REPORT ON INTERNATIONAL CONFERENCE ON CALCAREOUS SEDIMENTS

This conference was jointly organised by the Institution of Engineers, Australia and the International Society for Soil Mechanics and Foundation Engineering and was held at the Sheraton Hotel in Perth from 15 to 18 March 1988.

The catalyst for the Conference was the decision by Woodside Offshore Petroleum Pty Ltd to make available the experience gained on the North West Shelf of Western Australia.

The Conference proceedings comprise seventy six papers. These include 38 papers relating to various aspects of investigation, analysis, design and construction of foundations for the North Rankin 'A' Platform. The balance of the papers relate to a variety of projects throughout the world.

Included in the Conference were four sessions in which State of the Art reports were presented followed by selected presentations and general discussions. The following session reports summarise these discussions.

Session Report: - Lateral Loadings and Shallow Foundations

Reporter: Dr. M Allman

This session was to have consisted of state of the art presentations by Prof. L Reese on Lateral Loads and by Dr. K Hoeg on Shallow Foundations, followed by selected short presentations and a general discussion. Unfortunately Dr. Hoeg was unable to present his State-of-the-Art report and the only consideration given to shallow foundations during the session was in short presentations by R N Dutt and Prof. J Burland.

State of the Art Report:
The Response of Piles in Calcareous Soils to Lateral Loading
by
Prof. L C Reese

The report began by discussing the general background to the analysis and design of laterally loaded piles. The characteristics of calcareous soils which influence the lateral loading behaviour, and research that has been conducted on this problem were then discussed, followed by recommendations for further research and conclusions.

The analysis of laterally loaded piles requires the selection of appropriate models for the pile and for the soil. The method that has been used most widely to date for modelling the soil, particularly for the design of piles for offshore foundations, is the p-y method. In general, full-scale experiments are still critical to obtaining data on which to base recommendations for p-y curves. The p-y method was concentrated upon during the discussion of the response of calcareous soils.

The unusual nature of calcareous soils and problems with classification lead to some difficulties in modelling the response of the soil. Three fundamental characteristics of calcareous sediments were cited as significantly affecting p-y curves i.e. $CaCO_3$ content, cementation and crushing. The model described by Price (1988), principally related to monotonic loading for cemented calcareous soils, is very interesting and would suggest a highly non-linear p-y curve. With regard to cyclic loading, models such as that presented by Dobry et al (1988) may be useful although consideration of the permeability of calcareous soils is important.

Suggestions for further research were;

- improved near surface sampling;
- improved methods for obtaining engineering properties of calcareous soils;
- opportunities for full-scale testing should be taken; and
- further analytical work is needed.

The report was concluded with the following remarks:

- major difficulties exist in developing a rational method for predicting the response of calcareous soils to lateral loading;
- the Abbs (1983) model for p-y curves for calcareous soils provides the framework for design, and
- comprehensive site-specific testing, both laboratory and in-situ, are required for major structures, as well as conservative design.

Special Presentations

Lateral Loading - J D Murff

Murff discussed the foundation design for external struts for strengthening the first generation platforms in Bass Strait. To aid in the design of the pile to withstand lateral load, large scale tests were conducted in a pit of reconstituted calcareous sand, as well as centrifuge tests. Details of these test series can be found in Williams et al (1988) and Wesselink et al (1988), respectively. From the test results p-y curves were developed and good agreement was obtained between calculations from the p-y curves and the results of the pit tests.

Shallow Foundations - R N Dutt

Dutt discussed the behaviour of such foundation elements as jack-up footings, mud mats and gravity anchors in calcareous sands. For jack-up footings, general shear and local shear bearing capacity solutions generally overpredict the end bearing capacity in calcareous soil, mainly because of the effects of soil compressibility and scale. Spherical cavity expansion approaches have also been found to overpredict, although giving an improved predictidon, with scale effects still not accounted for. Difficulties arise in predictions as important parameters such as E, υ , and the volumetric strain δ show poor repeatability in laboratory tests, and the selection of the elastic parameters is very subjective. Dutt has found that using

$$\varphi' = \tan^{-1} (0.33 \ \tan \varphi)$$

in the general shear solution provides a good prediction of end bearing capacity in calcareous soils.

For mud mats the same considerations as for jack-up footings apply, although scale effects are less severe.

For gravity anchors the sliding resistance is best approximated by using φ' from direct shear tests or direct simple shear tests conducted at constant volume.

