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I SCOPE AND APPROACH OF REPORT

The Organizing Committee of the VII International Conference suggested that the four General Reports note achievements in our profession during the last five years and make recommendations for practical application of our knowledge, especially in predicting the performance of constructed facilities. Following suggestions by the Organizing Committee and his judgement, this Reporter selected the following theme for the first main session- Soil Parameters for Predicting Deformations and Stability. Having foremost in mind the practicing soil engineer, this Reporter gives emphasis to developments of immediate and near-term value to the practicing engineer. New theories, research tools and techniques, etc. are noted, but not considered in detail even though they may prove to be very useful in the future.

The Report emphasizes at the outset that a prediction involves both data and methods and that these two components are usually intimately interrelated. The proper selection of soil parameters thus depends on the use to be made of them. The Report uses four actual field situations as a framework for suggesting the present state of our profession and indicating recent developments.

The Geotechnical Profession has been exceedingly active during the period covered by this Report. Seventy six papers were accepted for this Session. Held since 1969 were regional conferences (European, Asian, Australian-New Zealand, Pan American, African, etc) and ASCE Specialty Conferences (the Cornell Conference on Lateral Stresses and the Purdue Conference on Performance). Excellent papers have appeared in the proceedings of these conferences and in important periodicals like the Journal of the Soil Mechanics and Foundations Division, ASCE, Geotechnique published by the Institution of Civil Engineers, London and the Canadian Geotechnical Journal. Noteworthy among the many other special conferences and symposiums was the Roscoe Memorial Symposium held at Cambridge University, England in March, 1971.

The Reporter faced a tremendous task in reviewing and evaluating the huge mass of published works covered by Session I. The Reporter received considerable assistance in his job from three sources. First, all National Societies of the International Society were requested by the Organizing Committee of this Conference to give each Reporter their assessment of significant contributions by their members since the Mexico City Conference. The Appendix of this Report contains reports from national societies.

The Reporter sought and received suggestions on an early draft of this Report and nominations of significant developments from a group of recognized engineers in our profession -- including Professor Ishihara of Japan; Professor Marsal of Mexico; Professor Morgenstern of Canada; Dr. Horn, Professor Mitchell, Mr. Focht of the U.S. and Professor Moh of Thailand.

Thirdly, the Reporter received considerable assistance from his four Co-reporters.

II PREDICTIONS

The civil engineer is required to predict during all phases of his professional activities -- planning, design and construction. He must predict cost, construction time, effects of a constructed facility on its environment, human acceptance of a constructed facility, and especially the performance of the constructed facility. The soil engineer must predict deformations and stability of a planned constructed facility. In fact, predicting is an integral component -- the very heart -- of the practice of civil engineering. Predicting is not however, engineering. The successful engineer must not only predict, but he must also make decisions and take actions on the basis of his predictions. The engineer's decisions and actions depend on his assessment of the accuracy and reliability of his predictions; in other words, his confidence in his ability to predict.

A prediction is a forecast. Typically a prediction is obtained by manipulating data according to methods, i.e. method + data → prediction. Figure II-1 suggests the key elements of the predictive process. The Reporter devoted his Rankine Lecture (1973) to a consideration of predictions, pointing out the importance of predictions in civil engineering and emphasizing the very intimate relationship between methods and data.

This Report is concerned primarily with one aspect of the overall predictive process, namely: the selection of soil parameters. Complete separation of this component from the other components is not reasonable because of the very close relationship of data and methods. From a pragmatic point of view, independent consideration of soil parameters is artificial and can be misleading. This Report, therefore, considers the selection of soil parameters in relation to methods of predicting being used in soil engineering practice.

PRINCIPLE

METHOD + DATA → PREDICTION

SEQUENCE

Determine Field Situation

Simplify

Determine Mechanism (s)

Select Method & Parameters

Manipulate Method & Parameters to Obtain Prediction

Portray Prediction

PREDICTION PROCESS

Figure II-1 Key Elements of the Predictive Process

Four of the Speciality Sessions at this Conference (Numbers 2, 3, 5 and 6) concentrate on methods of predicting the performance of various types of constructed facilities. Session 2 considers predictive methods employing non-linear stress-strain soil behavior. Session 3 considers predictions of deformation and stability for earth and rockfill dams. Session 5 is concerned with predicting lateral stresses on structures retaining clays and clayey soils. Session 6 considers methods of predicting the stability of deep excavations and of natural slopes. This Report will hopefully provide perspective and guidelines for selecting soil parameters for use in predicting defromation and stability for these situations.

III DETERMINING FIELD SITUATION AND SELECTING SOIL PARAMETERS

A. General

The engineer must obtain data in order to establish the actual field situation and help determine the mechanisms controlling performance. He uses geological inferences and results of field observations and measurements to establish such factors as: general nature and characteristics of soils, boundary conditions, loads and initial pore water pressures, in situ vertical and horizontal soil stresses. He then attempts to define the key elements of his problem and formulate a representative simplification, i.e., an idealized model that retains the basic characteristics and mechanisms controlling the actual situation. As part of the modelling process, the engineer selects for field and/or laboratory testing soil samples whose behavior is thought to be characteristic of the behavior of the larger soil mass. He also selects field and/or laboratory tests which are thought to model the field situation. The engineer then performs tests and selects parameters needed for his predictions.

This Report concentrates on the selection of strength and deformation parameters, although other soil properties are mentioned. Outside the scope of this Report is the use of soil data to "define the problem", i.e., select the appropriate model. However, it should be emphasized that correct modelling of an actual situation can be more important and often more difficult than selecting soil parameters for a given model to obtain a prediction.

We can obtain soil parameters either by an empirical (or semi-empirical) approach or by direct measurements in the laboratory and in the field. In the first approach an engineering property (strength, compressibility, permeability) is obtained from an empirical relationship to some index property. For example, relationships exist between sand compressibility and blows per foot in the standard penetration test; permeability and D_{10} particle size; undrained strength divided by consolidation stress and plasticity index for normally consolidated clays, etc.

In the second approach the parameter desired is directly measured. For example, undrained strength can be measured in a laboratory triaxial test or in a field vane test, etc.

In the semi-emprical approach to selecting a soil parameter the selection technique is often related to the method of making the prediction. A classic example is the Terzaghi-Peck method for determining allowable bearing stress on sands. Even direct measurement of a parameter can in a sense be semi-empirical. For example, corrections for the effects of sample disturbance on the one-dimensional compression characteristics of clays are largely based on experience.

Laboratory testing has inherent advantages and disadvantages relative to in situ testing. Laboratory tests can usually be performed faster and easier, and are thus cheaper. The results of laboratory tests are generally more readily interpreted because of the better understood boundary conditions and control of test conditions. The engineer can also investigate the effects of such variables as stress level, time, etc. to estimate changes in soil properties during and after construction.

On the other hand, laboratory tests possess two serious disadvantages relative to in situ tests. By employing small samples obtained from specific locations, laboratory tests can fail to give an accurate impression of soil conditions, especially where there are important spacial variations or local discontinuities. Further, laboratory tests suffer from the inevitable effects on soil structure -- i.e. "disturbance" -- involved with advancing a bore hole, sampling and transporting the soil, trimming the test specimen, etc.

There are major problems with in situ testing. The first concerns the amount of drainage that occurs during the test and its effect on the results. The degree of consolidation will depend on the soil type, the geometry of the test device, and the test duration. This factor will be most important with "rapid" tests that load the soil. The second problem involves the theoretical model that is used to interpret the test data. Complex boundary conditions and anisotropic soil properties generally require simplified assumptions that have unknown consequences. Finally, most in situ devices cause some disturbance to the surrounding soil. Exeamples of these problems are discussed in this Report.

The profession should see more of the following approach: selection of soil parameters from a program combining both laboratory testing and in situ testing. Further, the principles of probability should prove helpful in selecting soil parameters, especially in those situations where many test results are available and in selecting sampling locations.

B. Recent Work

Recent research on the measurement and interpretation of soil parameters will be divided into the following catagories:

1. In situ testing
2. New laboratory devices
3. Undrained stress-strain-strength behavior
4. Drained stress-strain-strength behavior
5. Dynamic tests and liquefaction.

Item (1) above is considerd in detail in this section, whereas the others are treated more fully in later sections.

There has been considerable work in developing and evaluating field devices and in situ testing techniques, as evidenced by the London Conference on In situ Investigations (1970), Sanglerat's (1972) book, and many papers to this Conference. For determining undrained properties, the field vane is still the most common test; however, there is increasing use and interest in various forms of cone penetrometer and pressuremeter test devices. Papers* to this Conference indicate the interest in these devices. Wiesel and La Rochelle et al illustrate the difficulty in interpreting the results of field vane tests (disturbance due to insertion; effects of delay time prior to running the test and the rate of rotation used, differences in shear resistance measured on the cyclindrical surface and on the ends). Several papers deal with the Menard pressuremeter (e.g Bronstein et al and La Rochelle et al), while Baguelin-Jezequal and Wroth-Hughes describe new or altered pressuremeter devices that minimize the effects of disturbance and are more versatile than the standard apparatus. The Cambridge device is particularly interesting. It consists of a long hollow cylinder which is jacked into the ground. Rotating cutters at the head chop a hole the diameter of the device and water washes out the cuttings. The authors also present new theoretical models with which to interpret the field data. The Reporter is particularly impressed by these advances and feels that the pressuremeter offers considerable promise when used in soils wherein the effects of drainage during the test are minimal and disturbance around the device can be controlled.

Of particular importance is the capability of measuring the in situ horizontal stress, and hence K_o, as an alternate approach to the hydraulic fracturing method (Bjerrum and Anderson, 1972).

La Rochelle et al compare values of s_u computed from field vane, cone penetration and Menard pressuremeter tests for the sensitive brittle Champlain Clay in Canada. The wide variation in results graphically demonstrate some of the

* In this Report, references to papers to the VII Conference will be noted by author's name underscored with a dashed line.

problems associated with in situ testing. The importance of test techniques with the pressuremeter is shown by Baguelin et al (1972). Studies such as these need to be extended.

The strength and compressibility of cohesionless soils are most commonly inferred from the results of the Standard Penetration Test (SPT) and the static cone penetration test. De Mello (1971) presents a detailed state-of-the art study of the SPT. Schmertman (1970) extended the work of de Beer and others in Europe to develop an improved method of estimating the settlement of structures resting on sand based on static cone penetration tests. He also correlates the results of N values from the SPT, the Dutch cone bearing capacity, and compressibility as measured by in situ screw-plate load tests.

Janbu and Senneset use a screw-plate device to get in situ measurements of compression modulus and an idea of the probable rate of settlement of sands and silts. Mitchell and Durgunoglu analyze the bearing capacity of the static cone penetration test and show excellent agreement between values of $\bar{c}$ and $\bar{\phi}$ backcalculated from the cone and strength parameters measured in triaxial compression tests. The Reporter concludes that static cone penetration and in situ screw-plate tests yield more consistent and interpretable data than can commonly be obtained from the SPT.

Unfortunately, this Session has only one paper (Osterberg) reporting any improvements on techniques or equipment for obtaining undisturbed soil samples.

Significant advances in laboratory testing devices enable the engineer to simulate better in situ strain-time conditions. Several Conference papers describe new equipment and improvements on existing devices. Bishop et al describe an automated method for performing drained stress path tests in triaxial compression, a true triaxial device (i.e. the intermediate principal stress and/or strain is controlled), an annular ring shear apparatus for measurement of peak and residual drained strength parameters, and a hydraulically loaded oedometer. An improved device for performing plane strain active and passive tests on undisturbed clay is described by Campanella and Vaid. Yoshimi and Oh-oka developed a ring torsion apparatus for cyclic loading simple shear tests in order to study liquefaction of sands. Woods and Sagesser used lasers and photographic techniques to measure soil deformations in dynamic model footing tests. The simple shear and true triaxial devices developed at Cambridge University should also be mentioned (Roscoe, 1970; Pearce, 1971).

Several Conference papers consider the undrained behavior of soft clays. The fact that homogeneous sensitive clays can exhibit a high degree of undrained strength anisotropy is now well established (e.g. Berre and Bjerrum, Campanella and Vaid, and Kinner and Ladd). Determination of the undrained modulus for use in deformation analyses is still very difficult, although advances are being made (e.g. Berre and Bjerrum, D'Appolonia, Poulos and Ladd, 1971). Berre and Bjerrum, Lacerda and Huston and Vyalov et al study the important topic of creep, relaxation and strain rate effects, as have Mitchell and his colleagues at Berkeley. However, little progress has been made in applying these concepts to actual field situations. There is increasing use of consolidated-undrained laboratory tests to minimize the effects of sample disturbance on measured strength-deformation properties, but disagreement exists regarding the best stress level (relative to in situ stresses) to employ (Berre and Bjerrum versus Kinner and Ladd).

Most of the Conference papers dealing with the drained behavior of soils concentrate on the influence of the intermediate principal strain or stress on "elastic" parameters of sands and on the effects of stress path on the stress-strain characteristics of clays (Berre and Bjerrum, Bishop et al, Campanella and Vaid, Morgan and Gerrard). These papers and work by others show the importance of duplicating the in situ stress conditions as closely as possible if realistic soil parameters are to be obtained.

The use of dynamic field and laboratory tests to obtain soil parameters has been expanded during the last four years. Stokoe and Richart compare the results of in situ and laboratory dynamic measurements of modulus and damping. Hardin and Drnevich (1972) presented detailed equations and graphs for determining dynamic shear modulus and damping. Seed and his Berkeley colleagues and Whitman and him M.I.T. colleagues continue to make significant advances in evaluating soil parameters for dynamic applications. It seems likely that dynamic modulus values obtained from in situ tests might have application in static problems, particularly for sands and silts where soil disturbance greatly affects static determinations of modulus.

Catastrophic failures caused by liquefaction of sandy soils during recent earthquakes have further stimulated the interest of researchers in the evaluation of soil liquefaction potential. Major work on liquefaction has been performed in the last four years by Seed and his associates in California(1969, 1970 and 1971) and Ohsaki (1970). In a paper to this Session Yoshimi and Oh-oka describe a new ring torsion apparatus for cyclic simple shear tests. The strain conditions in the ring shear apparatus simulate better field conditions than do cyclic triaxial tests and promise more reliable quantitative data for the evaluation of liquefaction potential.

IV EMBANKMENTS ON SOFT GROUND

A. Description of Field Situation

Figure IV-1 shows a 35 foot embankment placed at a site where there is a very thick layer of underlying clay. The results of laboratory and field tests on the subsoils are shown in Figure IV-2. A description of the embankment, results of laboratory and in situ tests, and the results of performance measurements are given by D'Appolonia, Lambe and Poulos (1971) and Wolfskill and Soydemir (1971).

