Laboratory Investigations, Including Compaction Tests, Improvement of Soil Properties

Recherches de laboratoires, y compris essais de compaction, amélioration des propriétés des sols

General Report

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Introduction

The papers assembled under Session 2 cover a large number of subjects. A few authors have limited the treatment of these subjects to the description of laboratory techniques, adding some test results as illustrative examples. Most of them however considered the test results of primary importance and with the help of hypotheses or theories arrived at a definite concept of the mechanical or physico-chemical behaviour of soils. A few authors used well-known techniques as a basis for the application of certain soil materials in practical engineering problems.

The subjects of the papers can be roughly divided in 5 groups:

(1) The behaviour of soil at increasing stresses (2/10, 2/17, 2/3, 2/24, 2/4, 2/28, 2/5, 2/11);
(2) Electro-osmotic, electro-chemical and physico-chemical phenomena (2/2, 2/25, 2/26, 2/16, 2/14, 2/1);
(3) Physical properties and phenomena (2/19, 2/22, 2/13, 2/7, 2/21, 2/23);
(4) Dynamic properties (2/8, 2/15);
(5) Improvement of laboratory techniques (2/12, 2/6, 2/9, 2/18, 2/20, 2/27).

(1) The Behaviour of Soil at Increasing Stresses

(a) Generalities

With the exception of 2/24, 2/28 and 2/11 the main technique used in the investigations is the *triaxial test*. The advantages of this technique, which permits the measurement of density changes and the building up of pore pressure are apparent. Many authors have used this technique in order to determine effective stresses in relation to changes of density up to the point of failure.

Some authors have paid considerable attention to the effects of pre-consolidation and density (2/3, 2/4, 2/5, 2/17) on the building up of pore pressure below and over the initial stresses and on the angle of internal friction.

Considerable progress in this direction is recorded.

It should, however, be observed that the standard triaxial practice, which has been followed in most investigations in order to arrive at conclusions, is subject to a number of objections.

The majority of difficult stability problems in soil mechanics are encountered in soft and medium soft soil layers and fine grained silts and sands.

A criterion of admissible stresses based on an arbitrarily chosen factor of safety and the failure point obtained at an arbitrarily chosen rate of deformation is not conclusive, since even much lower values of shear stress may lead to inadmissible deformations in the course of time (creep), followed by failure. The latter point has been investigated by few investigators in the past and the results so far obtained prove how necessary it is to gain further information on the shear stress-deformation-time relations.

The angle φ, based either on effective or on total shear stresses at failure does not sufficiently characterize the shearing resistance of a soil. Its application to stability problems by designers who are not informed on its intrinsic value has proved to be a dangerous procedure on many occasions.

No objections can be raised against the triaxial method as such, as it seems to be the most practical type of standard test yet available. A number of technical points should however be checked, such as the migration of pore water and the subsequent hydraulic gradients between dilating and compressing areas during the shearing process. The value of determining effective stresses from pore-water measurements could be based on these results.

A serious objection to the use of the triaxial method could be overruled if a complete series of principal stress ratios could be obtained on *one sample*. The advantage of such a procedure in the case of investigations on undisturbed samples is apparent. Ultimate deformations should be restricted to a minimum in order to reduce as much as possible the effects of remoulding or hardening by the application of a series of increasing shear stresses. The values of these magnitudes should be considered.

It is suggested that this point should be discussed.

Improvements in the direct shear test (2/24) have been noted with satisfaction. Further developments in this direction seem to be of great importance, as the uniform two dimensional simple shear strain can now be compared to the three-dimensional compression.

(*b*) *Discussion of Papers*

The *Coulomb–Hvorslev* criterion of failure has been modified by *Gibson* (2/10) on the strength of energy considerations. A true cohesion and a true angle of internal friction are introduced in this equation, the latter having been checked with the angle of inclination of failure planes in compression tests.

The energy put into the sample is divided in two parts: one part being due to the raising of the normal load; the other part to the shear movement under the shearing stress.

At the condition of failure the modified equation is written as follows:

$$\tau_f = \sigma_n' (\tan \varphi_r + g_f)$$

$$\text{where } g_f = \left(\frac{dh}{d\Delta}\right)_f$$

The parameter φ_r depends entirely on the coefficient of intergranular friction between the sand grains.

The author states that this expectation is justified by experiments of other investigators.

