ACTIVITY REPORT OF TC 22
COMPTE RENDU DES ACTIVITES DU COMITE TECHNIQUE - 22

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SYNOPSIS: Technical Committee on Indurated Soils and Soft Rocks (TC22) has taken part in various activities including publication of some reports. The final technical report "Testing methods of indurated soils and soft rocks - suggestions and recommendations" has just been published in January, 1994. It provides some suggestions and recommendations about the existing testing methods used for investigation of indurated soils and soft rocks, based on a comprehensive study. Testing methods considered in the final report are: uniaxial compression test, triaxial compression test, direct shear test, cyclic triaxial test, consolidation test, permeability test and strength deterioration test as laboratory tests; and direct shear test and loading test as in situ tests. Measurement technique of ultrasonic wave velocity and in situ stresses are also considered along with some geophysical exploration. This report summarizes the activity of TC22 chronologically and provides an outline of the final report.

INTRODUCTION

As the construction demand expands globally either due to increasing population or rapid pace of industrialization, places suitable for construction decrease. It is often the case to encounter poor sites, unfavourable geology and other geotechnical problems. Geotechnical engineers must decide either to abandon such poor sites or to improve their technology to deal with these difficulties successfully.

Indurated soil and soft rock exhibit a wide range of material behaviour and are well known to create difficulties in geotechnical engineering. Proper evaluation of their engineering characteristics requires special attention upon investigation. In geotechnical practice, however, these materials have often been investigated with the well known criteria and testing devices used for soil and rock.

Last few years have seen a splendid growth in research activities in the field of soft rock engineering, as evidenced from the publication of research papers in various journals, periodicals and magazines.

This report provides a chronological summary about the activity of TC22 and an outline of the final technical report which has just been published.

ESTABLISHMENT AND ACTIVITY OF TC22

Under the circumstance described in **Introduction**, the establishment of ISSMFE Technical Committee on Indurated Soils and Soft Rocks (TC22) was proposed by the former President of ISSMFE, Prof.Bengt B.Broms, in 1985 to succeed the ISSMFE Technical Committee on Undisturbed Sampling and Laboratory Testing of Soft Rocks and Indurated Soils which had been chaired by Prof.I.W.Johnston, Australia. The Japanese Society of Soil Mechanics and Foundation Engineering (JSSMFE) was asked to support TC22. The Japanese Society accepted the request and recommended Dr.Koichi Akai, then a professor of Kyoto University, as Secretary of the Committee. President Broms approved the recommendation and invited the membership of the Technical Committee.

In the period from 1985 to 1989, TC22 participated in various activities. Summary is given here. TC22 organized a discussion session on "Construction Problems Related to Excavation on Soft Rocks" at the 12th ICSMFE in Rio de Janerio, Brazil, 1989. During the session the following six reports were presented:

1. General report by Dr.L.Dobereiner;
2. Field and laboratory investigation on soft rocks by Dr.D.G.Coumoulos;
3. Assessment of bearings and dips of joints in soft rock slopes by dr.P.J.Huergo;
4. Large scale vertical excavation works in Neogene sedimentary soft rock mass by Mr.A.Denda;
5. Bottom heave in open pit excavations in marly formation, with special considerations to the gypsum-marl case by Prof.C.Oteo; and
6. Stability conditions of tunnels in fissured by Dr.A.Negro.

The discussion leader, Prof.I.W. Johnston, then led the floor to discussion in which Prof.T.Shinjo also talked about the effects of drying on weathering of mudstone. The discussion leader's report on "Material properties of soft rocks" was published in Vol.5 of the Conference Proceedings. At the same time, a report of TC22 was published and distributed under the title of "Recent Advances in Soft Rock Research".

The Technical Committee has continued its activity following the term of 1985 to 1989, under the approval of the new ISSMFE President, Prof.N.R.Morgenstern, with some changes in the committee members which were recommended by the related member societies. The terms of reference for this second stage are summarized as follows.

1. Modification and/or improvement of laboratory and in situ tests on indurated soils and soft rocks.
   1) The Technical Committee (TC22) will discuss the following:
      For natural indurated soils and soft rocks,
      - Uniaxial compression tests
      - Permeability tests
      - Ring shear tests

      For artificial soft rock
      - Laboratory tests in general
   2) The Japanese local task force committee will discuss the following:
      - Consolidation tests
      - Slaking tests
      - Cyclic shear tests
      - Creep tests
      - Geophysical exploration technique
2. Organization of an international meeting on this subject.
   1) TC22 will cooperate with Hellenic Society of SMFE in the International Symposium on Hard Soils and Soft Rocks, Athens in September 1993.
   2) TC22 will organize an international meeting around the 13th ICSMFE, New Delhi in January 1994.

