Technical session 2e: Marine and transportation geotechnical engineering

Séances techniques 2e: Géotechnique marine et de transport

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1 INTRODUCTION

The wide variety of topics covered in the 32 papers of this session shows the broad interest of geotechnical engineers in the-marine and transportation geotechnical fields. The papers were categorized by their primary field of application. Three fields were identified: offshore geotechnical engineering, pavements (road and airport) and railways. Tables 1, 2 and 3 list the papers associated to these three field, giving for each a brief description of the objectives of the paper, type of structure and/or soil type, tools used in analysis (numerical, experimental, empirical), material model used and the main conclusions reached.

To set up the session and bring perspective around the papers, and to promote some exciting discussion, this general report briefly reviews some of the recent advances in the state-of-the-art associated with offshore geotechnical engineering, pavements and railways. For both the marine (offshore) and transportation geotechnical engineering contributions to this session, the papers can be categorized under four main topics: soil characterization, physical modeling, theoretical modeling and monitoring. No less than 10 of the 32 papers deal with physical modeling, eight with soil or/and material characterization, five with modelling and eight deal with monitoring. In fact, only a few papers present case studies of foundation design.

2 OFFSHORE GEOTECHNICAL ENGINEERING

The topic of offshore geotechnical engineering is extremely vast. Only three main aspects are approached in this short review paper: foundation design, anchors in clay and offshore geohazards.

Most of the papers to this session (Table 1) contribute to one or several aspects of the topics covered below, except the last paper in the table which probably should have been placed in a session about determination of soil characteristics. The papers dealing with offshore geotechnical engineering can be classified as follows:

Topic	Authors
Foundation design, especially performance under cyclic loading	Hamre et al. Valore and Zicarell (quay wall)
Anchors in clay	Singh et al. Micic and Lo
Offshore geohazards	Strout and Sparrevik Puech et al. Kliner and Grozic
Pipelines	Cheuk et al Vanden Berghe et al
Modelling in the laboratory, centrifuge and in situ	Laue et al. Tufenkjian and Thompson Elmi and Favre Kikuchi et al.

2.1 *Foundation design*

Cyclic loading generates pore pressure and reduces the effective stresses in soils, causing average and cyclic shear strains that increase with number of cycles (Fig. 1). Knowledge about the behaviour of soils under cyclic loading is essential for the foundation design of the different offshore structures, including fixed offshore oil and gas platforms, near shore liquid natural gas (LNG) terminals, anchors for floating structures, harbours, breakwaters, storm surge barriers, etc. Wave loading will normally have load periods of the order of 10 s or more. The fundamental behaviour of soils is independent of the load period, and the general principles apply independently of period. The numerical values are however rate-dependent and will be a function of the load period.

The summary of key issues for offshore foundation engineering below is based on the contributions of Andersen (1991) and Andersen (2004).

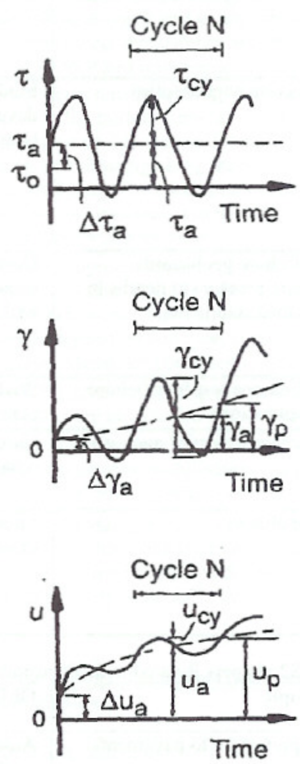


Figure 1. Shear stress (τ), shear strain (γ) and pore pressure (u) under cyclic loading (N= number of cycles, subscripts cy= cyclic, a=average, o=initial, p= permanent) (Andersen, 1991)