The writer however has found that the state of the optimal packing density of finely graded sands always corresponds to the maximum external stress, coinciding with the failure of the sample.

In that case $\Delta V = 0$, so that no part is played by the normal stresses and consequently $\sigma_n' g_f = 0$.

The criterion is thus reduced to its initial form.

The conclusions of the author therefore cannot be accepted without discussion.

Nash (2/17) using the undrained triaxial test, concludes that the compressibility and the angle of shearing resistance of a fine closely graded sand are substantially the same in the air dry and the wet state.

From a theoretical point of view it is interesting to note that pore pressure in preconsolidated samples does not build up according to the increase in cell pressure. This phenomenon may be due to the state of pre-stress between the grains, which does not allow for any substantial deformation below that stress.

In connection with his attempt to compare results of triaxial and shear box tests it is doubted whether such a correlation should be expected a priori.

In their study on pore pressure changes in two undisturbed clays *Bishop* and *Henkel* (2/3) state that in the case of a heavily overconsolidated clay a residual negative pore pressure results after removal of the shear stress and, in the presence of free water, leads to a softening of the clay. In a normally consolidated clay the residual pore pressure is positive and leads to further consolidation. The authors explain the softening of the overconsolidated clay by the increase of water content after repeated application of shear stresses.

Their conclusion, i.e. that the undrained shear strength of isotropically consolidated samples is superior to that of unidimensionally consolidated samples is evident since the hydrostatic effective pressure is smaller in the second case than in the first case.

It may be observed that pore pressure in the sample may differ from point to point, especially since shear strength applies to the state of infinitely increasing deformations.

A further objection might be raised since the response of pore-pressures in an undrained triaxial test is not entirely due to pure deviation stresses.

It follows from equation (1) that the change in pore pressure is a function of the deviation stress, whereas it may be concluded from equation (2) that it depends only on the increase of lateral pressure.

An important contribution to our knowledge of the shearing properties of soil has been made by *Roscoe* (2/24). By analysing the disadvantages of the standard shear box, the boundary conditions could be considerably improved, so that a uniform, two dimensional simple shear strain is approximatively realised.

A mathematical treatment of this case for an elastic material showed the state of stress at the boundaries and within the sample as a function of the average shear stress.

Comparison of test results obtained by means of this improved direct shear apparatus and of those obtained with the triaxial apparatus should prove highly interesting, especially with regard to the rheological behaviour of cohesive soils.

In a series of triaxial tests on sand, *Bishop* and *Eldin* (2/4) have studied the effects of isotropic and anisotropic consolidation (stress history) on the angle of internal friction.

The main conclusion inferred from test results is that no effect of stress history on the angle φ could be found in any compression tests carried out on saturated samples.

It may be observed that no such effect could be expected a priori, since ultimate stress conditions imply large deformations which cause large structural changes. Hence the effects of prestress must be lost in this procedure.

The statement on the relative small strain required to mobilise friction at decreasing minor principal stresses is of interest and wil be of great importance if used in connection with the pressure at rest, the values of which are given.

The use of the parameter $\frac{C_u}{p^n}$ is recommended as a practical quantity, since it seems practically independent of the initial density.

Tschebotarioff, *Ward* and *Philippe* (2/28) have made a special study of the compressive and the tensile strength of clays with regard to the main mineral components.

Montmorillonite showed the highest, kaolinite the lowest tensile strength, as could be expected. The water content and time hardening affected strengths and failure strains as well as the rate of the tensile strain.

Addition of sand to pure clay increased its strength. This phenomenon is explained by the greater adhesion to sand grains displaced by some clays.

The results are of importance for the study of the mineralogical, physico-chemical and mechanical strength relations of soils.

Casagrande and *Wilson* (2/5) have presented a number of important conclusions obtained from the comparison between the results of consolidated quick triaxial compression tests and those of slow tests.

The ratio of the effective principal stresses (as found by pore pressure measurements) below the pre-consolidation load was found to be higher than in slow tests. The conclusions drawn from the analysis of cell test results are particularly important since a complete range of principal stress ratios, below as well as above the pre-consolidation load can be obtained.

It has already been observed by *Keverling Buisman*, that slow tests should be carried out below the pre-load in order to allow for the decrease of the (total) principal stress ratio as a result of swelling.

On the strength of this reasoning this kind of test was always used when dealing with stability problems in connection with a decrease of the natural load (embankments of cuts, pits, etc.).

