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NEW PROBLEMS IN MARINE GEOTECHNOLOGY

PROBLEMES NOUVEAUX EN GEOTECHNOLOGIE MARINE

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SYNOPSIS: The paper describes some of the new problems in marine technology that have arisen since the XII ICSMFE as well as some challenges which may shortly have to be met. The brief for the paper set by TC14, was that it should have broad scope and focus more on identifying issues than defining solutions. Hence it covers problems arising from such diverse sources as new regulations to geographical expansion by the oil industry.

INTRODUCTION

At the Twelfth ICSMFE in 1989 the session on marine geotechnology addressed the subject of foundations for deep water structures. Since then the offshore oil industry, which is by far the largest user of marine geotechnics, has been subject to a four year period of turbulent and continuous change. This has resulted in the practitioner having to deal with new:

- codes and regulations,
- structures,
- field development procedures and experience,
- marine environments,
- geographical regions,
- results of research,
- technologies,
- applications,
- client cultures.

Thus Technical Committee 14 which covers Offshore Geotechnical Engineering for the ISSMFE considered it appropriate that the thirteenth ICSMFE should address the new problems and challenges which have arisen from these changes.

The civil engineering industry is also planning to use marine geotechnology on some planned major infrastructure projects such as the Straits of Gibraltar Crossing, Hong Kong Airport, Baltic Crossings, Straits of Messina crossing, Rion-Antirion bridge and the Jamuna bridge to name but a few. These structures give rise to problems at least as great as those associated with offshore developments.

The objective of this paper is to identify the new problems and challenges in marine geotechnology in order to stimulate others to provide solutions.

CODES AND REGULATIONS

A number of problems are related to the formulation and subsequent application of new codes and regulations covering Safety Case Assessment and Load and Resistance Factor Design (LRFD).

The Piper Alpha tragedy in 1988 was investigated by Cullen who produced his report in 1990. This recommended that Safety Cases be developed for Offshore Installations in the British Sector of the North Sea. Regulations were introduced in 1992 making it a statutory requirement to have Safety Cases approved for all new installations after May 1993 and for all existing installations by November 1995. Although these are specifically UK regulations, other governments are currently formulating similar legislation and the possibility is that within the decade a Safety Case approach will be adopted world-wide. The description of the Safety Case assessment given below is based on the UK rules, but the problems and challenges for the geotechnical engineer are likely to be universal.

The major hazards which impact on geotechnical design and must be addressed include shallow gas blowouts, vessel impacts, foundation failure, seismic effects, loss of stability and loss of station keeping. The implications for geotechnical design are:

- 1) A listing of relevant geohazards will be required for each installation, together with the precautions taken to reduce the consequential risks to persons to as low as reasonably practicable.
- 2) An increase in the geotechnical content for siting studies for mobile rigs.
- 3) An increase in the scope of engineering studies for new installations.
- 4) The introduction of Geographic Information Systems (GIS) to store and retrieve all seabed data.

- 5) In certain cases, foundation monitoring will be required to validate foundation design.
- 6) If current, rather than past codes, are used for the operational safety case on existing platforms, then it may be necessary to take account of the increase in foundation strength over the years and other positive effects such as rate of loading.

The requirements for all the above are reinforced by other considerations covered subsequently in this paper.

The introduction of an ISO code for offshore platforms based on API RP2A LRFD (1993) will have a considerable impact on foundation design and in particular the design of piles. Because the load factor for extreme environmental load is proposed to be 1.35 and the resistance factor for piles is 0.8, the "factor of safety" against extreme conditions is effectively 1.69, ignoring gravity loads. This compares with the API (1993) working stress design (WSD) requirements of 1.5. Hence piles may be longer. Figure 1 shows a plot of the ratio of pile length computed by LRFD compared to the existing WSD requirement for various combinations of environmental to gravity loading in uniform sand and normally consolidated clay. The increase will tend to be greater for piles in sand rather than in clay because of the limiting values for friction and end bearing applied in sand. The situation is complicated by the different treatment of tension loading in the two versions of the codes and means that in uniform soils, piles in sand could be up to 25% longer under LRFD than for WSD. For piles in variable strata the increases in length could be very much greater or less depending on whether the soil below the tip of the pile using WSD is decreasing or increasing in strength.