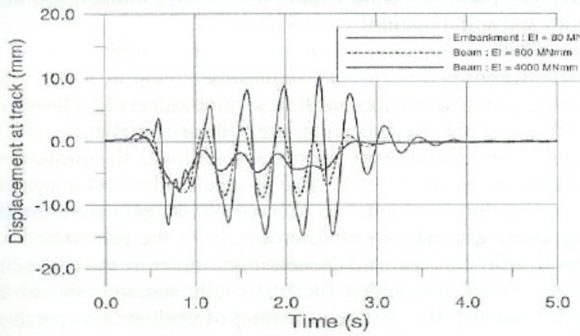


Figure 28. Effect of countermeasure based on longitudinal girder in the embankment, simulated with by VibTrain (Kaynia et al., 2000)

frequency domain having the drawback to deal directly with non linearity behaviour of materials. However, solutions in the time domain also exist (Hall, 2000 – mentioned by Madshus, 2001).

This last family of models are very powerful incorporating track-embankment-ground as they are able to simulate behaviour at all speeds from low up to the critical speed. Figure 27 shows the performance of the model VibTrain in prediction of upward and downward displacements of an embankment versus train speed. Figure 28 illustrates simulation results in different rail track structures corresponding to different conceptual solutions of countermeasure.

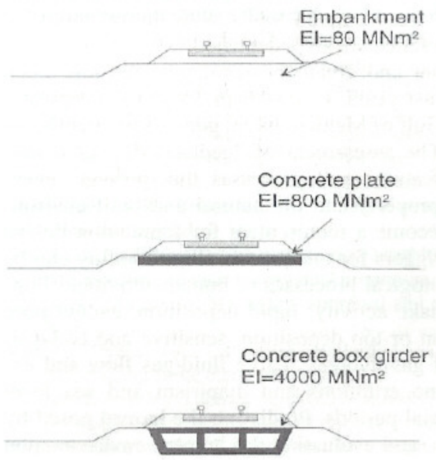
As referred by Madshus (2001), these models need further validation by field monitoring. It must also be added that in this context dynamic materials characterization should be strongly encouraged, as well as dynamic field observations, mainly for ballasts.

It must be referred that the framework of soil dynamics is an important basis for railways, but the peculiar aspects involving a very important number of cyclic loads (millions of cycles) is not concerned with the soil dynamic studies done in the field of earthquake engineering. Figure 20 illustrates a particular study for "laboratory" sands. However, in ballast the dynamic aspects are still not well known and this justify one of the ongoing European research program SUPERTRACK (Kaynia, 2003). This program also intends to put into operation a numerical model where, by incorporating the global behaviour of the whole of the railway platform and the supporting soil, will serve to quantify advantages and disadvantages, of the methods used at present in the maintenance of ballast platforms. It will be also possible to quantify and predict the consequences that can have, on this type of structures, the increase of the circulation velocity and the axle load in high speed trains.

This will facilitate, on a medium term, the adoption by the European Union of the adequate strategies to take into account these effects. This more fundamental work will develop tools to capture the main aspects involved with the serviceability of rail tack structures for high speed trains. In this respect allowed permanents deformations area a design criterion. These values are very restrictive and should be carefully fulfilled in order to avoid maintenance actions, critical for the operation of this type of structures.

5 CONCLUSIONS

Knowledge on the behaviour of soils under cyclic loading is an essential part of the foundation design of infrastructure and offshore structures. This includes structures subjected to wave loading, wind, earthquake loading, and traffic and machine vibrations. Structures subjected to wave loading are fixed offshore



oil and gas platforms, near shore liquid natural gas (LNG) terminals, anchors for floating structures, harbours, breakwaters, storm surge barriers, etc. Structures subjected to wind loading are wind power structures, bridges and tall buildings. Earthquake loading will influence slope stability, buildings and other structures, both offshore and on land. Traffic and machine vibrations will mainly influence the behaviour of structures and their serviceability. Wave and wind loading will normally have load periods of the order of 10s or more, whereas earthquake, traffic and machine vibration will have lower periods of about 1s or less. The fundamental behaviour of soils is independent of the load period, and the general principles apply independent of period. The numerical values, however, are rate dependant and will be a function of the load period.

