Prediction and Performance — General Report

Prévisions et Constatations

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INTRODUCTION

The session title "Prediction and Performance" is not very specific, and the authors of the diversity of papers submitted have interpreted the intentions of the organizers very differently. The technical questions listed under Session 1 are :

. Accuracy of predictions and its determination - case records.

. Application of probability and decision theory in design.

. Factors governing the performance of buildings and other structures, e.g., uncertainties in soil parameters and geological factors.

Specific aspects that ought to be considered within the theme are :

The influence on performance of construction delays, procedures, field control and quality assurance.

The importance of properly planned and designed field instruments and performance observation systems.

The IX ICSMFE Conference in 1977 included a spesialty session on the uncertainties in geotechnical engineering and the relationship between design and construction. Thus the stage was set for this session today, which through case studies and examples ought to focus on what may be learned from deviations between design predictions and actual performance observations. The discussion should point out inadequacies in present analyses and practice and provide guidelines for future contributions on the theme.

The General Report presents a review of the papers submitted to this conference session and considers important contributions within the theme published elsewhere since the IX ICSMFE Conference. As a special task, the Co-Reporter has reviewed the twenty-two invited papers prepared for the case history volume which recently was published as an addition to the proceedings from the Tokyo Conference. In his contribution to this case history volume, Peck (1981) states that "without the assurance on the one hand, or the warnings on the other, provided by well documented case histories, soil mechanics could not have taken its proper place in engineering practice".

The General Reporter has attempted to assemble the written contributions to this session in an orderly manner and to summarize and comment on their content so as to aid the delegates in the selection of papers of interest to them. The papers submitted will be indicated only by the names of the authors (underlined), while the other papers mentioned and reviewed are referenced in the usual manner and listed in the back of this report.

CASE STUDIES

Structural Foundations

Milovic, Stevanovic and Koprivica present the results of observed settlements for five almost identical 12-storey buildings founded on loess. The set-up is ideal for a useful study, and the presentation is good. The contact pressure beneath the strip foundations was approximately 170 kN/m^2, and the thickness of the loess deposit 20 m. The predicted values of the settlements varied between 6 - 11 cm for all five buildings. The settlement observations cover the period from 1972-1980, and the settlements reached values up to 55 cm. The unexpected and very large settlements were caused by wetting and saturation of the loess due to accidental infiltration from damaged water pipes. Settlements due to saturation are discussed in some detail, and laboratory results from tests on handcarved block samples down to a 10-m depth are presented.

Regarding the behaviour of loess during loading and wetting, Browzin provides a very useful overview of experimental data from floating ring oedometer tests. Results from loess deposits in twelve US-states are presented, and the author discusses pre-wetting elastic compression, post-wetting subsidence and post-subsidence consolidation.

Ehasz and Pavone present a very interesting case of constructing a large "rigid" mat, 116m x 82m, for a nuclear power plant. The designers aimed for a floating foundation with very small foundation movements. The authors specifically address the accuracy of heave and settlement predictions considering the unavoidable changes in the construction activities and scheduling. This is one of very few papers which discuss these important aspects. The authors stress the importance of maintaining and closely monitoring a comprehensive instrumentation system. The measurements should immediately be evaluated by engineers thoroughly familiar with the foundation design concept.

Withiam and Christiano propose a method for predicting settlements of mat foundations bearing on silty and clayey sands. Oedometer tests are employed to establish loading and unloading moduli of undisturbed samples as functions of soil density. The authors are to be complimented for the clear presentation and for giving a brief but useful review of existing computational methods before they proceed to predict the settlements of an exceptionally large mat. The approach is tested by applying the model to case histories of settlements of buildings founded on similar soils in the vicinity of the proposed structure.

Houghton, Leonard and Van Riessen ran 3-m^2 plate loading tests with applied pressures up to 2400 kN/m^2 to evaluate the deformational characteristics of a compacted fill. Testing methods and procedures are described, and comparisons are made between the observed and predicted deformations. The situation is well defined and clearly presented. The tests aimed at providing input to the design of two power plants with very heavy column loads and settlement sensitive equipment.

Becker and Lo present the case of a 9-m diameter and 22-m high tower silo bearing on a ring foundation at a site with a 3-m thick clay crust overlying an 18-m thick soft to firm clay deposit. The foundation performance during loading and unloading of the silo was monitored over a period of three years. The authors use a finite difference solution for the problem of axi-symmetric consolidation under intermittent loading of an anisotropic two-layer system. The deformation and consolidation parameters were determined from clay specimens trimmed from block samples. Comparisons between predictions and measurements of settlements, rebound and pore water pressures are presented in this high -quality, well-documented study. The authors give specific comments on the merits of a one-dimensional as opposed to an axi-symmetric analysis. However, they do not comment on the reliability of the recorded field data.