Shallow Foundations - J Burland

Burland briefly discussed the results of long-term observations made on the foundations of some 20m diameter by 50m high silos founded on deeply weathered carbonate material. The pressure-settlement curves showed a classical form with a very linear portion at small strains then a break followed by a steeper curve.

Cycled over 20 years, maximum settlements were 20mm, and when the load was less than the previous maximum pressure there is virtually no irrecoverable settlement. There was a shakedown with no brittle, "run-away" type situation.

Burland believes there are tremendous advantages to be made by making measurements from local displacements remote from the loaded area, as well as at the loaded area.

General Discussion

The chairman, **I W Johnston** (Monash University) opened the floor for discussion and suggested that four problem areas were apparent from the previous presentations and could form the basis of the discussion. The four problem areas were:

(i) cementation;
(ii) pore pressure generation;
(iii) soil compressibility; and
(iv) scale effects.

Unfortunately time only permitted the first two to be addressed.

Cementation

L C Reese (University of Texas, Austin) - it is difficult to be specific about the effect of cementation on lateral load behaviour as it is variable. Models must allow variations with both depth and distance from the pile. At the pile, cementation can breakdown, while further away the soil remains in a pre-peak condition. Most importantly, the presence of cementation can be detrimental, particularly with respect go gap formation.

J D Murff (EPRCO) - from my experience cementation generally gives a high monotinic stiffness and if there is no breakdown of cementation then there is little concern. However, there is a dearth of information on the effect of cyclic loading and the pressures at which cementation is likely to breakdown. Tests are needed to enlighten us in this respect and work in articially cemented soil is providing valuable information.

A F Abbs (Dames and Moore) - using our model (Abbs, 1983), if you reach the peak of the p-y curve you can get an "unzipping" action. This is alarming, however, I have never seen it happen or be reproduced in tests.

L C Reese - (in response to a question on the applicability of the pressuremeter expansion curve for deriving p-y curves). Any insitu tests which provides information on the soil is useful. Regarding the pressuremeter, it expands equally in all directions, whereas a pile moves in one direction only, so you cannot expect a one-to-one relationship. Design methods prepared at Texas A & M are useful for developing p-y curves from pressuremeter results. The self-boring pressuremeter is particularly useful, and it can be used to obtain fundamental stress-strain information and then be utilised to develop p-y curves.

L C Reese - (in response to a question on the effect of gapping). Gapping can be remedied by placing pea gravel at the surface, and offshore this may have potential, particularly where scouring protection is being provided. You could grade the scour protection from fine below to coarse at the surface. There are possibilities here for remedial action.

H G Poulos (University of Sydney) - gapping in uncemented calcareous soil was observed in model tests and this suggests there is potential for gapping to several meters depth in the North Rankin case. He enquired whether gapping was observed in the Bass Strait pit tests.

J D Murff - no gapping was observed in the pit or centrifuge tests in Bass Strait, just a conical depression.

Pore Pressure Generation

Chairman - what about the effects at pore pressure generation during cyclic lateral loading; does it affect stability?

T W Dunnavant (EXXON) - in the Bass Strait pit tests pore pressure generation was very minor under cyclic loading until the load level approached the monotonic capacity. Under working loads or 100 year loads, in uncemented material pore pressure generation is not a problem. Permeabilities from tests were variable but were as low as 10^{-5} cm/sec.

A F Williams (CSIRO) - there was a measureable effect on the stiffness of the response due to the small pore pressure generated during the pit tests, but it was minor.

T W Dunnavant - the pore pressure tended to reach a stable regime.

At this point the Chairman thanked all participants and closed the session.

Session Report: - **The Behaviour of Deep Foundations**

Reporter: **Dr. D Airey**

This section of the conference was dedicated to the axial response of deep foundations in calcareous soils. A state of the art paper was presented by Dr. M F Randolph which is briefly summarised below. This was followed by two prepared discussions. The first by Adrian Hyde looked at a method for estimating the axial capacity of piles from the results of triaxial tests, the second presented by Guy Houlsby looked at the effect on the end bearing response of layers of cemented material. Discussion was then opened to the floor.

