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# Modelling pile installation in centrifuge experiments

## Etude sur modèle d'installation de pieux lors d'expériences utilisant un centrifugeur

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**SYNOPSIS** The need to simulate pile installation at high acceleration levels in centrifuge modelling is discussed. The loss of similarity associated with failure to do this is most critical for axial loading in sands, less critical for lateral loading and perhaps not important in clays where volume changes during installation are small. Results show the effect of varying push installation rates for piles in clay with changes in load and in plug behaviour for open-ended piles. Final results demonstrate the behaviour of model piles subjected to impact driving which approaches but does not yet achieve similarity with field techniques.

### INTRODUCTION

Model studies have contributed to the development of soil mechanics and foundation engineering since the time that these became recognisable disciplines within the broad field of science and technology. At the first International Conference there was a single paper by Pokrovsky and Fedorov (1936) describing model studies carried out aboard a centrifuge. Papers on model studies using centrifuges have appeared in each of the Conferences since 1969 and recognition of the validity and power of combining conventional modelling techniques with the generation of self weight body forces and soil stresses by centrifuge accelerations has led to rapid increase in research and development in this area in the last fifteen years. Many geotechnical problems have now been studied and the two most popular have been various aspects of slope stability and pile behaviour.

The ideal model which is intended to simulate a realistic field situation will be subject to the same restraints as in the field and in addition must satisfy the varying requirements of modelling theory to the highest attainable degree. As in other areas of model engineering, it is often not possible to satisfy all similarity requirements simultaneously and something less than the ideal is the result of loss of similarity, although this will often be quite acceptable.

Pile behaviour in the field is recognised as being a function of many variables, of which the most critical is often the method of installation. The aim of the present paper is to review work which has been carried out over a number of years in modelling pile installation, 'in flight', into various beds of soil aboard a large centrifuge. The need for in flight installation is discussed initially and this is followed by discussion of various techniques used to date. The configuration and capacity of the centrifuge used and the principal features of the hardware aboard the centrifuge have been described by Craig and Rowe (1981). Details of single pile model studies involving installation and axial loadings in sand are given by Sabagh (1983, 84), in clay by Craig (1983, 84) and on installation and lateral loading in sand by Oldham (1983, 84).

### QUASI-STATIC INSTALLATION

Where single model piles are used in sand it is imperative that installation be carried out at appropriate acceleration levels so as to reproduce the pattern of stress which might be set up around the field pile subjected to field stress levels. Installation of a model pile at unit gravity, followed by centrifuging to increase the soil self weight will lead to a significantly different stress regime around the pile and different load capacity and deformation characteristics. The reasons for this are self evident and are discussed in detail by Craig (1984) whose data on the effect of the variations in acceleration level at the time of installation, on subsequent pile capacity, are confirmed by other researches, Ko (1984), Allard (1984). The magnitudes of the discrepancies are such as to cause serious doubt on any quantitative data from static axial loading of models where piles are installed at 1g. The only consolation is that errors introduced by 1g installation are conservative. No specific data are available from cyclic or dynamic axial loadings but it is likely the effects will be similar.

The effects of varying acceleration at installation on piles in sand may be less critical when they are subjected to static, cyclic or dynamic lateral loads. The reasons for this are two fold:-

- (a) Where the pile has any flexibility the behaviour under lateral loading is dominated by soil reactions in upper levels where installation induced stress changes are lowest.
- (b) The nature of the pile loading modifies the stress regime around the pile to a greater extent than in axial loading.

Only Oldham (1983) and Craig (1984) report lateral loading tests following in flight installation. Craig demonstrated the increase in stiffness of the pile-soil system under static loading after centrifuge installation when compared with 1g installation, while Oldham's comparison showed significantly smaller effects under cyclic loading.

Arguably in impermeable clays, when pile installation can be considered an essentially undrained phenomenon, the necessity for in-flight installation may be less critical than in sands.

Single pile installation in clay under high accelerations has been reported by Craig (1983, 84) and by Nunez and Randolph (1984). The latter used the combined self weight of a pile and pile cap to push a closed ended pile, while the author's results have all been obtained using a servo - controlled hydraulic actuator.