3. Cooperation and exchange of information about the behaviour of indurated soils and soft rocks
4. Liaison with IAEG and ISRM on this subject

In the International Symposium on Hard Soils and Soft Rocks at Athens in September 1993, organized by the Hellenic Society for Soil Mechanics and Foundation Engineering, TC22 presented an interim report of the committee activity during the second term, 1989-1993. Immediately after the opening ceremony of the symposium, a special talk of the TC22's activities was presented by Prof.T.Adachi in which also introduced were some case records of slope instability occurred at a construction site in soft rock.

During the symposium, a meeting of TC22 members was held at Athens Hilton Hotel with the symposium venue. Eleven members, including the Chairman, the Secretary and three Japanese local task force members, gathered. The main agenda were: 1) Final version of TC22 technical report; and 2) Continuation of the committee activity. It has been agreed then among the members that the final report is to be prepared not in a sense of the state of the art but in the sense of suggestions and recommendations to standardize the testing methods for indurated soils and soft rocks, regarding equipment used, sample preparation and so forth.

The final report "Testing methods of indurated soils and soft rocks - suggestions and recommendations" has just been published in January, 1994 and is available from the Japanese Society of Soil Mechanics and Foundation Engineering. The following is a brief description about the final report.

TESTING METHODS OF INDURATED SOILS AND SOFT ROCKS

Introduction

Indurated soil and soft rock exhibit a wide range of material behaviour and are well known to create difficulties in geotechnical engineering. Proper evaluation of their engineering characteristics requires special attention upon investigation. In geotechnical practice, however, these materials have often been investigated with the well known criteria and testing devices used for soil and rock.

Increase in fundamental knowledge on these materials and technological advances make it possible to re-evaluate the existing testing methods employed for indurated soil and soft rock. It should be noted that experience with indurated soil and soft rock has accumulated and that a clear understanding of these terms may exist at least on a regional basis, but the precise definition remains ambiguous.

This report is intended to provide technical suggestions for improving the testing methods widely used for indurated soil and soft rock.

Overview

Characteristics of indurated soil and soft rock

Indurated soil and soft rock pervade around the world and have given rise to numerous problems in the design and construction of geotechnical structures such as dams, bridges, tunnels and slopes.

Indurated soil and soft rock consist of a variety of materials and are sedimentary, altered or weathered rocks. Mudstone, siltstone, sandstone and shale are typical sedimentary soft rocks. They are formed suffering from insufficient consolidation, diagenesis or weak metamorphism. Cementation develops in the process of lithification but its magnitude is not great. The cementing agents and clay minerals involved are often affected by chemical changes, resulting in structural breakdown of rock. Weathering weakens hard rock in various extent and the physical and mechanical characteristics of weathered soft rock vary remarkably with the type of rock matrix and the degree of weathering. Tuffaceous rock consists of pyroclastic material. The degree of induration differs from site to site and is related to the development of zeolithic cement resulting from thermal and gravitational modification of volcanic glass.

They are known to exhibit a wide range of material behaviour, from soil to rock-like. However, the common observation on these materials may be summarized as follows:

(a) The mechanical and physical properties are somewhere between those of soil and rock.
(b) The uniaxial compressive strength ranges from 1 to 10 MPa ($<$ 20 MPa).
(c) The porosity is relatively large in comparison with the geological age and the water absorption varies from 10 to 50%.
(d) Cementation is expected to some magnitude between particles but can easily deteriorate due to environmental changes.
(e) The mechanical behaviour changes from brittle to ductile type depending on confining pressures.
(f) Pore water has a significant influence on the mechanical behaviour.

In connection with Item (f), the principle of effective stress usually holds in these materials, unlike hard rocks. Moreover, the mass behaviour is controlled by the mechanical characteristics of constituent materials rather than geological dicontinuities.

Identification of indurated soil and soft rock may be made based on their geological age but it is not always relevant. For instance, Tertiary and Pleistocene deposits in Japan often exhibit the behaviour described above and are considered to be indurated soil or soft rock; on the other hand, in North America and Europe older deposits are also considered as soft rocks. It is therefore essential to take into account not only the geological age but also the diagenetic processes the material has undergone.