State of the Art Report:
The Axial Capacity of Deep Foundations in Calcareous Sands
by
Dr. M F Randolph

Using data presented at the conference the principal engineering properties affecting pile capacity were restated; these are the high friction angle, the high voids ratio and resulting compressibility, and the fact that they are, typically, at least lightly cemented. The paper then went on to review the published data on the shaft capacity of driven, drilled and grouted, and driven and grouted piles. The data were compared with the design guidelines used in current practice. For driven piles, the low skin frictions were noted and particular emphasis was given to the difficulties associated with estimating the shaft capacity from pile driving records, and from the interpretation of cone penetrometer tests. Grouted section tests relevant to the behaviour of drilled and grouted piles were reported in several papers submitted to the conference. It is evident from the results of these tests that, unlike driven piles, partial cementation has a beneficial effect leading to higher lateral stresses and higher skin frictions. Again the difficulty of predicing the performance of these piles from cone penetration data was highlighted. Finally, grouted driven piles were mentioned as these appear to offer the advantages of drilled and grouted piles without their high cost.

The variable nature of the calcareous deposits was emphasised. This makes it difficult to develop analytical models that can adequately describe the stress-strain response. In such a situation it is essential to try and understand the mechanisms involved, and to try and formulate guidelines that have a rational basis as opposed to being entirely empirical. Nevertheless, a model is essential to explore the load deformation response of axially loaded piles, particularly under cyclic loading. A model was described that captured the main features of the soil response, and was used to predict the response of a typical drilled and grouted pile under cyclic loading.

The end bearing response of piles in calcareous soils was considered. This can be a significant portion of the overall capacity, especially for driven piles. Consideration was also given to the ability of open ended piles to form soil plugs and thus govern the ability of such piles to develop their full end bearing capacity.

G Mostyn (University of New South Wales) expressed concern regarding the way in which Dr. Randolph had fitted a straight line through the data from the grouted section tests performed in the Bass Strait. Any one of a number of lines could be fitted through the data and could be made to fit a number of a priori assumptions regarding the behaviour of the tests.

M F Randolph (University of Western Australia) - In field tests it is not possible to vary all the parameters that one would like to, which in this case would have included the grout pressure and pile size, because of cost restrictions. As a result it is necessary to interpret the field tests within the framework built up from numerical and laboratory experiments. In the case of grouted sections, many laboratory tests have been performed, particularly at the University of Sydney, which show a clear effect of confining stress. Unfortunately, only a small range of grout pressures have been used so that a variety of interpretations of the data are possible. However, when producing design guidelines it is necessary to consider all the available data from a range of sources. If field data are obtained then it is possible to check that the design approach is consistent with them.

T Hyden (ESSO) - The grouted section tests in the Bass Strait were performed to develop a revised design approach for the particular materials existing in that location. As such the exercise was successful and it was possible to construct a lower bound curve to the data which was used for design.

D Murff (EPRCO) I would like to add some additional comments on the grouted section tests performed in the Bass Strait. The tests were all performed from existing operating platforms and as a result there were limits on time and accessibility which meant that a very tight schedule had to be kept to. Numerous decisions had to be taken on site using one's best judgement of how the tests were going at the time. Later when one looks at the data in more detail it is always possible to determine more information that it would have been good to have obtained.

When the tests were performed we did not have any particular model in mind. Our aim was to obtain an appropriate design model for the soil at the test site which was very weak to very strong layers. The production of a suitable design model required very careful interpretation of the data and certainly a great deal of attention was given to the scale effects mentioned by M Randolph in his state of the art paper.

P G Fookes (Consulting Engineering Geologist, Winchester, U.K.) - I would like to expand on the statement of Dr. Randolph's that calcareous sands are angular. Uncemented carbonate sands can be broadly classed into three main groups; rounded ooliths, fragmented, and bioclastic or corraline. These sands can be either loose or dense. With time these sands can become cemented. At first a light micrite cement will bond the particles together and at this stage the sands will still be highly porous. Eventually a heavier cement will be formed that will close up the pores and this cement will be comprised of sparry calcite. The point at which these cemented sands can be considered to change from soil to rock lies somewhere between the light and heavy cementation. The chemistry of the cementing process is highly complex, but it is possible for the properties of the soil to change in engineering time. For instance, with the high pressures under the bells at North Rankin the light cement may dissolve, and then, perhaps as a result of the pore pressure dissipating, re-cementation may occur blocking the pores and possibly creating a much stronger material.

A Noorany (University of San Diego) I would like to caution against extrapolating the experience from Rankin to other sites of calcareous soils. Many particles from other sites contain internal cavities and I would like to ask how one would characterise the void ratio in these soils and what would the effect of the internal voids be on the stress, strain, strength response?