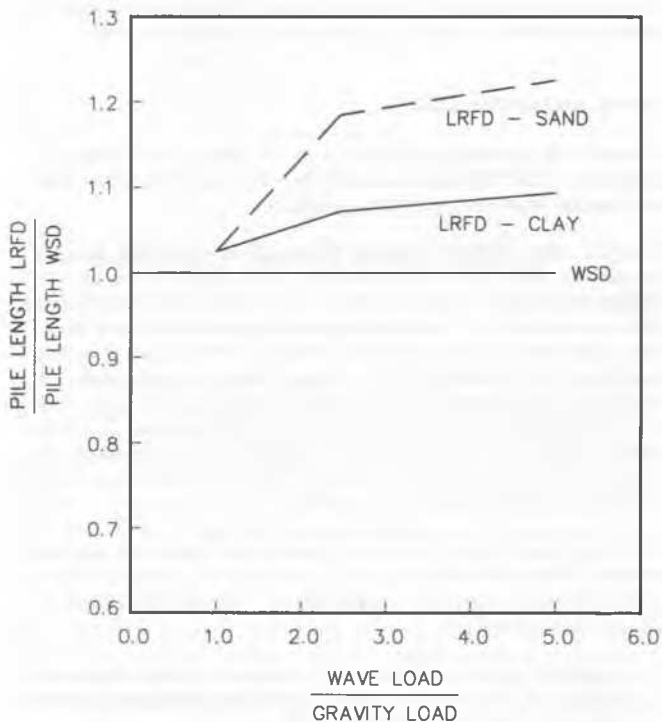


Fig. 1. Ratio of required pile length from LRFD to WSD

It must be noted that neither WSD or LRFD can be classified as "right" or "wrong" or more or less conservative. The problem is one of reconciliation.

In the author's opinion the LRFD approach has the advantage of taking risk and reliability into account and in the longer term, with fine tuning, should result in lower cost for a given specified level of safety. In addition it is more conducive to addressing questions such as whether the same level of reliability should be required for the foundation of a small unmanned platform as for a large drilling, production and accommodation platform.

It should be noted that both the Safety Case assessment and the LRFD codes are implicitly based on a probabilistic approach to design. This is a topic which has been an anathema to many geotechnical engineers. The problem up to now has been difficulty of obtaining adequate data at a reasonable cost and a lack of suitable processing software.

Changes to codes and regulations are often brought about by "events". "Events" are incidents that are not foreseen, otherwise they would be avoided. They may be accidents, sabotage, Acts of God or the result of working in an unfamiliar environment. The Piper Alpha accident quoted above is an obvious past example which led to the decision by the UK government to initiate "safety case" procedures.

Some "events" impact particularly on foundation design and past examples are: axial pile failure in Lake Marracaibo (1957), mud slides in the Gulf of Mexico during hurricanes (1961) and (1969) and the North Rankin piling experience (1983). At time of writing the most recent new "event" for which research and subsequently new design procedures are required relates to the Goodwyn jacket where the piles suffered a type of buckling failure during driving.

Until recently the numerous "events" world-wide relating to mobile rigs seem to have had much less impact on geotechnical practice than the much smaller number of "events" involving fixed platforms. This may partly be attributed to the lack of a "recommended practice" which can be updated for mobile rigs and the fact that they frequently move from one area of jurisdiction to another. However, work has been proceeding over the past few years among an industry group to produce a recommended practice. This will be published in 1994 and it is probable it will subsequently become an ISO code. The problem for the industry will be how to collect data, process it and complete the foundation analyses in the time and cost frames dictated by the offshore drilling industry.

NEW STRUCTURES AND FIELD DEVELOPMENT PROCEDURES

A number of trends in field development are emerging. These are:

- 1) sub-sea structures with pipelines connected to existing infrastructure,
- 2) re-usable concepts such as floaters and self elevating platforms,
- 3) unmanned lightweight structures,
- 4) large platforms with horizontal wells,
- 5) onshore processing,
- 6) skirt plate structures.

Changes are required in geotechnical design to accommodate suction as a means of foundation installation and support, anchorage and wellhead protection.