The rupture of soil samples under the combined effects of compression, torsion and tension has been studied by *Habib* (2/11).

Like *Nash* (2/17) the author has observed a volume decrease to be followed by an increase at increasing stresses.

No definite conclusions however can be drawn from test results since the failure strength seems to have been influenced by boundary conditions and the magnitude of the shear at failure cannot be read from the test data.

(2) Electro-Osmotic, Electro-Chemical and Physico-Chemical Phenomena

(*a*) *Generalities*

The electro-chemical effects observed in the electric treatment of soils are gaining the attention of many investigators. Results are often contradictory, which can be expected in a process of such an involved nature. There is a definite need for standards in order to predict the increase of strength of a soil layer by the input of electric energy through a certain amount of electrode material. Laboratory techniques should therefore be developed according to a well defined plan.

(*b*) *Discussion of Papers*

Begemann (2/2) has given some interesting particulars about the clay softening phenomenon around the anodes during electro-osmosis. The main application of this phenomenon is shown in connection with the decrease of penetration resistance of a zinc-coated foundation pile and of lateral friction of a circular shaft.

The application is especially interesting from a practical point of view, when the maximum depth of penetration of a foundation element is limited by lateral friction so as to prevent its reaching down to a hard layer.

A comparative study between the amount of energy needed drive the pile by conventional methods and by the method of softening through electro-osmotic treatment should be made in order to evaluate the relative importance of the application.

As no physical quantities of the soil are given, correlation with other cases cannot be made.

In their study on the compressibility of clays *Salas* and *Serratosa* (2/25) have treated the important subject of the relation between the physico-chemical and consolidation characteristics of clay fractions.

Consolidation, imbibition and permeability tests were carried out on betonite and kaolinite samples, saturated with different cations. Differences with bentonite were found to follow the order:

$$L_i > N_a > K > C_a > B_a,$$

i.e. the hydration capacity of the cations. With kaolinite differences were slight.

In a second series of tests, the effects on bentonite of liquids of different polar momentum were studied. Compressibility decreased with increasing momentum; secondary consolidation became extremely important.

All results are tentatively explained with the aid of the general theory of particle and double layer interaction.

Use is made of *Freundlich* diagram for a simple peptised colloid system.

However, lacking information on the intricate ionisation mechanism and the resulting double layers of the clay particles, this procedure seems highly speculative.

Aluminum anodes and copper cathodes were used by *Shukla* (2/26) in order to demonstrate the effect of electro-chemical treatment on the engineeering properties; shear strength, compressibility, permeability and compaction density showed increases.

The effect is most marked with beidellite, less with halloysite and least with kaolinite. The mineral composition is given in terms of the $S_iO_2 : R_2O_3$ and $S_iO_2 : Al_2O_3$ ratios. The author concludes that the treatment results in a deposition of aluminum hydroxide and a partial breakdown of the lattice structures of the clay minerals.

The effects of the electrochemical treatment on three clay samples and a sand sample have been discussed by *Murayama* and *Mise* (2/16).

The hardening effect due to the formation of aluminum-hydroxyde gel was observed by the authors and called electro-chemical consolidation.

In order to avoid confusion with the well-known *Terzaghi* mechanism, electro-chemical hardening or stabilisation is proposed as a more suitable expression.

It should also be observed that the width of the consolidated zone stated as 10% of the distance between the electrodes, depends on the scale of the test.

The treatment resulted a considerable improvement of the shearing properties of clay.

A stabilising process is described by *Keil* (2/14) for both cohesive and non-cohesive soils in which the permeability decreased with the addition of inorganic agents. The process is carried out by uniform mechanical mixing of the soil with fine grained sodium bentonite and a thixotropic pulp of unstable waterglass of a special composition.

The result is stated to be superior to every kind of clay soil as to impermeability, elasticity and resistance to erosion.

Results of laboratory investigations by *Barbadette* and *Sabarly* (2/1) show that substantial savings in cement can be obtained by adding clay to the grout used in the injection method. Triangular diagrams are used to represent the relation between density, viscosity and the ultimate mechanical strength for clay-cement-water-mixtures of varying composition.

(3) Physical Properties and Phenomena

(*a*) *Generalities*

Comparatively little progress has been made in the study of the physical properties of soil.