Since it is out of the scope, a detailed description about the mechanical behaviour of indurated soil and soft rock is not given here. Readers can consult references, for instance, by JSSMFE (1989) and HSSMFE (1993).

Role of testing

Geotechnical investigation is performed to obtain a proper understanding of the geotechnical characteristics of indurated soil and soft rock for the purpose of construction of civil engineering structures. The extent of investigation depends on the type of a structure under consideration and its importance and scale. Figure 1 shows the investigation and test items performed for these materials. Some of them are carried out not only at the designing stage but also during and after construction.

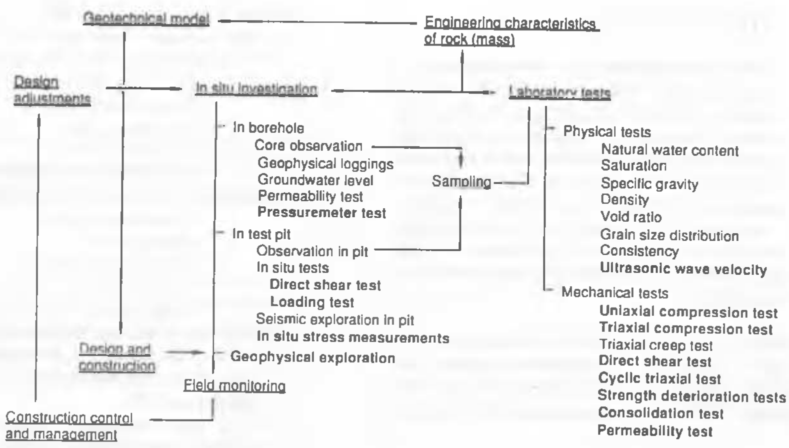

Figure 1. Geotechnical investigation and tests for indurated soils and soft rocks

Information obtained from geotechnical investigation is used for establishing a relevant geotechnical model on which design and construction are based. In other words, poor investigation could be fatal to rational design and construction. In geotechnical practice, however, these materials are often investigated with the well known criteria and testing devices used for soil and rock. the testing methods currently sued for these materials should be reviewed and modified considering their characteristics different from those of soil and hard rock. Figure 2 schematically shows the role of geotechnical tests and their re- evaluation. The followings, the objective of each testing method is extracted from the final report.

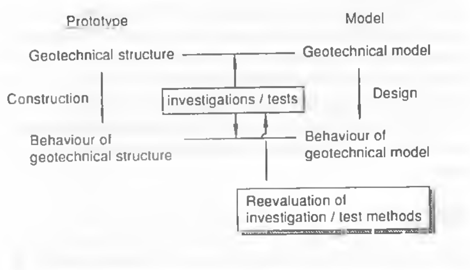

Figure 2. Role of geotechnical investigation and tests

Laboratory testing methods

Ultrasonic wave test

The objective of this test is to obtain the P and S wave velocities of soils or rocks by the measurement of ultrasonic wave velocity in laboratory.

Two testing methods, transmission method and resonance method, are adopted for its test, the latter being more popular. The pulse used in transmission method has either a high frequency (100 k to 2M Hz) or a low frequency (1 to 100 Hz) (ISRM, 1978). The pulse generator is placed on one end plane of a sample, and the receiver is located on the other end or the side of the sample. The transmission method with the receiver and the generator set on each end is described in this section.

Uniaxial compression test

The uniaxial compression strength test is the most widely used rock test in engineering practice. It is intended for strength classification and characterization of intact rock. The determination of the uniaxial compression strength is usually performed according to the "Suggested Methods for Determining the Uniaxial Compression Strength and Deformability of Rock Materials" prepared by the Committee on Laboratory Tests of the International Society of Rock Mechanics (ISRM, 1979) and the testing methodology is comprehensively reviewed in Hawkes and Mellor (1970). However, several aspects of this testing procedure are not adapted to weak rocks and are discussed in this section.

There are several factors which influence the strength and deformability of weak rocks; those related to sample preparation and testing procedure and those related to the condition and nature of the rock. The influence on the nature of the rock on strength and deformability is not expanded in this section. Emphasis is placed on a detailed interpretation of the stress- strain characteristics of weak rocks, on how the sample conditions (moisture content, anisotropy, etc.) can influence their results and on the particular testing procedures which should be considered when testing weak rocks.