A Hyde (University of Bradford) Tests have been performed on a range of carbonate sands and a standard siliceous sand, the results of which are described in the paper by Golightly and Hyde (1988). In agreement with the data for carbonate sands reported in several papers submitted to this conference, our carbonate sands exhibited negative dilatancy and lower shear moduli at all stress levels than the siliceous sand.

Using Rowe's stress dilatancy theory and the pile skin friction load transfer relations of Frank and Randolph, theoretical predictions of skin friction mobilisation for the sands tested have been obtained. The predictions show that, as expected, the pile skin frictions mobilised by carbonate sands are much lower than for the siliceous sand.

The analysis set out in this presentation is still at an early stage of development; it assumes a rigid pile and a linear elastic soil. Improvements are required to account for material non-linearity, pile compressibility and to determine a more appropriate transfer function.

G Houlsby (University of Oxford) The variability of calcareous soils has been mentioned several times during this conference. In this discussion the importance of the layering will be emphasised, in particular the effects of having a strong layer amongst rather weaker layers and its effect on the end bearing pressure of piles.

A series of model pile tests have been carried out at Oxford University and have been described in the paper by Houlsby, Evans and Sweeney (1988). In these tests artificially cemented layers of sand have been embedded at the mid-depth of a calibration chamber containing uncemented sand. The stress level in the chamber is controlled through rubber pressure bags. The very small scale of the laboratory tests when compared to the full scale situation should be noted, the calibration chamber was 450mm diameter by 700mm high.

The principal variables studied were the effects of stress level, layer strength and layer thickness. From these tests a distinct pattern emerged in which the end bearing capacity in uncemented sand is controlled by the stress level, and in thick layers of cemented material is controlled by the layer strength. Failure of the layer was ductile at lower layer strengths and high stress levels, and brittle for high layer strengths and low stress levels. It is the pattern of behaviour with varying layer thickness which is, however, particularly interesting.

Houlsby et al (1988) discuss the results of five tests, one in purely uncemented sand and the others with cemented layers of thickness 0.5, 1.5, 3.0, and 5.0 times the pile diameter. A low confining stress was used and the cemented layers all failied in a brittle manner. In these tests the pile is continuously jacked into the specimen, so that the resulting curves are somewhat analogous to CPT profiles. Two important features emerge. Firstly the load begins to increase when the pile is within about 2.0 to 2.5 diameters of the top of the layer. Secondly, failure of the layer occurs when the pile is within 3.5 diameters (rather less for thinner layers) of the base of the layer. The load then reduces very rapidly towards the value in uncemented sand.

A result of this pattern is that the maximum load developed in thin layers is much less than that achieved in thick layers. For a layer of only 0.5 pile diameters thick, even a very strong layer causes only a minimal increase in load. Another feature is that the maximum load is developed when the pile tip is a short distance above the layer, not when it is at the surface of the layer. This means that to gain benefit from a thin strong layer the pile tip should be placed 2 to 3 pile diameters above the layer, and not directly on the strong layer.

The above results were obtained for continuously penetrating piles. Houlsby et al (1988) discuss a similar set of results for piles initially built in at the top of the cemented layer. These results are relevant to cast in-situ piles, or open ended piles which are grout plugged after driving. The tests show a very rapid build up of load, but again much lower maximum loads in thin layers, with virtually no benefit being derived from a strong layer 0.5 pile diameters thick.

In the context of the North Rankin A platform the "pile diameter" should be equated with either the bell diameter, or because of the close proximity of the bells, with the bell group diameter. The implication of the small scale model tests is that any layer of less than about 6m in thickness would have minimal impact on the foundation capacity (although it may of course influence the small displacement stiffness).

M Khorshid (Woodside) Could Dr. Houlsby give us more information about the modelling of the North Rankin profile and how the model results compared with the theoretical analyses.

G Houlsby We did not attempt to model the precise Rankin profile, but rather we attempted to model the model of the profile adopted in the finite element analyses. In practice, we had to further simplify the profile for the small scale model tests, and only drained tests could be performed. The following observations were made:

1. The model test gave a significantly stiffer response at small displacements than the finite element analyses.

2. A sudden failure occurred in the model test at a lower bearing pressure than in the finite element analyses. The model drained test looked like the undrained finite element analysis but with a higher capacity.

