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General Report - Ground Stresses and Displacements

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1 INTRODUCTION

The topic of ground stress and displacement is so wide as to preclude any objective treatment of the "state of the art". The prediction and subsequent monitoring of stresses and displacements associated with engineering activity spreads over the gamit of soils, soft rocks and hard rocks, and is of profound importance in all facits of geotechnical engineering. It is through the ongoing process of comparison of predictions of stresses and displacements with subsequent quantitative data obtained from monitoring that advances will be made in the ability to reliably predict the performance of engineering activity in soil and rock.

A total of eight papers are presented under this heading, most of which, to a greater or lesser extent, feature comparisons between "predictions" and "observations". All, except for the paper by Enever, Windsor and Walton, deal with aspects of the performance of soils and/or very weak (weathered) rocks. The paper by Enever, Windsor and Walton is concerned with stresses in medium strength and hard rocks. Several fields of engineering activity are covered by the eight papers, ranging from tunnelling in soils, weak rocks and hard rocks, foundations in/on soils and weak rocks, soil and rock-fill embankments and retaining walls in soil/weak rock.

One obvious feature of most of the papers is the predominant reliance on displacements as a measure of the performance of engineering structures in/on soil/rock. This underscores the need for continued development of reliable methods of stress measurement/monitoring to provide data for comparison with predictions.

A feature of the cases in which displacements predicted by numerical modelling were compared with corresponding measured values is the practice of "calibrating" predictions to match observations by adjusting the material properties used in the predictive process, and then employing the "adjusted" properties for subsequent predictions. While a common practice, care must be exercised when using this method to ensure that a combination of non-representative properties is not employed when matching predictions with observations, leading to erroneous extrapolations. This practice emphasises the need for continued effort to be devoted to refinement of the techniques used to assess material properties and associated environmental parameters (e.g. *in situ* stress, groundwater regime).

Several of the papers emphasise the need for use of predictive processes consistent with the mechanisms controlling the physical situations concerned. In some cases, existing predictive methods can apparently provide answers in practical accord with observations, provided due care is taken in applying the predictive technique. Other cases, however, emphasise the need for continued development of predictive methods capable of more realistic simulation of the physical mechanisms concerned.

An observation common to several of the papers is the apparent ability to reasonably predict performance in ideal or "average" conditions, but the relative inability to predict "worst case" performance due to specific combinations of "deviant" ground conditions. This further emphasises the need for the development of improved and more convenient methods of site investigation, conducive to wider application in geotechnical investigations.

2 SPECIFIC PAPERS

The papers by Adikari (Behaviour of Storvatn Dam, Norway - A case of prediction versus performance) and Goh et al. (Behaviour of a diaphragm wall with top-down construction method) demonstrate the potential for application of the Finite Element Method to studies of the performance of rockfill embankments and deep cuts in soil and weathered rock respectively. In both cases two-dimensional non-linear analyses were carried out to provide estimates of deflections, strains and (in the case of the former paper) stress changes for comparison with observations. In both instances reasonable agreement was evident after appropriate adjustment of the material properties. In the case of the Storvatn Dam analysis, the authors conclude that non-linear analysis did not produce information significantly better than for a linear analysis. In the case of the diaphragm wall analysis, the authors emphasise the advantages of being able to study the influence of material properties parametrically, with a view to using the information for construction management.

The paper by Pedler and Skotnicki (Boundary element analyses of surface movement associated with faulted structures) also demonstrates the potential for application of numerical modelling techniques. In this case the boundary integral method was used, with incorporation of a representation of specific discontinuities, to predict displacements and stress changes in a sequence of soft coal measure sediments subject to boundary deflections resulting from groundwater drawdown and/or mining excavation.

Two case studies involving two-dimensional, linear boundary integral analysis are cited. In both instances only limited comparison with observations has been possible to the date of writing.

The papers by Sinclair et al (Settlements over bored tunnels - fantasy and fact) and McDonald (The real world of embankment settlement) both deal with the application of relatively simple analytical techniques to the prediction of settlements, and the comparison of predictions with observations for a range of geological conditions within the general description of soils/weak (weathered) rock. In the case of the former paper, the so called "lost volume" technique was employed to estimate the settlement profile overlying bored tunnels in soil and weathered rock, while in the latter case a number of variants of consolidation theory have been applied to the settlement of soil embankments. Both papers demonstrate the possibility of obtaining predictions in reasonable accord with observations in some situations, but equally demonstrate the limitations associated with the application of generalised predictive techniques without due attention to specific site conditions. Both papers draw attention to the benefits that can potentially be obtained by compiling experience from a variety of sites in a wide range of geological conditions. Such a process must, however, be accompanied by a detailed examination of the respective mechanisms pertaining to each case. Both papers imply a case for detailed site investigation and subsequent detailed modelling of perceived "extreme" situations.