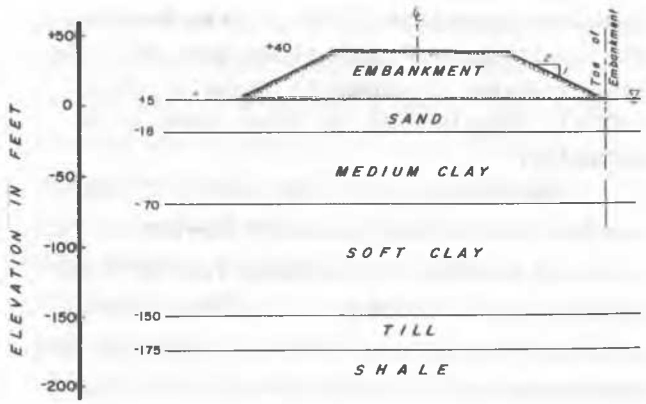


Figure IV-1 Embankment on Soft Clay

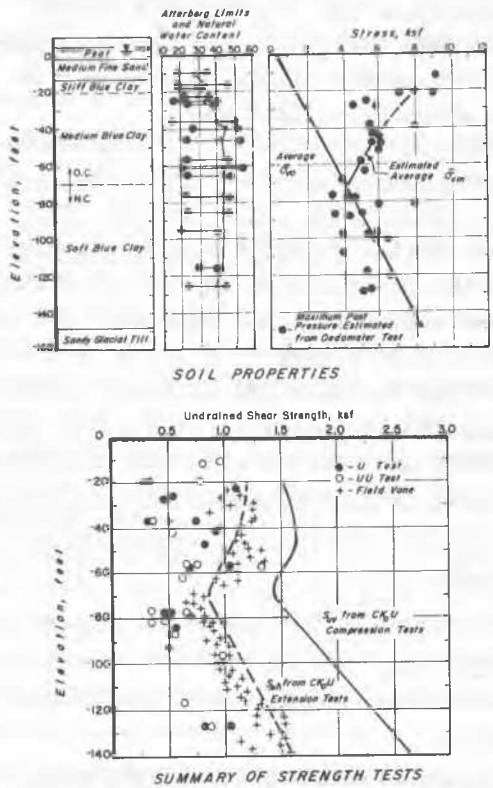


Figure IV-2 Lab and Field Test on Embankment Subsoils (after D'Appolonia et al, 1971)

For the embankment and subsoil profile shown in Figure IV-1, the engineer needs to predict the factor of safety against ultimate failure versus height of the embankment, the settlement of the base of the embankment versus time, and the lateral movement of a vertical line at the toe of the embankment. Table IV-1 indicates the various aspects of performance which are to be predicted along with possible methods of making each prediction.

PREDICTED	METHOD	PARAMETERS	SELECTION OF PARAMETERS
I STABILITY DURING CONSTRUCTION (Undrained)	A TOTAL STRESS METHOD	s_u	FIELD TESTS - field vane, pressuremeter, static cone penetrometer UU LAB TESTS - triaxial compression, incl. unconf. compr. CU LAB TESTS - triaxial compression - tests duplicating other stress systems, e.g. plane strain, simple shear, etc.
	B EFFECTIVE STRESS METHOD	$\bar{c}$, $\bar{\phi}$	$\overline{CU}$ & CD LAB TESTS } e.g. triaxial compression, plane strain, direct shear
		u	Requires field measurements
II INITIAL SETTLEMENT (Undrained)	A ELASTIC	E_u, $\nu = 0.5$	EMPIRICAL CORRELATION - e.g. E_u/S_u = constant UU LAB TESTS - not recommended CU LAB TESTS - triaxial compression
	B FINITE ELEMENT	E_u, $\nu = 0.5$ $S_u(V)$, $S_u(H)$	CU LAB TESTS - requires tests duplicating in situ stress systems
		K_o	FIELD TESTS - pressuremeter, hydraulic fracturing LAB TESTS - K_o test
III FINAL CONSOLIDATION SETTLEMENT	A ONE-DIMENSIONAL	In situ stress history, m_v	LAB OEDOMETER TESTS
	B SKEMPTON-BJERRUM (1957)	In situ stress history, m_v	LAB OEDOMETER TESTS
		A	$\overline{CU}$ LAB TESTS - triaxial compression
	C LAMBE STRESS PATH (1964, 1967)	Measured vert. strain	CD LAB TESTS following typical in situ stress paths
	D FINITE ELEMENT & FINITE DIFFERENCE	$\bar{E}$, $\bar{\nu}$	CD LAB TESTS that should follow typical in situ stress paths
IV RATE OF CONSOLIDATION SETTLEMENT	A TERZAGHI 1-D	C_v	LAB OEDOMETER TESTS
	B FINITE ELEMENT & FINITE DIFFERENCE	C_v, $\bar{\nu}$	LAB OEDOMETER and CD stress path tests
		k_h / k_v	LAB PERMEABILITY TESTS on vertical and horizontal specimens
V LATERAL DEFORMATION (Undrained)	A ELASTIC	E_u, $\nu = 0.5$	SEE II A
	B FINITE ELEMENT	E_u, $\nu \approx 0.5$ K_o $S_u(V)$, $S_u(H)$	SEE II B
VI LATERAL DEFORMATION during CONSOLIDATION	A FINITE ELEMENT	$\bar{E}$, $\bar{\nu}$	SEE III D
		C_v, k_h / k_v	SEE IV B

Table IV-1 Predicting Performance of Embankment on Soft Soil

B. Recent Work

The recent work will be discussed in ligth of the various methods of prediction and selection of soil parameters presented in Table IV-1. Emphasis is placed on those areas where significant advances have been made.

Undrained Stability During Construction

The value of undrained strength, s_u, for a total stress stability analysis is commonly determined from a combination of field and laboratory tests. The data in Figure IV-2 illustrated the wide divergence among the values of s_u that can be obtained by the different techniques. For example, strengths from consolidated-undrained compression (CU) tests were several times larger than those from unconcolidated-undrained (UU) tests and about 50 per cent higher the field vane strengths. As discussed in Section III-B, there is often considerable difference among the three types of field tests noted in Table IV-1.

The principal problems in arriving at the appropriate in situ value of s_u are the ill-defined conditions in most field tests and sample disturbance, anisotropy and strain rate effects in lab tests. Regarding the latter, proper use of CU tests can minimize the effects of disturbance, so that CU tests duplicating the in situ stress system can be used to estimate the degree of anisotropy. Kinner and Ladd show that CU compression tests will greatly overestimate the average in situ strength for lean sensitive clays. Berre and Bjerrum compare the results of compression and extension tests for a number of soft clays. They also show that the strain rate used during triaxial tests has an important effect on s_u, especially for plastic clays.

In light of all these problems, the engineer would obviously like a simplified but reliable approach to the problem. Bjerrum (1972) has proposed such a method. Figure IV-3 shows Bjerrum's method and indicates the fourteen embankment failures on which he based his method.

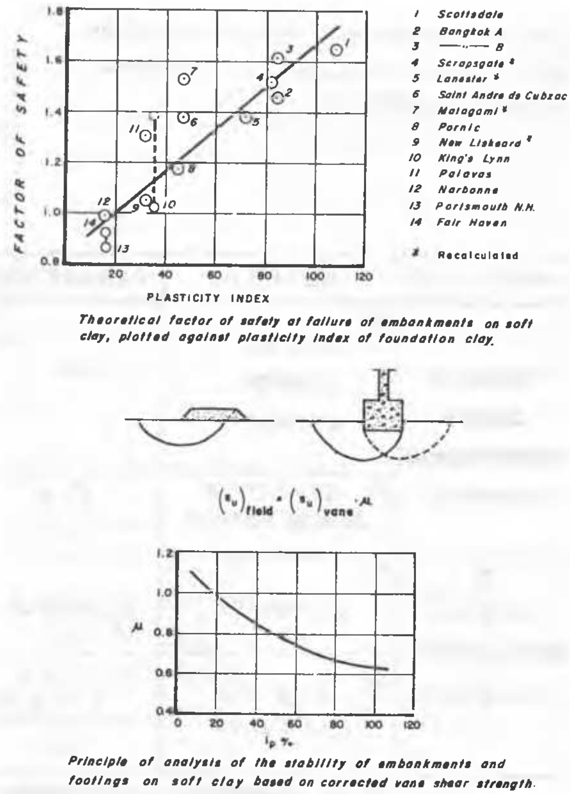


Figure IV-3 Bjerrum's Method for Analyzing Stability (after Bjerrum, 1972)

To use Bjerrum's method, the engineer obtains the field vane strength and the plasticity index of the soft clay. He then corrects his field vane strength using μ obtained from the Bjerrum relationship of μ and PI. The engineer then makes an undrained stability analysis employing the "corrected" field vane strength. Bjerrum's proposed method has several desirable features:

1. It is simple;
2. It is less dependent on soil disturbance than a method involving unconsolidated-undrained laboratory tests;
3. It involves less risk of missing an underlying weak layer than does an approach based solely on laboratory tests.

Bjerrum's method is based on limited field experience and obviously needs further examination. For example, D'Appolonia, Lambe and Poulos (1971) concluded that the field vane gave a measure of field strength for the embankment shown in Figure IV-1 that was too low. Bjerrum's method would "correct" the field vane by reducing it from the measured values -- obviously in the wrong direction. Further, the engineer can have difficulty in selecting the appropriate plasticity index when working with a stratified soil like a varved clay.

Undrained Settlement and Lateral Deformations

The use of elastic theory to predict undrained deformations ignores the effect of local yielding that is likely to occur with embankments on soft ground, even at very high factors of safety. Thus empirical values of E_u/s_u have been proposed to account for the increased deformations caused by yielding. D'Appolonia and Lambe (1970) presented a finite element technique that considers yielding using a bilinear-elastic model with strength anisotropy. D'Appolonia, Poulos and Ladd (1971) developed simplified charts to get initial settlements with yielding and present recommended values of E_u/s_u based on several case studies. Höeg (1972) considers yielding with a strain softening material.

Thus the methods are available, but there is a lack of good case studies correlating field data with predictions based on laboratory and in situ measurements of K_o, s_u and E_u.

Final Consolidation Settlement

While most practicing engineers still rely on one-dimensional analyses, there is increased used of the Skempton-Bjerrum (1957) and stress path (Lambe, 1964, 1967) methods. Bishop et al's automated stress path test apparatus greatly facilitates use of the latter method. But again there is a dearth of good case histories comparing the methods. There are too little data to evaluate the finite element and finite difference techniques which rely on determination of "elastic" constants (see, for example, Christian et al, 1972 and Davis and Poulos, 1972).

A correct evaluation of the stress history, especially the maximum past pressure, is vital to any of the methods. Bjerrum (1972) discusses this point in detail. The use of constant rate of loading consolidation devices (e.g. Wissa et al, 1971 and Bishop et al) and better sampling techniques can greatly improve the determination of maximum past pressure.

Rate of Consolidation Settlement and Lateral Deformation

The finite element and finite difference techniques, such as referenced above, have been used to make parametric studies of the effects of horizontal drainage on the rate of consolidation settlement. These provide very useful guidelines, but the profession has little experience in the best approach to determining the necessary soil parameters for use in practice. The ratio of horizontal to vertical permeability k_h/k_v is particularly important but difficult to measure (Rowe, 1972). Nelson et al discuss this point. Chang, Broms and Peck present an interesting case of two embankments on a highly plastic clay where the degree of consolidation based on settlement observations was three to four time larger than that based on measured excess pore pressures. They attributed the discrepancy to pore pressures generated by secondary compression.

There are very few well documented case studies comparing predicted and measured lateral deformations after construction. This is a particularly difficult problem because consolidation can cause inward movement, whereas undrained and drained creep can produce outward movement.

Our profession can expect advancement to our knowledge of embankment performance from carefully integrated investigations involving laboratory tests, in situ tests, theoretical analyses and reliable measurements of prototype performance. The 1972 ASCE Purdue Conference presented several such cases. The Swedish Geotechnical

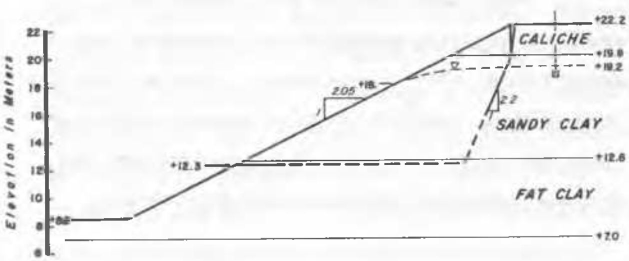
Institute and the Norwegian Geotechnical Institute are presently conducting full scale field load tests. Particularly useful are reports from the Norwegian Geotechnical Institute on its various test fills. We can also expect valuable results from the extensive program of field measurements being conducted by the Mexicans on their various earth dams. References to this work are noted in the Mexican National Society Report in the Appendix of this Report.

The Reporter requests discussion of the best methods for obtaining the necessary parameters to predict undrained stability and lateral deformations and long term settlements due to consolidation (amount and rate) for embankments constructed on soft ground.

V NATURAL SLOPES

A. Description of Field Situation

The stability of natural slopes remains a problem of paramount tance to the geotechnical engineer. Excavations, applied surface loads, and changes in environmental conditions -- especially increases in pore water pressures --can result in slides of natural material.



	γ_t t/m³	w_L %	w_p %	PI %	w_n %	S_u t/m²
CALICHE	1.9	—	—	—	—	—
SANDY CLAY	2.1	28 to 33	14 to 17	14 to 19	15 to 20	20 to 80
FAT CLAY	2.1	60 to 68	23 to 25	40 to 43	28 to 32	70 to 150

	SANDY CLAY C(t/m²)	SANDY CLAY $\bar{\phi}$	FAT CLAY C(t/m²)	FAT CLAY $\bar{\phi}$	FS
PEAK	2.3	37.	1.6	20.	2.02
RESIDUAL	0.	33.	0.	8.	.50
REMOULDED	0.	33.	0.	22	1.03

Figure V-1 Slide in Natural Cliff Side

A slide in a natural cliff side at Amuay, Venezuela is shown in Figure V-1. Observations at the toe and crest indicate a wedge type failure similar to that shown. Figure V-2 presents the results of drained direct shear tests on the two overconsolidated clays involved in the slide. (Triaxial test results confirm the envelope for remolded fat clay.) Table V-1 lists possible techniques for predicting the factor of safety of this natural slope against sliding.

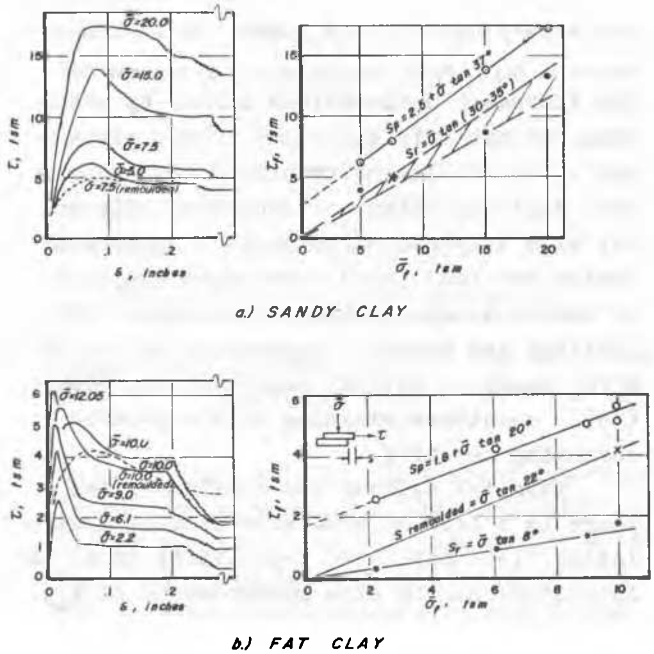


Figure V-2 Shear Tests on Cliff Side Soils

If the engineer uses peak strength parameters to predict the factor of safety for the Amuay slide he gets a factor of safety far in excess of unity (FS=2.0); if he uses residual strength parameters he gets a factor of safety far below unity (FS-0.50). He thus faces the serious and perplexing problem of how to determine strength parameters for predicting the factor of safety of the natural slope.

