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## Geological aspects of geotechnical engineering

### Aspects géologiques de génie géotechnique

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**SYNOPSIS** Analytical methods used in soil mechanics are based on considerable simplification of geological structure. The influence of geological conditions on geotechnical engineering is discussed. The inverse - influence of Man's activity on geological conditions - has become evident at present. Therefore, the knowledge of engineering geology and some other geological disciplines is important for geotechnical engineers. Geotechnical engineering should be separated from civil engineering and be engaged in foundation, fill, dam, and subsurface problems. Geomechanics is one of the bases of geotechnical engineering; it is concerned with studying the mechanisms of geological processes. Use of back analyses for integral evaluation of earthen masses, the observational method, and monitoring for decreasing the time and costs of construction are discussed. Combating geological hazards is one of the important geotechnical problems in the near future. Discussion topics are commented upon.

#### INTRODUCTION

It is a great honor for me to deliver this Theme Lecture before the International Conference on Soil Mechanics and Foundation Engineering - the highest forum in our field of science. Two circumstances make my task more responsible.

Firstly, this is the jubilee conference when we sum up the results of the enormous progress in the field of soil mechanics and foundation engineering during half a century all over the world. I am among a few of this audience who presented papers to the First International Conference in 1936 and, thereby, I can rank myself among the participants of the heroic stage of soil mechanics history.

An immense road almost fifty years long from Harvard to San Francisco passed through many capitals and cities of the world - Rotterdam, Zurich, London, Paris, Toronto, Mexico, Moscow, Tokyo, and Stockholm. Many important events and great changes took place during this time, many prominent scientists astonished us with their discoveries, and the need of our knowledge grew everywhere. Our science developed in front of the elder generation of soil mechanics experts and became now one of the leading sciences of the civil engineering profile.

Secondly, the Theme Lectures of this Conference should have a new, particular feature; they are not meant to be State-of-the-Art or General reports but more the type of papers presented as Rankine or Terzaghi lectures. I understand this requirement as the wish of the Organizing Committee of the Conference to deal not so much with the past or the present as to look forward, to think about the future, about the ways of further development of our science. These ways must be adequate to problems standing before the human society even now; they will

be of prime importance in the turn of the century.

We live in a very dynamic, difficult, and interesting time. The duration of this century is negligible compared with the lifetime of humanity. Nevertheless, enormous man-induced changes in nature, planned and unforeseen, reasonable and unreasonable, occurred during the present century. Similar environmental changes would need many milleniums and even millions of years in normal natural conditions; they take place nowadays during the lifetime of one generation. These changes are concerned directly with this lecture.

Our present is not like our past, and the future will not be as the present. We apply to history just to understand better our present state and to conceive the forthcoming problems.

The beginning and the end of the last 50-year period were important turning points in soil mechanics thinking; they deserve to be analyzed.

Terzaghi's brilliant discovery of soil mechanics, marked by publication of "Erdbaumechanik auf bodenphysikalischer Grundlage" and "Principles of Soil Mechanics" in 1925, gave a great impulse to civil engineers dealing in foundations and earth structures. They obtained, lastly, a new tool enabling them to calculate the mysterious earth; true, as a material with intricate properties that change depending on stress state and time.

The idea that earth may be treated as an ordinary building material like concrete or steel was attractive. Thus, soil mechanics became a kind of strength of materials applied to soils. In early investigations soils were considered exactly as a material, their structure being of no importance. This is confirmed by methods of soil preparation for

testing; they were dried, ground, sifted, and mixed with water.

However, soil mechanics, even at the earliest stage of its development, was never like soil science, dealing with soil properties only; problems pertaining to soil masses were considered as well, such as stability of slopes, pile foundations, retaining walls, flow nets, etc. It should be particularly emphasized that homogeneous soil and the simplest geological structure were meant in all these problems.

It could not be otherwise in that stage of study; our aim is not to criticize but to understand the state of the problem. Creation of a science on the strength of such material as soil was a great progress. We all remember the triumphant road of soil mechanics. It associates in our memory with names of such prominent scientists as Bishop, Bjerrum, Casagrande, De Beer, Florin, Gersevanov, Goldstein, Kerisel, Lambe, Leonards, Mitchell, Murayama, Peck, Roscoe, Schultze, Seed, Skempton, Suklje, Taylor, Terzaghi, Tschebotarioff, Tystovich, Whitman, and many others. However, knowledge of strength of materials enables the calculation of comparatively simple elements of structures or machines but not the structures or machines themselves. Sciences of subsequent level such as structural mechanics or science of machines serve this purpose.