Hansteen, DiBiagio and Andersen (1981) present predictions and performance data for an offshore gravity platform placed on an overconsolidated clay with interbedded sand layers. A joint industry-sponsored project made it possible to instrument and monitor the behaviour of this gigantic North-Sea structure over a two-year period during which the platform experienced a number of storms. The authors present the field instrumentation system for observation of deformations, pore water pressures, base contact stresses, accelerations and strains in the concrete shafts. The data, automatically recorded, were registered over 20-min. periods with normally a 3-hour pause. During these 20 min. periods, the sensors were logged 2 to 8 times per second, and more than 2500 periods were recorded. The data were analyzed and compared to theoretical calculations. The total settlement of the structure amounts to approximately 35 cm, or 30% less than predicted. The secondary settlement due to cyclic loads and creep amounts to about 1.3cm per year, and the build-up of pore water pressure due to the cyclic loads was no more than about 10 kN/m^2 for the storms experienced. The project offered a unique opportunity to evaluate the soundness of the design for this new type of offshore platform and its foundation.

Janbu and Senneset discuss the magnitude of settlement that may accumulate under tanks and silos due to drained, cyclic loads. Based on the results from a number of drained triaxial compression tests with slow cyclic loads, the authors define a dimensionless strain resistance R_ε :

$$R_\varepsilon = \frac{dN}{d\varepsilon_{cu}}$$

where N = number of load cycles

ε_{cu} = cumulative strain

The authors present dimensionless resistance numbers as function of the degree of shear strength mobilization in the triaxial sand samples. The computational model is applied to analyze the settlements of a grain silo, base 20 m x 50 m, on a saturated, 40-m deep sand deposit. The analysis separates out the three strain contributions from initial loading, cyclic effects and creep. The scope is well defined, and the paper is clearly presented.

Vermeer discusses the relative merits of existing mathematical stress-strain models for describing sand behaviour. He presents arguments in favour of elasto-plastic theory and proceeds to formulate a model based on plasticity concepts. Vermeer uses the model to predict the pore pressures under a caisson on saturated sand subjected to cyclic loading. It was assumed that after some load repetitions the caisson would reach a cyclic steady state, and the elasto-plastic model with isotropic hardening was considered applicable. As a rule the model produces a short cyclic transient state and then a cyclic steady state (shakedown). The pore pressure variations within such an "elastic" cycle were predicted and compared to field observations. This part of the presentation is very brief,and it is difficult to evaluate the merits of Vermeer's model, which, however, looks very promising.

Morgan and Walker report two cases with observations of creep during heave. The heave was caused by two significantly different mechanisms : (1) release of vertical stress by a 15-m deep basement excavation in clay, and (2) increase of moisture content in a soil which was previously dried from the heat of a kiln in a factory. The authors present a very useful review of previous experience as well as detailed observations from the two well-documented case histories. They conclude that good predictions may be made for situations involving stress release, but present knowledge concerning cases of moisture content increase is rather limited.

Horvat, Szavits-Nossan and Kovačić discuss undrained deformation analyses for a cylindrical tank on soft clay. The soil stress-strain relationship was defined on the basis of consolidated, undrained triaxial compression tests. The vertical settlements under an oil tank during test loading are presented and compared to the results from different non-linear finite element analyses. The presentation is rather sketchy, and the Reporter does not find sufficient information to be able to evaluate the proposed mathematical models with the associated input parameters, and the stated conclusions.

Hartikainen presents an interesting case of foundation improvement for a grain silo. The silo was placed on a mat, 24 m x 55 m, on top of a very loose silty sand layer about 10-m thick which was reinforced by stone columns to prevent liquefaction. Piles were suggested in the tender documents but later abandoned in favour of the more economical alternative. The paper is well presented and contains much useful information. The author discusses the differences between estimated and measured settlements of the silo, as well as construction aspects, in-situ density control, and structural behaviour. The details of the settlement predictions are not documented.

In one of the very few papers concerning piles submitted to this session, Bæk-Madsen and Lagoni describe pile foundation problems in weathered chalk. The paper discusses earlier experience with this rather special soil and the Danish code of practice. From an extensive program with laboratory and in-situ tests, the authors collected the information required for the pile design. Valuable results from cone penetration tests, pressuremeter tests, vane tests and plate- and pile loading tests are included.