COMPONENT OF PERFORMANCE	METHOD	PARAMETER	SELECTION OF PARAMETER
FACTOR OF SAFETY After face cut, t_o	Total Stress Stability Analysis Effective Stress Stability Analysis	Su $\bar{C}_p, \bar{\phi}_p, u$	Su from triaxial or field shear tests $\bar{C}_p, \bar{\phi}_p$ from direct-shear, rotating shear or triaxial on undisturbed samples u from measured field pore pressures
Any time, t	Effective Stress Stability Analysis	$\bar{\phi}_r \leq \bar{\phi} \leq \bar{\phi}_p$ $0 \leq \bar{c} \leq \bar{C}_p$ u	$\bar{\phi}_r, \bar{C}_p, \bar{\phi}_p, u$ obtained from above and below or $\bar{\phi}$, $\bar{C}$ from experience with similiar failed slopes or $\bar{c} = 0$ $\bar{\phi} - \bar{\phi}_p$
Long time, t_∞	Effective Stress Stability Analysis	$\bar{\phi}_r$ $\bar{c} - 0$	$\bar{\phi}_r$ from repeated direct shear or rotating shear

Table V-1 Predicting Stability of Natural Slope

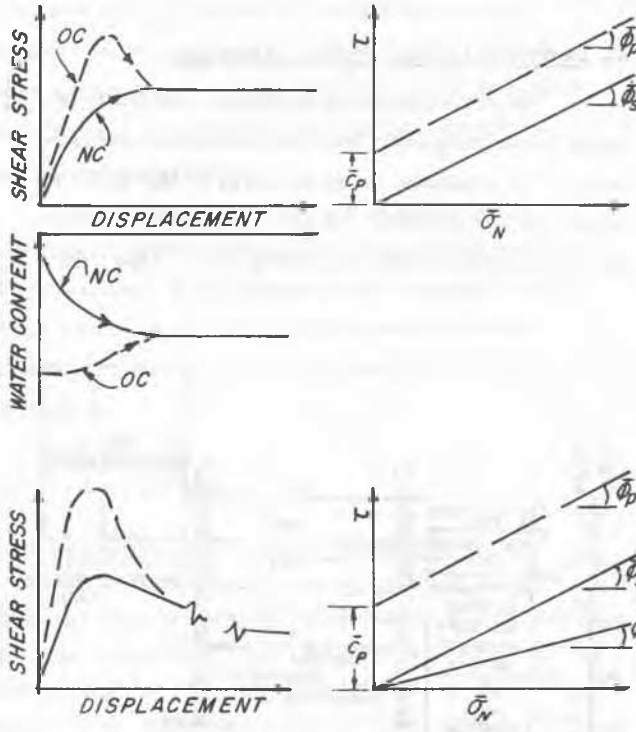


Figure V-3 Strength Behavior of Overconsolidated Clay

B. Recent Work

This Session has very few papers dealing with the stability of natural slopes. Biarez presents field measurements of creep movements of a natural slope. Lo and Lee present an integrated finite element and limiting equilibrium solution to predict the factor of safety with time of a strain softening material. Singh et al consider the effect of low effective stress strength parameters for an overconsolidated clay.

In recent years the major contributor to our knowledge of the stability of natural slopes has been Skempton (especially in his fourth Rankine Lecture, 1964, and his Mexico City Report) and his various associates. In 1970 Skempton updated his earlier work. Figure V-3 and Table V-2 present Skempton's recommendations. If his recommendation of using the remoulded normally consolidated strength is applied to the Amuay slope, one obtains a factor of safety of about one. The Reporter requests discussion on Skempton's recommendations presented in Table V-2.

Additional work on the methods of analysis such as that by Bishop (1971), Duncan and Dunlap (1969) and Lo and Lee which consider the influence of the stress distribution within the slope on the mechanism of failure plus laboratory and field work which indicate how to incorporate field strains or displacements and strength changes into our analyses are expected to advance our understanding of the behavior of natural slopes.

SOIL	FIELD STRAIN HISTORY	STRENGTH (cohesion)	PARAMETERS (friction angle)
Intact Clay	Little or no strain	$\bar{C}_p$ (or slightly less)	$\bar{\phi}_p$
Overconsolidated Clay fissured	Little or no strain	0	$\bar{\phi}_s$
Overconsolidated Clay, fissured or non-fissured	Large strains from geological processes or previous sliding	0	$\bar{\phi}_r$

Table V-2 Skempton's Recommendations for Predicting Stability of Natural Slope (after Skempton, 1971)

VI Excavations

A. Description of Field Situation

The construction of facilities especially in urban areas frequently involves supported excavations. For example, in many parts of the world major subway systems require deep, open excavations of the type shown in Figure VI-1. This figure shows a braced excavation which existed during the construction of the South Cove station of the Massachusetts Bay Transportation Authority subway in Boston, Massachusetts. Figure VI-2 presents data on the subsoils at the South Cove excavation. The soil engineer needs tools to predict the vertical and lateral deformations both within and adjacent to the supported excavation. He must also be able to predict the factor of safety against a shear failure of the excavation. Table VI-1 notes aspects of performance for which the engineer must make predictions along with techniques for making the predictions.

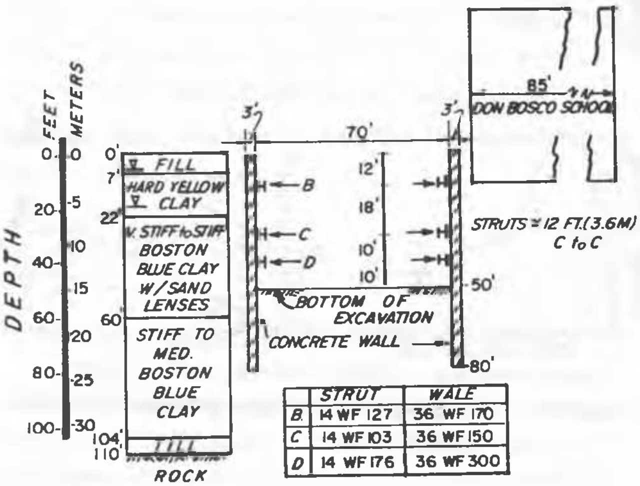


Figure VI-1 Braced Excavation for Boston Subway

COMPONENT OF PERFORMANCE	METHOD	PARAMETER	SELECTION OF PARAMETER
Load on Support System	Terzoghi-Peck	S_u	Unconfined Compression Tests
	Finite Element	S_u, E_u	Undrained Triaxial Tests on consolidated samples
Deformations	Peck	S_u	Unconfined Compression Tests
	Finite Element	S_u, E_u	Undrained Triaxial Tests on consolidated samples
Stability of Excavation Bottom	Bearing Capacity formula	S_u	Field Vane, Unconfined, Triaxial
	Finite Element	S_u, E_u	Undrained Triaxial Tests on Consolidated samples

Table VI-1 Predicting Performance of Subway Excavation

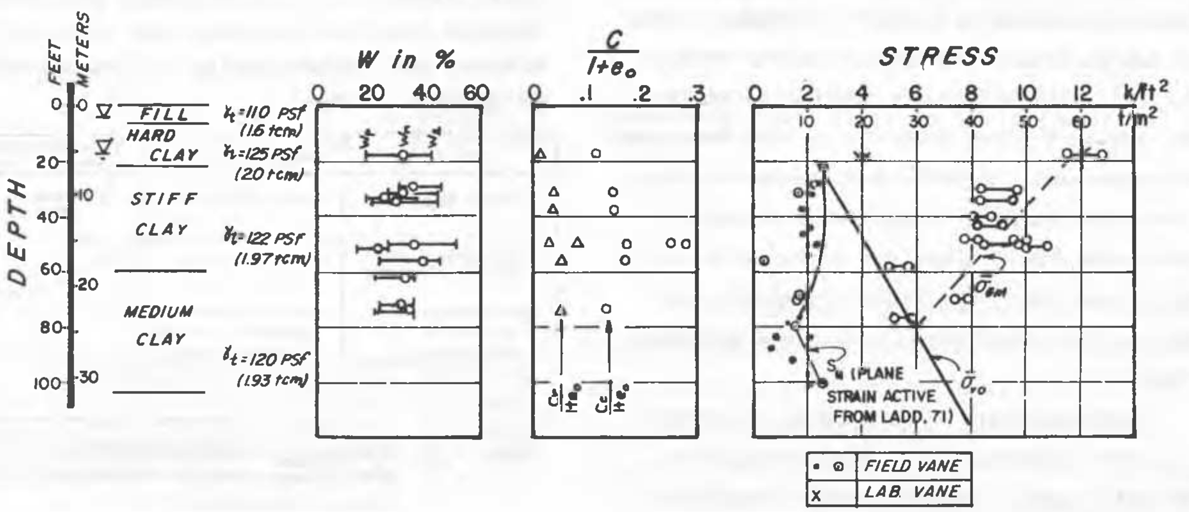


Figure VI-2 Lab and Field Tests on Subway Soils

B. Recent Work

At Mexico City Peck presented an outstanding State of the Art Report on excavations and tunnels. Proceedings of the 1970 ASCE Specialty Conference contain several useful contributions especially ones in which predicted and measured performances were compared.

The Reporter recommends Bjerrum's Report at the 1972 European Conference held in Madrid. Bjerrum gives attention to the important question of selection of parameters to predict stability and deformation. In a technique similar to that employed for the stability of loads placed on soft soil, Bjerrum proposes a correction factor for field vane undrained strength. The correction factory considers both rate of strain and anisotropy.

Predictive techniques employing finite elements are being increasingly used to predict vertical and lateral deformations within and adjacent to

California colleagues and this Reporter and his M.I.T. colleagues suggest that reasonable predictions can be made using finite element techniques and stress-strain parameters obtained from consolidated-undrained triaxial tests for clays.

"Reasonable" means predicted deformations within $\pm$100% of measured performance. Chang and Duncan (1970) describe the procedures they followed in selecting soil parameters for use in the finite element method to predict the performance of the Buena Vista pumping station.

This Reporter is uncomfortable about the widespread use of undrained shear strengths in predicting the stability of excavations. Rowe's work as described in his 1972 Rankine Lecture supports this Reporter's concerns. As discussed by Rowe a clay may have a fabric which results in a relatively high lateral permeability. Rowe notes cases where high permeability permitted rapid softening of plastic soils in a matter of hours. The same problem can occur in fissured clays.

Although predicting the performance of supported and unsupported excavations is one of the most challenging problems confronting the soil engineer today, especially in major urban areas, there are no papers in this Session which describe specific cases of obtaining soil parameters for making such predictions.

The Reporter requests discussion on the selection of strength to be used in stability analyses of excavations, both supported and unsupported and of the selection of stress-strain parameters for predicting deformations within and outside an excavation.

VII FOUNDATIONS

A. Description of Field Situation

The foundation engineer must predict the settlement which will occur subsequent to the placement of foundation loads. He is intersted in the settlement as it varies with time and particularly concerned about differential settlements. If excavations in soils with heave potential are to be made, the foundation engineer must also predict the heave caused by the unloading of the soil during excavation. In addition, lateral movements of the foundation may be of concern. There is evidence that lateral movements can cause serious damage to the supported structure.

Figure VII-1 shows the foundation situation for a high rise building in Caracas, Venezuela. Because of economic and scheduling considerations, a shallow direct foundation is highly desireable. The subsurface profile and some of the soil properties are shown in Figure VII-2. The soils are primarily dense alluvium extending to great depth. They are competent foundation materials. However, the structural loads are very large and the structure itself imposes strict tolerances on the allowable differential settlement. This type of situation is becoming increasingly important, especially with foundations for nuclear power plants. Accurate predictions of movement are needed, but prediction

methods and experience in selecting soil parameters are poorly developed.

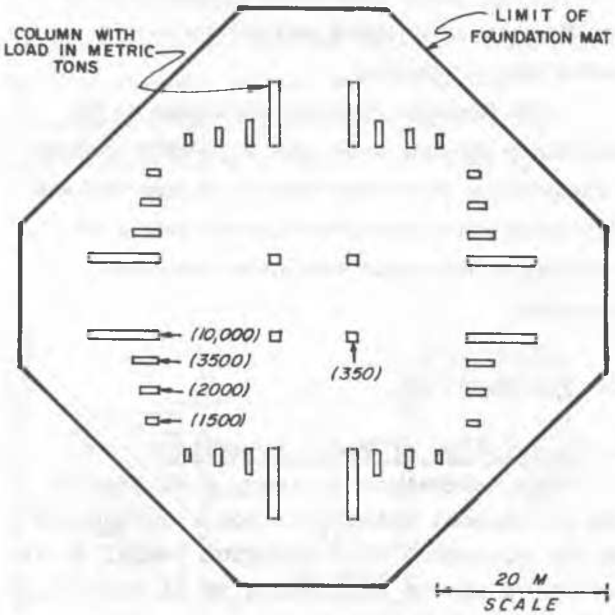


Figure VII-1 Foundation for High Rise Office Building

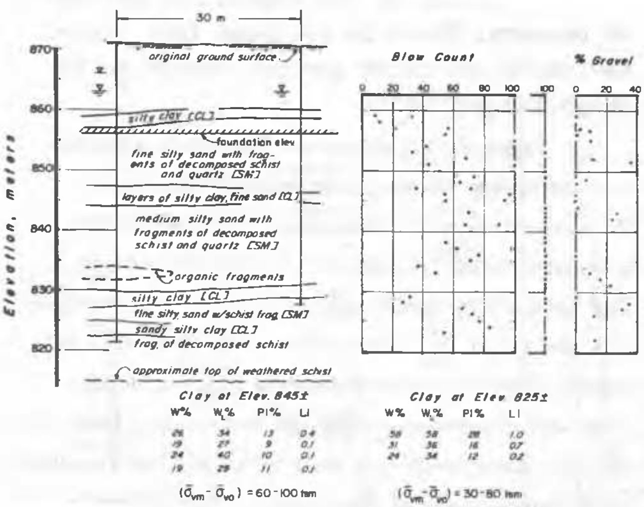


Figure VII-2 Lab and Field Tests on Office Building Subsoils

For the conditions shown in Figs. VII-1 and 2, the foundation engineer must predict the total settlement and the differential settlement. Further he must predict the relation between differential settlement and the stiffness of the foundation mat and the structural framing of the basement portion of the building. The problem of the foundation engineer is complicated by the fact that the subsurface profile consists of both granular and cohesive soils having varying compressibility.

Table VII-1 suggests several methods available to the foundation engineer for predicting settlements. The cohesive layers are thin compared to **the size of the loaded area, so that one-dimensional compression is probably an accurate idealization. Use of the methods based on static cone penetration for estimating settlement of the granular soils is not possible because the soil is too dense to force the penetrometer into the ground. Methods based on the Standard Penetration Test are difficult to apply because the blowcounts are influenced to a large extent by gravel size particles.**

Experience with similar, heavily loaded foundations in the same area indicates that total settlements in the range of 5 to 8 cm. can be expected and that most of the settlement is associated with compression of the granular soils. Because the maximum allowable differential settlement be-tween adjacent columns, as computed by the structural engineers, is 2 cm., it is very important to predict accurately the relation between differential settlement and foundation stiffness. For a flexible foundation, large differential settlement can be expected because of the wide variation in column loads and the unfavorable distribution of columns over the foundation area. Rational analysis of differential settlement in this case requires predictions of the average stress-strain behavior of the soil under the imposed stress conditions and also predictions of the variation in soil properties over small lateral distances.