More emphasis needs to be placed on geotechnics applied to pipelines, including seabed mobility, see Figure 2. Because transportation of hydrocarbons may now occur prior to processing, temperatures are higher and the risk of upheaval buckling is increased. The prediction and prevention of this phenomena is a major problem in which marine geotechnology could play a major role. Existing trenching techniques become less effective as the boulder content of the soil increases. Either more tolerant trenching equipment, or better site investigation techniques need to be developed for characterising deposits which contain boulders.

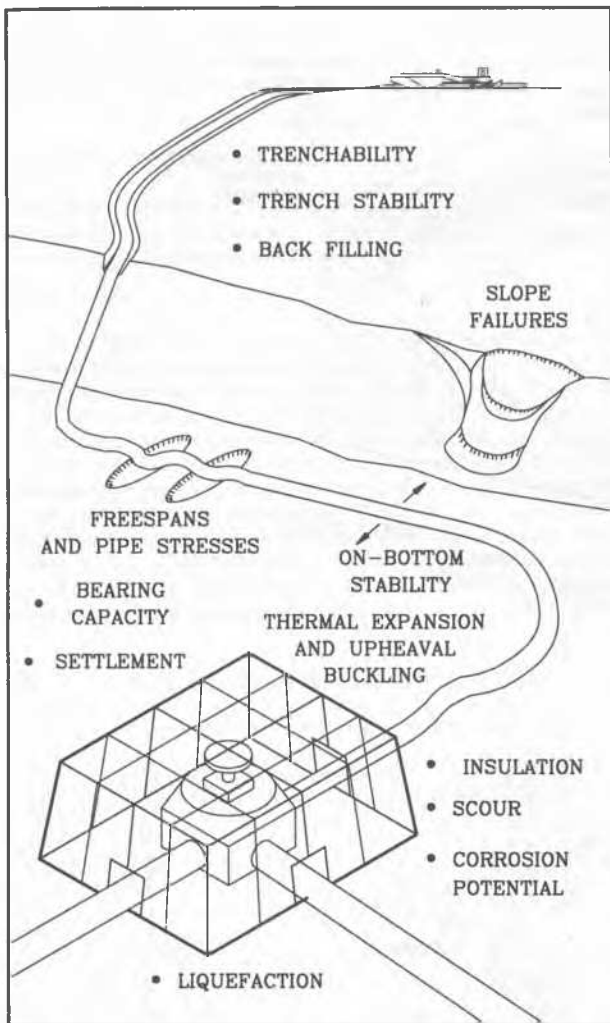


Fig. 2. Seabed problems for small structures and pipelines

The life of many fields is being extended, often by the replacement of, or additions to, the existing topsides. This can give rise to foundation loads higher than those for which they were designed. This requires the assessment of the very long term capacity of foundations e.g. after 20 or 30 years, and is yet another new problem in marine geotechnics. Alongside this is the problem of seabed subsidence in the long term, which is also difficult to quantify.

In contrast to the long term problems of upgrading existing platforms, recently introduced field development procedures are giving rise to two new problems. The first relates to the short term capacity of piles. The time between driving piles and loading offshore structures has, in some cases, dropped to a matter of days and yet pile design techniques are based on medium term capacities which may be much higher. Methods are needed for predicting pile capacity from time of installation to many years thereafter. The second problem is concerned with the effect the wells may have on the foundations. Many new structures are compact in plan and supported on vertical piles, whereas previously battered legs and piles were the norm. The consequence of this is that the spacing between wells and piles has been significantly reduced to the extent that in some cases piles cannot be regarded as being installed in virgin soil; an assumption on which most pile design procedures are based. A Minimum Offshore Support Structure, illustrating both problems is shown in Figure 3.