Feda predicts the load-settlement relationship for a reinforced concrete pile of cross-section 0.35 m x 0.35 m and length 8 m. The pile was driven into a rather complex soil deposit with alternating layers of cemented clays, clay stone and silt stone. The predicted settlement at the operational load was 10 mm. This estimate was based on relatively little soil testing and relied heavily on previous experience. Test loading of the pile resulted in a settlement of 4 mm. The analysis of the load test results showed that the actual value of skin friction was lower and that of the pile point resistance higher than predicted. The author discusses the reasons for the deviations between the prediction and the observed performance.

Bobe and Pietsch propose a semi-empirical procedure for computing the load-deformation behaviour for a rigid, shallow footing. They recommend the use of a variable deformation modulus which does not only represent a material property but also depends upon the load and the geometry of the loaded area. Although the authors claim that this procedure is superior to available approaches, the Reporter believes that this may prove true only for rather special situations. Bobe and Pietsch do not discuss how to determine the deformational characteristics of the soil, and they present no comparisons of prediction and field performance.

Gusev and Rossikhin discuss analytical procedures to compute settlements and contact pressures under rigid footings, plates and beams. No prediction-performance comparisons are made based on either laboratory or field tests.

Cordary, Gambin and Van Wambeke review theoretical predictions of settlements based on linearly elastic theory. They propose equations and diagrams for calculating initial and final settlements of footings and discuss divergences between elastic behaviour and actual soil behaviour. The authors compare their relationships to the semi-empirical settlement calculation method based on pressuremeter moduli as recommended by Menard and Rousseau (1962). They claim that their procedure is superior. However, the paper contains no comparisons between predicted and measured behaviour in the laboratory or in the field.

Of prediction-performance papers published elsewhere, the Reporter recommends the ones by :
Imael and Klym (1978) who test and analyze the behaviour of rigid piers in layered cohesive soils;
Bhushan et al. (1979) who predict the behaviour and perform full-scale lateral load tests on twelve drilled piers in clay;
Blanchet et al. (1980) who report field testing and analyses of the behaviour of friction piles in soft, sensitive clays;
Poulos (1979) and Randolph and Wroth (1978) who present analyses and observed settlements of single piles;
Reese (1978) who emphasizes the construction methods and design procedures for drilled shafts;
De Ruiter and Beringen (1979) who describe the design and installation of offshore piles.

Focht et al. (1978) present an example of a very well documented and valuable case study of a mat foundation. Weber (1978) reports predictions and performance observations for a mat foundation when piles are driven in the vicinity. Bell and Iwakiri (1980) present a comparative study of the settlement behaviour of 33 large tanks on soft ground. The paper considers both tanks that performed satisfactorily and tanks that failed.

Embankments on Soft Ground

Session 1 includes several good case studies on this subject which is becoming a "classic" situation in geotechnical engineering (e.g., ASCE, 1972, Bjerrum, 1973).

Cole and Garrett present a very valuable contribution on the predictions and performance of two road embankments on soft alluvium. It is difficult for the reader to digest all the condensed information presented, but the paper is one of the most significant contributions to this session. The initial design of the embankments overestimated the drainage characteristics of the alluvium with the result that neither embankment could be completed as planned. The coefficient of consolidation of the alluvium was found to be very low when the vertical effective stresses exceeded the preconsolidation stresses. After extensive site trials, additional vertical drains were installed and the embankments completed. The authors refer to a field procedure developed for determining in-situ drainage characteristics of soils stressed above the preconsolidation stress (Nicholson and Jardine, 1981).

Cox reports the settlement observations over a 55-km long stretch of a highway on soft Bangkok clay. Total settlements 10 years after construction vary between 100-240 cm. Post-construction settlements were found to be influenced critically by whether the induced stresses from the embankment loading exceeded the apparent preconsolidation stress or not. The author presents a good, practical case study and is able to summarize the available information so the reader may evaluate the results. He also presents predictions and post-predictions with a brief evaluation of available computational procedures.

Sarać and Popović describe the case of an embankment constructed on a 10-m layer of peat and organic clay. The 5-m high embankment was widened by berms to a total width of 75 m. The scope is well defined, and the paper is clearly presented. The case is analyzed as one of one-dimensional consolidation, and comparisons are made with field observations of pore water pressures and settlements. It was found necessary to perform a large number of oedometer tests to arrive at statistically meaningful parameters, especially when predicting the coefficient of permeability.