The significance of viscous or rate effects in clays cannot be overemphasised. There are conflicts between various aspects of time scaling in models where creep, inertia and fluid flow may all be of significance and discussion on this topic relevant to the piling problem has been raised by Randolph (1979) Craig (1983, 84) and Nunez and Randolph (1984).

Craig (1983) reported the effects of varying the rate of installation by continuous pushing, of hollow pipe piles into beds of uniformly consolidated plastic Derwent clay. Very similar results have been obtained for a remoulded boulder clay from Cowden in North-East England. Figure 1 shows the load/penetration curves for the latter over a range of installation times,  $t$ , varying by  $10^3$ . Comparison of loads at a penetration of 22 diameters as a function of a time factor  $T = c_h t / d^2$ , Figure 2, suggests large increases in load on account of viscous effects at one end of the spectrum and consolidation at the other, relative to a minimum installation load corresponding to a mobilised undrained strength consistent with laboratory data obtained in standard tests. ( $c_h$  = coefficient of consolidation,  $d$  = pile diameter). Despite the large variations in installation loads, subsequent performance of all piles in the series was very similar when load tested at a consistent rate, Craig (1983).

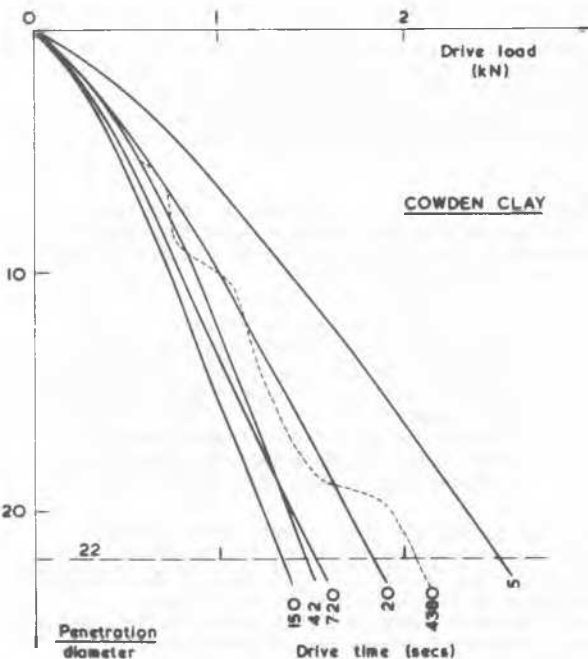


Fig.1 Load versus penetration - effect of drive duration

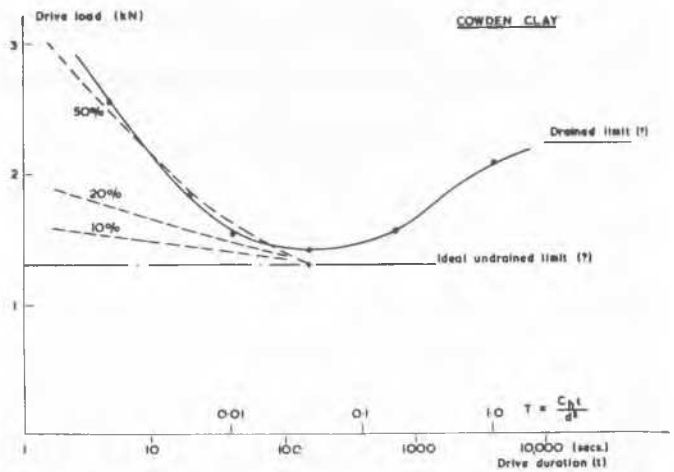


Fig. 2 Drive load versus installation time factor

Figures 3 and 4 show further data from the two test series described above. The pipe piles plug with clay and become in effect closed ended beyond a certain installation depth. The results indicate that the length of the internal plug is related to the drive time and that the longer plug lengths are associated with the lowest installation loads in each soil.