The papers by Lo et al. (A study of the influence of anisotropy on the response of foundation of multi-story building) and Small and Brown (Finite layer analysis of the effects of a sub-surface load) both deal with applications of the "Finite Layer" method of stress analysis to problems of surface and/or buried foundations in layered soil deposits. In both cases the predictive technique was used to estimate deflections and contact pressure distributions in proximity to the loaded region. In neither case was there a comparison with observations of the same quantities.

The former paper treats a specific case of the raft foundation supporting a multi-storey building founded in Shanghai Clay. The paper describes a laboratory programme designed to obtain information on the deformation properties of the clay necessary for a cross-ansiotropic analysis, and the results of the subsequent analysis. The influence of variations in material properties was examined parametrically. The predicted contact pressures were found to be relatively insensitive to the material properties, including the degree of anisotropy. The use of the anisotropic solution did not appear to significantly alter the predictions obtained from the isotropic solution for the long term (drained) situation, but indicated a significant potential impact of anisotropy in the short term (undrained) case.

The latter paper presents a general epproach to a class of problems (buried load) and draws on the results of a number of idealised cases for illustration.

The paper by Enever, Windsor and Walton (Pre and post excavation stress measurements) deals with two specific cases in which comparisons are made between virgin rock stress measurements conducted from the surface during the site investigation stage of tunnelling projects, and the results of underground stress measurements conducted subsequently, in proximity to the surface measurements, from the respective tunnels. In both cases the hydraulic fracture technique was used for the initial site investigation, and the overcoring technique for the subsequent underground measurements. Both cases suggest good agreement between the results of the two measurement programmes, with best correspondence for a relatively simpler, horizontally bedded, sedimentary environment compared to a more complex metamorphic environment.

This paper illustrates the ability to determine *in situ* stress in advance of detailed planning and highlights the benefits to be obtained from an integrated pre and post excavation stress measurement campaign.

3 GENERAL COMMENTS

Figure 1 shows an idealised schematic representation of the interaction between the components of an integrated geotechnical investigation revolving around the prediction and monitoring of ground stresses and displacements. Highlighted in Figure 1 are three general areas of concern that the authors' consider of importance in any attempt to refine the prediction of ground stresses and displacements, and to more reliably make use of such predictions in project design and/or control. Each of the three areas has been discussed in the review of the specific papers contained in this section. The intention is to pursue open discussion on each of the areas:

1. Improvement to methods of determination of material properties, particularly a move toward an increased reliance on *in situ* testing techniques and an integration of material response *in situ* with the geological environment.

2. Closer matching of predictive tools with the physical mechanisms pertaining to the situations being studied.

3. Greater reliance on monitoring of stress changes as a feedback to refinement of predictions, rather than predominant reliance on monitoring displacements.

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* **Area for discussion**

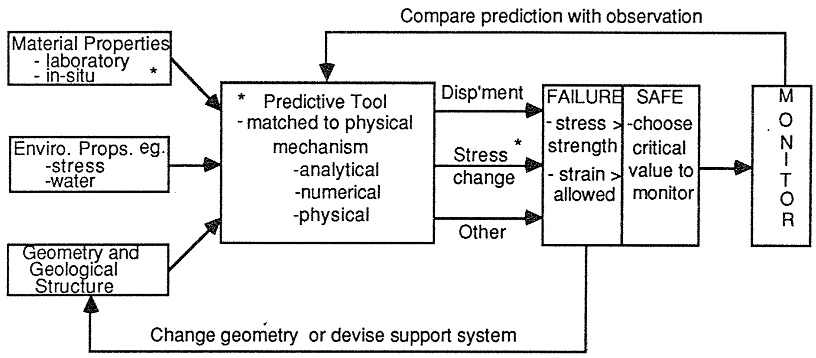

Fig. 1. Schematic of elements of an integrated geotechnical investigation