PREDICTED	METHOD	PARAMETER	SELECTION OF PARAMETER
Total Settlement	Based on SPT *-Terzaghi & Peck* *-Peck & Bazaraa* *-Meyerhof* *-D'Appolonia*	*Blowcount N from SPT*	*Must use judgement because gravel affects N values*
	Based on CPT *-Schmertmann* *-Others*	*Static cone penetration resistance*	*Difficult or impossible to apply in dense soil because exceed capacity of penetrometer*
	Plate load test	*Settlement of standard plate*	*Plate loading test is not representative for large mat because only the surface soil properties are measured*
	Wave velocity measurements or other dynamic tests	*Shear modulus & Young's modulus*	*Requires correlation to adjust for strain level*
Differential Settlement	*Empirical rule*	*Type of soil and building*	*Difficult to apply experience in judging relationship between differential settlement and foundation stiffness*
	Subgrade reaction *Elastic theory*	*Modulus of subgrade reaction* *Elastic moduli*	*Many assumptions & judgements must be made because total settlement cannot even be predicted well*

Table VII-1 Predicting Settlement of Office Building

B. Recent Work

At the 1972 ASCE Specialty Conference on Performance of Earth and Earth-Supported Structures, D.C. Moorehouse presented a valuable report on shallow foundations This report and other papers on settlements of foundations submitted to the same conference show that our methods for predicting settlements in cohesionless soils need 2485 improvement. Most methods in use are purely empirical or semi-empirical such as those based on the Standard Penetration Test or on the static cone penetration. Among the latter methods, Schmertmann's promises are improvement in the state of the art. Analytical methods involving elastic theory have found only limited application because of the difficulty of evaluating the in situ stress-strain properties for settlement analysis. In situ penetration tests and dynamic tests appear to have more promise for determining stress-strain parameters on stiff soils than do laboratory tests.

Few papers accepted for this Session relate directly to foundations. Meigh, Skipp and Hobbs report on field and laboratory creep tests on weak rock as foundation material for nuclear power plants. They found that the values of the short term modulus obtained from plate tests in the field tended to be lower than the values obtained from drained laboratory tests. Bauer et al describe the determination of the undrained Young's modulus for desiccated crusts of clay deposits. Plate bearing tests gave better indications of the behavior ot a full scale footing loading test than did laboratory tests.

Dies et al describe the determination of values of the Young s modulus and Poisson's ratio for silty sand from triaxial tests. The values are used in a finite element analysis of settlements under a stockpile of ore. Sovinc and Vidmar present data on settlements caused mainly by deviatoric stresses from preloading and reloading of two tanks on a thick clay deposit. They compare these data with results from laboratory tests.

VIII OTHER SITUATIONS

Obviously the practicing soil engineer faces situations other than the four described in the preceding chapters. In Recent years there has been considerable activity in Japan and the U.S. on predicting the nature of earthquakes and their effects on constructed facilities. The works of Seed and his California associates and Whitman and his M.I.T. associates are noteworthy.

The engineer concerned with earth dams needs to predict deformation and stability. The finite element method is receiving increasing use in these predictions. Kulhawy and Duncan (1973) compare predicted and measured deformations for the Oroville dam in California. Marsal has prepared for the Casagrande Memorial Volume a useful feature on the properties of rockfill for dams.

Hakimi et al present predicted and measured pore water pressures in partly saturated soils. Pells presents construction pore pressure data from three earth dams. The measured pore pressures showed trends that do not agree with predicted values. Pells attributed the disagreement to the high initial horizontal stress generated by heavy compaction.

Construction in cold climates has forced engineers, especially in the U.S., Canada, and U.S.S.R., to deal with frost and permafrost problems. The profession can expect during the next few years considerable activity in the area of stability and deformation of pipelines, roads and structures founded in cold climates.

IX FUNDAMENTAL AND LABORATORY INVESTIGATIONS

This chapter considers fundamental and laboratory investigations, especially those reported to this Conference. The investigations range from basic studies on the forces between individual soil particles to the behavior of soils during laboratory tests involving various stress systems.

Even though geotechnical engineering has greatly matured in the last two decades, fundamental and laboratory investigations continue to be of considerable importance. The practicing engineer needs the results of such investigations in order to identify mechanisms involved with his practical problems and thus be able to select appropriate techniques predict the performance of a constructed facility.

A. Soil Structure

Soil Structure refers to the forces between adjacent soil particles and the relative arrangements of soil particles. Research on soil structure has helped considerably in delineating soil behavior. For example, we now know that shear strains tend to align clay particles into parallel arrangements. Improvements in X-ray and microscopic techniques have permitted the fundamental researcher to further our knowledge of soil structure. Even so, soil structure investigations will be most helpful in improving our understanding of behavior rather than giving us parameters which can be substituted directly into expressions for predicting the performance of constructed facilities. Characterizing structure numerically has not been satisfactorily done.

There are four papers to this Conference (Borowicka, Nasimento, Murayama and Matsuoka, and El-Sohby and Andrawes) which consider the structure of granular soil. Four papers (Vyalov et al, Ter-Stepanian et al, Kulkanri and Feda et al) consider the structure of fine grain soils. These papers on structure of fine grain soils consider creep an important problem.

B. Models

Four papers to this Conference consider theoretical models for consolidation of soil.

Keinonen proposes a model for consolidation of cohesive soils based on the transfer of effective stress through water films surrounding clay particles. Nuyens and Huergo and Sonpal and Katti develop rheological models to describe the consolidation of soils that do not follow Terzaghi's one-dimensional theory. Battelino describes a method of obtaining the coefficient of consolidation from oedometer tests. A fifth paper by Habibagahi reports the effects of temperature on consolidation test results.

Several papers propose constutive relations to describe the stress-strain or stress-strain-time behavior of soils. Hanrahan and Shahrour obtain a relationship among stress, strain and time for a remolded silt by separating the volumetric and shear components of strain. Fedder and Breth use a similar approach to characterize simple shear behavior. Goldscheider and Gudehus employed a true triaxial device to assist them in developing an elastic-plastic constitutive relation for sands Arnold and Mitchell applied hollow cylinder triaxial tests on a uniform sand to confirm some of Roscoe's concepts about the theory of plastic potential, work hardening and the shape of the yield surface for soil. Lacerda and Houston invert the Singh-Mitchell creep equations to obtain strain-time relations to describe stress relaxation. Marsal develops a stress-strain equation for granular material from a statistical approach. The effects of cyclic loads and stress history are included in Shackel's method of determining an empirical constitutive relationship. Finally Morgan and Gerrard and Silveira and Silveira use cross-anisotropic elastic equations and demonstrate how to obtain the necessary parameters from laboratory tests. Morgan and Gerrard account for non-linearity by a series of linear increments.

C. Apparatus

This Session has nine papers concerned with laboratory test apparatus and testing techniques. Goldstein and Lomize propose compression increments as short as three hours and compare the results of tests from the rapid rate of loading with those from tests using more conventional loading rates. Various types of triaxial loadings were employed. The authors also report the results of pure shear tests on sands.

Two papers (Verstraeten et al and Wahls) report the results of laboratory tests on soils to be used as subgrade materials. Thurner describes a device similar to the Norwegian simple shear device to investigate the deformation properties and shear strength of compacted soil.

Yoshimi and Oh-oka describe a new ring torsion device which can conduct simple shear tests under nearly plane strain conditions. They present typical results of drained and undrained tests on sand.

Three papers (Goldscheider and Gudehus, Ramamurthy and Rawat and Marsal) describe true triaxial devices. The Coldscheider and Gudehus device employs six interconnected stiff plates which can be moved in the three principal directions by pairs of rams. Ramamurthy and Rawat describe their modified Universal Triaxial Apparatus and present results of drained tests on Ottawa sand. They compare the strength of sand under different stress states.

Marsal first p esents a statistical theory assessing the frictional resistance generated within granular soil. He then describes an apparatus in which the ratio of the principal stresses can be controlled. The apparatus can take very large samples one cubic meter in volume and containing particles up to 10 centimeters in diameter.

Goldstein and Lomize and Morgan and Gerrard also employ true triaxial devices.

Several laboratories have installed and are using automatic recording devices many of which are described in papers to this Session. Certainly the use of automatic systems to record laboratory and field data coupled with computers to reduce the data to a manageable form has allowed the engineer to devote more effort to actual research and engineering.

D. Centrifugal Model Test

The centrifuge model test is receiving increasing interest. Bolton et al describe to the Conference the development of the centrifuge test and consider the applicability of the test to soil engineering problems. Mikasa and Takada discuss the significance of the test.

Bolton et al describe the use of the centrifuge to study cuts, foundations and slopes. They conclude that at the present state of development the centrifuge can produce three-dimensional failures at a fraction of the cost involved with field tests. They feel that the centrifuge test permits the comparison of alternate schemes and indicates the type of failure to be expected.

Mikasa and Takada present some results of centrifuge tests including failures of slopes and sheet piling in cohesive materials.

The centrifuge tests appear to have considerable potential in indicating the types of deformations and failures which might be expected in field problems. The Reporter would like discussion on the applicability of the centrifuge test to obtain soil parameters to be used in the prediction of prototype performance.

E. Soil Behavior

A large number of papers to this Conference report stress-strain-time behavior of soils under various stress systems. Bishop, Green and Skinner review recent developments in testing procedures for studying the stress-strain-time relationships of strain-softening soils. This paper is particularly welcomed by the Reporter since it deals with the theme of this Report -- soil parameters for predicting performance. The authors give guidance and perspective on the difficulties of using laboratory tests to obtain soil parameters. The authors emphasize the importance of correlating field performance with laboratory studies of the strength and deformation characteristics of the relevant soils.

Campanella and Vaid present the results of plane strain tests on a normally-consolidated, undisturbed, sensitive marine clay. Their results suggest that the undrained behavior is independent of the total stress paths as long as there is not a reversal in the direction of the principal stresses during shear. Pells et al present a comparison of triaxial and direct shear tests on typical cohesive fill materials, and Sketchley and Bransby compare extension and compression plane strain tests on slightly over-consolidated Kaolin.

Stamatopoulos and Kotzias showed the variation of constrained modulus with vertical consolidation pressure. They also examined the reliability of estimating the constrained modulus from dry density and other characteristic soil properties.

Several papers to this Conference report on stress-strain tests on sand. Tassios and Sotiropoulos present results of triaxial tests. Esta and Hajal report the influence of dilatancy on the behavior of dense sands. Thurairajah reports the results of drained and undrained, compression and extension triaxial tests on a fine sand subjected to stress reversal. Tatsuoka and Ishihara investigated deformation characteristics of sands at small strains with triaxial compression and extension tests. Ishihara in a separate paper compares plane strain and triaxial strength tests and compares the stress-strain behavior in the plane strain test with that of a model wall. Finn and Snead report on creep and creep rupture characteristics of a natural undisturbed clay as determined from triaxial tests. Lashine compares repeated loading of silty clay to transient creep. Alberro and Santoyo present the results of long term tests on Mexico City clays and discuss time effects on the effective stress strength parameters.

Taylor and Tarton describe a free vibration torsion test to obtain dynamic soil properties.

Lee, Ingles and Neil present the results of compression tests on cement-stabilized soil and sandstone. Yamanouchi and Murata present compression and strength test results on a structurally unstable soil of volcanic origin. Webb presents the results of laboratory tests on pulverized fuel ash, dredged fine sand and mixtures of the two materials

F. Remarks

Over half of the papers accepted for Session I fall into this section on fundamental and laboratory investigations. A number of these papers give the engineer background information, if not direct help in selecting parameters to solve the four situations highlighted by this Report. The severe, and probably necessary, restrictions on the length of papers for our International Conferences encourage papers of the type noted in this section. Further, this Reporter concludes that much of the research and publication in the geotechnical field is being done by those with little or no intimate contact with real engineering problems. The Reporter cannot help lamenting that more of the research effort was not devoted to investigations involving field performance data as well as laboratory test data.

X TOPICS FOR DISCUSSION

The Reporter requests that discussors present only material of immediate or near-term value to the practicing engineer. Following are questions and topics on which discussion is requested.

1. Which in situ test devices offer the most promise for yielding reliable soil parameters for predicting stability and deformation?
2. Present and evaluate predictive techniques based on in situ measurements of soil parameters. Of particular interest are techniques like Bjerrum's stability method for an embankment on soft soil and for a supported excavation.
3. Do laboratory model tests, especially the centrifuge test, have utility for determining parameters for predicting prototype performance?
4. Describe situations wherein the principles of probability and decision theory have been effectively used or have promise of use in practical soil engineering problems.
5. How should an engineer determine the strength for predicting the stability of a supported excavation in clay and for predicting the lateral movement of the supporting walls?
6. How should the soil engineer determine the strength parameters for perdicting the factor of safety as a function of time for a natural slope in an overconsolidated clay'-- a situation similar that shown in Figure V-1?

XI SUMMARY AND CONCLUSIONS

Since the Seventh International Conference held in Mexico City in 1969, the geotechnical field has grown and matured. Both researchers and practitioners have been exceedingly active. The seventy-six papers in this Session reflect only a small part of the activity.

Useful regional conferences (European, Asian, Australia-New Zealand, Pan American, etc and ASCE Specialty Conferences (the Cornell Conference on Lateral Stresses and the Purdue Conference on Performance) have been held since the Mexico City Conference. Excellent papers have appeared in the Proceedings of these conferences and in important journals like the Journal of Soil Mechanics and Foundation Division, ASCE, Geotechnique published by the British Institution of Civil Engineers and the Canadian Geotechnical Journal.

Our profession certainly does not suffer from a scarcity of conferences and publications.

The geotechnical practitioner needs tools to predict the performance of constructed facilities. A prediction is a forecast obtained by manipulating data according to some method. In addition, he needs to know the reliability of each of his predictive tools. It is illusory to hope for scientifically derived methods employing unique soil parameters to yield exact predictions. This Reporter hopes for:

1. Prediction techniques, each consisting of a combination of certain methods and certain data to give a reliable prediction of a certain aspect of performance;

Since the Mexico City Conference there have been no breakthroughs on "the strength and deforma bility of soils". There have been many contributions to our knowledge of this topic and to the application of this knowledge to engineering practice. Some of these significant contributions and trends are noted in the following paragraphs.

Further development of the finite element method of analysis has had considerable impact on the testing of soils because of the need for new and more reliable soil parameters. Major work at the University of California at Berkeley, Imperial College, the Norwegian Geotechnical Institute and M. I. T. has contributed to the selection of such parameters for finite element analysis.

Papers to this Conference and elsewhere add to the overwhelming evidence that the stress-strain behavior of a soil can depend very significantly on the stress system, stress path, and rate of strain. Whereas standard test procedures are appropriate for identifying and comparing soils, they are usually inappropriate for determining stress-strain-time characteristics for use in predictive techniques.

This Report employed four important and common field situations as a framework for discussing the selection of parameters for predictions of stability and deformation. Appealing is Bjerrum's (1972) method of predicting the stability of a load on a soft soil employing a correction factor to undrained shear strengths obtained by the field vane. We can hope for more proposals of this type along with evaluated field cases and fundamental research which will help establish the limitations and reliabilities of these tools.

Laboratory tests continue to be an important means of developing fundamental information on the behavior of soils and assisting in the solution of engineering problems. There is, however, a growing disenchantment with the use of laboratory tests alone to obtain soil parameters. Rowe in his Rankine Lecture (1972) emphasizes how important soil fabric can be on soil behavior especially permeability. Rowe shows that the engineer must carefully consider fabric if he is to obtain appropriate data on rate of compression and undrained strength from laboratory tests.

Some in our profession feel that research based primarily on laboratory tests has reached the point of diminishing returns. For example, Lumb (1972) in his General Report to the Fourth Asian Regional Conference suggests that further refinement of test apparatus will yield no significant gain in information. He feels that scatter in test results should be handled according to the principles of probability. Others feel that some benefit can still be derived from further laboratory research, especially from investigations on the influence of stress system, stress path, and creep-strain rate on soil behavior.