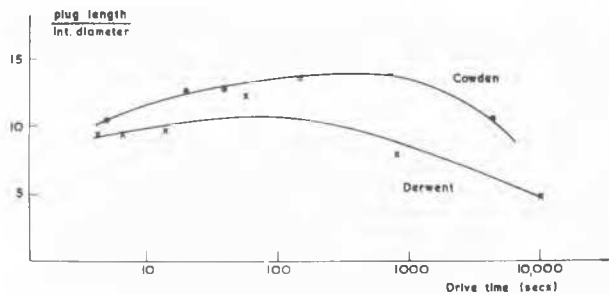


Fig.3 Effect of drive duration on plug length

IMPACT DRIVING

All the tests described so far have attempted to achieve the laudable aim of an installation in flight in the centrifuge, but even these do not truly simulate field installation processes which may involve impact driving or the use of rotary boring rigs. One major challenge to the next generation of centrifuge modellers will lie in developing a capability for simulating these and other construction industry techniques. Development of manipulation skills and robotics can be anticipated, which may match recent advances in instrumentation and in digital signal processing.

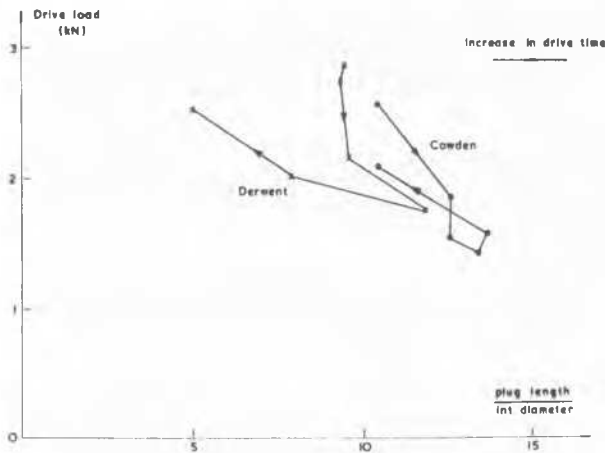


Fig.4 Effect of plug length on drive load

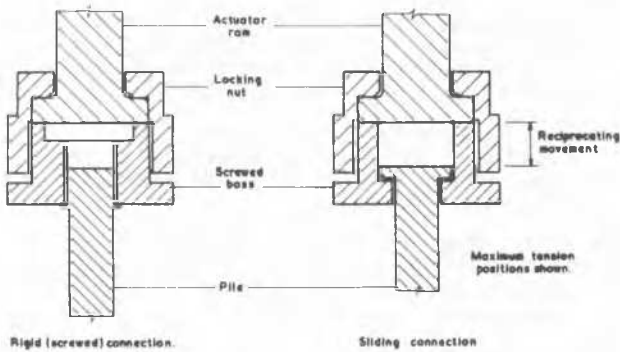


Fig.5 Impact driving - pile head arrangement

In the short term some results are presented from attempts to move towards simulation of impact driving for pipe piles.

The first approach developed was to utilise the servo-hydraulic actuators which had provided the earlier quasi-static push. With suitable computer software and interfacing, input signals could be programmed to apply controlled compressive loads to a pile head with return to a nominal zero load at frequencies upto 50Hz. The particular equipment available proved capable of driving piles into beds of moderate strength clay at these frequencies but installation into sand beds generally required greater loads with a lower frequency blow. Initial trials used a rigid connection between pile head and actuator ram which resulted in application of tension loading in that part of the cycle when the servo system sought no load.

Slight modification involved inclusion of a sliding connection at the pile head, Figure 5, and brought about an improvement in the load/time characteristics Figure 6. Figures 7 and 8 show comparisons between static and impact loading into beds of uniform clay and clay above sand. In the dynamic loading the curves represent the envelope of maximum loads, blow by blow, as penetration advances. Comparison of the dynamic