Sandroni, Neto and De Carvalho present results of field and laboratory investigations of settlements of a peaty deposit loaded by a hydraulic fill. The laboratory program included conventional consolidation tests on samples collected before and after placement of the fill, as well as long term (10 months) consolidation tests. The authors find that while the laboratory tests gave realistic compressibility values, the coefficients of consolidation determined in the laboratory were about 100 times smaller than the ones backfigured from the field measurements under the fill. The authors present interesting results concerning the rate of primary and secondary settlements, but the reader is not given sufficient information to be able to evaluate the reliability of the conclusions.

Przystański and Rzezniczak propose methods to predict the consolidation characteristics of peat and the strength increase as a function of effective stress level and aging. The calculated settlement with time compares well with the results from two laboratory oedometer load increments at stress levels less than 60 kN/m^2. No results are given for higher effective stresses. Shear strength values obtained by the field vane and K_o-consolidated, undrained triaxial compression tests are compared. The field vane gave consistently higher values, but very little information is given regarding laboratory- and field testing details. The Reporter finds the paper hard to follow partly because of the unfamiliar terminology used by the authors.

In a well-presented paper, Shibata and Sekiguchi summarize the results from three test embankments on soft foundations and refer to other literature. The authors propose an observational method for predicting the impending foundation failure by measuring the lateral deformations at the toe of the embankment. They suggest a critical limit of the ratio of increase in embankment load divided by the corresponding measured increase in lateral deformation at the toe. The influences of the embankment loading rate and partial foundation drainage are discussed, but the treatment is rather sketchy.

Vidmar and Gaberc present analyses and performance data for a highway embankment on very soft, partly organic soils. In order to reduce the post-construction settlements, they used the methods of vertical wick drainage, preloading, light fill material and partial excavation of the top peat. The reliability of the simplified analyses using soil parameters determined from laboratory tests was checked by field measurements made on a 160-m long test embankment. The paper represents an interesting study of much practical value, but the Reporter finds it difficult to evaluate the accuracy of the comparisons between measured and computed values and the subsequent conclusions.

A number of good papers about embankments on soft ground have been published elsewhere. The Reporter has noted the following : Lacasse et al. (1977), Foott and Ladd (1977), Leathers and Ladd (1978), Law and Bozuzuk (1979), Larsson (1980), and the very extensive review by Tavenas and Leroueil (1980).

Earth- and Rockfill Dams

Amaya, Cubillos and Sierra present the results of pore water pressure measurements in the core of a 237-m high earth- and rockfill dam. The dam was completed in 1975, and pneumatic piezometers have been used to register pore pressures during construction, first filling of the reservoir and subsequent drawdowns and fillings. A very interesting and complete record of performance data is presented in a well written paper which is much longer and more detailed than the average paper submitted to Session 1. The paper contains no real predictions but valuable discussion and analysis of data. Thirty-eight pneumatic piezometers were installed, and the authors believe that thirty-three of them are giving reliable results. Some additional comments on the reliability of the instrumentation techniques and recorded pore pressure measurements would have been useful.

Cole and Cummins summarize the measured stresses and movements in a 180-m earth and rockfill dam during construction. The authors present the case study very well, including the field instrumentation, the theoretical analyses and the performance observations. They compare their findings with results presented elsewhere in the literature, and also discuss the reliability of the field measurements.

(This aspect is passed over lightly in most papers.) The extent of the analyses is fairly limited, and it is difficult to conclude how sucessful one might be in explaining the observed behaviour by employing the finite element analyses and constitutive stress-strain models described by the authors.

Doležalová and Leitner present analyses and measurements of stresses and deformations in a 90-m high earth- and rockfill dam during construction. The constitutive model in the finite element analyses used soil parameters derived from the field measurement observations during the early part of construction. The authors present an interesting study, but it is difficult for the reader to evaluate the merits of the suggested analytical procedure, as it is not clear what are predictions and what are back-calculations.

In addition to the many valuable case studies published in the proceedings of the International Congress on Large Dams (1979), the reader should be aware of the following contributions : Eisenstein and Law (1977), Jaspar and Peters (1979), Peters and Lamb (1979) and Dascal (1979).

Retaining Structures

Shen, De Natale, Bang and Mitchell report a very interesting, well-defined and clearly presented case study involving a 10-m deep test excavation above the water table. The soil deposit was composed primarily of interbedded layers of sandy silts and silty clays with lenses of granular river deposits. The purpose was to monitor the field performance of a relatively new lateral earth support system during and following the period of construction. The system is based on the concept of soil reinforcement. Predictions were obtained by finite element analyses. The study shows that the analyses correctly predict the vertical and horizontal deformation patterns and anchorage forces. However, as no soil moduli are presented based on in-situ or laboratory tests, the Reporter assumes that the moduli required to achieve the correct magnitude of deformations were back-calculated from the field measurements.