The special use made of physical quantities in order to determine statistical variations in large sand deposits deserves the attention of those interested in field investigations (2/27).

(*b*) *Discussion of Papers*

The problem of foundations in Black Cotton soil, which is subject to considerable seasonal swelling and shrinkage has been treated by *Palit* (2/19).

Laboratory investigations on remolded soil layers of different thicknesses and water contents were carried out in order to measure the swelling pressure. Some difficulties were encountered during these investigations, as the measurement of the swelling force required a displacement of the dynamometer.

Rengmark and *Eriksson* (2/22) have described the technique of measuring the swelling properties at absorption of water by a soil sample. The softening of the soil was measured by wedge penetration.

The application of cheap earth linings in order to reduce seepage losses from irrigation canals has lead *Holtz* (2/13) to make an investigation on the usefulness of soils for that purpose.

The properties of a number of soils have been investigated (permeability, shearing strength and compacted density) and their suitability has been indicated in a chart, classified according to their analytical composition.

In their paper on "Stable Density" *Dwawan*, *Khanna*, *Sharma*, *Bahni* and *Dhan* (2/7), have considered the effect of compaction on the subsequent swelling and loss of pre-stresses in the grain structure on one hand, and on permeability on the other. The authors consider the necessity of a certain degree of compaction according to the practical application (compaction for roads and runways on the basis of stability considerations; embankments of reservoirs, canals also on permeability considerations). In many cases ultimate densities are not needed, since swelling will gradually reduce these to a lower stable value. Higher moisture contents will result in a decrease of permeability and a substantial saving of the compactive effort.

Subba Rao and *Wadhawan* (2/21) have studied the effects of the temperature of dehydration on permeability changes as a function of time. Marked increases in permeability were observed at temperatures from 60° to 650° C, which might be due to a gradual loss of adsorbed water in the first instance, and a clustering of soil particles at higher temperatures.

It should however be observed, that—depending on the mineralogical composition of the soil—many reactions take place, which may alter the composition of the soil and thereby alter its properties.

In this respect the study is not conclusive.

Rengmark and *Eriksson* (2/23) have studied the effects of vapour diffusion for the special purpose of explaining the accumulation of water from a coarse grained sand or gravel layer into a finely grained soil. It was found, that vapour transport considerably increased with temperature differences and decreased with the fineness of the intermediate layer.

(4) Dynamic Properties

(*a*) *Generalities*

Dynamic properties are mainly considered with regard to vibration problems in foundation engineering. Two main questions have still to be studied: the dissipation of vibration energy (extent of soil mass in vibration) and the irreversible deformations (settlements of foundations). As a matter of fact these magnitudes should be correlated with the soil properties.

(*b*) *Discussion of Papers*

The natural frequency of vibration of foundations and the effect of vibrations on the bearing capacity of sand have been studied in model tests on sand by *Eastwood* (2/8).

The author pointed out the divergent test results obtained by other investigators.

Eastwood found that the natural frequency differs in accordance with the intensity of the dead load, dimensions of footings and the wet or dry state of the sand.

The author has found, that the formula:

$$N = \frac{1}{2\pi}\sqrt{\frac{F}{M}}$$

does not fit test results and that the assumption $M = M_f + M_g$ leads to erroneous conclusions, as the spring constant F and the mass of soil invibration M_g cannot be considered as constants.

It is observed, that the formula cannot be applied such as is derived for a vibrating system, in which conservancy of energy is maintained. In sand masses however energy will be dissipated in frictional effects due to irreversible movements of the particles and heat. The effect of different densities should therefore be taken into account.

The behaviour of sand affected by vibrations has been studied by *Mogami* and *Kubo* (2/15).

It is suggested, that under the influence of vibrations the strength criterion may be put as a modified expression of the *Coulomb* equation, by the introduction of the quantity u as a reducing factor of the effective normal stress.

No account however is given of the basis of this criterion, though the fundamental reason is recognised as being due to the vibrational movements of the particles.

(5) Improvement of Laboratory Techniques

(*a*) *Generalities*

Laboratory techniques seem to have attained a qualitative optimum, since few substantial novelties are published. The papers (2/12) and (2/20) represent exceptional features in this respect.

(*b*) *Discussion of Papers*

Haefeli and *Zeller* (2/12) described a new method of model investigations for three-dimensional seepage problems. By the use of glass spheres of 2 mm diameter and glycerine the disturbing influence of the capillary zone is practically ruled out.