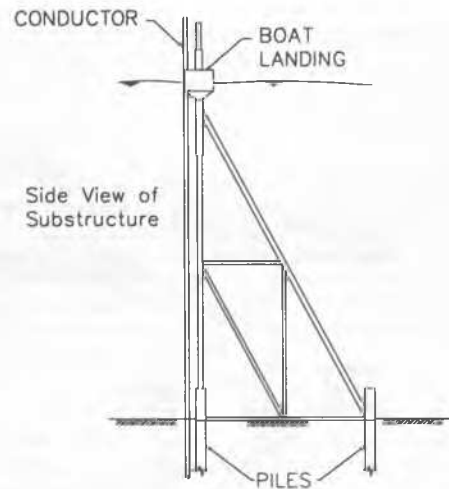


Fig. 3. Minimum offshore Support Structure

There has been a trend for structures to be supported on fewer but very much larger piles of high capacity. There are problems in relating piles with diameters in excess of 3m and design capacities of 100MN to a test data base made up largely of piles of 0.5m diameter and capacities of less than 10MN. An extended data base is required, together with improved design procedures.

Measurements on piles during driving used to be used to give additional information on short term pile capacity. However current driving procedures and cost pressures mitigate against this and a new approach is required to remedy the situation. In general driving predictions for vertical piles, driven underwater with a hydraulic hammer in a single stage, are less reliable than for steam hammers on raked piles. Driving is now often much easier than predicted, giving rise to concerns about short term capacity.

Floating structures require anchoring and reliable design rules exist only for a limited range of soil types and anchor configurations. This is clearly an unsatisfactory situation which must be resolved particularly in the light of the Safety Case regulations.

The use of Jack-up rigs as production or support units is becoming more common and again design guidelines are insufficient and must be improved for the Safety Case. The introduction of the "recommended practice" in 1994 will assist but not necessarily solve the problems.

MARINE ENVIRONMENTS

New field developments are planned in both very shallow water and deep water. For shallow water, seabed mobility and the impact on the environment are the chief concerns. Deep water will provide more complex problems, new phenomena and new soils.

Experience to date in deep water has been gained in the Gulf of Mexico, offshore Brazil, in the Mediterranean and offshore Norway. Field development studies including soil investigations and full geotechnical and foundation design have been performed in 1100m of water and were discussed at the twelfth ICSMFE. Shortly, detailed studies will be performed in 2000m or even 3000m of water. The geophysical and geotechnical hardware exists from cable route and nuclear waste disposal studies, and more is currently being developed, to collect the seabed data. The major problems will be in engineering design and include the seabed materials; oozes, pelagic clays, turbidity deposits, calcareous formations, and gas hydrates; and the seabed topography which may be quite rugged and subject to instability particularly in seismic areas, see Figure 4.

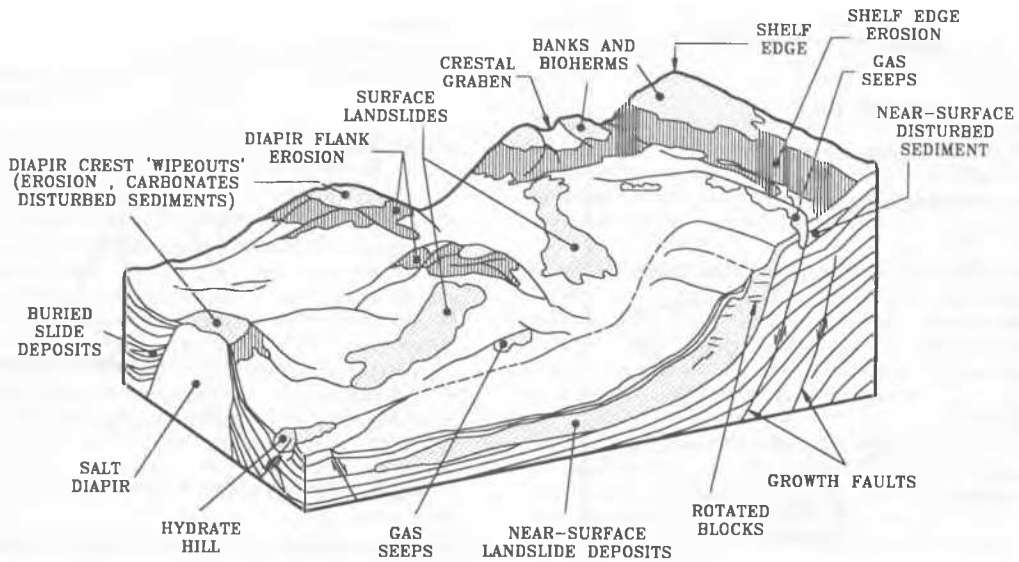


Fig. 4. Schematic block-diagram showing the relationship of various deepwater geological phenomena (Prior (1987), Campbell et al (1986))



Fig. 5. Offshore investment intentions

Civil engineering projects invariably give rise to problems relating to the collection of soil and rock data due, for example, to high currents, uneven seabeds and environmental constraints.