Unfortunately, the situation regarding earthen structures and foundations was otherwise. Soil mechanics and conclusions drawn through consideration of simple soil models were applied to complicated natural conditions. The available mathematical machinery was used and numerous design methods were proposed which have rapidly and extensively spread. These two circumstances are interrelated since difficulties of the mathematical analysis required accepting a number of assumptions, one of which was simplifying the geological setting.

#### GEOLOGICAL IMPACT ON GEOTECHNICS

Euphoria caused by the possibility to use freely engineering methods in calculation and design of foundations and earth structures was not long-lasting. Considerable schematization of geological structure was needed for applying soil mechanics solutions, limited by a number of simplifying assumptions and using mathematical methods; therefore, the obtained results, in case of complicated geological and hydrogeological conditions, were far from reality.

Two types of soil mechanics problems should be distinguished: (1) earth-fill structures; and (2) excavated earth structures and foundations of engineering structures.

In case of earth-fill structures (earth dams, embankments, roads, airfields, and other fills), the operation practice makes it possible to choose the type, design, reference sections, and materials; such performance may be likened to design of structural elements. In case

of excavated earth structures (cuts, tunnels, large underground openings, etc.), and foundations of engineering structures, dams, etc., the work is carried out in an environment formed during a long history of geological development. Its result depends essentially on disposition, mode of occurrence, and properties of soil bodies. It is certainly possible to improve the soil properties by means of dewatering, grouting, piling, etc., in accordance with information obtained as a result of site exploration. However, such improvements fail in efficiency in a number of cases owing to insufficient knowledge of geological conditions and their substantial simplification on boring results interpretation, due to the unrevealed role of minor geologic details and inevitable uncertainties associated with performance forecast at given sites and, finally, with difficulties of execution control. The misuse of soil mechanics is the well known result of disregarding the physical side of the process and of overestimating the mathematical methods. Such performance may be likened to a case of construction using the existent complicated structures, when the type and the elemental properties of these structures are known insufficiently and when only a little poorly calculable and controllable strengthening may be effected.

Attention is deserved by the fact that soil mechanics in its initial stage of development produced better results in northern regions laid down by young Quaternary deposits than in southern areas of the northern hemisphere, composed by overconsolidated Tertiary clays. Later on, understanding of the nature of overconsolidated clays became possible based on concepts of stress history and geological pressure. They led to important conclusions on recoverable strain energy locked in the clay shales by diagenetic bonds (Bjerrum, 1967). Study of the lithified overconsolidated clays and clay shales is also of great paleogeographical significance for reconstructing the formation conditions of these rocks and the distribution of vertical and horizontal stresses acting in the past.

The tendency towards misuse in soil mechanics, existing undoubtedly even in our days, is stimulated by a tradition to publish results of successful use of soil mechanics and to gloss over the failures. Only the cases of serious failures and collapse of large structures gain notoriety, especially when they are accompanied by human victims and glossing over becomes impossible.

As a rule, engineers are between the technical Scylla prompting the construction of more solid structures if the geological conditions remain uncertain, and the economical Charybdis insisting on cheaper decisions.

A civil engineer dealing with such materials as concrete, steel, plastics, or wood is in a much better position, since the science supplied him by calculation and design methods may serve as reliable maps for a ship to pass safely the strait between these insidious rocks. But the subsurface engineer dealing with soils of unsafe composition, weak or unstable, having complicated geological history,

is in a much worse position, and the world learns often about a recurrent shipwreck when the vessel has been destroyed against the technical Scylla. Unfortunately, the cases of unnecessary costs associated with ignorance and compensated by useless constructions or surplus structure dimensions are less known, and economical Charybdis remains thus in the background.