Bredenberg, Adding and Sjøkvist present the design and construction of a tie-back wall used during the reconstruction of an 18-m high rockfill dam. The wall consisted of drilled-in, reinforced, tubular steel piles. A comprehensive field control programme was prescribed. Emphasis is placed on the construction and control aspects as the prestressed tie-backs were anchored in sound rock. The paper is very well presented, the design assumptions clearly stated, and the performance discussed. The authors have summarized a valuable case record.

Forrest presents the engineering challenges associated with the design and construction of a large cellular steel sheet pile cofferdam for a drydock. The author stresses the aspects of construction and field performance observations with less emphasis on the soil mechanics predictions. To prevent liquefaction during potential earthquakes, deep compaction within the 23-m diameter cells was achieved using a large vibrating probe. Compaction was carried out without unduly increasing internal lateral earth pressures. The maximum interlock tension was found to be below the 1/4 height of exposed sheeting as is often assumed in the design of such structures. The overall situation is rather complex, but the case is nicely summarized and presented. It is a valuable case study involving cellular cofferdams.

Bertero and Marcellino discuss the stability of slurry trenches used for construction of reinforced concrete diaphragm walls. The authors present very useful information on practical aspects of the construction and construction control. They emphasize the importance of the specific weight of the bentonite suspension, and present the contractors'experience from several case studies with different soil conditions.

Of other papers related to earth pressures and retaining structures, the Reporter has noted the one by Duncan (1979), who presents an excellent example of a clear, concise and well-documented prediction-performance study of long-span metal culverts. Burland et al.(1979) discuss how field observations can be used, firstly to develop valuable insight into mechanisms of ground behaviour, and secondly to determine soil parameters for use in design. Ingold (1979) investigates the structural failure of a long, reinforced concrete cantilever retaining wall, and Chang and Forsyth (1977) present the predicted and observed behaviour of a reinforced earth wall. Rosenberg et al. (1977) discuss the design, construction and performance of a slurry trench wall close to existing foundations.

Other Cases

Tsien and Gu present a method for computing land subsidence in Shanghai, China. The proposed analysis accounts for cumulative settlements due to cyclic variations in the ground water table. Secondary compression is not considered. The comparisons between computed and actually measured data (from 1965-1978) regarding excess pore pressures and settlements show good agreement. To evaluate the prediction method, the reader, however, needs more details with respect to how the soil parameters were selected for the analysis. The authors present an interesting case and show the effectiveness of ground water recharging into the aquifers to control the land subsidence in Shanghai.

Chan, Radhakrishna and Klym studied the effectiveness of ground insulation with styrofoam pads to limit the depth of frost penetration. The authors present the results of the field monitoring program of three test installations. They predicted ground temperatures with a two-dimensional, transient heat conduction finite element computer program. The effect of the styrofoam pads was well predicted, and the authors conclude their paper with a series of very useful design recommendations based on their experience.

Charlie, Mansouri and Ries provide a promising approach to evaluate the likelihood of liquefaction of sand deposits as a result of construction blasting. To predict the time history of pore water pressures and particle velocity around buried charges, the authors develop a numerical analysis combining Biot's theory and Finn et al's (1976) empirical relation describing the tendency of soil to compact due to shear strains. The computational procedure is applied to predict the results from a test blasting program with buried charges. The analytical method greatly underpredicts the changes in pore pressures and particle velocities, but correctly predicts the pattern of behaviour. The authors present a useful and well-documented contribution to a subject which suffers from a lack of evaluated experience. Furthermore, the method of detonating and analyzing the effects of buried charges may assist the profession in evaluating the liquefaction potential of saturated deposits in earthquake-prone regions and offshore.

Hartlén and Ingers investigated the behaviour of fine-grained, dredged material by placing a test embankment on a hydraulic clayey fill overlying a barge-deposited silty clay. They present measured vertical and horizontal movements under the embankment as well as excess pore pressures versus time. The section on prediction of settlement should have included more details on exactly how the determination of the field modulus of compressibility was done. The paper represents a well-documented case study and should prove useful to all interested in the behaviour of dredged material. The authors also give practical advice on the dredging process itself, particularly on how to achieve material suitable for land reclamation and for supporting structural loads.