3. A second model test was performed in which the boundaries were adjusted to be identical to those used in the finite element analyses. This meant that the boundaries were much closer to the pile in this test. There were appreciable differences in the two test results, particularly at large pile deformations, suggesting that the boundaries used in the finite element analyses were not chosen sufficiently far away from the pile.

D Murff I have a question regarding the effectiveness of thin hard layers. Surely the response will depend on the strength of a layer relative to the surrounding layers. Will this not govern whether the behaviour is brittle or ductile?

G Houlsby In our tests the stress and strength levels were appropriate to the Rankin site, they were not identical but covered the range of values found there. From the evidence of these small scale tests is appears that a layer of less than half the diameter of the bell or bell group, would have no effect on the response. But, it is of course very dangerous, and often inappropriate, in soil mechanics to extrapolate from the results of small scale laboratory tests to the field situation.

D Murff Our experience in the Gulf of Suez with a layer of calcified limestone rock 1m to 2m thick, with piles of 1.5m diameter is worthy of note. The material both above and below this layer was very weak. During installation of the driven pile it was found that some of the piles could not penetrate through this hard layer. We were not happy with the piles resting on this thin hard layer and in some places were able to drive them through. This was achieved by having a full head of steam on the hammer we were using to drive the piles, and by ensuring we were going as fast as possible, when we reached the hard layer.

M Fahey (Univeristy of Western Australia) - The "free falling" piles at North Rankin were held up on relatively thin cemented layers. Can this be explained from the results of the work presented by Houlsby et al?

J Dolwin (Earl and Wright) The strong layers at 40m and 60m depth were both approximately 4m thick and the layer at 90m was somewhat thicker. However, the thicknesses of the individual layers were highly variable over the site.

G Houslby If indeed, the layers were 4 metres thick then I would expect them to have a significant effect as this would be approximately 2 pile diameters.

M Sweeney (BP) The thickness effects described in the paper by Houlsby et al were obtained from tests with piles that had closed ends. For an open pile being driven without plugging it is likely that it will be the wall thickness, not the pile diameter, which will be relevant. Thus a layer of more than 2 or 3 wall thicknesses in depth would be expected to have an appreciable influence on the ease of driving.

J Cuckson (SIPM) I would like to make some observations regarding the Rankin story.

The first task was to define the problem. Initially it was felt that as the stress level was high under the foundation the problem was one of estimating the settlement. We wanted to know what the appropriate load displacement curve was. Then a new ingredient was introduced, namely, did we have a drained or an undrained problem? If we had the latter then it appeared that there was a capacity problem. This shows the importance of determining the nature of the loading, an aspect of the story that apparently received little attention early on.

Classification was also a problem. At first it was felt that the North Rankin site was unique in Australia, but it has since become clear that this was not so. Nevertheless, it proved possible to fit all the samples into one of five categories on the basis of simple index tests. Subsequently a sixth category, the eposanded material was added.

Another difficulty lay in selecting appropriately conservative numbers. The model failed to duplicate the very brittle response of much of the test data and it was not clear if this was necessarily a safe assumption. For instance, the case of a footing punching through a strong layer above a weak layer is not necessarily a brittle problem. It is important to distinguish the behaviour of a small element from that of the overall structure.

A model was selected with a deviatoric and a volumetric yield surface. A large number of tests were performed to evaluate this model. It turned out that the deviatoric surface was of far greater importance although as many tests were performed to investigate the volumetric response. It is necessary to think about the stress path that will be applied in practice and concentrate on performing the most appropriate tests.

M F Randolph I would like to comment on the point made by John Cuckson regarding the assumption that ignoring the cementation is necessarily conservative. Plasticity theory states that if one ignores part of the strength then one should be on the safe side as regards capacity. However, the same is not true for the settlements required to reach that capacity. Under the working loads and owing to the effect of cyclic loading one leg could break through a relatively weak layer while the neighbouring legs are held up on the cemented layer. As a result of the cyclic loading this leg may accumulate displacement and this may give rise to a problem of differential settlement. In such a case it would clearly be necessary to consider the effects of variable cementation under the different legs.

J Cuckson I agree with the comments Mark Randolph has made regarding the assumption that a lower strength is a safe assumption. However, the situation at North Rankin was rather different because of the effects of the variable layering with depth. Not only did the different layers have different strengths but they also had different states of drainage so that in some layers the behaviour was drained and in others undrained. Also, under different bells there were different patterns of layering and different degrees of hardening within these layers. Even within a plasticity sense, therefore, one cannot make general statements because different layers behave differently.