Though the model-tests shown, deal only with problems connected with the effect of a horizontal filter well on groundwater movement in steady flow, the method seems to be especially suited for the study of non-steady flows, such as in reservoir dams at rapid draw-down of the water level.

Another contribution to the improvement of the hydrometer technique is the torsion balance described by *Dhawan*, *Jagat Ram*, *Khanna* and *Handa* (2/6).

A hydrometer technique using special graph paper and nomogram is described by *Gandahl* (2/9).

A triaxial apparatus for tests on gravels with particle sizes of 2 inches or more is described by *Noell* (2/18).

A close study of methods for the measuring of capillary permeability and height of capillary rise has been made by *Peltier* (2/20) who derived several formulae on the basis of *Darcy*'s law.

Test results seem to accord with these formulae quite well. A new (L.C.P.C.) capillarymeter is proposed which proved to be practical in use and permits the determination of both physical quantities separately. It seems to be especially suited for capillary heights of rise from 1 to 20 meters.

No indications on the replicability of test results are given.

A study on correlations between a number of physical quantities ("peak" diameter of grain size distribution, the natural, maximum and minimum dry densities and the permeability) of sand samples from alluvial deposits of the Mississippi valley has been made by *Shockley* and *Garber* (2/27).

The statistical material shows a rather high coefficient of correlation between the maximum and minimum dry densities and the natural dry density on one hand and the "peak" diameter on the other hand.

The authors are well aware of the limitations of the procedure. However, in view of the fact that some of the factors governing the nature of sand deposits obey the same physical laws, statistical correlation to some degree should be expected and therefore the proposed method of investigation should be encouraged.

(6) Conclusions

(*a*) Papers belonging to this session cover a large member of subjects. They are roughly divided in 5 groups:

(1) The behaviour of soil at increasing stresses;
(2) Electro-osmotic, electro-chemical and physico-chemical phenomena;
(3) Physical properties and phenomena;
(4) Dynamic properties;
(5) Improvement of laboratory techniques.

(*b*) By far the most important subjects of group 1 are introduced by the authors of six papers who used the triaxial test for their investigations.

With regard to all quick tests on clay (no drainage being allowed) the following points have to be considered:

(α) Deformations under compression are not homogeneously distributes, hence stress-gradients in the pore-water will develop and pore pressures at the boundaries of samples cannot be considered to represent the state of stress in the major part of the sample involved in the process of shearing.

(β) The rate of deformation at increasing shear stresses may have considerable effects on strength.

(γ) Results of tests in terms of ultimate strength only (critical stress ratios or shearing strength or angles of internal friction) are of little value since design in foundation engineering should be based on permissible stresses derived from the ratio between "stress-deformation-rate of deformation" (D–γ–τ ratio), obtained from test-results.

The magnitudes:

variables τ = shear stress
γ = shear strain
D = rate of (shear) strain $= d\gamma / dt$
constants η = coefficient of (apparent) viscosity
τ_f = equilibrium shear stress

have the advantage that they represent well-defined magnitudes with a physical meaning[1]), contrary to such magnitudes as e.g. the angle φ, the cohesion, the shearing strength, which often show a lack of proper definition.

(δ) As the behaviour of soil-material depends on so many factors, attempts have been made to simplify experimental investigations as much as possible by the introduction of constant magnitudes.

Taking those mentioned in the foregoing section as an example, either τ, γ or D may at the same time be taken as constant magnitudes in experimental investigations.

τ = constant, represents the case of controlled stress, whereas D = constant represents the case of controlled (rate of) strain.

γ = constant, which by analogy could be called the case of controlled deformation.

[1]) Actually the strain and the rate of strain should be related to the permanent part of the deformation γ_p. It is suggested however, that for practical purposes the elastic part of the deformation of soft soils could be neglected in consideration of the total deformation γ_t.

(ε) Current methods of investigations on D–γ–τ ratios, of soils following one or more of the preceding systems of control, should be subjected to a critical examination with regard to their uniformity of stress and deformation distribution and of boundary conditions during the execution of tests.

An example of such an examination is given in Paper 2/24.

For practical applications the behaviour of cylindrical samples in compression tests offers many advantages, since undisturbed samples usually are obtained in this shape. It is however extremely rare, that replicas of undisturbed samples are available in a sufficient number to obtain a complete range of D–γ–τ ratios.