Habib, Luong and Le Tirant evaluate the reliability of using very small model tests for predicting the capacity of anchors in both clay and sand. A model of an anchor scaled down by a factor of ten enabled excellent predictions of the embedment depth and the anchoring capacity of a prototype in soft clay tested in the laboratory. On the other hand, tests on anchors embedded in sand illustrate the need to use large models before extrapolation of the results to prototype situations. The authors give a well organized and clear presentation, which first goes through the requirements of the scale modelling laws.

Surprisingly, no paper submitted to Session 1 discussed the use of centrifuge testing in geotechnical engineering (Bassett, 1979). Ovesen (1979) presents an excellent and educational illustration of the use of small size model footings on sand tested in the centrifuge. Andersen et al. (1979), in a true prediction-performance paper, describe the use of the centrifuge to study the cyclic displacements and the accumulated settlements under an offshore gravity platform. The same situation is treated by Prevost et al. (1981).

Wolle, Benvenuto and Carvalho describe their experience with the settlements of clayey and silty sands (termed collapsible soils) at the proposed sites of irrigation canals in Brazil. The studies undertaken included laboratory tests, field tests, and the possibility of improving the foundation by ponding an experimental stretch of the main canal. The authors provide a frank presentation of the difficulties and problems encountered. The laboratory oedometer test results varied widely, probably due to the heterogeneity of the soil specimens, and it was found possible to predict only an upper bound on total settlements. The predicted settlements at the instrumented canal section were about twice the maximum observed settlements, which exhibited very large scatter. The series of laboratory tests did not prove conclusive regarding ponding as a means of foundation improvement. The adopted design was not to proceed with ponding, but to replace the top layer of settlement-prone soil with compacted earth fill.

APPLICATION OF STATISTICS, PROBABILITY AND DECISION THEORY

Statistics and probabilistic procedures provide a framework that can assist the engineer to organize, accumulate, interpret and evaluate experience. The theory of probability may become a powerful link between theoretical soil mechanics and geotechnical engineering practice. Furthermore, the Bayesian approach in statistics allows objective information to be combined with subjective judgement and paves the way for statistical decision making in design (ECSMFE, 1979, ASCE, 1979).

Biarez, Favre, Lareal and Boissier present a very useful paper concerning deterministic and probabilistic calculations of the bearing capacity for a shallow footing as well as for a pile. The authors consider the uncertainties associated with loads, soil parameters and calculation methods. The paper also presents the results of an extensive investigation of the characteristics of sands. The test data are used to illustrate the uncertainties associated with the definition of strength parameters as a function of the different variables studied. The authors then present two example calculations following deterministic and probabilistic approaches. They warn that probabilistic methods should be used with some caution, but recommend that deterministic analyses at least should be supplemented by semi-probabilistic approaches which would pinpoint the relative uncertainty of the parameters used. The paper is very educational and should be translated into English to reach a wider audience.

De Beer, Lousberg, De Jonghe, Wallays and Carpentier discuss the use of probabilistic procedures and partial safety factors in pile design. Results are presented from pile loading tests in stiff, fissured clay and in deposits of dense sand. The authors conclude that they are in a position to design piles for other similar sites by the use of cone penetration tests. They recommend applying three partial safety factors, one to avoid large pile deformations, a second covering the uncertainty related to pile tip bearing capacity, and a third for skin friction. The magnitudes of these factors are determined from the statistical treatment of CPT-data and previous experience. The paper is a very valuable and practically oriented contribution in an area where too many papers over the years have presented excercises in applied mathematics.

Valalas, Hatzigogos and Tsotsos describe the influence of spatial variability of soil deformation characteristics on contact pressure distribution and settlement predictions for foundations. The authors use a dynamic relaxation method in their proposed analyses. From the soil profile data they compute the mean value and standard deviations of spatial averages as well as correlation coefficients between spatial averages. This is an important aspect when judging our ability to make good predictions in geotechnical engineering. The Reporter refers the interested reader to the contributions by Vanmarcke (1977), Baecher (1979), and Tang (1980), who applies similar analyses to the uneven penetration resistance of foundation skirts under gravity platforms installed in the North Sea.

It is important in a variety of geotechnical and pavement engineering problems to predict the eventual moisture conditions under a covered area. Potential benefits include thinner pavements, use of less costly sub-standard materials and more accurate prediction of heave and settlement. Haupt presents a large amount of data that were analyzed statistically to arrive at conclusions as to the most important factors affecting the moisture regime. The author produces empirical prediction techniques applicable to southern African conditions. The study, which is thorough and well presented, includes linear and non-linear regression analyses, and is an excellent demonstration of the systematic use of statistics.