On the possibility of differential settlement within a group, this in unlikely because the piles are physically joined together so that one cannot advance ahead of the others. There is some possibility for some slight differential settlement but not for gross movement.

M F Randolph In that case instead of differential settlement one will get load concentration which could be jut as damaging for the structure.

G Houlsby I would like to add that it can, indeed, be unsafe to ignore part of the strength. Within plasticity theory generally ignoring strength is going to be safe, but in some cases it can be unsafe. These cases are when one has a highly frictional material and when one is dealing with materials that exhibit brittle failure.

I Smith (University of Manchester) I would like to make a number of remarks concerning my involvement in the fascinating Rankin story.

Computing: I would like to emphasise that the Rankin remedial measures were computer designed. This was because there was no alternative, indeed if there had been one it would undoubtedly have been implemented because engineers are, in my view, wrongly suspicious of computer solutions.

Classification: We did have a viable classification of the Rankin material into 5 categories. Speakers at this conference have made many references to the infinite complexity of calcareous soils. This complexity is certainly not confined to calcareous soils. I am reminded of Rowe's Rankine lecture in which he said that most of the sites I have examined could be broken down into 3 or 4 horizons or materials at which point the behaviour could be comprehended and some analyses could be performed. It is disappointing to see that many of the papers submitted to the conference make no mention of the categorisation, based on the results of hundreds of drained and undrained tests, that we spent many hours developing.

The drained/undrained problem: In performing analyses of the plate load tests conducted at Rankin we intially assumed drained behaviour and found that the results were relatively insensitive to parameter variation, and they indicated adequate foundation strengths. An undrained analysis was then performed. This caused a major re-assessment of what we were doing because the analysis indicated we might have a capacity problem. To determine whether we had a drained or an undrained problem we, had to perform further analyses. From this we found that there were two orders of magnitude of permeability between the drained and undrained solutions. However, it was not possible to accurately determine the permeability and we therefore had to take the worst case and assume that we had an undrained problem.

Conservativeness: To be conservative we took low φ' values and generated high pore pressures in all our analyses. However, we were worried that it could be unconservative to be conservative in situations where there was a strong layer overlying a weak layer as the strong layer could shield the material below and lead to a lack of pre-loading.

Punch through: We do not appear to have the conventional jack-up punch through problem where you plunge at great geometric variations into a lower weaker material but rather a problem where the lower layer has already sensed the load and the total response does not show a dramatic decrease in load.

Session Report: - Geology, Fabric and Classification Systems

Reporter: J P Trudinger

This section of the conference, chaired by **Prof. Van Weele**, addressed geological aspects of calcareous sediments including their origin, composition, texture, diagenesis and classification systems. The state of the art paper was presented by **Prof. P Fookes**, and is briefly summrised below. This was followed by two prepared discussions. The first by **Dr. G Price** presented the results of fabric studies carried out on calcareous sediments; the second by **Mr. F Bullen** discussed the use of coralline materials as engineered fill.

State of the Art Report: Geology, Fabric and Classification Systems by Prof. P G Fookes

Prof. Fookes commenced his address with a review of the compositions and origins of carbonate sediments including calcareous sediments. He showed the various textures and fabrics that resulted from a range of clastic grains and precipitates and illustrated the mineralogical changes that typically follow deposition - from aragonite to calcite and, ultimately, dolomite.

He then described and illustrated the various types of sediments that accumulate in the various onshore and offshore depositional environments including the beach zone, lagoons, reefs and continental shelf. Changes in the depositional environment over short distances and fluctuating sea levels explain the extreme variation in sediment types which have been observed over short lateral and vertical intervals.

Prof. Fookes went on to discuss <u>diagenesis</u> - the changes that take place after deposition which, in the case of calcareous sediments includes cementing, solution, mineralogical changes and micritisation. He pointed out that some of these changes can develop in "engineering time". He stressed the value of having specialised sedimentologists carry out detailed geological studies as these commonly lead to insights that are highly significant in terms of engineering response of the sediments. He also mentionoed the value of chemical analyses of pore fluids.

Finally Prof. Fookes introduced the subject of classification of carbonate sediments. Geological classification systems are based on grain size, grain shape, constituent material types and type of cementation. Engineering classification systems have added consideration of the strength of the substance.

