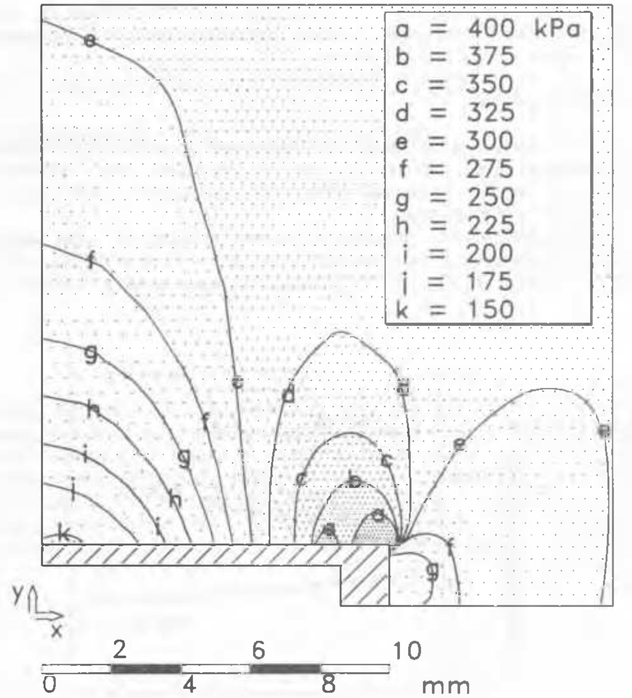

Fig.4. FEA output, showing arching effect build-up by vertical stress contours, in soil-type "E" cell interaction (cell's body hatched by 45° slanted lines)

problems; their responses are primarily linear and provide precise measuring of the induced pressures inside the soil sample independently of their position, as can be seen from Fig. 5.

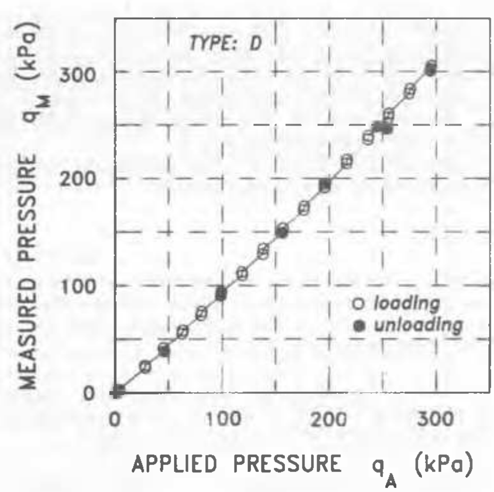

Fig. 5. Experimental behaviour of a type "D" cell

This is mainly due to the practically undeformable behaviour of the de-aired water sealed inside the cell's cavity, so far maintaining the sensing surface's deflections, under pressure, to a minimum extent.

The FEA models, set up to simulate this type of cells interaction's behaviour, show evidence in strict agreement with the experimental data.

CONCLUSIONS

The exposed experimental analyses, supported by the numerical ones, permitted us to evaluate the calibration factors to be adopted when the pressure cells will be used in experiments.
Consequently, the pressure values sensed by the transducers during a test will be multiplied by a factor K, as that shown in Fig. 6, to obtain the true acting pressure.

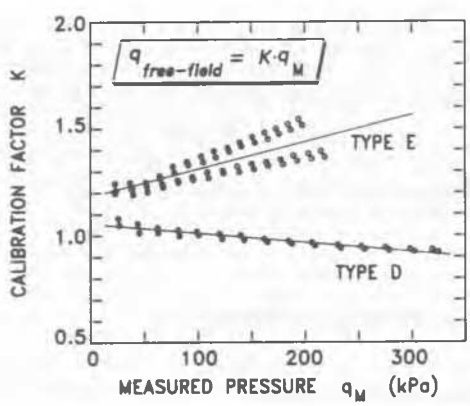

Fig. 6. Calibration factors of types "D" and "E" transducers, after soil-cells interaction analysis

It can also be pointed out from the same figure that type "D" cells presented a maximum shift from the real value within ±5%, while type "E" presented a maximum shift of approximately -50%.

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