(1) Offshore

Cyclic loading generates pore pressure and reduces the effective stresses in soils, causing average and cyclic shear strains that increase with number of cycles. Key issues for the foundation design of offshore structures include bearing capacity, cyclic displacements, dynamic foundation stiffnesses, settlements due to cyclic loading and soil reaction stresses. The following soil parameters are needed to analyze the foundation design aspects of offshore structures: cyclic shear strength, cyclic shear modulus, damping, permanent shear strain due to cyclic loading, pore pressure generation and recompression modulus. These soil parameters can be determined from triaxial and DSS laboratory tests with various combinations of average and cyclic shear stresses. A convenient way to interpret and present the data from cyclic laboratory tests is to plot contour diagrams of average and cyclic shear strains and permanent pore pressure as functions of average and cyclic shear stresses. Such diagrams contain the information required to derive cyclic shear strength and deformation characteristics for foundation design of structures subjected to combined static and cyclic loading. Calculation procedures based on such soil data framework have been verified by back-calculations and predictions of prototype behaviour, and by model tests.

A key aspect of offshore design these recent years has been to find innovative ways to reduce the foundation costs. This trend is expected to continue in the future. Anchors have been used with success in deepwater, as they provide reliable and economical foundation solutions. The reader should read the two keynote papers prepared for the ISFOG conference in Perth, Australia medio September, which present the results of an industry-sponsored study on the design and analyses of suction anchors in soft clays (Andersen et al 2005 on suction anchors, Murff et al 2005 on vertically loaded drag anchors). These two papers, prepared jointly by a large group of engineers and scientists working in the field, represent the state-of-the-art on anchors in clays. The two summarize a number of prediction methods and data related to installation performance and holding capacity of anchors. Research topics with the potential for improving current practice are also identified.

Working at greater and greater water depths has also been the focus over the last years. In less than 20 years, deepwater milestones in the Gulf of Mexico have gone from depths of 300 m to 2000 m. The assessment of "geohazards", or events due to geological features and processes that present severe threats to humans, property and the natural and built environment, has rapidly become a requirement for foundation design in deepwater. The triggers for underwater slope stability can be natural on-going geological processes or human activities. Triggers include earthquake activity, rapid deposition, excess pore pressures, toe erosion or top deposition, sensitive and collapsible soils, melting of gas hydrate, active fluid/gas flow and expulsion, mud volcano eruptions and diapirism and sea level lowering during glacial periods. Predicting the hazard posed by geological processes, and evaluating the human, environmental and economical consequences of geohazards require that each of the uncertainties in the situation to analyse are quantified and addressed properly. The integrated evaluation by geologists, geophysicists and geotechnical engineer is essential. A state of the art study was made for the extremely large underwater Storegga slide where the offshore Ormen Lange gas field is located. The results have been compiled by Solheim et al. (2005) in the thematic volume of Marine and Petroleum Geology. The positive conclusion of this intensive work made it possible to approve the development of the field.

(2) Transportation

An urgent mutation of conventional characterization and specifications of subgrade soils and unbound granular materials for pavements and railways is necessary to pursue the changes in advance design and new construction technologies. Moreover, it is also necessary to optimize the use of traditional materials and allow the utilisation of new materials. In this context the use of performance based tests should be more used in practical applications. At laboratory level the precision cyclic triaxial test seems to be a good compromise, facilitated by the existing new CEN standard. The test protocol allows to determine parameters for modeling as well for ranking materials based in the resistance to permanent deformation. Physical model tests are also very useful mainly those simulating traffic loading by a moving wheel; these tests are more representative of loading conditions inducing the rotation of planes of principal stresses, not possible by the cyclic triaxial test. Permanent deformations under traffic loading will be more representative by this type of physical tests and consequently more appropriated for calibration of numerical models and validation of design methods.

At field level and particularly at construction quality control it is encouraged to move from local index tests (spots) to mechanical continuous measurements, such as roller-integrated continuous compaction, "portancemeter" and spectral analysis surface wave (SASW). This last technique is very promising since is the only field tool providing continuity between the design, laboratory and construction. To evaluate the bearing capacity of pavements and railtracks after construction rolling dynamic deflectomters using laser technology should become routine tests.