Weak rocks are defined in this section as having a uniaxial compression strength between 0.25 and 25 MPa, as suggested by the International Society of Rock Mechanics (ISRM, 1978b).

Triaxial compression test

Triaxial compression test has often been carried out to investigate the mechanical properties of indurated soils and soft rocks. The main purpose of triaxial compression test is to obtain strength and deformation parameters used in the design method and in constitutive models. The principle of the effective stress can only be used under the condition that the compressibility of geomaterial is much larger than that of the pore water.

For a conventional constitutive model derived based on the continuum mechanics, an uniform deformation in the specimen is assumed. In reality, however, shear bands and strain localization can often be observed when the peak stress is approached or after it is reached.

Further research is, therefore, necessary to determine the failure parameters in constitutive models for indurated soils and soft rocks.

This section discusses a triaxial compression test method suitable for soft rock material in some details and the associated problems are pointed out. Its application and interpretation are also presented with a critical view.

Direct shear test

Direct shear test on indurated soils and soft rocks are performed to measure peak and residual shear strength. The results are employed for the stability analysis of dam foundation, the evaluation of the bearing capacity of bridge and in the limiting equilibrium analysis of slope stability (JSCE, 1991).

The most commonly used direct shear test is the box shear test. The limitations of direct shear tests compared with conventional triaxial compression tests are: (a) a specimen is progressively failed due to nonuniform distribution of stress and strain on the failure surface; and (b) a complete prevention of drainage is very difficult and the pore water pressure cannot be measured.

Direct shear tests are however widely used in the determination of shear strength parameters, c and ϕ, since the direct shear apparatus is simple and easy to operate. Furthermore, the direct shear apparatus is useful to soft rocks containing the plane of weakness such as bedding plane, crack, etc.

In case a residual shear strength at large displacements is required, either a ring shear test or a multiple reversed shear test should be carried out (JSCE, 1991).

Consolidation test

Consolidation tests on indurated soils and soft rocks are performed to understand mechanical properties, rather than deformation characteristics of the materials. It has been shown that there is a threshold pressure above which indurated soils and soft rocks exhibit different mechanical behaviours. Prior to other strength tests, it is therefore important to determine the preconsolidation pressure from the consolidation tests, since it is one of the key parameters in the evaluation of the threshold pressure described above.

Due to nature of indurated soils and soft rocks, too long a time is required in the conventional Oedometer tests. To overcome this, several new consolidation test methods are suggested, where time required to complete a set of tests is drastically reduced and automatic data acquisition system is often available. These new methods are introduced, and their problems are discussed in this section.

Cyclic triaxial test

Cyclic triaxial test is used to obtain deformation and strength properties of ground material under cyclic load such as earthquake. Soft rock has higher homogeneity than hard rock; thus, the dynamic properties are often investigated in laboratory and used in seismic design of more important civil engineering structures.

In principle, there are two types of testing methods; one is to obtain the dynamic deformation characteristics including shear modulus G and damping ratio h. For example they are utilized to evaluate the responses of ground and structure under earthquake. For important structure, the test is conducted under a wide range of strain from very small to large failure level. Another is to obtain the strength characteristics under cyclic loading. It is performed not only for short loading range such as earthquake but also for fatigue loading with longer frequency.

There are many types of tests to obtain dynamic deformation characteristics, depending on the shear strain level. They can be obtained using cyclic triaxial tests with a wide range of strain. When sinusoidal load is applied to a column sample, the relationship between stress and strain shows hysteresis loop. Shear modulus is then calculated from the slope of this loop whereas damping ratio h is defined as a ratio of energy consumed to given energy under one cycle. G and h depend on not only shear strain but also confining pressure. It is therefore necessary to take into account the stress condition in ground of interest.

Dynamic strength characteristics are investigated by applying sinusoidal load with constant amplitude, or irregular cyclic loading such as earthquake wave. It is not easy to define strength. Strain is gradually accumulated under normal confining pressure, and failure suddenly occurs (Nishi, 1984). It seems therefore rational to define strength at that state of stress and strain.