Matsuo and Asaoka summarize a systematic procedure for updating information and improving subsequent predictions for a project in progress. It represents a method to introduce probability and Bayesian concepts into the observational method and design-as-you-go approach. The authors address an important topic, and the Reporter feels that this is one of the fruitful ways statistics, probability and decision theory will be used in the future. The interested reader may find it useful, as background material, to study the paper by Folayan et al., 1970.

Förster and Weber compute the probability of slope failure considering the effects of the different, assumed density functions for the random variables and correlations between the variables. It is a purely analytical study with no performance observations, and the authors do not refer to the many earlier papers published in the literature on the same topic.

Juszkiewicz-Bednarczyk and Werno discuss analytical methods of how to determine the consolidation parameters for a visco-elastic spring-dashpot model of one-dimensional consolidation. Gibson and Lo (1961) formulated an approximate method for determining the relevant soil parameters from experimental data. The authors propose a different approach based on the method of least squares to increase the reliability of the prediction. They use an iterative procedure to minimize the error function with respect to the unknown soil parameters. Comparisons are presented between analytical results and observations from oedometer tests on samples of peat. The authors have provided another useful example of the application of statistics.

Nascimento evaluates the mechanisms of surface erosion in cohesionless soils and proposes a laboratory method to determine the angle of repose in sand. The author considers the coefficients of variation for the imposed shear stress due to water flow and the shear resistance of the granular bed. Correlations are presented between the computed safety coefficient based on mean values, the probability of incipient erosion and the above mentioned coefficients of variation.

Wittmann (1979) discusses the use of statistics in the formulation of filter criteria. This represents a most interesting application. The author analyzes the filtration process on the microscopical scale, taking into account statistics of mean values and extreme values.

STRESS-STRAIN-TIME FORMULATIONS

Case records of settlement of sensitive clay have revealed that excess pore water pressure in the middle of the compressible layer exists over long periods of time, - much longer than conventional consolidation theory seems to predict. Poorooshasb, Law, Bozuzuk and Eden postulate a new mathematical model for the consolidation behaviour of sensitive clays. They discuss the concept that pore water pressures may be generated by the collapsing clay structure, and conclude that for highly structured clays it is not valid or useful to separate the consolidation process into so-called primary and secondary phases. The proposed model assumes that, above a critical stress level, the rate of deformation is directly proportional to the magnitude of overstress and the instantaneous value of void ratio. The paper is clearly presented, and results obtained from the postulated model are compared with experimental data obtained in a modified oedometer of diameter 114 mm.

Schiffman and Cargill apply the theory of finite strain consolidation to sedimenting marine deposits. The proposed formulation is non-linear and accounts for the variations of permeability and compressibility as consolidation proceeds. The self-weight of the sediment is an integral part of the theory, and the formulation is limited to monotonic loading. A comparison is made between non-linear, finite strain consolidation and a linear, infinitesmal strain theory. It would have been interesting to see a comparison between the two theories when similar stress-strain moduli were used in both cases. The paper presents no prediction-performance comparisons, but the authors are to be complimented for a very clear and readable presentation with a well defined scope.

Oka proposes a mathematical model that describes the time-dependent stress-strain behaviour of normally consolidated clay, including creep, stress relaxation and secondary compression. The constitutive equation is based on the work at Cambridge University and viscoplastic theory. The author compares his analytical results to results from strain-controlled, consolidated-undrained, triaxial compression tests with one-day and seven-day consolidation time prior to shear. Analytical and measured results agree very well.

Wei, using energy considerations, develops an expression for the yield locus of soils. Then, by means of an associated flow rule, he derives the general formula for the elastic-plastic stress-strain relationship. It is shown that the predictions obtained by the proposed model agree with the results from undrained and drained laboratory triaxial compression tests. Comparisons are made with predictions from the Cam-clay model, which the author finds to be a special case of his proposed, more general model. The model in its present form seems to suffer from the assumption of an isotropic clay starting with an isotropic state of stress. The Reporter is looking forward to future comparisons Oka and Wei will make with results from stress paths other than the special ones obtained in triaxial compression tests (e.g. Prevost and Høeg, 1977, Prevost, 1979).

Juarez - Badillo presents a general compressibility formulation for soils under isotropic (equal all-around) stresses. The equations are very simple and provide results that check with data previously published in the literature. The author proceeds to propose that the relationship may also apply to triaxial tests with constant σ_3/σ_1 and for the critical state conditions, but no prediction-performance comparisons are presented.