In situ testing offers considerable promise, not only for defining an actual problem, but also for selecting soil parameters to be used in predictive techniques.

Many papers to this Conference consider in situ testing. In spite of the considerable advances which have been made, these papers indicate that much remains to be done. For example, different in situ tests often yield widely divergent values of the same parameter. Further, there is a dearth of good case histories comparing measured performance with that predicted by in situ tests.

This Reporter recognizes the importance and promise of continued fundamental research on the behavior of soil. He expects, however, that our profession will advance steadily in the area of strength and deformability of soils along the following lines:

1. The application of present technology to practice;
2. Improvement of in situ measuring devices and techniques;
3. The development and evaluation of semiemprical techniques for predicting stability and deformation;
4. Research to delineate mechanisms of soil behavior and to improve our understanding of the predictive techniques.

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Specialty Conference, American Society of Civil Engineerins, Lateral Stresses and Earth-Retaining Structures", Cornell University, Ithaca, New York, June, 1970.

Specialty Conference, American Society of Civil Engineers, "Performance of Earth and Earth-Supported Structures", Purdue University, Lafayette, Indiana, June, 1972.

PAPERS ACCEPTED FOR SESSION I

Alberro, J. A., E. V. Santoyo, "Long-Term Behavior of Mexico City Clay".

Arnold, M., P. W. Mitchell, "Sand Deformation in Three-Dimensional Stress State".

Battelino, D., "Oedometer Testing of Viscous Soils".

Baguelin, F., J. F. Jezequal, A. Le Mehaute, "Study of Pore Pressure Occurring During Pressuremeter-Test".

Bauer, G.E.A., J. D. Scott, D.H. Shields, "The Deformation Properties of a Clay Crust".

Berre, T., L. Bjerrum, "Shear Strength of Normally Consolidated Clays".

Biarez, J., B. Boucek. "Viscoplasticity of Clay In Situ and in Laboratory".

Bishop, A.W., G.E. Green, A.E. Skinner, "Strength and Deformation Measurements on Soils".

Bolton, M.D., R. English, C. C. Hird, A. N. Schofield, "Ground Displacements in Centrifugal Models".

Borowicka, H., "Rearrangement of Grains by Shear Tests with Sand".

Bronstein, M.I., V.V. Mikheev, K. V. Ruppenait, V. V. Lushnikov, V. B. Shvets, "The Pressuremeter Method of Investigating Soil Properties and its Theoretical Basis".

Campanella, R.G., Y. P. Vaid, "Influence of Stress Path on the Plane Strain Behavior of a Sensitive Clay".

Chang, Y.C.E., B. Broms, R. B. Peck, "Relationship Between the Settlement of Soft Clays and Excess Pore Pressure Due to Imposed Loads".

Dies, J. F., J. M. Dupas, M. Londez, "A Soil Strain Problem-Analysis and Results".

El-Sohby, M. A., K. Z. Andrawes, "Experimental Examination of Sand Anisotropy".

Esta, J. B., M. Hajal, "Behavior of Dense Sands before Failure".

Evdokimov, P. D., L. D. Aptekar, S. S. Bushkanets, T. F. Lipovetskaya, "Shear Resistance of Soil Foundation of Structures".

Feda, J., B. Kamenov, P. Klablena, "Investigations of Creep and Structure of Clayey Materials".

Fedder, D., H. Breth, "Rheological Investigations by a New Apparatus".

Finn, W.D.L., D. Snead, "Creep and Creep Rupture of an Undisturbed Sensitive Clay".

Goldscheider, M., G. Gudehus, "Rectilinear Extension of Dry Sand: Testing Apparatus and Experimental Results".

Goldstein, M., G. Lomize, "Deformation and Strength of Soils".

Habibagahi, K., "Temperature Effect on Consolidation Behavior of Overconsolidated Soils".

Hakimi, Marchand, Orliac, "Pore Pressure in Partly Saturated Soils: Prediction, Laboratory and in Situ Measurements".

Hanrahan, E.T., M. Shahrour, "Prediction of Strain Rates using e_g, e_k Parameters".

Hartlen, J., R. Pusch, "Interpretation of Creep Measurements of Stiff Clay".

Heijnen, W.J., "The Dutch Cone Test: Study of the Shape of the Electrical Cone".

Ishihara, M., "Application of Plane Strain Test to Earth Pressure".

Janbu, N., K. Senneset, "Field Compressometer-Principles and Applications".

Joustra, Ir. K., "New Developments of the Dutch Cone Penetration Test".

Keinonen, L. S., "An Energetic Model of Consolidation in Cohesive Soils". 2485

Kinner, E. B., C. C. Ladd, "Undrained Bearing Capacity of Footing on Clay".

Kulkarni, R. P., "Effect of Structure on Properties of Marine Clay".

Lacerda, W. A., W. N. Houston, "Stress Relaxation in Soils".

La Rochelle, P., M. Roy, F. Tavenas, "Field Measurements of Cohesion in Champlain Clays".

Lashine, A.K.F., "Deformation Characteristics of a Silty Clay under Repeated Loading".

Lee, I. K., O. G. Ingles, R. C. Neil, "Controlled Deformation of a Cemented Soil and Sand".

Lo, K. Y., C. F. Lee, "Analysis of Progressive Failure in Clay Slopes".

Marsal, R. J., "A True Triaxial Apparatus to Test Rockfills".

Meigh, A.C., B.O. Skipp, N. B. Hobbs, "Field and Laboratory Creep Tests on Weak Rocks".

Mikasa, M., N. Takada, "Significance of Centrifugal Model Test in Soil Mechanics".

Mitchell, J.K., H. T. Durgunoglu, "In-Situ Strength by Static Cone Penetration Test".

Morgan, J. R., C. M. Gerrard, "Anisotropy and Non-Linearity in Sand Properties".

Murayama, S., H. Matsuoka, "A Microscopic Study on Shearing Mechanism of Soils".

Nascimento, U., "Contribution to a Theory of Internal Friction".

Nelson, J.D., Z.C. Moh, E.W. Brand, "Laboratory and Field Consolidation of Soft Clay".

Nuyens, J., P. J. Heergo, "Consolidation of a Loess and a Loessial Silt".

Osterberg, J.O., "An Improved Hydraulic Piston Sampler".

Pells, P. J.N., "Stress Ratio Effects on Construction Pore Pressures".

Pells, P. J. N., P. M. Maurenbrecher, H. F. W. K. Elges, "Validity of Results from the Direct Shear Test".

Ramamurthy, T., P. C. Rawat, "Shear Strength o Sand Under General Stress System".

Shackel, B., "The Derivation of Complex Stress-Strain Relations".

Silveira, A., E. B. S. Silveira, "Elastic Parameters for Soils with Cross-Anisotropy".

Singh, H., D. J. Henkel, D. A. Sangrey, "Shear and K_o Swelling of Overconsolidated Clay".

Sketchley, C.J., P. L. Bransby, "The Behavior of an Overconsolidated Clay in Plane Strain".

Sonpal, R.C., R.K. Katti, "Consolidation - An Analysis with Pore Pressure Measurements".

Sovinc, I., S. Vidmar, "Preloading Effects on Deviatoric Soil Displacements".

Stamatopoulos, A.C., P. C. Kotzias, "The Specific Constrained Modulus".

Stokoe, K. H. II, F. E. Richart, Jr., "In-Situ and Laboratory Shear Wave Velocities".

Tassios, T. P., B. P. Sotiropoulos, "Strength and Deformability of Sands under Various Conditions".

Tatsuoka, F., K. Ishihara, "Stress Path and Dilatancy Performance of a Sand".

Taylor, P.W., I. L. M. Parton, "Dynamic Torsion Testing of Soils".

Ter-Stepanian, G., S. R. Meschian, R. R. Galstain "Investigation of Creep of Clay Soils at Shear".

Thurairajah, A., "Shear Behavior of Sand Under Stress Reversal".

Thurner, H. F., "Testing Machine for Investigation of Compacted Soil."

Verstraeten, J., V. Veverka, A. Fagnoul, A. Bolle, "Apparatus for Dynamic Study of Fine Grained Road Soils".

Vyalov, S.S., Yu. K. Zaretsky, R. V. Maximyak, N.K. Pekarskaya. "Kinetics of Structural Deformations and Failure of Clays".

Wahls, H. E., J. H. Brewer, "Gyratory Testing of Subgrade Soils".

Webb, D.L., "The Use of Pulverised Fuel Ash in a Reclamation Fill".

Wiesel, C. E.," Some Factors Influencing In-Situ Vane Test Results".

Woods, R. K., R. Sägesser, "Holographic Interferometry in Soil Dynamics".

Wroth, C. P., J. M. O. Hughes, "An Instrument for the In Situ Measurement of the Properties of Soft Clays".

Yamanouchi T., H. Murata, "Brittle Failure of a Volcanic Ash Soil 'Shirasu' ".

Yoshimi, Y., H. Oh-oka, "A Ring Torsion Apparatus for Simple Shear Tests".

APPENDIX

Reports of National Societies

Czechoslovakia

Drained triaxial tests with water saturated medium sand were carried out with constant cell pressure (standard tests) and with constant mean normal stress. The effect of different loading paths on the form of the Mohr's envelope was slight but noticeable. In the latter case Mohr's envelope was curvilinear. The path-dependent behaviour of the sand was explained by the structural changes of the sample during the testing process (published in: Feda, J., 1969. The influence of loading path in the plane σ'_1 $\sigma'_2 = \sigma'_3$ on the shear strength of Zbraslav sand. Acta technica ČSAV 14, 1:92-128).

A measure of the structural changes of the above samples may indicate their volume strains. Their analysis proved that they may described by a system of linear deformation surfaces $\varepsilon_v = f(\sigma'_m, \varepsilon_1, n_o)$, where ε_v, ε_1 - volumetric and axial strains, σ'_m = mean effective normal stress, n_o - initial porosity, which differ for standard and σ'_m = const tests. In the latter case volume strains were larger (published in: Feda, J., 1970. Volume changes of sand in triaxial test. Proc. 2 nd Seminar Soil Mech. Found. Eng., Lodź, Poland, pp. 107 - 123). Sands cannot be therefore held for structureless media and their behaviour simulates the behaviour of cohesive soils.

The structure of a granular medium was analysed using Boltzmann's principle. The structure of a simple array of equi-diameter rigid spheres can be characterized by a frequency curve of the number of contacts of individual spheres. In the case of its symmetry the structure is termed spontaneous, if asymmetric-dominant. Extremely loose or dense structures are dominant and the volume changes during the test tend to form a spontaneous structure which is more probable (higher value of entropy). This explains why the phenomena of dilatancy and contractancy exist /published in: Feda, J., 1971. Struktura partikulárních láteck a Boltzmannův princip (Structure of particulate matter and Boltzmann's principle - in Czech). Stavebnícky časopis 19, 5: 310-330/.

The amount of entropy may be expressed by a plastic potential which, on contrary to the Prager-Drucker conception, must contain besides the peak angle of internal friction its residual (or constant-volume) value too (published in: Feda, J., 1971. Plastic potential in soil mechanics. Proc. First Nat. Conf. Theor. Appl. Mech., Varva Nov. 3-6, 1969, 1:387-399).

Denmark

The Danish Geotechnical Institute, whose research activities are performed by a group joint with the laboratory of Soil Mechanics at the Technical University of Denmark, moved in 1970 to its present site. At about the same time the professorate in Soil Mechanics, vacant after the late Professor J. Brinch Hansen, was filled. As a consequency most of the efforts have until recently been concerned with construction of new research facilities and reorganization of the teaching in Soil Mechanics at the University.

In the course of this work the following new research facilities have been developed.

I. A triaxial apparatus taking 20 x 20 cm cylindical samples of dry sand between frictionless pressure heads, the hydrostatic stress being put on by means of a vacuum inside the sample. This apparatus is being used for the study of failure and deformation properties of sand in axisymmetric state.

2. A modification of this apparatus taking cubical samples of the same dimensions, being used for the study of general three dimensional failure and deformation properties of sand.

The concurrent theoretical work is concerned with mechanics of granular materials and with the study of plane and axisymmetric failure and deformation problems by means of the theory of plasticity, the finite element, and allied methods.

In Denmark most of the surface is covered of very firm soils and the foundation pressures are therefore very high. The deformations of these soils could not be investigated with sufficient accuracy in the normal laboratory equipments because the deformations of the apparatus itself was of the same order of magnitude as that of the sample. The strength properties was influenced by the creation of a distinct ruptive surface. After construction of new stiff oedometers and triaxial apparatus very close agreement was obtained between different kinds of laboratory tests and field tests and observations. These resulted in a stress-strain relationship for moraine clay published in a Ph.D. thesis in 1967 (in Danish). In bulletin no. 27 from D.G.I. (1970) were the main results of this work published. In the last two years the triaxial apparatus has been changed a little in order to make it usable for the students at "Danmarks Ingeniørakademi".

Germany

BRIEF REPORT

Strength and deformability of soils were studied in the Institut für Bodenmechanik und Felsmechanik along three lines:

1. behaviour of regular and irregular packings of spheres (theory and experiments);

2. behaviour of real soil samples and its description by constitutive equations;

3. measurement of stress and strains in real soils.

Until recently these studies were mainly concentrated on granular materials, but some work was also done with silts and clays. The following contributions of the past 5 years belong to Session I. A list of references and several summaries are added in an appendix.

1. Packings of spheres

Earlier work by IDEL (7) and WITTKE (14) was continued by RAJU (11) WESELOH (12) and BRAUNS (2)

RAJU (see abstract) applide the results of Mindlin and co-workers to calculate the stress-strain behaviour of a hexagonal prism built up as a regular packing of spheres under at rest condition. Experiments agreed with this theory for loading, and only slight deviations were obtained for unloading.

WESELOH (see abstract) studied stability and deformation of a face-centered cubical packing under biaxial conditions. The stability calculation of this non-conservative system was carried out by means of failure mechanisms observed in tests. This work proves the importance of internal and external kinematical conditions for the stability of granular material.

BRAUNS (see abstract) calculated the stress-strain behaviour a regular packing under axisymmetric conditions for high stresses by taking into account brittle failure of the particles. Tests agreed fairly well with these calculations. Results of recent tests (as yet not published) with random packings of glass beads (samples 15 cm diameter, 45 cm height) under cell pressures up to 1.400 kg/cm^2 seem to support the theory.

2. Behaviour of real soil samples

Samples of sand and (in some cases) clay and silt were loaded and deformed in successively improved laboratory equipment. Some microscopic and continuum theories were developed to evaluate the tests.

ABEL (1) (see abstract) calculated the cohesion of regular and irregular packings due to capillary bridges at the grain contacts. The theory was supported by triaxial tests with moist sand.

GUDEHUS (5) and GOLDSCHEIDER (3) used the concepts of modern continuum theory to work out a mathematical description for large three-dimensional deformations of physically non-linear rate-independent materials. Formulations for finite and incremental stress-strain relations were developed.

MEISSNER (8) and WIBEL (13) (see abstracts determined the coefficients of a tensorial second-order finite stress-strain relation by triaxial tests with lubricated end platens and oedometer tests, both with dry sand. Based on this constitutive equation a finite-element program vas developed for axi-symmetric deformations. This was specially applied to calculate stresses and deformations within the sample in a conventional triaxial compression test. The calculated stress and strain inhomogeneities agreed fairly well with the observations in a 1m (diam.) x 2m (height) sand sample. Recent tests (the results of which are not yet published) with the lead shot radiograph technique were carried out to get a more detailed insight into the failure mechanism of a triaxial sample.