Strength deterioration tests

Slaking test

Slaking may be defined as a phenomenon of structural breakdown of a mass of indurated soil and soft rock into small size particles due to change in moisture content resulting from environmental changes such as drying-wetting. When encountered with slope instability of cuttings and embankments, landslides, mud pumping of railway roadbed and high rock pressure upon tunnel support in indurated soils and soft rocks, it is essentials to identify slaking rock and evaluate its degree and extent for the purpose of not only prevention and remedial measures but also design and construction.

Swelling test

Swelling may be defined as a time-dependent volume increase involving physico-chemical reaction with water. The swelling mechanism is a combination of physico-chemical reaction with water and stress relief. The reaction with water is usually the major contributor to swelling, but it can only take place simultaneously with or following stress relief. Swelling can occur in rock and soil. It is not possible, however, to define a boundary between rock and soil in general, and swelling rock and expansive soil in particular. Therefore, there may be certain ambiguities concerning the above boundary in this section.

The engineering problems caused by swelling are widely recognized in slope stability of cuttings, squeezing of tunnels, and underground excavations of indurated soils and soft rocks to determine them for purposes of design.

Identification test

In the design and construction of dams, bridge foundations, slopes and tunnels in indurated soils and soft rocks, it is necessary to know what extent strength deterioration has occurred to. It is also desirable, prior to actual construction of these structures, to assess the degree of strength deterioration through mechanical as well as physical property tests performed on the specimens retrieved from the site, and to understand and predict the mechanical behaviour of the material. For example, when excavating tunnels in hills or mountains, it is very difficult to carry out accurate geological investigations until actual construction begins. Instead simpler and easier methods like slaking tests discussed in the previous section should therefore be implemented. From our past experience it is known the amount of expansive clay minerals (e.g., montmorillonite) and CEC (cation exchange capacity) values may be used as indices to evaluate degree of swelling (or decrease in strength). In this section, four methods used to determine strength deterioration of indurated soils and soft rocks, i.e., X-ray diffraction tests, CEC (cation exchange capacity) tests, ignition loss tests and chemical analyses will be described with some of their filed implementations.

Permeability test

The volumetric water permeability measurement device is described in this section which is named Super Low Water Permeability Measurement Apparatus, SULPER (Araki et al., 1992). It measures water permeability of a core specimen, 50 mm in diameter and 20 mm in thickness, parallel or perpendicular to the core axis. A cell with 100 mm in diameter and thickness is often used for the water permeability measurement.

SULPER has a water tight cell to hold a specimen prepared either by coring or by compacting a soil sample and is equipped with a capillary tube at the top of the cell for measuring the water volume flowing through type specimen. Prescribed water pressure is applied to the specimen from the cell bottom in order to flow water into the specimen; the magnitude of pressure depends on the permeability of the specimen. The size of specimen is kept constant mechanically during measurement.

In situ testing methods

In situ direct shear test

In situ direct shear test is performed to determine the shear strength of soft rock mass directly. Since the strength of hard rock mass is controlled by discontinuities such as joints and bedding planes, it is usually determined from in situ shear test. On the other hand, in sedimentary soft rock, the strength and deformation properties of rock mass are relevant to those of intact rocks. The mechanical behaviour of foundation rocks are therefore often evaluated in laboratory tests such as triaxial compression tests on core samples. However, sedimentary soft rocks contain planes of weakness and in situ shear strength determined may be affected by such factors as discontinuities, inhomogenity and anisotropy. Therefore it is desirable to carry out in situ direct shear tests in order to evaluate properly the strength of foundation rock for important engineering structure, e.g., concrete dams and fill dams.

In situ loading test

The objective of in situ loading tests is to evaluate the deformation characteristics of rock mass in situ. For soft rock masses two types of in situ loading tests are mainly performed: pressure tests in boreholes; and plate loading tests in test pits. These tests are carried out under static loading conditions in order to obtain elastic parameters for design. Recently in situ loading tests are also carried out as creep tests for investigating deformation behaviour under long duration of loading or as dynamic tests for investigating rock mass behaviour under seismic conditions. Moreover, bearing capacity tests may also be conducted upon performing in situ loading tests, for obtaining some information on the bearing capacity of rock mass. This section describes the current state of in situ loading tests and their problems.

Pressuremeter test

Foundation deformations are either time-dependent consolidation or time-independent deformations which occur instantaneously after load application. For stiff, over-consolidated soils and soft rocks the immediate component of settlement is in the order of 60% of the 50 year settlement as compared to about 16% for normally consolidated soils (Eisenstein and Morrison, 1973).