THE VALUE OF PREDICTION-PERFORMANCE STUDIES

In his Rankine lecture, Lambe (1973) emphasized and illustrated the importance of predictions to the practice of civil engineering. He discussed the value of prediction-performance studies and classified predictions in three categories :

A - Predictions made before construction and based entirely on data available at that time;

B - Predictions made during construction based on data made available during the initial parts of construction;

C - "Predictions" made after the event being predicted has occurred.

Lambe concluded then that type B predictions, although helpful, normally prove not nearly as useful and educational as type A predictions. Furthermore, one must exercise great care when attempting to use type C predictions to "prove" that the analysis technique derived from the observations has general applicability. Based on the reviews summarized herein, the Reporter finds that these comments from 1973 ought to be underlined.

In their paper on "pitfalls of back-analyses", Leroueil and Tavenas provide a series of interesting examples. Although the back-analysis of case histories has greatly improved our knowledge, they suggest that on many occasions such procedures have led to unreliable or even misleading results. Based on an interesting review of a number of cases, the authors provide a useful reminder very appropriate for this session.

Preferably, all aspects of the soil response, e.g. induced pore pressure changes, strain components and the strength mobilization, should be looked at simultaneously and understood in a consistent manner before general conclusions may be drawn. This requires unbiased field observations of all aspects of the situation. In many cases referred to in the literature, only one or a few aspects are studied. If the few comparisons between analytical and measured results are satisfactory, the back-analyst draws broad and bold conclusions as to the general applicability of the predictive method. Furthermore, in many situations reported, key input parameters in the back-analyses have had to be assumed, and the results of the analyses directly reflect the initial assumptions. Users of back-analyses should always look for self-cancelling errors, which may occur so often in complex field situations.

Magnan, Baghery, Deroy and Queyroi present an excellent summary of problems encountered when checking the reliability of a prediction. Although the paper specifically discusses the settlement behaviour of soft clays subjected to embankment loads, the authors also offer so many generally valid observations and comments, that their paper is reviewed in this section on the overall value of prediction-performance studies.

The paper should be studied by all who interpret field measurements. The authors describe in simple terms both common and special problems related to instrumentation. They discuss the potential errors in soil parameter selection, including systematic bias from laboratory test results and spatial variability of soil properties. The study is well-organized, and the extensive experience of the authors enables them to provide reliable assessments of various types of equipment. They present a frank discussion of past short-comings and positive results from recent experience. It is strongly recommended that the paper be translated into English.

DiBiagio et al. (1977, 1979) discuss the importance of simple but properly planned and designed field instruments and performance observation systems. In the more recent paper, the authors evaluate the performance monitoring programs for the North Sea gravity platforms.

CONCLUDING COMMENTS

Presenting complete, well-documented field case studies within the space allotted to the average conference paper, is difficult. However, some of the authors have done remarkably well.

The Session includes only a few true prediction-performance papers, as most contributions present "after-the-event" predictions.

Some of the papers discussing applications of statistics and probability, and the contributions on reliability of field observations and back-analyses, are very valuable.

The Reporter offers the following comments in an attempt to prepare the ground for the discussion at this conference and for future fruitful sessions on the theme :

- There is a particular need for well-documented field case studies involving failures. Legal and other considerations may prevent complete disclosure of relevant information, and the profession at large is missing many of the lessons that could be learned. Efforts should be made to ensure that such case studies are made available or at least summarized.
- Potential dangers inherent in the use of back-analyses to document the predictive capability of the computational procedure, are reviewed in this report. They deserve attention.
- To encourage the use of statistics and probability in geotechnical engineering, simple, practical applications should be presented to the profession. The mathematical tools are available, and they ought to be used in the portrayal of test results, probabilistic description of soil profiles, site investigation strategies, evaluation of reliability and decision making under uncertainty.
- More emphasis should be placed on the influence of construction procedures and delays on field performance. In general, the interaction between the contractor and the geotechnical consultant has barely been touched upon in the papers submitted to this session.
- The author must make an effort to define how the soil profile was simplified in the analyses and how the soil parameters were determined. For instance, it is not adequate to refer to the undrained strength of a clay without specifying what type of test and testing procedures were used. The value of prediction-performance studies and of empirical correlations depends on such information.

Unfortunately, many of the authors of the papers submitted do not seem to have studied readily available, recognized references on subjects closely related to their own. A brief review of previous key contributions ought to be a requirement.

Furthermore, some of the papers submitted do not really fit into the theme of Session 1. The National Societies must be more diligent in ascertaining that "the subject must refer to the theme of the session and to one or several of the technical questions which are to be considered in that session".

The evaluation and discussion of the papers by the Reporter may contain some misunderstandings or errors in interpretation, for which he apologizes.

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