A truly triaxial deformation apparatus was built by GOLDSCHEIDER and GUDEHUS (4) (see abstract) starting from an idea of HAMBLY (6). A detailed description of apparatus and test results for dry sand will be published in 1972. This apparatus is rather complicated as it allows large threedimensional strains, but there is as yet no other apparatus that satisfies the requirements of the theory of simple materials (5).

At present sand and clay samples are tested under biaxial and axisymmetric triaxial conditions for comparison with the truly triaxial tests (and for practical reasons). Homogeneity of deformations is improved as compared with conventional tests by lubricated platens and height/width ratios below 1.

3. Measurement of stresses and strains

The lead shot radiograph technique for measuring strains in soils is applied in Karlsruhe since two years. Results are not yet published, however, PRANGE (9) has developed telemetric cells to measure stresses in the interior of soil masses. These cells were used, e.g., in the work of MEISSNER (8). An improved version for measuring normal and tangential stresses was developed by PRANGE (9) (see abstract).

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* VK - Veröffentlichungen des Institutes für Bodenmechanik und Felsmechanik der Universität Fridericiana in Karlsruhe

Creat Britain

Work with soil models in a centrifuge was pioneered by A.N.Schofield while he was at Cambridge and has been extended since he took the Chair at NMIST (Manchester) where he has built a large centrifuge, described by Lyndon and Schofield (1970) and in his paper with English, Hird and Bolton to this Conference. The work at Cambridge continued after he left, and this is described by Bassett in his paper to this Conference. Professor Rowe at Manchester University has also built a large centrifuge which he has described in 1971 (see Ref. below). He has also mentioned it in the 12th Rankine Lecture which will be published in Geotechnique for June 1972.

Professor Roscoe (Cambridge) began looking at soil structure with a scanning microscope and gave some remarkable micrographs in 1967. The effects of sample preparation for this type of study have been considered by Barden and Sides (1971).

A joint venture between the Norwegian Geotechnical Institute, Imperial College (London University) and Building Research Station, England, resulted in three ring-shear apparatii, built by Geonor. The apparatus at Imperial College and work done with its, are described by Bishop et al 1971. More of the work at I.C. is described by Bishop, Green and Skinner in their paper of this Conference. Look particularly at Skinner (1969).

Work at the Building Research Station (Geotechnics Division) has been described by Lewin and Burland (1970) and an interesting piece of apparatus has been described by Lewin (1971).

The 10th and 12th Rankine Lectures describe important work at Cambridge and Manchester. The untimely death of Professor Roscoe in a car accident shortly after he gave the Rankine Lecture lead to the Memorial Symposium, the Proceedings of which give an invaluable collection of work relating to this Session. This and other relevant books are given at the beginning of the following list of references which includes papers describing some of the more important work related to this Session.

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India

Shear Strength of Over Consolidated Expansive Clay
S. Satyanarayana, B.V. Ramganatham and K. Ramasastry (Indian Geo. Jn., 1971, vol. 4, no. 4, 374-82)

Physical concepts as well as test results of this investigation go to show that Hvorslev's analysis of shear strength of overconsolidated clays based on the hypothesis of parallel shear lines is an over simplification of the actual behaviour and a suitable modification incorporating the variation of the slopes of the shear lines is made. It has now been possible to express this variation in terms of preconsolidation pressure and some constant indicative of the initial soil structure. A general expression for shear strength of overconsolidated clays has been obtained in terms of overconsolidation ratio defining the preconsolidation pressure, the variation of the slope of the actual slope of the shear lines and some constants indicative of the initial soil structure.

Influence of Moisture on the Shear Parameters of Partially Saturated Cohesionless Soils by Raju, V.S. and Khemka, V.N. (Jn. of the Indian Geo. Soc., 1971, vol. 1, no. 1, pp. 70-84).

The behaviour of partially saturated cohesion less soils in shear under fully drained conditions has been studied. Triaxial compression tests with volume change measurements on two types of medium sands have been carried out at different densities and moisture contents. Due to capillary tension in the pore water, apparent cohesion develops. This cohesion is dependent on pore size, degree of saturation, density and angle of internal friction ϕ. For the sands tested the measured values of C' range from 0 to 0.28 kg/cm^2. It was found that the angle of internal friction ϕ' is affected by the moisture due to lubrication effect of water films. The reduction with respect to the over dry condition in the value of ϕ' is of the order to 5^o for the sands tested. This decrease is dependent on mineral composition of the soils. This indicates that if the shear strength of dry samples is used in desigh for long-term stability, it would lead to unsafe design. Though there is a reduction in the value of angle of internal friction ϕ', the apparent cohesion C' can be used with advantage in the design of slopes of temporary excavations and struttings, as up to a critical normal stress and moisture content the value of the shear strength of moist samples is higher than that of dry samples. This will result in considerable economy in design of slopes of temporary excavations and struttings.

Effect of Rate of Strain on Strength of Obra Sand by Dr. Shamsher Prakash Copal Ranjan (Synopsis)

Large size (30 cm x 15 cm) direct shear apparatus with rates of strain varyig from 0.023 per cent per second to 1.205 per cent per second have been used to investigate the effect of rate of strain on strength of dry Obra sand. The results show that: (i) angle of internal friction of sand increases by 2.6 per cent, (ii) the modulus of deformation increases slightly with decrease in time of loading, (iii) strain at failure practically remains constant at different rates of strain, and (iv) there is a linear variation between rate of strain and time of loading a log-log plot.

Strength Anisotropy in Cohesive Soils by Kera, R.P. Krizek, R. J. (Abstract)

Directional variations in the shear strength of cohesive soils may occur to such a degree that the applicability of conventional methods for analyzing the stability of earth masses are unsatisfactory or uneconomical. Similarly, strength anisotropy may significantly affect the strength values obtained from many of the commonly employed laboratory and field testing techniques. These problems and their engineering implications are discussed in the light of a proposed interpretation for intrinsic and induced strenth anisotropy, the results from several experimental studies, and the description of two failure criteria for anisotropic materials.

Shear Characteristics of Soil-Gravel Mixtures by Dodiah, D., Bhat, H.S., Somasekhar, P.V., Sosalegowda, H.B., Ranganath, K.N. (Synopsis)

The material actually used for earth structures will have -4 as well as +4 fractions of soil though laboratory tests to determine the engineering properties of soils are conducted on -4 fraction. The properties obtained may, therefore, be entirely different from corresponding properties of the soil-gravel mixtures in the actual structures. It is, therefore, necessary to find out whether it is possible to estimate the density, shear and permeability values of the soil-gravel mixtures without resorting in each case to elaborate large-scale testing of the actual material proposed to be used. Such a correlation is significant in view of the economical and safe design of every increasing number of earth structures. This paper deals with the study carried out to correlate the shear characteristics of soil-gravel mixtures with those of -4 fraction.

The important findings of the study are:

1. The angle of internal friction increases with the increase in the gravel content; greater the size of gravel, higher the angle of internal friction at all percentages.
2. With increase in gravel content up to 30 per cent the cohesion does not decrease with respect to that of -4 fraction. Hence there is always an improvement in the shear parameters with the addition to gravel up to 30 per cent.

3. While the angle of internal friction continuously increases with increase in the percentage of gravel, the maximum dry density increases up to a certain percentage, 40 to 60 per cent, depending upon the size of gravel and then drops down.

4. While using soil-gravel mixtures, if density is the criterion for the design and if very coarse material is met with, then the allowable percentage of coarse material may be limited to about 40 per cent or less.

5. If angle of internal friction is the criterion in the design of embankment, where soil having very coarse material may be as high as to 50-70 per cent provided the material is used in the casing.

A Three-Dimensional Tensile Strength Test for Cohesive Soils by N. Bansi Lal (Synopsis)

The importance of the study of tensile strength of cohesive soils is brought out. A three-dimensional hollow cylinder test for evaluating tensile strength of cohesive soils is described. Internal pressure through the central hole of a specimen is employed to introduce tensile circumferential stress in the material. Failure in tension is evidenced by vertical tension cracks on the surface.

Various combinations of circumferential and vertical stresses on the material to produce failure have been used to develop an "envelope" giving the limiting state of stresses. Such "envelopes" have been developed for three different types of cohesive soils.

Uniaxial Compressive Strength of Rocks for Irregular Lumps by L. S Srivastava Shyam Behari (Abstract)

The paper describes the method of determination of uniaxial compressive strength of rocks by testing irregular lumps. It has been found that the lump strength expressed as the average applied stress at fracture 'I_A' (fracture load divided by the average contact area of the sample with the platens of the testing machine) has a good correlation with the uniaxial compressive strength 'q' of 2.5 cm cubes and the following relations may be used for evaluating the uniaxial compressive strength of the rocks:

For Lumps of 500 to 100 gm weight $q = 573 + 0.26\ I_A$

For Lumps of 50 to 100 gm weight $q = 548 + 0.31\ I_A$ where q and I_A are in kg/cm^2.

Mexico

ROCKFILL MATERIALS

Triaxial testing of specimens 113 cm in diameter, started in 1963 has been continued to date in the Institute of Engineering of the Mexico University. Information is available on the strength of ten different types of materials. In several of them, the effect of gradation and compactation has been studies (reference: Marsal, R.J., "Resistencia y Compresibilidad de Enrocamientos y Gravas"; Instituto de Ingeniería, UNAM, 1971).

The scale factor is being studied in both triaxial and one-dimensional compression. In the former case, the results obtained with specimens 113 cm in diameter are being compared with those from 20 cm specimens. In one-dimensional compression, specimens 113 cm and 33 cm in diameter are tested; the height of the specimen is equal to its diameter in both series. Geometrical similarity has been adopted as the scaling criterion (unpublished reports by Campusano R. and Ramírez de A.L., Instituto de Ingeniería, UNAM).

For two materials, the effect of wetting after placement has been studied, order to determine the minimum amount of water required to induce a compression equivalent to that produced by flooding (Ramırez de Arellano, L. "Efecto del Humedecimiento en la Compresión Unidimensional del Material para los Respaldos de le Presa La Angostura", publication of the Instituto de Ingenieria, UNAM, 1971).

On the other hand, theoretical studies on the approach have been pursued. The corresponding experimental work has just been started in a "true triaxial apparatus for testing a cubical specimen 100 cm in size. The maximum normal stress in any direction is 100 kg/cm2 (reference: Marsal, R. J. "A True Triaxial Apparatus to Test Rockfill" 8th Int. Conf. on Soil Mechanics, Moscow, 1973).

GRANULAR SOIL TESTS

In the Hidraulic Resources Ministry laboratory was carried out a device for shear resistance measurements on cylindrical speciments of 19.5 cm in diameter and 29.0 cm long of granular soils (gravel and sand). This test is very simple and permits to obtain shear resistance parameters with approximate values. Correlations were obtained between shear resistance by this test and triaxial methods using 15.0 cm in diameter specimens on different materials. (Published Ingeniería Experimental, Secretaría de Recursos Hidráulicos.)

SOFT SOIL TEST

Actually at this Laboratory of Experimenting with a new device, three dimensional deformimeter for determine deformations due to volumetric variations on expansive clays. (Internal publication of Ingeniería Experimental, Secretaría de Recursos Hidráulicos.)

PERFORMANCE OF ROCKFILL DAMS

Field Observations

In the Institute of Engineering of the Mexico University field measurements have been continued at several dams already instrumented with heights between 50 and 150 meters (reference: Marsal, R.J. and Ramírez de A. L., "Eight Years of Observations at El Infiernillo Dam", Proceedings Purdue Conference, ASCE, June 1972).

At present, an extensive instrumentation is being installed at La Angostura Dam, and the first observations have been reported (reference: Ramírez de A.L. and Moreno E. "Field Measurements at La Angostura Coffer Dams". Proceedings Purdue Conference, ASCE, June 1972).

Designs have been improved, and a study has been performed on the precision and long-term reliability of various instruments used in the observation of dam behaviour (Silva, C., report to be published, Instituto de Ingeniería, 1972).

INSTRUMENTATION

There is sufficient information at the Hydraulic Resources Ministry related to 6 dams instrumentation varying from 33 at 139 m height; which foundations are on different materials.

These data are reported in the following table: (Internal publication of Ingeniería Experimental, Secretaría de Recursos Hidráulicos.)

DAM	HEIGHT	FOUNDATION
Netzahualcoyotl (Rockfill)	139	Conglomerate
Lázato Cárdenas (Earth)	95	Volcanic agglomerate Conglomerate
ENDO (Earth)	60	Basalts, lacustrine deposits and Sandy tuff
Francisco Zarco (Rockill)	40	Gravel and sands Talus deposits
Requena (Rockfill)	35	Clayed and silty soils
Guadalupe (Rockfill)	33	Clayed and silty soils

There is in addition, available information related with design, construction and performance of 50 earth and rockfill dams constructed in Mexico by Secretaría de Recursos Hidráulicos. (Reference: Mexico Dams, Secretaria de Recursos Hidráulicos.)

I. In the Public Works Ministry studies and instrumentations were carried out on soil masses with the purpose of obtaining the proper method of correcting the failures in such soil structures: 5842

a.) Failures on natural hillsides of slope materials which overly ancient geologic failures in the Tijuana-Ensenada highway. At kms 12 + 360 and 16 + 800 the failure surface was determined by using inclinometers of the Slope Indicator type; correcting these failures by removing material from headboards with a total volume of 80,000 m^3.

At kms 15 + 050, 15 + 200, 15 + 350 and 20 + 415 the geometric and depth of the sliding surface was determined by the same type of inclinometer. These failures were stabilized by permeable trenchs. At km 15 + 500 the geometric and

and depth of failure surface were determined by installing inclinometers and the stabilization of this failure was attained with the construction of a filter gallery, previous installation of piezometric units for water table determinations.

At km 20 + 000 inclinometers "Slope Indicator" type were installed for determining geometric and depth of the failure surface, which was stabilized by retaining wall located at slope foot of embankment. (Information available at S. O. P., Depto. de Geotécnia, Xola y Av. Universidad.)

b.) Circular failures

At kms 318 + 000 and 320 + 000 of Mexico-Tuxpan highway. At this site inclinometers "Slope Indicator" type were installed for determining geometric and depth of sliding surface. After analysing this data the problem shall be solved.

From all geotechnical studies carried out, 70 failure cases were solved which included a total footage of 2000 km (Information available at S.O.P., Depto. de Geotécnia, Xola y Av. Universidad).

c.) Public Works Ministry

Instrumentation of the test embankments corresponding to Mexico Acapulco railroad, wich are located at Texcoco Lake, near Mexico City. In these test embankments were installed vertical sand drains in order to accelerate the soil consolidation. We are now comparing actual results with the theoretical.

II. A Slope Sliding in Minatitlan, Ver. Petroleos Mexicanos

The instrumentation as means for detecting the failure mechanisms proved an invaluable tool to ascertain the cause of the periodic slidings observed in a 2:1 slope 520 feet long and 50 feet high in an argillaceous sand embankment limiting a portion of the apron where the Pemex Minatitlan, Ver., México Refinery is built.

The instrumentation program was planned on a reference point grid and a line of Wilson recording clinometers which followed the axis of the area regarded as unstable.

The sample drilling program and the observation of displacement showed that the failure occurred below the embankment base, on a layer of hardened asphalt mat. (Petroleos Mexicanos Internal File, 1970).

III. Public Works Ministry

A fault instrumentations (scale mode) for determing pressure variation induced by an overburden was simulated by sand material. The system was instrumented by electrical strain gages. We are now obtaining measurements. (Information available at S. O. P., Depto. de Geotécnia, Xola y Av. Universidad.)