Special Presentations

Dr. Price (CSIRO) presented a talk which was based on the fabric studies that he had carried out on calcareous sediments from the N.W. Shelf and elsewhere. He presented a series of photomicrograph slides to illustrate the wide differences in texture and fabric that occur within one group of calcareous sediments - the calcarenites. These slides clearly showed both the variation in the nature of detrital grains of differing origins and the nature and degree of cementation and recrystallisation in a range of sediments.

Dr Price recommended fabric studies to assist in classifying calcareous sediments when existing broad classification categories do not provide sufficient distinction between sediments with significant differences in engineering behaviour. He also demonstrated, again by means of photomicrographs, that fabric studies can provide insights into the nature of deformation that occurs in laboratory tests.

Mr F Bullen (Queensland Institute of Technology) spoke about the use of calcareous materials, specifically coralline materials, as engineered fill in the Pacific Islands to the north of Australia. In many cases these materials represent the only readily available sources of fill in the islands. He also mentioned the variability of the deposits and the phenomenon by which the compacted coralline materials increase in strength with time. The suitability of these sediments for engineering purposes was found to depend largely on the presence of plastic fines.

General Discussion

In the very brief discussion period that followed these three talks, **Asij Noorany** (University of San Diego) introduced the classification system that he had developed for marine sediments and offered copies of a paper describing the system. **Marjorie Apthorpe** (Consulting Palaeontologist, Perth), following a question by Prof. Fookes, reported that on the N.W. Shelf in the North Rankin area, aragonite is the predominant carbonate mineral to a depth of 95m.

Session Report: - State of the Art Review - The Mechanical Properties of Carbonate Soils

Reporter: P A Hefer

Understanding of the mechanical properties of carbonate soils has progressed since the first offshore platforms were installed in these materials in the Bass Strait during the late 1960's. Initial designs based on quartz sand characteristics were later proven to be optimistic when open ended pipe piles were driven more easily than expected. Much research has since been performed on these materials and this session was intended to provide an update of current findings on their mechanical properties.

The session comprised a state of the art review, four selected presentations on the topic and a forum for limited discussion at the end.

State of the Art Report
by
Dr. R M Semple

The report focused on bioclastic sands and silts with a carbonate content of greater than 90% and formed on continental shelf areas. These materials were selected due to the foundation problems which are so often associated with them. Materials of this type are characterised by highly angular grains and are generally highly porous and variably cemented. The few intergranular contact points led to high intergranular contact stresses and consequently failure of these contact points may occur at relatively low applied stress levels. Reorganisation of the particle structure then occurs which results in irrecoverable strains. The phenomenon can be seen in the high unload stiffness generally displayed by these materials. Foundation response is governed by the compressibility of the soil.

Dr. Semple clearly demonstrated that the dominant characteristic of bioclastic soils is the high void ratio or porosity and suggested that the performance of these materials may be anticipated after consideration of the initial void ratio together with the cementation characteristics. After a review of test data, it was suggested that compressibility, strength, cyclic degradation, bearing capacity and pile skin friction of quartz and bioclastic sands are comparable when these soils have the same void ratio. Unlike granular silicate soils which generally exhibit a tendency to dilate, bioclastic materials contract on shear. Therefore, conventional soil mechanic theory and empiricism do not, as a rule, apply. However, design methods incorporating compressibility effects, based on appropriate test data, can provide reasonable predictions for these materials.

Special Presentations

Professor K Knight (KDM Consultants, South Africa) presented results of a cyclic triaxial testing programme carried out on samples of calcareous sands recovered from Richards Bay in South Africa. The programme was undertaken to establish whether rational geotechnical principles could be used to formulate a design approach for large diameter pipe piles driven in these materials.

Dr. M R Coop (City University, London) presented some interesting results and observations from a triaxial testing programme carried out for BP International on biogenic carbonate sand from Dog's Bay, Ireland. Samples were isotropically consolidated at cell pressures of up to 8 MPa and subsequently sheared using a variety of stress paths. Some of the major observations made from the results of the consolidation phase of these tests were that particle crushing occurred at relatively low stresses and that the exceedingly high unload stiffnesses recorded are indicative of the irrecoverable strains that results from a re-organisation of the particle structure. It was further observed that the critical state could not be reached in the drained tests and it is therefore likely that routine triaxial tests on these materials are generally terminated prematurely.