GEOGRAPHICAL REGIONS

The balance of investment intentions by the International Oil Companies appears to be swinging away from traditional areas, such as the USA and North Sea, to other parts of the world, see Figure 5. Some is in countries from which non-national organisations were previously excluded, such as those which made up the former Soviet Union, Vietnam and Yemen; the rest is to areas which are believed to give the highest return on investment such as West Africa, the Far East and Middle East.

The implications for geotechnical engineering are that new types of seabed conditions will be encountered. For example, the Caspian Sea presents one of the most challenging marine geotechnical environments in the world because of its mud volcanoes, tectonic activity, shallow gas and sloping seabeds. In tropical areas, calcareous and cemented sands and clays are common as are soft rocks and corals. These are known to present formidable problems for foundation design and installation and more will become apparent as development proceeds. Arctic and sub-Arctic regions present different subsurface conditions including gravels, cobbles and boulder beds, silts, gas hydrates, freezing and thawing phenomena, and the consequences of ice erosion. For a few years valuable experience of Arctic soils was being obtained offshore Alaska and Canada until development all but stopped in 1986. Much more remains to be learnt. There are regions of high seismicity in both the tropics and the Arctic.

In remote regions, data collection using existing techniques can become extremely expensive because of the time taken to mobilise to site. New compact acquisition systems need to be developed which can provide high quality site investigations at an affordable price.

OUTCOME OF RESEARCH

The greatest proportion of research funds for marine geotechnolgy is directed towards piled foundations. As always the problems are to convert research findings into design practice and these are discussed below.

Piles in Sand

For open ended piles driven into a sand layer it is current practice to calculate the end bearing as being the lesser of: the friction of the soil plug against the inside wall of the pile, or the end bearing of a closed ended pile of the same outer diameter. Frequently the closed end pile capacity may be as much as twice the other, see Figure 6. Many organisations have conducted tests to determine how long a plug of sand has to be inside a pile to mobilise maximum end bearing. The conclusion each time is that it is substantially shorter than would be conventionally calculated from "inside friction". Unfortunately most of this research is confidential and the problem now is to collect it into a coherent package which would facilitate widespread acceptance of a new design procedure. Since significant cost savings could result, this work should be given a high priority.

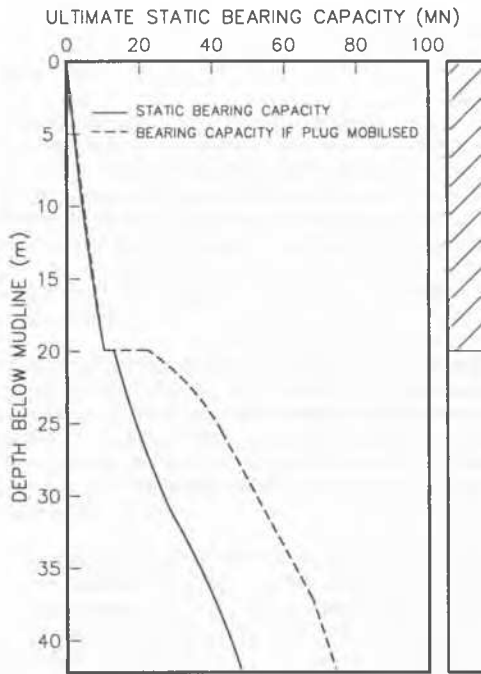


Fig. 6. Example of the influence of plugging on ultimate static bearing capacity

Other current problems relating to the end bearing of piles in sand are the application of limiting values and the rate of build up or decrease of end bearing as a pile enters or leaves a sand stratum. Design needs to become more explicit and use a quantitative rather than qualitative assessment of the relative density and elastic modulus of the sand. A similar design approach could be used for skin friction in sands. The benefits would be more reliable and consistent designs and a reduction in costs for piles in dense and very dense sands. There would also be fewer surprises, which cost money, in loose and very silty sands.