Geotechnical engineering differs from the other types of engineering such as structural engineering, hydraulic engineering, mechanical engineering, etc., by the extreme variety of materials used and a very limited possibility to select them. Properties of materials we deal with change in very broad ranges not comparable with those for conventional building materials such as iron, brick, cement, or timber. Coniferous timber from Canada and Siberia or steel channels from the US and India have equal properties. This may not be said about soils and rocks. The same primary material sedimented simultaneously on the bottom of the lower Cambrian Sea on the continental platform of the Baltic Shield and in the geosyncline of North America. Half a billion years elapsed since its sedimentation produced quite different materials - the plastic blue clay in the neighborhood of Leningrad and the clay shales of the Appalachians. Quite different rocks may come out even within the same sedimentation region; examples are found in the thick series of the Middle-Jurassic lower terrigenous geosyncline formation in the northern Caucasus. In the northern foothills it is exhibited mainly as gray clays; nearer to the Caucasian ridge this series turned into semi-hard schistose clays and clay shales as a result of weak regional metamorphism, and farther south into hard phyllitic shales. Therefore, determining the age of rocks, so important for geologists, has little significance for the geotechnical engineer and much more important is determining the state of rocks. From these facts it transpires that for identifying soils we have to describe them in detail and perform diverse analyses.

By the beginning of the last 50-year period, the tendency towards consideration of geological factors was established, first from the position of soil structure and then that of geological structure. An understanding of the necessity for studying undisturbed soil samples arose, concepts of overconsolidated and sensitive clays were worked out, etc. A number of papers presented to the First International Conference on Soil Mechanics, held in 1936, reflect the tendency to consider the soil structure.

Further investigations over the past 50 years broadened and enriched the soil mechanics arsenal. New directions of the science were formed, such as mechanics of frozen, structured, partly saturated, collapsive, sensitive, anisotropic, expansive, stabilized, organic, and other soils. New approaches to solving the problem were worked out, such as critical state soil mechanics, where the material behaves as a frictional fluid, and neither compaction nor dilation occurs (Schofield and Wroth, 1968); non-linear soil mechanics; mechanics of particulate media, where the soil is not

substituted by a simplified continuous medium, but appears in its inherent discrete nature and is treated as a stochastic system (Harr, 1977). Owing to new investigations made during the past decades, soil mechanics enriched its content and passed to the level of elasticity or plasticity theories applied to the soils.

Terzaghi (1961) explained the important difference between structural engineering and applied soil mechanics in the following way: "Many problems of structural engineering can be solved solely on the basis of information contained in textbooks, and the designer can start using this information as soon as he has formulated his problem. By contrast, in applied soil mechanics a large amount of original brain work has to be performed before the procedures described in the textbooks can safely be used. If the engineer in charge of earthwork design does not have the required geological training, imagination, and common sense, his knowledge of soil mechanics may do more harm than good. Instead of using soil mechanics he will abuse it".

The same could be applied word-for-word to structural engineering too in that hypothetical case if it possessed quite elaborate elasticity and plasticity theories but had no structural mechanics as a science on principles and methods of strength, deformability, stability, and vibration analyses of structures.

Structural mechanics is comparatively a young science, which originated at the turn of the 19th Century. However, long before its beginning excellent bridges and aqueducts were built in antiquity, and stately cathedrals were erected in the Middle Ages without knowledge of structural mechanics. Naturally, one had to do such work based only on intuition, experience, a large amount of brain work, construction training, imagination, and common sense. Only men of genius could fulfill such work. In our days calculation of similar complicated engineering structures is a routine work, and study of calculation methods is included in the structural mechanics syllabus for undergraduates of civil engineering departments.

#### GEOTECHNICAL IMPACT ON GEOLOGY

By this somewhat conditional heading, changes in geological environment induced by Man's technical activity during the last epoch are understood. Man began to transform nature from the beginning of the Holocene, approximately nine or ten thousand years ago, when he moved from hunting and food gathering to agriculture and cattle breeding. This important transition from food appropriation to food production, called the Neolithic Revolution (Childe, 1948), was accompanied by population explosion. Virgin dense forests in a vast longitudinal strip stretching through North Africa and South Asia, and later on in South Europe and Central America, were cut down and burned for growing cereals and grazing cattle. Later, these primitive fields and pastures gave up, in part, their place to steppes, and later on to semi-deserts and

deserts due to desertification. Man's activity became a powerful geological agent changing the earth's face with an increasing rate and intensity. Island-like districts of human technogenetic influence on nature broadened, became more intensive, merged together, and enveloped the greater part of the earth's surface.