IV. Large Tank Foundations on Soft Soils. Ciudad Madero, Tamps. (Petroleos Mexicanos).

On an area neighboring the Panuco River mouth which soil is characterized by soft, highly compressible strata, the selected construction method for the foundation of large tanks for storage of petroleum products was: construction of conventional mats on the ground level after the consolidation of the soil by means of embankments which applied 1.5 times the design load. The embankments were formed by the sand used for rising the general grade of construction areas. (CICM Proceedings of the VIII Civil Engineering Meeting, Mexico, 1969.)

V. Oil Harbor in Pajaritos, Ver. (Petroleos Mexicanos)

In Pajaritos Lagoon, close to the Coatzacoalcos River mouth, a harbor was planned for handling ships transporting petroleum products.It included an access canal between the river and the lagoon and piers at the maritime terminal.

Before the harbor construction soil mechanics studies were made to establish the stable slopes for 37 feet water depth in fine and silty sands of recent deposition in a high sismicity area where the problem to deal with was the liquification failures. (Petroleos Mexicanos Internal File, 1972).

STRESS-STRAIN ANALYSIS

Analysis by the finite element method have been carried out for El Infiernillo, La Villita and La Angostura dams. For El Infiernillo, an incremental non-linear analysis was made for the construction stage (reference: Alberro, J. "Stress-Strain Analysis of El Infiernillo Dam", Proceedings Purdue Conference, ASCE, June 1972).

In the case of La Villita dam the analysis comprised both the construction and the first filling of the reservoir, accounting, in the latter stage for deformations induced by flooding of the upstream shell (reference: Alberro, J. y León, J. L. "Estado de Esfuerzos y Deformaciones en la Presa La Villita", Instituto de Ingeniería, UNAM, 1971 and Alberro, J. "Analysis and Behavior of a Concrete Cutoff Wall", Fourth Panamerican Conference on Soil Mechanics, Puerto Rico, 1971).

Before the construction of La Angostura Dam, analytical studies were undertaken using the finite element method, of both the longitudinal and transversal sections of the dam (references: Covarrubias, S. "Análisis de Agritamiento mediante el

Método del Elemento Finito de la Presa La Angostura", Instituto de Ingeniería, UNAM, 1970 and Covarrubias, S. and Romo. M. "Analisis de esfuerzos y deformaciones durante la construcción de la Presa La Angostura", Instituto de Ingeniería, UNAM, 1972).

SLOPE DEFORMATIONS

A method has been developed to correlate slope deformations with the safety factor. As a result, simple charts are obtained permitting the prediction of deformations of homogeneous slope, once the conventional safety factor is known (reference: Reséndiz, D. and Romo, M. "Analysis of Embankment Deformations", Proceedings, Purdue Conference, ASCE, June 1972).

TESTING OF SOFT SOILS

Institute of Engineering of the University of Mexico

A triaxial cell was developed the Institute of Engineering, UNAM, in which the axial load is applied through three wires working under tension; thus, friction is virtually eliminated (reference: Santoyo, E. and Reséndiz, D. "A Precision Triaxial Cell", Journal of Materials, ASTM, Vol. VI, December 1971). Using this equipment the effect of the rate of deformation on strength and pore pressures has been investigated (reference: Alberro, J. and Santoyo, E. "Long-term Behavior of Mexico City Clay", 8th Int.Conf. on Soil Mechanics, Moscow, 1973).

SEEPAGE ANALYSIS

Institute of Engineering of the University of Mexico

The practical application of Monte Carlo Techniques to seepage through anisotropic media was studied. A special emphasis was placed on covergence and precision of the solution (reference: Auvinet, G. "Monte Carlo Techniques Applied to Water Flow Analysis in Soils" Revista Latioamericana de Geotechnic, Caracas, Vol. 1, No. 2, 1971).

PILED FOUNDATIONS

Institute of Engineering of the University of Mexico

The pile-soil structure interaction has been analysed in the general case. Boundary conditions including negative skin frictions were established, from which stresses within the soil mass are computed, thus enabling settlement analysis (reference: Resendiz, D. and Auvinet, G. "Analysis of Piled Foundations in Consolidating Soils", 8th Int. Conf on Soil Mechanics, Moscow, 1973).

CHANNELS

At the Hidraulic Resources Ministry there is available information about a test instrumented channel, covered with hidraulic concrete and supported by expansive clays (reference: Internal Publication at Ingeniería Experimental, Secretaría de Recursos Hidráulicos).

Public Works Ministry

Scouring studies on pier No. 2 of Papagayo Bridge by using an aerodynamic tunnel. The tests carry out on the laboratory give up qualitative data for design of several protections, from which the best was elected. (Information available at S. O. P., Depto de Geotécnia, Xola y Av. Universidad).

PAPERS

Public Works Ministry

1. Instrumentation made on a phy

1. Instrumentation made on a physical model simulating the conditions of pier No. 2 foundation of "Mariano García Sela" bridge. (Published at Revista de Ingenería, Facultad de Ingeniería, enero de 1971, volume XLI, No.1, Ciudad Universitaria, México).

2. Stabilization of some moving (sliding) soil masses in the Tijuana Ensenda higway, (Paper presented at XIV international Conference on Highways. Tokyo, Japan, 1971).

3. Mexican Experience related with some aspects of cuts and embankments stability. (Paper presented at XIV International Conference of Highways, Tokyo, Japan, 1971).

4. Highways Instrumentation, (Paper presented atVIII Congreso de Ingeniería Civil en México, D.F. en 1969).

5. Aerodynamic Tunnel applied on highway projects, (Paper presented at Panamerican Conference on Highways. Quito, Ecuador, 1971).

6. Sliding soil mass stabilization at km 15 +050 on Tijuana-Ensenada highway. Presented at Panameri can Conference on Highways. Quito, Ecuador, 1971)

7. Movements control on a Mexico City Building. (Presented at V National Conference on Soil Mechanics in Mexico, D.F., 1970).

8. Boulevard construction over a lacustrine soil, (Presented at VIII Conference of Civil Engineering in Mexico, D.F., 1969).

9. Paper related with Minatitlan-Coatzacoalcos highway performance. Presented at V National Conference on Soil Mechanics, Mexico City, D.F. 1970.

10. Subgrade protection against water action. Presented at Seminario de Drenaje en S.O.P., 1969. (Information available at S.O.P. Dept. de Geotécnica, Xola y Av. Universidad, México.)

11. Highway subdrains. Presented at Seminario de Drenage en S.O.P. en 1969. (Information available at S.O.P., Dept. de Geotécnica, Xola y Av. Universidad, México.)

12. Natural subgrades. Technical studies for projects. Presented at Seminarios de Terracerías en S.O.P. en 1970. (Information available at S.O.P Depto. de Geotécnica, Xola y Av. Universidad, México.)

13. General aspects related with construction of highway subdrainage. Presented at Seminario de Terracerias en S.O P., 1971. (Information available at S.O.P., Dept. de Geotécnica, Xola y Av. Universidad, Mexico.)

14. Highway enlargement. Presented at Seminario de Terracerías en S.O.P., 1971. (Information available at S.O.P., Depto. de Geotécnia, Xola y Av. Universidad, México.)

Zeevaert Leonardo, Consulting Engineers
Main Papers Published.

Free vibration torsion test to determine the shear modulus of elasticity of soils (First Panamerican Conference on Soil Mechanics and Foundation Engineering, Vol. 1, Caracas, Venezuela, 1967).

Design of compensated Foundations. State of the Art Report. Joint Committee ASCE and International Association for Bridge and Structural Engineering. Committee No. 11, Planning and Design of Tall Buildings. Lehigh University. Bethelem, Pennsylvania, 1972.

RESEARCH PAPERS

1. Study of structural performance of flexible pavement by a circular test track. The main purpose of this study consists of evaluate the influence of quality and thickness of subgrades course on the flexible pavement performance. ("Pista circular para el estudio del comportamiento estructural de Pavimento" VI Congreso Panamericano de Carreteras, 1971 Santiago Corro C., Instituto Nacional de Ingeniería, UNAM.)

2. Study of flexible pavement performance by experimental sections. This study comprises performance observation of flexible pavements under traffic conditions known on 3 test sections, from which 2 sections are located in the Sn. Luis Potosí-Troncoso road, and the other in Izúcar de Matamoros, Pue. (Reporte No. 240 de enero de 1970 del Instituto de Ingenieria UNAM, patrocinado por la Secretaría de Obras Públicas, Santiago Corro C.)

3. Determination of structural capacity of flexible pavements by dynamic deflectometer "DYNAFLECT" considering regional factors constants. "Estudio del comprotamiento de Pavimentos Flexibles en tramos representativos de la Red Nacional", Santiago Corro C., Enrique Radilla C. Diciembre, 1971. (Information available at Instituto de Ingeniería UNAM, Ciudad Univeristaria, México, D.F.)

4. "Main Findings from the Experimental Research in Mexico". Third International Conference on the Structural Design of Asphalt Pavements, London 1972, Santiago Corro C.

Sweden

Swedish Literature
Up-to-date methods for investigating the strength and deformability of soils (laboratory and field testing of soils for their strength, deformative and rheological properties).

1. Strength and deformation properties of soils as determined by a free falling weight, by Orrje, O. and Broms, B. Proc. Swed. Geotechn. Inst., No. 23, 1970, 25 pp.

The strength-deformation properties of cohesionless soils (sands) under dynamic loading are determined by measuring the retardation of a free falling weight when it strikes the surface of a soil mass. The reaction force on the weight is calculated from Newton's second law and the penetration of the weight into the underlying soil by integrating twice the retardation-time relationships with respect to time. The load-deformation relationships as determined by this method are compared with those from static load tests. The test results indicate that the dynamic load-deformation relationships are effected mainly by the dry unit weight of the sand and that a free falling weight can be used to check the relative density and the degree of compaction of a particular soil.

2. Compression tests on morain in a large oedometer (in Swedish: Kompressionsförsök pa morän i jätteödometer) by Högberg, E., Sed. Geot. Inst. Repr. a. Prel. Rep. No. 39 (Symposium on Morain, 1969, arranged by the Swedish Geotechnical Society on 3rd December 1969) Stockholm 1970, p. 51-56.

In order to determine the settlements at the foundation on coarse cohesionless soils a large oedometer has been constructed at the Chalmers University of Technology, Gothenberg. The ring of the oedometer consists of a steel sheet of 7.7 mm and has an inner diameter of 696 mm and a height of 500 mm. The compression is determined by three dail gauges on the stamp. To determine the horizontal earth pressure in the oedometer, 27 strain gauges are used and glued in horizontal direction at three levels on the outer side of the oedometer ring. The load is applied by a flat Freyssinet hydraulic jack, 430 mm in diameter, which is connected to an oil pump. The material is compacted at desired water content in two layers, 180-200 cm thick. Stones of a maximum size of 128 mm can be included. Each layer is compacted by a 200 mm cylindrical falling weight of 50 kp, which is falling from 45 cm height 170 times (equal to Proctor compaction). To get an even distribution **of the pressure a plate of dry concrete is cast on a plastic foil which is placed upon the soil specimen. The load is applied in steps in three cycles. Each loading step is applied during 20 minutes. Recording of the compression is made at 20,40 seconds** and at 1.20, 2.40, 5, 10 and 20 minutes. Some measuring results are presented.

3. Testing machine for investigation of compacted soil (In Swedish: Kompressions-och skjuvapparat för moränmaterial), by Thurner, H., Swed. Geot. Inst. Repr. a. Prel. Rep. No. 39 (Symposium on morain 1969, arranged by the Swedish Geotechnical Society on 3dr December 1969) Stockholm 1970, p. 121-126.

A testing machine has been developed at the Royal Institute of Technology, Stockholm for samples with a diameter of 150 mm and a height for shear test of 50 mm and for compression test of 150 mm. Samples of particles up to 20 mm can be tested. The sample is surrounded by a rubber membrane 1 mm thick and 4 mm high steel rings making it possible to keep the diameter constant during testing but allowing the sample to be compressed without friction forces around the circumference. The vertical force is applied by a lever system and has a maximum force of 3600 kp corresponding to a stress of 20 kp/cm on the sample. Forces, pure pressures and deformation are measured by electrical transducers and automatically registered by a type written and a paper-tape punch. The test results can be presented in computer-drawn diagrams. The machine was originally intended for mainly earth dams but is also useful for other constructions.

4. Compaction properties. Proposal for geotechnical laboratory regulations. Part 5. (In Swedish) Packningsegenskaper. Förslag till geotekniska laboratorieanvisningar) Byggforskningens Informationsblad B2: 1971. Stockholm 1971, 38 p.

In order to prepare regulations for general geotechnical laboratory investigations, the Swedish Geotechnical Society has appointed a special laboratory committee, The Committee's work shall comprise 11 parts and the first issues shall be regarded as tentative ones. After some years of use a more final edition (manual) shall be issued. The present contribution, which is the first one presented, contains, except symbols and definitions and factors affecting the compaction work (content of water and stones, etc, compaction procedures to be recommended in the laboratory and in the field. Among laboratory compaction methods are treated heavy methods (corresponding to, e.g. Modified Proctor) and light methods (e.g. Standard Proctor), vibration methods and loose pouring of the field methods) are treated cylinder, water and sand volumeters, respectively, paraffin pycnometer and isotop methods. Reliability of the methods are dealt with. Various types of blanks with examples are included.

5. The compressibility of cohesionless soils, (In Swedish: Friktionsjordars kompressibilitet), by Andreasson, L, Byggmastaren 50 (1971) No. 4, p. 4-7.

Analysing the deformations in relation to other properties of the soil (compactness, grading, grain shape, grain strength, grain size) can be made by using comparatively simple theoretical models, the author says. The analysis is derived from the author's own tests and on tests described in the literature. The data are from compressometer or oedometer tests on purely frictional soils, from silt-sand fraction up to stone fraction, but confined to tests of compression from the first loading of material that had not been **loaded previously. The soils have in this case been exposed to pore-water suction: the materials were either dry or saturated. The relationship is shown between the modul number m, C_u $(= \frac{d_{60}}{d_{10}})$ and e_0 for 430** different compression tests representing about 70 different friction soils, mostly sands. The results from the empirical analysis are directly useable for the estimation of settlement of, e.g., fills, where void ratio and grain size curve are known.

6. Scandianvian Geotechnical Meeting in Gothenburg on September 5-7, 1968 (In Swedish: Nordiska geoteknikermötet i Göteborg den 5-7 september 1968), Väg-och vattenbyggaren (1968) No. 8, p. 71-135.

One of the four sessions was dealing with "Deformation in soils" and some of the twelve papers are dealing with methods for the measurements of the settlements. For one case (settlement at spread foundation on boulder clay) it was reported that surprisingly good agreement was obtained between calculated and measured settlements according to the pressiometer method. (The latter investigation is also later reported in Swed. Geot. Inst. Repr. a. Prel. Report No. 30, Stockholm, 1970, p. 67-77, in Swedish).

7. Settlements in over-consolidated clay. (In Swedish: Sättningar i överkonsoliderad lera), by Hansbo, S., and U. Lindblom, Byggmästaren 50 (1971) No. 5, p. 4-9, 11 Fig. 1 Table, 7 Ref.

In the calculation of consolidation settlement of a slightly over-consolidated clay, where the effective stresses τ' after load application approaches or exceeds the pre-consolidation pressure τ_c', it is important that the pre-consolidation pressure is correctly estimated. Even a small miscalculation of the pre-consolidation pressure can lead to substantial errors in the settlement calculations. The traditional method of determining τ_c', by oedometer tests has sometimes also been questioned. Under certain conditions it is not possible to use the available standard solutions of the consolidations equations with sufficient accuracy. The paper deals with the pertinent settlement analysis for a building in Bofors, Sweden. The analysis shows that in this case the pre-consolidation pressure τ_c' from a standard routine oedometer test was correct and that the pore-water pressure equalization was roughly in accordance with Terzaghi's consolidation theory. On the other hand, the agreement between the consolidation course with regard to pore pressures and to settlements not so good.