To predict the instantaneous deformation of over-consolidated soils and soft rocks the theory of elasticity can be utilized. However, the modulus of deformation is very sensitive to sample disturbance and attempts to measure it in the laboratory are usually unsuccessful. Settlement studies of large buildings founded on glacial tills and soft shales based on oedometer test results have overestimated the actual settlements by factors of 10 to 30.

Pressuremeter tests have been used for foundation design in soils for several decades (Baguelin et al., 1978). This section presents recommended procedures for use and interpretation of the pressuremeter test in hard over-consolidated soils and soft rocks to determine the elastic modulus of deformation.

In situ stress measurements

Design, construction and maintenance of underground structures including tunnels and underground storage tanks are affected by many factors, such as in situ initial stresses, ground water regime, strength and deformation characteristics of rock mass, and physical properties of lining materials. Among these key parameters, in situ stresses are affected by the gravitational force (rock cover from the ground surface to the point of interest), crustal forces originated by the plate tectonics, and forces arising from the crustal movement the rock mss has experienced so far. When the rock cover is small, the effect of free boundary (ground surface) on the state of in situ stresses may not be neglected. In addition, in the vicinity of a major fault, local disturbance in the in situ initial stresses may exist. In these areas, magnitude of in situ initial stresses would vary greatly from one place to another, this possibly being reflected in the results of stress measurements (JSSMFE, 1988).

In situ stress measurements are therefore inevitable in the safe design and construction of large, important civil engineering structures. In spite of its recent remarkable advancement, stress measurements are sometimes omitted in practice, since there are no known specifications and experiences with which the results of stress measurements are directly applied as design data. There is also a general feeling among site engineers that "Stress measurements are time consuming and expensive". For the future development of in situ stress measurements, it should be shown that the accuracy of stress measurements has been remarkably improved, and that the stress measurement techniques have reached the same high calibre as in in situ shear and plate loading tests for which the specifications have already been laid out.

This section intends to classify different stress measurements methods from the fundamental principles used, and to discuss characteristics and application limits of each method. Possible problems are then pointed out in their application to soft rocks. Several case histories of stress measurements in soft rocks are also introduced.

Geophysical exploration

Geophysical exploration has been widely used in mining and petroleum engineering for developing underground resources. In the field of construction in Japan, elastic wave exploration with a reflection method and electrical exploration with a resistivity method have very often been used for about 50 years for investigation of local geology and ground water in sites of constructing tunnels, dams and bridge foundations, in landslide areas, and in areas of developing ground water. Since then, new exploration methods have been developed or the geophysial exploration techniques used in mining and petroleum engineering have been applied in construction engineering with some modification.

In recent years, geophyscial exploration is also used for evaluating engineering property of rock masses based on various physical loggings, and for classifying rock masses and grounds and estimating their geotechnical constants based on geotomography with elastic velocity, resistivity, etc. and other techniques. Technique and accuracy, of detecting anomaly in underground such as openings and of estimating the distribution of baserock and the location and the fracturing degree of fault, are being improved and put into practical use.

The current state of these exploration methods for soft rock is not much different from that for hard rock; however, an improvement is being made in exploration techniques for soft rock. This section focuses the status of geophysical exploration methods used especially in Japan.

CONCLUDING REMARKS

Technical Committee on Indurated Soils and Soft Rocks (TC22) has participated in various activities such as organizing a discussion session in international meetings, publishing technical reports and so on. It has also made an effort to promote international cooperation and exchange of information about difficulties in dealing with indurated soils and soft rocks. As an outcome of the activity from 1989 to 1993 of the technical committee, the report "Testing methods of Indurated Soils and Soft Rocks - Suggestions and Recommendations" is published which is available from the Japanese Society of Soil Mechanics and Foundation Engineering.

With regard to continuation of the committee activity, French Committee will volunteer to sponsor the TC22 activity. The past TC22 activity will be presented in the French council meeting and general guidelines and suggestions as to what is to be studied will the summarized. Possible terms of reference are retaining structures, underground excavation and collection of the field data in correlation with laboratory results.

Finally, I would like to thank all the members of the Technical Committee as well as the Japanese local task force committee for their never-ending devotion in pursuing our hard tank expected by the International Society.

Members of ISSMFE Technical Committee on Indurated Soils and Soft Rocks (1989 - 1993)

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