Technogenetic transformation of the earth's surface is quite evident at present and will be a most important problem in the near future. This problem refers directly to us since much depends on how reasonably the subsurface engineers carry out their tasks. To this end, the engineers must know what near and remote consequences will be induced by their activity in the geological situation. The problem of the technogenetic influence on the geological environment is enormous, and even a concise review in this lecture is impossible. Therefore, I shall confine myself to several examples.

The intensive deforestation of large areas causes soil erosion, barring of mountain slopes, formation of deserts, landslides and mudflows, shallowing of rivers, disastrous floods, accelerated washout, extending the big river deltas, etc.

Quarrying and mining are man-made rock breaking, the latter being made at depths unusual for natural processes. The amount of displaced substances is measured by thousands of cubic kilometers annually and continues to increase rapidly.

New technogenetic forms of relief have been formed - areas of soil erosion and sand deflation due to deforestation, badlands, man-induced deserts, accumulative ridges, terraced slopes, roads, dams, silted water reservoirs, deep opencast mines, waste dumps, spoil heaps, tailing piles, etc.

Big water reservoirs, irrigation, leakage from water supply and sewer lines, and drainage change considerably the ground water table. In cities supplied with water from remote sources, the dome-like rise of the groundwater table occurs and swelling of expansive clays or settlement of collapsible loessial soils may take place. In cities supplied with underground water, deep cones of influence are formed and consolidation of clay strata, due to the increase of effective stresses or restoration of karst processes, are possible. The chemical composition of underground water changes due to pollution, leakage, waste storage, and infiltration of solutions.

Landslides in highly developed countries are caused mostly by unreasonable human activity, e.g. by excessive undercutting of slopes, deforestation, high pore pressure after watering, high seepage pressure due to rapid drawdown of water reservoirs, etc.

Local base levels for the upstream parts of drainage networks are formed due to construction of dams; river bed erosion is stopped and deposits begin to accumulate. River regulation stops lateral erosion. Intensive washout of banks accompanied by landslides

occurs at water reservoirs in plains. Diversion of the runoff from one basin into the other through the construction of hydroelectric plants changes the drainage system. A noticeable part of the river runoff is used by Man for his needs even now; undoubtedly, most of it will be used repeatedly in the future, and the river erosion will be preserved in the upper reaches only.

Many sections of shores are protected with embankments, piers, breakwaters, and quay walls from abrasion. Marshes are drained in the Netherlands and the shallow sea bottom is filled up in Japan and some other places. The process of shore protection and winning of sea bottom on shelves will continue. As the length of protected shores increases the abrasion role will diminish.

Technogenetic subsidence of the ground surface results from mining and extraction of water, gas, and oil. Man induces earthquakes by creating big water reservoirs owing to increasing the load on the ground surface and by increasing the pore pressure, i.e., decreasing the effective shear strength of rocks.

During more than 2.5 billion years the same set of rocks was formed as a result of consolidation of sediments. These were clays and argillites, sands and sandstones, limestones, dolomites and marls, volcanics, diatomites, coals, salts, etc. Technogenetic sediments formed during past millenniums differ markedly by their great variety. They represent such an independent genetic type as, e.g., alluvial or volcanic sediments. Technogenetic deposits are distinguished by their origin conditions (arable lands, fills, refuse, waste, etc.) and material content (terrigenous, chemogenetic and organogenetic deposits, organomineral mixtures, etc.). They do not depend on the environment (location of parent rocks, hypsometric position, climate, tectonics, sedimentation conditions, etc.) and contain man-made rocks (brick, concrete, metals, plastics, rubber, glass, ashes, asphaltic concrete, slags, etc.). The thickness of technogenetic sediments in different localities varies considerably; in some places it reaches several tens of meters.

Not only the scales but also the rates of technogeneous transformation of the earth's surface are amazing. It suffices to say that "At present, the earth's surface occupied by dwellings and other engineering structures account for 4% of dry land and will comprise 15% by the year 2000" (Sergeev, 1982). Naturally, these are average figures and in developed countries the part occupied by structures, roads, etc., is considerably higher; thus, in Great Britain this ratio (14 to 15%) was reached even by the end of the 1960's (Avrill, 1969).