A presentation by **Dr. P K Currie** (Koninklijke/Shell E & P laboratory, The Netherlands) served to further highlight some of the aspects discussed in his paper entitled "Testing of Chemically Stabilised Calcareous Materials" published in volume 2 of the General Proceedings of this Conference. Selected results of tests carried out on North Rankin cores treated by injection of a two-component epoxy resin system (EPOSAND) developed by Shell were presented. The impregnation process was clearly demonstrated using images obtained from microphotography taken at different stages during the process. Independent laboratory testing carried out in Australia and The Netherlands produced consistent results. The unconfined compressive strength of the treated core showed an increase of up to four times over that of the untreated core.

The final presentation by **S McKean** (James Cook University, North Queensland) consisted of an outline of an interesting research programme together with CSIRO in which pile driving performance in a harsh coral reef environment may be predicted from site investigation results. The methods being investigated involve heavy dynamic probing and instrumented rotary core drilling. These techniques are being applied alongside existing piled foundations where pile driving records are available. The research programme also includes testing in a disused quarry near Geelong in Victoria where calibrations for the equipment will be carried out.

General Discussion

Limited time was available at the end of this session for discussion. Those contributions to the discussion are, however, presented below:

Dr. A Norany, (University of San Diego) expressed an interest in Dr. Semple's observation that at comparable void ratios, the behaviour of quartz and carbonate sands might be the same and suggested that this phenomenon would simplify geotechnical procedures in the future. A question was then directed at Dr. Semple in which he was asked whether a sample of carbonate sand and a sample of quartz sand both reduced to smaller particles by grinding and tested at the same void ratio under the same mean confining stress would display similar friction values.

Dr. R Semple (Dames and Moore) replied that although in some regards certain materials properties could end up being the same, there would always be a difference in the fiction angle as the mineral sliding friction is different for quartz and carbonate sands.

Dr. G Price, (CSIRO) congratulated Dr. Semple on his premise that the initial void ratio was the critical factor regarding the mechanical properties of calcareous material. He pointed out that observational evidence obtained from fabric studies carried out on North Rankin samples which contained a large proportion of quartz sand grains and which were tested under high pressure, indicated fracturing of both the quartz and carbonate grains at a similar frequency. It was therefore concluded that there is no real difference in terms of grain strength between the two materials. Dr. Price also suggested that the models put forward by Dr. Semple, although well suited for the angular calcareous materials which are predominant in the vicinity of the North Rankin platform, were not necessarily applicable to other sites where these materials can be dominated by well rounded particles with low void ratios and where the individual carbonate grains can have very low strengths. Examples of such materials are calcarenites which are dominated by faecal pellets.

Dr R Semple reiterated that grain crushing is an important characteristic in any granular soil. This is the mechanism whereby a granular soil yields whether it be a quartz or a carbonate sand. It is an intrinsic characteristic that the reduction in friction angle and the yield behaviour is a grain crush phenomenon.

Dr. J Cuckson, (SIPM) pointed out that as one of the technical advisers to Woodside Offshore Petroleum on the North Rankin platform project, the subject of void ratio was raised as early as 1982 and followed through to about 1986 when it became a hotly contested issue during the upgrading of the platform foundations. Dr. Semple was therefore commended for his presentation in which new light was thrown on the subject and for paving the way to a simple perspective when dealing with these materials in the future. △

AUSTRALIAN GEOSCIENCE COUNCIL
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CURRENT ACTIVITIES

Report on Australian Geoscience 1988

One of the regular activities of the AGC Executive is to plan and compile the annual report on Australian Geoscience, which is published in the BMR Report series. Contributions are sought each year from appropriate people throughout the geoscience community. Australian Geoscience 1988 has been published, and copies will be available for distribution to all AusIMM Branches. Copies will be sent for display and distribution at the next International Geological Congress in Washington.

Conference on Crisis in Science for Primary Industries

A one day Conference was held in Canberra on 30 May 1989 to address the crisis in science education, training and careers now facing the Australian mining and agriculture industries. Objectives of the Conference were:

- to identify the needs of the mining and agriculture industries for R & D to meet the challenge of sustained technological advancement into the 21st Century;
- to confront Government with the need for sustained support for primary industry R & D, irrespective of the difficulties confronting manufacturing; and
- to alert Government that R & D for mining and agriculture requires an assured number of quality scientists and technologists trained in Australia.

CONCLUSION

This summary of the activities of AGC and FASTS is designed to show that these umbrella organisations are fulfilling a vital, if perhaps not always obvious, role in promoting science in general, and geoscience in particular, in todays fairly hostile community and political environment. I hope that individual AusIMM members will support the endeavours of these organisations whenever the opportunity arises. ■