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CENTRIFUGE SIMULATION OF PILE DRIVING AND VERTICAL LOADING USING A ROBOT

SIMULATION D'UNE CENTRIFUGEUSE DE BATTAGE ET CHARGEMENT VERTICAL D'UN PIEU A L'AIDE D'UN ROBOT

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SYNOPSIS: The paper deals with a robot which carries out simulation of pile driving interlaced with penetration and pulling tests at different depths without stopping the centrifuge until the end. The model represents a pile of 1.9m diameter open pipe and 7.5cm wall thickness driven down to 30m. Precise instrumentation is possible at a length scale of 1:50. The paper describes the installations and gives some example results.

INTRODUCTION

The behaviour of an off-shore pile subject to loads of varying directions, frequencies and durations, strongly depends on the variations of the corresponding stress field in the soil. By conserving the stresses due to gravity the centrifuge maintains the stress history of the various loads as long as it rotates. When the centrifuge stops, the stress field is mostly obliterated. Therefore, a programme of pile driving and testing which takes months in situ must be accomplished within 1-2 non stop working days on the centrifuge.

The test programme was composed of three different operations: driving, penetration tests of large displacements, pulling tests at large displacements. Those were interchanged which had to be done without loss of precision. On the rotating centrifuge this could only be achieved by robotics. The installation to be described is a "one degree of freedom robot". It is in fact the first robot ever to be built on a centrifuge. The idea however is not new: while, industrial designers readily use formulae of rather large approximations, they desire scale modeling to simulate with utmost precision in-situ operations. Otherwise they have no use for simulation. Time and again there are calls for modeling of digging, construction and testing operations on the centrifuge "exactly" as they are carried out in situ.

At present it can be stated that the piling and testing robot is performing very well, which might promote further robotics on centrifuges.

The work, under a contract to Exxon Production Research Co. was carried out by a team of CEA-CESTA and LMS(*) following the ideas of the author (on a sabbatical leave at LMS).

SIMILARITY

(Index m is for the model, the scale is A*, A* = Am/A).

The pile driving operation simplest to simulate was chosen, that of a ram free falling on the pile's head. The centrifuge simulation conserves the materials and the scales of velocities and stresses. It follows that the dynamic signals are conserved provided all the pieces are built to scale from the materials in situ. The problem of the cushion which clearly could not be built to scale was critical. It was solved separately. A "free fall" on the centrifuge means a guided fall. The model ram had to strike the "cushion" "horizontally" on all its surface at once. That means that the anvil lodging the "cushion" had to be held in place relative to the ram's guiding system (a bronze cylinder) with 0.1mm precision. The anvil was screwed to the pile the vertically of which had to be maintained during the whole course. For this purpose, the pile was passed through a teflon ring at the soil's top level. On the other hand, loading tests called for a motion free of friction relative to this ring. As a result, the pile had to be milled with precision and all the wires and strain gages placed in indentations inside the outer wall of the (open-pipe) pile.

(*) **CESTA**: Centre d'Etudes Scientifiques et Techniques d'Aquitaine of the Commissariat à l'Energie Atomique at Barp near Bordeaux.
LMS: Laboratoire de Mécanique des Solides - Ecole Polytechnique, Palaiseau, France.

The driving system was fixed on the cross-beam of the robot, which held the pile's anvil in place; and during the whole motion a tolerance of ±0.15mm in the teflon ring was maintained.

In that way the repeatability and form of the dynamic signals and the friction free static signals were assured.

According to the stress wave theory, the only controlling parameter is the impact velocity which is nominally

$$v_m = \sqrt{2g_m h_m}$$

h_m is the stroke. (The loss due to friction under the Coriolis forces was found to be about 30%). A provision for changing the stroke was thus included, which together with the choice of the "cushion" fully controlled the impact conditions.