There are no genuine Quaternary areas on the earth; acid rains fall even in Greenland and an increased content of DDT was detected in penguin meat in the Antarctic. The most intensively transformed regions now are megalopolises - extremely urbanized strips of highly concentrated population, as on the

Atlantic shore of the USA; it stretches from Boston to Washington for a distance up to 1000 km and reaches in some places 200 km in width. Smaller megalopolises are in Europe, Asia, and America. The dimensions and the number of the megalopolises will increase.

Enormous changes now in progress on the earth under the influence of a new, previously unknown, geological agent - human activity - permit the Holocene to be considered the transition epoch from the Quaternary or the Pleistocene to the Quinary or the Technogene (Ter-Stepanian, 1983).

Man will creep deeper into the earth's crust searching for mineral products, he will use wider underground openings for practical purposes, and he will construct more boldly in unpopulated regions, in areas where soils with intricate properties (frozen, collapsive, weak, expansive, sensitive, and others) are widespread. Requirements upon our profession will increase constantly.

#### SOIL MECHANICS AND ENGINEERING GEOLOGY

Two consequences follow from the above. The first consequence is that a complicated situation has arisen in geotechnical engineering. On the one hand, well elaborated soil mechanics is available. It is able to solve different theoretical and practical problems where the soil appears as a material. The list of these problems was enlarged essentially due to usage of numerical methods, mainly the finite element method with application of computers. On the other hand, there are certain difficulties for adequate presentation of the real soils with their complicated development history and multiple bonds in the form of design variables.

The absence of a subsequent level science which could play the same role relative to soil mechanics as structural mechanics plays with regard to the elasticity, plasticity, and creep theories begins to tell. The absence of such science can not be compensated by further development of soil mechanics since not only application of engineering principles is needed here but an approach from the standpoint of natural history too.

The second consequence consists in the fact that the ever-increasing technogenetic pressure on nature requires the overtaking development of the above-mentioned science which could serve as a key to understanding the remote results of the human activity and to forecasting the changes of the earth's face; the chief thing is to direct engineering activity expediently in order to make reasonable Man's impact on nature. Engineering Geology is the science of the geological cycle that deals with these problems. It is the most ancient field of geological activity, going back to the time when Paleolithic Man had to estimate the strength of the cave roof or to choose a flint or an obsidian among other stones. This science experiences a rebirth in the present century. Many prominent scientists added their names to the history of Engineering Geology - Arnould, Berkey, Denisov, Fukuoka,

Hutchinson, Jaky, Legget, Lomtadze, Maslov, Müller, Popov, Savarensky, Sergeev, Stini, Tavenas, Terzaghi, Thomson, Varnes, Zaruba, et alii.

It can not be said that necessity for a new approach is a discovery. By contrast, there are numerous confirmations that such a question was moved and not once. It took mainly the shape of the problem of interaction between soil mechanics and engineering geology, or speaking more narrowly and concretely, it developed into the question of whether a specialist in civil engineering must know engineering geology and in what degree.

One of the first to put this question was probably the American engineering geologist C. P. Berkey (1929). He described the role of engineering in the practice of engineering geology as follows: "The position of a geologist is analogous to that of an advisor to the court. He may formulate the opinion but never render the final decision... It is his duty to discover, warn, and explain, without assuming the particular responsibility of the engineer who has to design the structure and determine how to meet all the conditions presented and stand forth as the man responsible for the project."

In the beginning of the fifties, Burwell and Roberts (1950) stated in the same way their opinions concerning the function of the engineering geologist in a large engineering organization. However, this standpoint was not generally accepted. The Soviet engineering geologist, N. N. Maslov (1949), at that time noted that engineering geology makes it possible to solve all problems which have arisen by using applied soil mechanics, which thus becomes its main basis. This scientist showed practically the efficiency of simultaneous use of results supplied by both disciplines.

