

SESSION 4: PILES

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Paper by E.H. Davis and H.G. Poulos

Dr P.T. Brown (University of Sydney) queried whether it was possible to use the electro-osmosis technique to relieve negative skin friction in the case of concrete piles by using the reinforcing steel as the cathode. In reply, Prof Davis said that in principle there seemed to be no reason why not.

Dr I.W. Johnston commented that there had been successful attempts using reinforcing bars of reinforced concrete piles, however the results were less spectacular than those from steel columns.

Dr I.W. Johnston (Monash University) commented on the validity of Esrig's boundary condition used by Davis and Poulos. Although the diffusion equation applied, their solution assumed a linear voltage gradient between the electrodes, giving maximum pore pressure at the electrodes after some considerable time. On the basis of laboratory and field tests, this linear voltage gradient did not exist, but the gradient was extremely high at the electrodes giving maximum pore pressures at the electrode very quickly. This would account for the two-hour relief of downdrag instead of the 24 hours as predicted by the authors. He also suggested that great care should be taken in the use of electro-osmosis with the pile as the cathode, since the adhesion would be much reduced. However, after removing the current, the shaft adhesion would increase dramatically, possibly to a level greater than without electro-osmosis. This was brought about by electro-chemical bonding which could be strong and rigid. Any subsequent clay consolidation might quickly induce more pronounced downdrag. Prof Davis, in his reply, commented that, in the Cutler Circle Pile Test, the voltage gradient was not linear, and was proportional to the reciprocal of the electro-chemical effects. Davis emphasised that at this stage the electro-osmosis method should be regarded as an interesting observation and not as a superior alternative to other methods such as bitumen coating.

As a point of interest, Dr Johnston mentioned that the test pile at Hamilton was used as an electro-osmosis trial after Poulos' work. With the pile as the anode, the ultimate resistance was increased by a significant amount.

Paper by J.M.O. Hughes, H.D.W. Fendall and P.R. Goldsmith

Dr J.P. Carter queried the influence of the cone angle at the tip of the model piles on the horizontal stresses measured in the soil immediately after installation. Since all the test piles had 45° pile tips, the author could not make any comparisons. Mr Fendall suggested that the pile tip configuration would have little effect on the stress distribution, based on comparisons with flat end piles.

Mr T.A.H. Dodd asked whether any difference had been noted between the sand movements observed in photogrammetric and x-ray techniques, since these involved respectively half-triaxial and full-triaxial stress fields. Dr Goldsmith answered as follows:

1. The model experimental study was carried out entirely on the axis of symmetry of the model piles. This was achieved in the stereo photogrammetric case by splitting the model pile so that the glass plate lay in the plane of the axis of symmetry, and in the radiographic case, by ensuring that the lead shot placed in the sand mass lay in the plane of the axis of the model piles by constraining the pile during installation.

2. The effect of friction developed between the glass plate and the model piles in the stereophotogrammetric study was insignificant when compared on the basis of radial soil displacement profiles measured at the level of the top of the pile tip, and those obtained from the radiographic technique. These radial displacement profiles were rigorously measured at various steps of pile installation by driving (at approximately 1D increments of installation).

The radial soil displacement profiles averaged over ten increments of pile installation, obtained from both the radiographic and stereophotogrammetric techniques showed the average displacement profiles to be in close agreement. From this it could be concluded that the effect of friction between the sand and the glass plate in the stereophotogrammetric technique was insignificant, in that the radial displacement profiles were not significantly modified.

Dr P.J. Hoadley commented that considerable care was necessary when the results of

small scale model tests were to be extrapolated to the behaviour of prototype structures. The model pile tests discussed by the authors did not satisfy the requirements of similitude, so that the general state of stress and the consequent strains in the soil would not be similar to full scale pile loading conditions. Many of these limitations could be overcome by using centrifugal model testing techniques, and a number of geotechnical centrifuges were in use or under construction. Cambridge University had developed equipment to perform cyclic lateral load testing on both single piles and small groups of piles. In figures 14 and 15 of the paper the interaction between two piles was displayed for the very large pile displacement equivalent to 50% of the pile diameter. He asked how the interaction factors varied with pile spacing at much lower pile displacements corresponding to normal working load conditions? (ie, at 0.5 - 10% of pile diameter?) In this range, did the interaction factors vary with displacement or applied load? Could the authors also comment on the reason for choosing to model rigid piles rather than longer flexible piles which are more frequently used in practice? He also asked how the measurements of lateral pressure and displacement along the pile compared with the suggested p-y curves developed by Reese, Cox and Koop. Had any tests been done with repeated or cyclically applied loads, and if so, was there any change in the behaviour of the pile group?