There exist a lot of in situ tests to evaluate stiffness of materials using different induced stress and strain levels, as well as load and strain rates. The analyses of these tests require sound theories incorporating non-linear behaviour of soils and granular materials, as well the state conditions of the materials. The application of these results to design need corrections to taken into account the representative environmental conditions prevailing during the service life of the structure.

There is an urgent need to move from the empirical rules used in routine design of pavements and rail tracks to a mechanistic approach making use of the knowledge of the mechanical behaviour of soil mechanics framework, non saturated soil mechanics and soil dynamics.

Open questions and further developments:

Research needs of anchors include several aspects (Andersen et al. 2005), and only key questions are addressed herein.

During the installation of suction anchors, the profession should establish an agreed basis for the safety factor against plug failure during installation. Acceptable design values for the safety factor should also be determined. As the penetration resistance and the required penetration underpressure depend strongly on the remoulded shear strength, research should be done to establish the optimum method of evaluate this parameter. Bearing capacity factors should also be determined for different geometries and boundary conditions of internal stiffeners and external protuberances. Moreover, studies should be made on the interface shear strength of carbonate rich soils, both in terms of the radial stress and the interface friction angle.

With respect to the bearing capacity of suction anchors, further work should address the uncertainties related to whether a crack will develop or not along the active (windward) side of a suction anchor. Set-up along the skirt walls should be documented with relevant experimental data, both from model tests and prototype data. The effect of large displacements at failure should also be investigated, as well as the effect of strain softening on the anchor capacity. Since there is today no consensus on the safety factors to be used for suction anchors, this aspect should be carefully considered.

For vertically loaded drag anchors, validation of the results obtained analytically should be done with comparisons of analytical results with model and prototype observations.

The main challenges today in the field of offshore geohazards are related to risk assessment for deep and ultra-deep sites. In addition, although the knowledge, technology and tools required for deep and ultra-deep water site investigations have improved significantly over the past decade, there still remains a need for improvements to reduce the uncertainties in the geohazards assessment (e.g. Nadim and Locat, 2005):

- Geophysical, geological and geotechnical site investigation techniques
- Effects of sample disturbance
- Location and quantification of gas hydrates, and their effects on soil behaviour
- Presence of gas and their effects on soil behaviour
- Tools and methodology for prediction and measurement of pore pressures
- Interpretation of sediment rate, stress conditions, pore pressure conditions
- Field measurements and monitoring of geohazards
- Methods and techniques for early warning
- Analysis tools for assessment of seabed instability and failure probability
- Quantification of uncertainties in analysis parameters
- Material models, mechanical models and analysis tools for stability assessment
- Slope stability and dynamic slide mechanisms, including progressive and retrogressive failure
- Effect of earthquake loading on soil strength and post-earthquake stability
- Analysis tools and methods for evaluation of consequences, e.g. slide dynamics and run-out, slide velocity and impact, and tsunami generation, impact and run-up

In analyzing geophysical .tests, such as bender elements in laboratory or SASW in the field where is the limit of applying mechanics of continuum mechanics to particulate medium?

In soil dynamics the damping ration has been studied for many soils. However, the behaviour of very dense unbound granular materials is less known. Moreover, the effect of a big number of cycles (millions) should be considered, particularly their influence in the damping ratio.

A more fundamental approach for granular materials should be focused in micromechanics of particulate medium, incorporating the glue created by capillarity stresses in non saturation conditions of the material.

There are a lot of different mechanical field tests to evaluate construction quality control. What is the best test relating field, laboratory and design?

The serviceability criteria in routine design of pavements and railtracks are of empirical basis. The use of new materials, different loading conditions, different environmental conditions and new technologies in construction require design methods based in a mechanistic-performance basis. For pavements mechanistic models should be developed considering the peculiarities of soils and unbound granular materials: non linearity, pre-straining, state conditions, effective stress concept; number of cycles. For railtracks dynamic aspects should be considered (integrating ground, embankment and track), as well as residual settlements very restrictive for high speed trains.

Material models and structural models should be calibrated and validated for design by full scale tests with specific instrumentation. Vibration measurements in ballast are of relevance to understand its performance and conclude about countermeasures applications.

In which concerns railtracks for high speed trains a question remain: what are the conditions dictating the choice of a ballast track or a ballastless track?