In the beginning of the sixties, Banks (1961) considered the expediency of labor division between the civil engineer and the engineering geologist. At the same time Terzaghi (1961b) published his important paper, entitled "Engineering Geology on the Job and in the Classroom," where the significance of engineering geology in soil and rock engineering was outlined. Terzaghi considered that Berkey's assertion concerning the role of the engineering geologists was correct; however, he emphasized the importance of full appraisal of the inevitable uncertainties having engineering significance and added that "The more an engineering geologist knows about engineering the better he is qualified to detect the weak spots in a project resulting from geological conditions which had escaped the attention of the engineer. He will also be in a better position to find out where significant additional information could be obtained by supplementary borings. However, under no circumstances should he try, or be asked, to tell the engineer how to proceed."

He ends his paper by a layout for a one-semester course (40 one-hour lectures) in engineering geology for civil engineer departments. The material is divided into two parts: Engineering aspects of geological topics, and geological

aspects of engineering operations. It is assumed that the students are already familiar with the elements of physical geology. Terzaghi states that "In the realm of earthwork engineering, the instances are rare in which an engineering problem requires the services of an engineering geologist, provided the civil engineer is adequately trained."

Concerning this statement, Ripley (1962) remarked that whether professional geologic advice is necessary or not depends on three factors: The relative importance of the project, the complexity of the regional geology, and the extent of geological training and experience of the civil engineer concerned. The first two points are of objective significance and, hence, beyond our control. Regarding the third point, it is obvious that not only the necessity but the efficiency of the professional geologic advice as well strongly depends on the geologic training of its recipient.

In order to avoid misunderstanding in the following, the lecturer likes to emphasize that he is not against professional geologic advice when necessary, but he is against the acknowledged incompetence of subsurface engineers in respect of geological conditions of the site.

In the beginning of the seventies, the problem was discussed by Dearman (1971). He defined engineering geology as "the science or discipline of geology applied to design, construction, and performance aspects of engineering structures in and on ground." Dearman points out that engineering geology is "not some special type of geology but the whole spectrum of the science, including paleontology, stratigraphy, structural geology, and petrology."

In the beginning of the eighties, the Engineering Group of the Geological Society of London discussed the question, "Should engineering geology be taught and, if so, how?". No definite answer was obtained. Soon afterwards Henkel (1982) delivered the Rankine lecture on "Geology, Geomorphology, and Geotechnics," where he discussed the role of geomorphology as a link between the geologists and geotechnical engineers. As all of his precursors, Henkel joins with Berkey's concept on the geologist's role, which is to discover, warn, and explain while the engineer should design, decide, and be responsible for the project.

We see that leading scientists in our profession practically every decade returned to the same problem, whether a civil engineer should master engineering geology or not. They found repeatedly that it is unnecessary and that the civil engineer must be content with engineering geologists' expert opinions. In spite of their unanimity, the problem was put repeatedly again.

"Nothing is ever settled until it is settled right," (Kipling). If so, the problem is withdrawn. If the problem is settled incorrectly it will emerge again and again. All eternal questions have the same background.

The point is not the incorrect thinking of prominent scientists but changes in our life. Probably the solutions proposed in the thirties and even the sixties were quite correct for that time and civil engineers with a broad spectrum of training had to be satisfied with geological consultations. But, it will not be appropriate for the future, when Man's impact on nature will be stronger.

In my opinion, fundamental knowledge of engineering geology is necessary for a subsurface engineer to the same extent as knowledge of physiology for a surgeon. They both can not be satisfied by expert opinions and must understand themselves their action and its result. The value of expert opinions expressed by highly skilled specialists can not be denied, especially in involved cases, but the engineer in charge of important decisions should not act by prompting only.

#### TRAINING OF SPECIALISTS IN GEOTECHNICAL ENGINEERING

There is a rather strange situation in the field of geotechnical engineering. No one university or college is training specialists professionally for this important branch of investigation and construction, and those who are engaged in this job came from related professions; there are civil engineers, engineering geologists, mining engineers, etc. The main body are the civil engineers. In the process of training they receive sufficient knowledge on the technique of subsurface engineering, unnecessary knowledge on construction above ground, and quite insufficient knowledge on engineering geology. The problem of discrepancy between the knowledge received in universities and colleges, and the task which should be carried out in practice is important today and it will be more important tomorrow. The majority of attendants will work in the next century - it has drawn so near. Are the profession ready for the 21st Century?