It is therefore of great interest to study the effects of a range of constant values of increasing magnitudes (of either D, γ or τ) *on one specimen only*.

It is suggested that the effects of *pre-consolidation* should be reproduced by the results of tests as D–γ–τ relations, similar to the behaviour of samples subjected to a range of normal stresses in the consolidation test.

In order to reduce the effects of *softening* or *hardening* at increasing deformations or rates of deformation, certain limits —if possible related to the practical case under consideration— should not be surpassed.

(*c*) In the field of the applications of the electric treatment attention is mainly concentrated on electro-chemical effects in soils.

The understanding of the phenomena of hardening by means of suitable electrodes still is limited by our lack of knowledge of the behaviour of soil colloids.

It is to be expected that no substantial progress will be made until the mechanism of these physico-chemical phenomena is known for a wide variety of soils.

In order to predict the effects of the electro-chemical treatment on the soil in situ, a suitable laboratory technique should be worked out.

Apart from this procedure, field tests on a reduced scale seem to offer greater practical possibilities. Discussion of this point however is outside the scope of this report.

The same considerations could be applied to the methods of adding chemical agents to the soil. Here also practical applications either on a laboratory or field scale are far ahead of the understanding of the fundamental concepts of physico-chemical behaviour, as in the case of the effects of ion-exchange on mechanical soil properties.

(*d*) The behaviour of saturated soil masses in vibration offers considerable difficulties for two reasons. We still lack sufficient information on the dissipation of vibration energy into the soil, due to irreversible deformations (displacements of soil particles) and heat. The extent of these deformations should in any case be correlated to the properties of the soil.

Proposals for Discussion

(1) *The extent of hydraulic gradients of pore pressure in the quick triaxial test as a consequence of inhomogeneous deformations.*

(2) *The effect of the rate of deformation on the shear strength in the quick triaxial test.*

(3) *The advantages of using well defined physical magnitudes such as:*

τ = *shear stress*
γ = *shear strain*

D = *rate of shear strain* = $d\gamma / dt$
η = *coefficient of (apparent) viscosity*
τ_f = *equlibrium shear stress.*

In stead of magnitudes such as: the angele φ, *zhe cohesion and the shear strength, in order to describe the behaviour of samples in compression.*

(4) *A critical examination of current methods of investigation with regard to their uniformity of stress and deformation, and of boundary conditions.*

(5) *The effects of applying a range of increasing stresses on one specimen, with special reference to the reproduction of the pre-consolidation load, to softening and herdening and the practical limit of the applied stresses.*

(6) *The causes and extent of energy dissipation in soil masses subjeted to vibrations.*

Sommaire

Les rapports ont été répartis en 5 groupes selon leurs sujets. Un aperçu des points principaux a été donné pour chaque groupe.

Chaque rapport a été traité séparément, ses caractéristiques ont été indiquées, ainsi que les points susceptibles de faire l'objet de discussions.

Pour conclure le rapport passe en revue ceux des sujets traités qui offrent un intérêt général.

Sujets de discussions

1° *Importance des gradients de pression de l'eau interstitielle dans les essais triaxiaux rapides, résultant des déformations non-homogènes de l'échantillon.*

2° *Effet des variations de la vitesse de déformation sur la résistance limite au cisaillement dans les essais triaxiaux rapides.*

3° *Avantages de l'introduction de grandeurs physiques bien déterminées telles que:*

τ = *la contrainte de cisaillement*
γ = *la déformation de cisaillement*
D = *la vitesse de déformation* = $d\gamma / dt$
η = *le coefficient de viscosité (apparente)*
τ_f = *la contrainte-équilibre de cisaillement à la place des grandeurs: angle* φ, *cohésion et résistance au cisaillement aux fins de décrire le comportement des échantillons pendant l'essai de compression.*

4° *Examen critique des méthodes courantes de recherche, considérées sous l'angle de l'uniformité de la distribution des contraintes, des déformations et des conditions aux limites.*

5° *Effet résultant de l'application d'une série croissante de contraintes sur un seul échantillon, par rapport à la possibilité de reproduire l'état des contraintes dans le sol; l'amollissement, le durcissement et la limite pratique des contraintes appliquées.*

6° *Causes et extension de la dissipation de l'énergie de vibration dans les masses de sol soumises à des vibrations.*