In his reply, Mr Fendall said that, as indicated by figure 13, the interaction effect varied approximately linearly with pile deflection up to a displacement of 0.05 to 0.1D, thereafter remaining essentially constant. The authors' research to date had been directed mainly towards this 'steady state' condition as a first step towards a full understanding of pile interaction.

The lateral response of a rigid pile was more affected by a change in soil strength than is a flexible pile. Therefore rigid piles show the effect of pile interaction to a greater extent than flexible piles. Hence the reason for their use.

A small number of tests were performed with cyclic loading of groups in dense sand. Two significant points were noted: a) the resistance of the group decreased with increasing number of cycles, and b) the proportion of load resisted by the front pile increased slightly with additional cycles; ie, interaction effect increased.

Prof B. Ladanyi suggested that in the dense vibrated sand, a high initial horizontal stress must have existed before the pile driving.

No direct measurement of the horizontal soil stresses after vibration of the sand was made. These were likely to have been much higher than those in the sand placed by pluviation for which $K_0 \approx 0.4$. However, it

was interesting to note from figures 4 and 5a that the peak lateral pressures after driving were almost the same for each soil placement method.

Paper by A.F. Williams

Mr R.L. Rodway made the following comment with reference to the high normal stresses which result from interface dilation. The induced stresses appeared to be 'locked in' and did not fall away as socket slip progressed. Because of the importance of the presence of high normal stresses in design, he asked about the likely maintenance of these in the long term. Mr Williams answered that the long term values of locked in normal stress and slide resistance depended on radial consolidation of the rock mass and creep under the particular stress condition. All the field tests were designed to reflect drained rock behaviour, hence consolidation effects had been allowed for. The normal stresses developed were within the elastic range, so that no creep would be expected. However, if the side resistance was close to the peak value, some creep settlement might be experienced, which would cause a small redistribution of load. Unfortunately, the work had been restricted to tests over periods of 30-50 hours and further work was needed to cover longer periods.

Prof Ladanyi made the following comments:

First, I would like to compliment the author for the excellent work he has done in investigating the side resistance of rock socketed piles. The analysis of the pile-rock interface interaction mechanism and the experimental data on the subject shown in the paper, represent an important step towards a better understanding of that mechanism. This work has also some important implications in the practical design of rock socketed piles, because it gives an experimental proof of the mobilisation and conservation of the lateral normal stress at the pile rock interface, which gives rise to the frictional component of the side resistance.

My only comment concerns eq. (6) used by the author for evaluating the mobilised lateral normal stress. The equation is valid for a linear response of the rock mass to stress characterised by the Young's modulus of the mass, E_m . One way to evaluate the mass modulus E_m from the rock modulus E_i is by using the mass factor j_m mentioned by the author. Another possible method would be to modify eq. (6) so as to take into account the opening of radial cracks around the pile, which would have a similar effect. Such an equation, valid for zero radial tensile strength of the rock mass and for σ greater than twice the radial ground stress p_h , but smaller than its uniaxial comparison strength, is (Ladanyi, 1976):

$$\sigma = \left[\frac{\Delta R}{R} \left(\frac{E_i}{1 + \nu} \right) - p_h \right] \left[(1 - \nu) \ln(\sigma / 2p_h) + 1/2 \right]^{-1}$$

Reference:

LADANYI, B. (1976) Quasi-static expansion of a cylindrical cavity in rock; in Engineering Applications of Solid Mechanics, Symposium, University of Toronto, vol.2, pp 219-240.

Paper by H.G. Poulos

Mr D.B. McInnes asked why the pile was stopped short of the shaley clay; how the

stiffness of this would be determined if it was to be involved and how the local settlement response would change in these circumstances. Dr Poulos replied that the pile did stop short of the shaley clay. The initial load was taken up by skin friction and hence there was no noticeable improvement in the stiffness values for small displacement values. In the latter stages of the loading (large displacement) an improvement would have occurred if the pile had penetrated the shale layer because of the enhanced end bearing capacity.