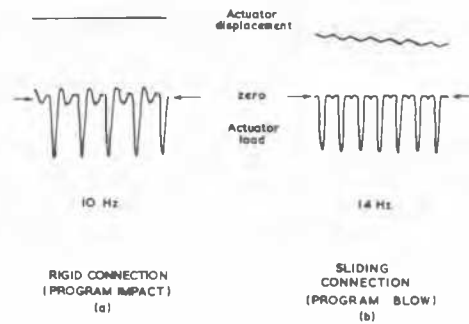
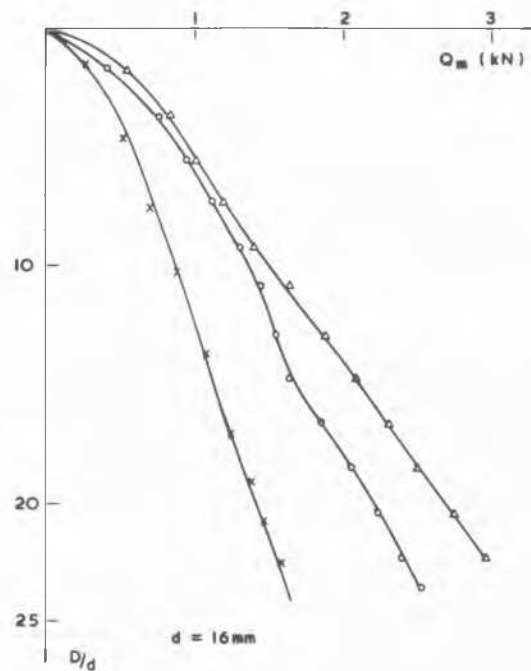


Fig.6 Impact driving - load traces



		Plug (mm)
x	(a) Static (3 mins)	212
o	(b) Dynamic 14 Hz (30 secs)	136
Δ	(c) Cont. penetration (4.2 secs.)	131

Fig.7 Comparison of static and dynamic driving - uniform clay

loads in Figure 7 with the loads from high speed continuous penetration suggests that the instantaneous pile velocities following impact were limited. Contrary to expectations the impact loading produced shorter plug lengths than those measured in static installation.

A second generation of impact driving equipment is under development, which aims to generate much higher velocity impacts. The pile driver consists of a brass weight lifted by a rotating cam which allows a free fall drop down vertical guide shafts under centrifugal

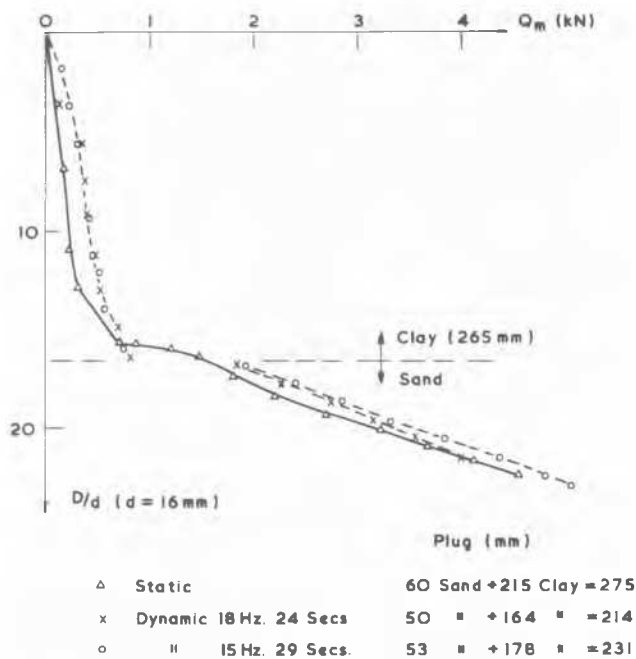


Fig.8 Comparison of static and dynamic driving - mixed strata

acceleration. At present the cam is rotated at limited speed, by a computer controlled stepper motor through a gear box and belt drive. The whole hammer assembly is rigidly held below the servo-controlled actuator. An LVDT measures the pile set after each blow and the feedback control utilises this signal to bring the hammer block down to maintain a fixed position relative to the pile head.

If this technique proves capable of generating an adequate controlled impact of high velocity a higher blow rate may be obtained by rotating the cam with a higher speed hydraulic motor. Whether such a technique will be necessary is questionable. In sands the blow signature is the crucial target for simulation and blow count rather than blow rate may be the significant parameter. In clays where the complications of simultaneous viscous, inertial and drainage effects are met the combination of high velocity and high frequency may even be counter-productive. As mentioned earlier the behaviour post-installation of piles pushed into clay does not appear to be very dependent on the installation technique and the prime aim at present is to determine whether model soil plug movement will be altered by the driving technique variations.

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