At v*=1, l*=t*, high frequency noise becomes a major obstacle and transducer wires have to be shielded. Accordingly, the wires inside the grooves in the pile were covered with an aluminium strip. The groove thus had a depth of 0.4mm. The minimal wall thickness of the model pile could not be smaller than 1.5mm. Adding together all the restrictions on the scale reduction it followed that the minimal scale was l*=1/50. The maximum intended penetration was 50m in situ. The CESTA centrifuge (10m arm) can service models of up to 3m height. The present installation provides for a penetration of 30m in situ at l*=1/50. The model pile has a diameter of 38mm and wall thickness of 1.5mm. Its length is 700mm (open pipe).

Another critical parameter is the consolidation time scale which is $(l^*)^2$ unless provision is taken to reduce the permeability by l*. This can be carried out in sand by adding fine particles, provided l* is not too small. If this is carried out, then the blow frequency becomes meaningful. A controlled rate driving was provided, up to 2Hz.

Following the similarity rules, the correct dynamic parameters are velocity and strain (stress). In the absence of permeability reductions the rate of static tests should follow that in situ. It is a well known fact that beyond the yield point a pronounced time effect is present in sands. It could be related to grains re-arrangement. Accordingly the robot can perform push-pull cycles between the capacities at up to about 0.2Hz.

The proper parameters are the displacement u over the diameter d (u/d), the force F reduced by the steel area A_s (u/A_s), and the strain ϵ.. The unit of strain is $10^{-6} = 1\mu d$, not to be confused with $10^{-6} s = 1\mu s$.

THE MECHANICAL SYSTEM

In a manner of a testing machine (e.g. Instron), a rigid horizontal cross-beam was driven up and down by two vertical screws of diameter 4cm, which were on their part driven by a servo motor. The hammer was fixed to the beam. The ram was milled with precision, the lower part being rectified. It moved freely inside a bronze cylinder. The upper part of the ram had a rimmed cavity, into which two grips could penetrate in order to lift the ram. The ram's release happened when the shoulders of the grip hit tripping blocks. The position of the tripping blocks was varied by a servo motor. The grip's up and down motion was activated by another servo motor. During driving a proximity transducer activated the follow-up of the cross beam.

The electric motors were brushless tri-phase modulated wave train ones: the rotor had a permanent distribution of magnetic masses which were subject to the forces of a rotating magnetic field created by the stator coils' currents. A cummutator system (10,500Hz) created in each coil a series of square pulses of constant amplitude and varying spacing and polarity for acceleration, deceleration or constant velocity. The weight saved by the high angular velocity of the motors was partly lost through the need to use several reductors. At g*=50 friction losses were high and efficiency low. This point is considered to be important for the design of robots for the centrifuge. The control was based on two encoders placed on the motor's shaft which produced 4x1024 pulses per turn - a precision of about five seconds on the angle.

During static tests the anvil was locked to the cross beam. The locking was activated by two pneumatic jacks, fixed on the cross-beam together with their control transducers.

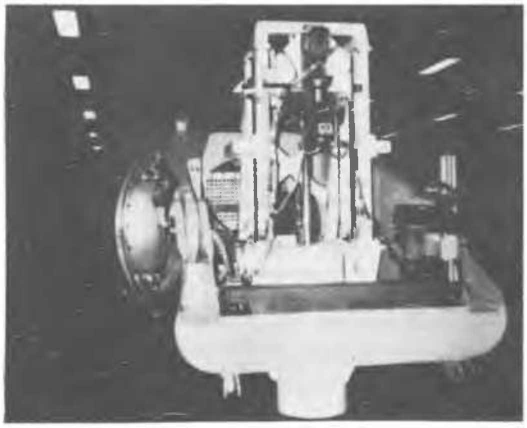

Fig. 1. The machine.

MEASUREMENTS

The acceleration was measured by a miniature transducer fixed at the bottom of the anvil, on the axis.
Dynamic strain signals were measured at the top and at the toe.
Static strains were measured at the top, the toe and two intermediary levels.