LIST OF PAPERS IN SESSION TS2E

Abdelkrim, M., Bonnet, G., de Buhan, P.: Modelling the residual settlement of geotechnical structures submitted to long term cyclic loading.

Badv, K.: Some geochemical and mineralogical characteristics of Urmia Lake deposits.

Calle, E., Sellemeijer, H., Visschedijk, M.: Reliability of settlement prediction based on monitoring.

Cheuk, C.Y., White, D.J., Bolton, M.D. Deformation mechanisms during uplift of buried pipes in sand.

Edil, T.B., Sawangsuriya, A.: Earthwork quality control using soil stiffness

Elmi, F., Favre, J.-L.: Penetrometer interpolation using seismic data for offshore application.

Erlingsson, S.: Numerical modelling of unbound granualar materials in thin pavements structures.

Gnanendran, C.T.: Effects of combined cyclic vertical and horizontal loading on unsealed airstrips: model study.

Gomes Correia, A., Anh Dan, L.Q., Koseki, J., Tatsuoka, F.: Stress-strain behaviour of compacted geomaterials for pavements

Hamre, L., Bye, A., Søreide, O.K., Athanasiu, C.: Study of transient pore pressures due to cyclic loads to optimize the foundation concept for Sakhalin Platforms.

Hayano, K., Kitazume, M.: Stress distributions and its evaluation in asphalt pavement ground subjected to roller loading.

Kikuchi, Y., Otani, J., Mukunoki, T., Yoshino, H., Nagatome, T.: Permeability on lightweight treated soil mixed with air foam.

Kliner, J.T.R., Grozic, J.L.H. A new method to estimating gas hydrate content in soil specimens.

Kodikara, J., Ranjith, P.G.: Modelling of salt migration in stabilised pavement materials.

Kopf, F., Adam, D.: Dynamic effects due to moving loads on tracks for highspeed railways and on tracks for metro lines.

Laue, J., Springman, S.M., Nater, P., Graemiger, E., Ducksch, A. Creating seafloor conditions in geotechnical centrifuges

Lee, J.L., Stokoe, II, K.H., Bay, J.A.: The rolling dynamic deflectometer: A tool for continuous deflection profiling of pavements.

Micic, S., Lo, K.Y.: Increasing pullout resistance of offshore foundations in soft clays

Momoya, Y., Sekine, E.: Deformation characteristics of railway asphalt roadbed under a moving wheel load.

Nurmikolu, A., Kolisoja, P.: Extruded polystyrene (XPS) foam frost insulation boards in railway structures.

Puech, A., Dendani, H., Meunier, J., Nauroy, J.-F.: Geotechnical characterisation of Gulf of Guinea deepwater Sediments.

Queiroz, R.C., Macari, E.J.: Method for estimating railroad track settlements due to dynamic traffic loads.

Sargand, S.M., Kim, S.-S.: Forensic study of the Ohio SHRP Test Road U.S. 23 flexible test pavement.

Singh, B., Datta, M., Gulhati, S.K. Suction development during pullout of superpile anchors in soft saturated clay.

Strout, J.M., Sparrevik, P.M.: Multilevel subsea piezometer system.

Tufenkjian, M.R., Thompson, D.: Shallow penetration resistance of a minicone in sand.

Vallejo, L.E., Chik, Z.: The evolution of crushing in granular materials and its effect on their mechanical properties.

Valore, C., Ziccarelli, M.: Safety appraisal and rehabilitation of a quay wall.

Vanden Berghe, J-F., Cathie, D., Ballard, J-C.: Pipeline uplift mechanisms using finite element analysis.

Vinogradov, V.V., Yakovleva, T.G., Frolovsky, Yu.K., Zaitsev, A.Al.: Evaluation of slope stability of railway embankments.

Wijeyakulasuriya, V., Ramanujam, J., Creagh, M., Soward, G.: Performance of some unbound roadbase materials form Queensland.

Wilkinson, A., Haque, A., Kodikara, J., Adamson, J., Christie, D.: Physico-chemical aspects of cementitious slurry design for the stabilisation of reactive soils.

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