Because of the scale and number of the problems related to pile design in sand an extensive programme of large scale pile tests, funded by industry and some government organisations, commenced in 1993.

Pile Design in Clay

In the 1980's several large scale pile tests were performed in clay soils. The results were released into the public domain in 1992. Many of the lessons learnt from these tests have already found their way into recommended practice, however the results could be used to tackle some of the remaining problems mentioned in this paper. In particular, the variation of pile capacity with time could be investigated both for "old" structures undergoing safety case assessments and "new" structures which may have to carry maximum load shortly after pile installation.

Rate and Cyclic Loading Effects

Evidence from research indicates that pile capacity under a load that increases and then decreases rapidly, such as that due to waves, is significantly higher than under a load that is built up and then held constant, such as platform weight. This is called the rate effect and played a part in the reasoning behind the reduction in factors of safety for piles from 2.0 for operational conditions to 1.5 for extreme environmental conditions in the WSD code. However high rates of loading are often associated with repeated applications and under certain circumstances these may reduce pile capacity; this is the cyclic loading effect which has been the subject of much research.

At present these effects are ignored in design practice with comfort being taken from the fact that they are self-cancelling. However, with new codes and types of structure this approach may no longer be adequate. For example in the LFRD code, different load factors are applied to the constant gravity load, variable gravity load and environmental load. However a single resistance factor is applied to the pile capacity. There could be scope for having a resistance factor which varies with the ratio of wave to gravity loads (i.e. rate effect) and with the degree of cyclic loading. This would have the advantage of providing foundations with a consistent level of reliability and provide vital cost savings for structures with relatively higher environmental loads, such as lightweight jackets and deep water platforms.

The driven pile has not proven itself for all soil types and environmental conditions. Research has been performed on alternatives such as drilled and grouted piles, wedge piles and grouted driven piles. However the results have not as yet been converted into design and construction control guidelines and this situation must be rectified before they can have a widespread application.

NEW TECHNOLOGICAL DEVELOPMENTS

Like any other discipline, geotechnics adopts new technical developments from elsewhere in the interests of cost, safety and reliability. It is speculation as to which new piece of hardware or software will have the greatest potential for meeting future needs, particularly when they are not yet operational. However, there are four interrelated products which are actively being worked upon which should affect foundation practice; global positioning systems, 3D seismic, cheap powerful computers and geographical information systems. The problem for the marine geotechnologist are first, to understand the new technology and secondly, to extend it to new applications.

One outcome could be the generation of shallow seismic data of sufficient clarity and reliability to be used in conjunction with seabed probing and the fewer boreholes for foundation design. This would solve the problems of the cost of data collection in remote regions and for mobile offshore drilling rigs mentioned previously. It could also enhance our abilities to apply a probabilistic approach to design. Another possible outcome could be the more widespread use of 3D finite element programs for foundation design.

NEW APPLICATIONS

Geotechnical engineers are constantly seeking new applications for their technology and each time they are successful they have overcome one set of problems only to be faced with another. Currently a small number of enlightened oil companies are applying geotechnics to:

exploration, using geochemical surveys and drilling pilot holes for shallow gas;

well design when hydraulic fracture testing may save a casing string;

decommissioning, for platform removal, cuttings removal and seabed cleaning;

environmental work for seabed assessments and base line studies.

In all cases geotechnics has to be combined with other disciplines such as chemistry and marine biology.

CLIENT CULTURE

During the early 1980's most international oil companies had strong central engineering and research and development departments which co-ordinated geotechnical work throughout their organisation. They produced specifications, arranged service contracts, anticipated new developments and advised project teams, exploration departments, operating staff and drillers. Today, with a few notable exceptions, most oil companies have drastically cut staff levels and have the project team as their only commissioning agent for geotechnical work. The consequence has been that marine geotechnology is becoming reactive rather than proactive and one must question whether this can remain so, if the problems discussed in this paper are to be solved expeditiously.

CONCLUSIONS

It is clear that marine geotechnology faces many new problems. Some are due to the introduction of new regulations and alternative field development concepts and are thus well defined. Others will arise as the oil industry moves to new regions and deep water and are thus less certain. However the greatest problems of all may be due to "events", which have yet to occur and by their nature cannot be foreseen.

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