The force F was measured by four transducers fixed on the cross-beam.
The displacement u was measured by counting the pulses of the encoders which controlled the servo motor of the cross-beam. Additional information was given by a linear potentiometer of 600mm stroke.

Data acquisition was carried out by a multi-channel digital transient recorder for the dynamic and cycling signals and by a multi-channel sampler for static signals. The nominal frequency for blow signals was 80,000Hz (sampling rate 0.5 to 10M Hz). The sampler operated at 1/2Hz (1s per full sample). The data acquisition was controlled by a PC.

IMPACT CONDITIONS

From the stress wave theory it follows that the first "half cycle" of the impact signals, before echoes arrive can be measured by laboratory tests at 1g without soil. Those tests are controlled by the stroke h. An installation was built and used in order to tailor the signal by chosing the right cushion.

A comparison to an in-situ signal is given in figure 2. The mock cushion which provided the correct signal was subjected to hundreds of blows. Thus the continuously good performance during a complete centrifuge test was secured.

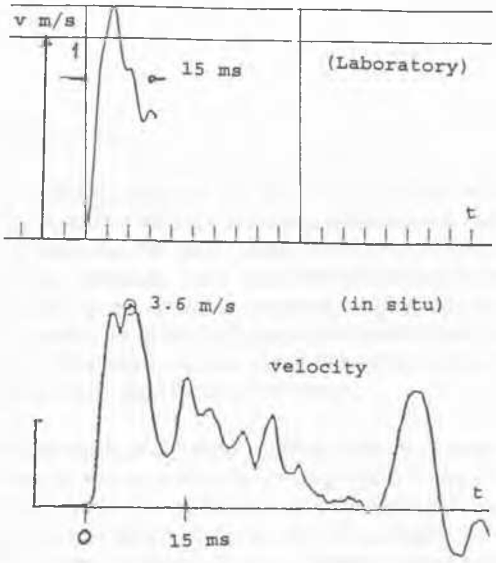

Fig. 2. Similitude of impact (1g).

TESTS

Tests were carried out on a fine grained Fontainebleau sand, at a relative density of about 85% The sand was rained into the experimental cell and then saturated.

Driving operations were carried out by single blows and automatic series of blows and dynamic data acquired for both. Before each static test five consecutive blows signals were acquired. At chosen depths intricate loading tests in both directions, and either slow or rapid cycling were carried out.

All the results looked realistic. Figure 3 is an example of the dynamic signals which are at the heart of the method. Those signals were highly repetitive.

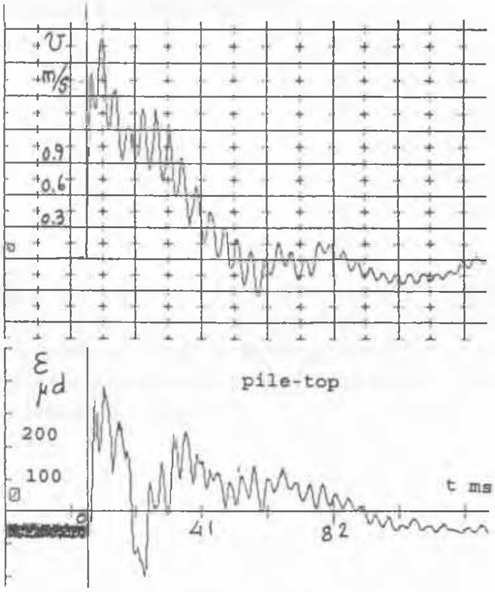

Fig. 3. Dynamic signals - in situ values (depth 11 m).

CONCLUSION

A robot for pile driving and vertical load testing was built and used. The machine performed correctly. Signals of good quality which look realistic were obtained. Future tests using the same machine look promising.

REFERENCE

Zelikson, A., Raines, R.D., Malalel, P. (1992). Robotics for centrifuge simulation of pile driving and testing. Proc. 4th Int. Conf. on the Application of Stress-Wave Theory to Piles. F.B.J. Barends editor, The Hague, The Netherlands.