8. Settlements in moraine subsoils, (In Swedish: Sättningar vid grundläggning på morän), by Hansbo, S. and B.A. Torstensson, Byggmästaren 50 (1971) No. 4, p. 8-14.

The article describes settlement tests at a hospital erected in 1966-1967 and founded mostly on piers on moraine containing boulders. The compressibility of the moraine was tested in a giant oedometer. The observed settlements (initial, long term, and settlement differetials) are compared with calculated settlements based on Jaky's method and the theory of elasticity. The tests show that it is possible to calculate the average settlement for buildings on slab foundations on coarse-grained sub-moraine using the slope of the oedometer reloading curve. In addition it is shown that the maximal settlement differential in this type of foundation can be of similar magnitude or greater than the average settlement. In this case the settlement differences are so small that they do not cause settlement damages. The average allowable bearing capacity, 800 Kn/m^2, could probably have been doubled without damage to the building.

9. Testing of a settlment measuring method, "Swedish Road Research Institute Model 69" (In Swedish: Utprovning av en sättningsmätningsmetod, "Väginstitutets modell 69") by Lundgren, N., Stat. Väginst. (Swed. Nat. Road, Res. Inst.) 1971, Internrapp. No. 24, p. 7 app., 29+8 Figs., Stockholm

In connection with the construction of road embankments consisting of soils and stones placed in layers, iron nettings are placed on levels where settlement measurements are to be made. The iron wire nets are not affected by the vertical movements due to the humidity in the embankment. When the embankment is completed, a vertical borehole is made from the nets by means of a pneumatic boring machine. A plastic casing tube is inserted through this hole. Into the casing an electro-magnetic sounding rod is then sunk by means of which the level of the nets can be measured. By the determination of the distance from the top of the tube, which first is levelled, to the various nets in the measuring point one can obtain the level of the nets, i.e. that of the corresponding soil and block layer at the time of the measurement. The accuracy of the method is $\pm$ 5 mm.

U S S R

Investigations of problems of the deformability and strength of soils in the USSR are being conducted along the following lines: studies of their rheological properties and consolidation, studies of the complex stressed state and the establishment of generalized laws of deformation and strength, studies of the mechanizm of soil deformation and the formulation of phisical theories, the development of new methods and the improvement of existing methods of field investigations in the mechanical properties of soils.

1. Investigations of the Rheological Properties of Soils

To describe creep processes use is made of the equations of various phenomenological theories; the ageing theory, the flow theory, the hereditary creep theory, etc.

In the works of various Soviet investigators (Vyalov, 1970, 1972, Coldstein, 1971, Zaretsky 1972) various forms of "stress-strain-time" relationships, entering into these equations, are experimentally substantiated, methods are given for their determination, the influence of the composition and properties of the soil are investigated, etc. Applied, in particular, is the relationship $\dot{\gamma} = A\tau^{m}, t^{-n}$, where $\dot{\gamma}$ is the strain rate, τ is the stress and A and n are parameters. This relationship establishes the power (at n≠1) and the logarithmic (at n=1) laws of creep. Also proposed is a linear-fractional law of deformation:

$$\gamma = \frac{\tau \delta t}{G_o\left[T + t\left(1 - \frac{\tau\delta}{\tau_o}\right)\right]}$$

where G_O, T and δ are parameters determined experimentally.

This equation contains both deformative and strength characteristics, and it describes

*This paper has been published in detail in the book "Doklady k VIII Mezhdunarodnomy Kongressy po Mekhanike gruntov i fundamentostroeniyu" (Papers for the VIII International Conference on Soil Mechanics and Foundation Engineering) in Russian, Stroiizdat, Moscow, 1973.

both the prelimiting and limiting states of the soil.

The following relationships, linking the magnitude of the load τ and the time t_f, after which this load causes failure, are proposed for describing the process of the decrease in strenth:

$$t_f = \frac{T}{\delta}\,\frac{\tau_0-\tau}{\tau-\tau_\infty} \quad \text{or} \quad \frac{\tau_0}{\tau} = \frac{\beta}{\ln\frac{t+t^*}{B}}$$

where δ, T, β and B are parameters.

the first of these equations (Zaretsky,1972) determines the decrease in strength from the instantaneous value τ_0 to the limiting long-term value τ_∞. The second equation describes the unlimited decrease in soil strength at $t \rightarrow \infty$ (S.S.Vyalov,1970).

It has also been shown (Sorokina and Stroganov,1971) that in the process of strength reduction, the angle of internal friction remained practically constant whereas the limiting long-term cohesion decreases by 41 per cent with respect to the instantaneous values.

A number of authors have carried out experimental investigations of soil creep. These include triaxial compression under the condition of independent application of all three principal stresses (G.M.Lomize,et al.), experiments with the influence of the temperature of the soil taken into account (S.R.Meschyan), experiments taking into account the jumpwise character of the deformation process (G.A. Ter-Stepanyan), etc. The results of these investigations are set forth in papers submitted to the present Conference.

Mention should be made of Professor N.A. Tsytovich book (1973), containing a special section on soil rheology, and Professor M.N. Goldstein's book (1971), in which a number of soil models and the corresponding rheological equations of state are considered.

2. Investigations of Soil Consolidation

Investigations (Tsytovich, Yu.K.Zaretsky et al,1970) have confirmed that the percolation consolidation theory is valid only for uncompacted, water-saturated soils. In order to describe the consolidation process for the majority of soils, it is necessary to take the influence of the rheological (viscous) properties and the structural bonds of the soil into account. Settlement due to creep, depending upon the compaction, constitutes from 35 to 165 per cent of the settlement due to percolative consolidation. The influence of structural bonds affects the magnitude of the initial pore pressure and the character of the dissipation of this pressure.

A consolidation equation for clayey soils, taking into account the factors: percolation, compressibility of the liquid phase, creep, initial pore pressure, and the incomplete transmission of the initial pressure to the water, has been proposed for the one-dimensional case.

Here the deformation law for the soil skeleton is taken in the form of the equation of linear hereditary creep.

A generalization of the Biot-Florin model has been proposed. It is based on the propositions discussed above but has been extended to the case of a three-dimensional stressed state.

The solution of an equation of consolidation (Tsytovich, Ter-Martirosyan), taking into consideration the rheological properties of the soil skeleton) enables the magnitude of the settlement and its variation with time to be determined in the form

$$S_t = ph(a_1U_1 + a_2U_2)$$

where a_1 and a_2 = coefficients of primary and secondary relative compressibility.
U_1 and U_2 = ratios of primary and secondary consolidation of the soil

A.I.Ksenofontov proposed that the consolidation theory be dealt with as a relaxation theory.

It has been previously shown experimentally (Maslov) the the consolidation time is not proportional to the squares of the thickness of the layers being compacted, as follows from the percolation theory. More detailed experiments by the same author revealed a dependence of the exponent on the type of soil and the compacting procedure.

3. Investigations of a Complex Stressed State

Earlier works (Vyalov, Lomize, et al), in particular those published in the Proceedings of the V, VI and VII International Conferences, showed that the deformation of shape E_i, as well as of volume E_m depend upon all three stress tensor invariants or, which is the same, upon the intensity of the tangential shesses σ_i, the mean normal stress σ_m and the magnitude of $\sigma_j = \sigma_1 \cdot \sigma_2 \cdot \sigma_3$.

The object of subsequent investigations was to find the form of the above-mentioned relationships, as well as the influence of the loading conditions. Investigations (with sandy, clayey and frozen soils) were conducted with the aid of various instruments for the different kinds of stressed states.

Triaxial compression apparatus was used to study soil creep processes under the condition that σ_i =const and σ_m =const. Usually each value of σ_m corresponded to a series of tests at various σ_i. Also used for creep tests was an instrument in which the specimen was subject to hydrostatic pressure and a torque. In a somewhat different arrangement a torque was applied to the specimen together with a vertical compressive force.

A combination test scheme was realized in an apparatus in which a hollow cylindrical specimen was tested by torsion and a vertical compressive load with simultaneous application of internal and external hydrostatic pressures (differing in magnitude). This arrangement allows various kinds of stressed states to be produced (Lomize and Ivashchenko). A similar purpose is achieved in apparatus for testing cubical soil specimens. The principal normal stresses are applied independently of one another through rubber membranes to three pairs of opposing faces and the corresponding principal linear strain values are measures. This apparatus enables a stressed state to be developed corresponding to Lode strain parameters from-1 to +1 (Lomize, 1970, Malyshev,1969). Additional experiments were conducted in which the strains at the faces of the cubical specimen were made to increase at a constant rate.Measured, in this case, were the principal stresses that were developed.

Investigations of the interrelation of σ_i and σ_m showed that the deformation in shape ε_i and in volume ε_m depend both on the shear deviator stress and on the hydrostatic pressure σ_m. In one work (Vyalov,1970) it was proposed that the above-mentioned relationship be expressed: for deformation in shape as

$$\sigma_i = \varphi_1(\varepsilon_i) + \varphi_2(\varepsilon_i)\Phi(\sigma_m)$$

where $\Phi(\sigma_m)$ is a function characterizing the influence of the hydrostatic pressure; and for volumetric strain as

$$\sigma_m = \psi_1(\varepsilon_m) \pm \psi_2(\varepsilon_m)\psi(\sigma_i)$$

where the first term characterizes the influence of the hydrostatic pressure and the second that of the shear stress.The plus and minus signs indicate that the influence of this stress may lead either to loosening of the soil or to its additional compaction.The criterion for the beginning of loosening is the attainment of a certain critical value by the soil porosity in the process of deformation. The time factor is taken into account by introducing the creep function ψ (t) into these equations.

Lomize (1970) dealt with the influence on strain, not only of σ_i and σ_m, but also of σ_j, i.e. the type of stressed state.

$$\varepsilon_i = f\left[\frac{\sigma_i}{\sigma_m + H}\left(\frac{\sigma^3}{\sigma_j}\right)^{\alpha}\right] \quad \text{and}$$

$$\varepsilon_m = f_1(\sigma_m) + f_2\left[\frac{\sigma_i}{\sigma_m + H}\left(\frac{\sigma_m^3}{\sigma_j}\right)^{\alpha}\right]$$

It is also shown that a similarity of the stressed and strained states is achieved only
2485 in eases when the type of stressed state does not change in the course of the experiment (μ_σ=const.). If, however, μ_σ changes, the loading path affects the axial alignment of the stress and strain tensors and the dilatancy of the medium. At this, the stressed and strained states cease to be similar.

Taking the stressed state into account,the condition of soil strength is expressed by the equation

$$\sigma_i = n + m\sigma_m\left(\frac{\sigma_j}{\sigma_m^3}\right)^{\alpha}$$

For a stressed state,corresponding to the value $\mu_\sigma = \pm 1$, the equation becomes the Mises-Schliecher strength criterion.

M.V.Malyshev (1969,1970) established that if this criterion is used without taking the type of stressed state into account,an excessively high value of the angle of friction may be obtained.

A formula was proposed for recalculating the angle of internal friction for the various stressed states realized in the experiment. This formula is based on the proposition that the real and ideal slip planes do not coincide in soils. Special attention was paid to the problem of the rates of deformation of soil in the limiting state. The concept of the plastic potential is employed for this purpose.

4. Investigation of the Soil Structure and the Deformation Mechanism

Considerably more interest has been attracted in late years to investigations of the structures and the structural properties of soils (Sergeev,et al, 1971). An integrated method, combining optical, X-ray,photographic and diffractometric procedures, has been worked out for investigating clayey soils. A new method of structure study consists in investigating the magnetic anisotropy of soils. Special attention has been paid to the investigation of the structural mechanical properties of loose and highly porous volcanic and lunar soils (Cherkasov,et al, 1970).

Macrostructural investigations of soils in the process of deformation have been conducted by S.S.Vyalov, and his coworkers. On the basis of their study of the konetics of the structural changes, a physical theory of soil deformation and failure was proposed. It was found that microfissures and other defects are formed in the soil and failure occurs when the extent that a volume element of the soil is damaged by fissures reaches a certain critical value.

On the basis of the propositions of the kinetic theory of viscosity, it has been accepted that the activation energy U of the soil particles is expressed by the equation

$$U = U_0 \pm U_d - U_{or}$$

where U_0= potential (initial) bonding energy between the soil particles.
U_d= change in this energy due to the formation of microfissures
U_{or}= change in energy due to rearrangement and reorientation of the particles.

Assuming that the energy distribution among the particles obeys Boltzmann's distribution law $N=N_0 \exp(-U/K\theta)$, where N is the number of activated particles, θ is the absolute temperature, and N_0 and K are constants a soil deformation equation has been obtained. The derivation of this equation is given in the paper by S.S.Vyalov, Yu.K.Zaretsky, R.V.Maximyak and N.K.Pekarskaya submitted to the present Conference.

5. Field Investigations of Mechanical Properties of Soils

Investigations of problems concerning in-situ soil tests were conducted along three lines in the Soviet Union:development of new designs of apparatus and the improvement of test procedures; theoretical substantiation of testing methods; and the accumulation of experimental data and the establishment of their correlations.

For determining the specific cohesion c and and angle of internal friction φ from penetration test data, V.G.Berezantsev had previously proposed a theoretical solution that related these parameters with the specific penetration resistance R.

In a later work (Berezantsev,et al.,1971) values of c and φ, calculated from penetration test data, were compared to values of these characteristics determined by direct methods (triaxial compression,single-plane shear and rotational shear).Values of c and φ determined by these three methods do not agree with the values calculated from penetration test data. A better agreement is reached in solving the theoretical problem with the nonlinear envelope of the limiting Mohr circles taken into account.

Along with the application of ordinary sounding,work has begun in combining the sounding and radioactivity logging methods (Ferronsky,1969). A combined apparatus (with continuous remote control) has been developed which enables the moisture content, unit weight, specific sounding resistance and soil resistance along a side surface, as well as the natural gamma-ray background to be determined.

In the field of pressuremeter techniques. much attention is being given in the USSR to the extension of the possibilities of this method, in particular to the determination, not only of deformative,but also of strength characteristics of soils by pressuremeter tests. From an examination of the elasto-plastic state of the soil surrounding a well, one work (Ruppenait and Bronstein, 1971) sets forth a theoretical solution establishing a relationship between the radial pressure the displacement of the walls of the well, the modulus of deformation the cohesion and the angle of internal friction of the soil.

It is known that the value of E obtained in pressuremeter tests does not agree with values obtained in plate tests.

The paper of Mikheev,Ruppenait,et al.submitted to the present conference,sets forth a new theoretical solution of the axisymmetric elasto-plastic problem.This solution takes into consideration the difference in the values of the compression and tension moduli.Such a solution eliminates the discrepancy between the results of plate and pressuremeter tests.

Amont the new designs of pressuremeters,the following deserve mention: 1.The NIIOSP pressuremeter whose distinctive feature is the availability of two measuring cylinders enabling the accuracy of strain measurement to be adjusted: 2. The Fundamentproject pneumoelectric pressuremeter having pulse-type soil strain gauges; this pressuremeter is distinguished for its light weight and the absence of special auxiliary loading chambers; 3. The pressuremeter developed by the Ural Polytechnic Institute in which the pressuremeter chamber has ribs that become embedded in the walls of the well. This apparatus enables the soil to be sheared along a given cylindrical surface (by rotating the ribs) simultaneously with the transmission of the radial pressure.

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