The impression may be formed that the lecturer's position is not realistic. Strengthening the engineering geological training of those civil engineers who will be engaged in geotechnical engineering is desirable but impossible. The program for civil engineering students is overburdened as it is and a 40-hour program may be included at best, as it has been proposed by Terzaghi and probably was actually realized in the majority of the universities and colleges. However, it is not a matter of such a program, but probably of a ten-fold larger one, necessary for training full-blooded specialists in the field of foundations, dams, and subsurface engineering. Such a proposal does not seem to be realistic.

A solution may be found in specialization of the training. Geotechnical engineering should be separated from civil engineering. The term "geotechnical engineering" seems to be more suitable and precise than the usually applied term "foundation and subsurface engineering," if only for the reason that the dam engineering holding a conspicuous place in our work is neither foundation nor

subsurface engineering. Quite adequate terms exist in German: der Hochbau for civil engineering and der Tiefbau for geotechnical engineering.

Students of geotechnical engineering departments should learn not only engineering geology, but also a number of other geological and geophysical disciplines such as sedimentology, stratigraphy, tectonics, hydrogeology, clay mineralogy, paleogeography, seismology, and so on.

These disciplines in no case should be simplified versions of the science intelligible and sufficient for engineers; on the contrary, they should, together with exposition of the basic material, give special chapters referring to studying the small areas in a large scale. Expounding the content of these special chapters is beyond the scope of the present lecture; however, in order to explain my idea, I shall bring on the off-chance those questions which must be reflected there. It is easy to see that all these questions are not considered in ordinary manuals on geological sciences, and the engineering geologists themselves have to work out the methods and investigate these problems in the course of routine work.

In stratigraphy, apart from describing the successive formation of the geological bodies and their initial correlation in space, a very detailed segmentation of the sedimentary and effusive rocks should be shown, especially the subdivision of the Quaternary deposits into thin layers and seams distinguished by the totality of lithologic, petrographic, mineralogical, microfaunal, and palynological features. This is necessary for correlating soil strata within small areas, clarifying their deformation due to mass movements on slopes, and understanding landslide mechanisms.

In geomorphology, apart from studying the large forms of relief - dry land and sea bottoms, medium forms - river and trough valleys, glacial and karst regions, plains, and plateaus, small forms of relief should be investigated in detail. It is essential to distinguish features of erosion, landslide and karst relief; to differentiate outliers of peneplanation planes and terraces; to recognize solifluction and accumulative ridges, furrows and hill-side trenches, frost mounds and frost heaves, salt domes and rim synclines, dolinas and poljes, etc. Information of great value may be obtained in the very early stages of exploring the site through the scrutiny and interpretation of relief.

In paleogeography, apart from reconstructing the geographical conditions of large districts of the land in an ancient geological period shown on a small scale, consideration must be given to establishing the relief development history of small areas on a large scale, beginning from a certain reference moment. Among these are: Determining the river position before lava flows flooded the ancient river valley, the probable hydrogeological conditions in the past, the current distribution in a shallow basin, etc. This may also be significant for forecasting the geological

situation in altered hydrogeological conditions due to technogenetic impacts.

The same may be said about other disciplines of the geological and geophysical cycles - sedimentology, tectonics, hydrogeology, seismology, etc. The prospective geotechnical engineer equipped with this knowledge will be able to proceed more successfully to engineering geology as a science on the engineering significance of geological phenomena and processes, and ways of monitoring them. Many special chapters of these geological disciplines or their separate paragraphs are already written and published in different scientific papers, particularly in case histories, and the immediate task is to extract them from there, to analyze, and to systematize. It does not follow from the above-mentioned that textbooks of the listed geotechnical disciplines taught prospective geotechnical engineers should be greater in volume than those which are taught now to prospective geologists. On the contrary, they may be of even less volume despite the fact that they contain a number of special chapters. Here one should bear in mind the important conclusion made by R. Peck (1962) that there are really two aspects of geology, a system of knowledge and a method. The basic results of the system of knowledge concerning the history of the earth and life on it should be well known to any intelligent layman. But the system of knowledge also contains an enormous amount of information about the means of obtaining these results and different obsolete standpoints which were rejected by crystallizing the modern concepts. This information may be omitted freely by the prospective geotechnical engineers, especially those parts which are connected with endogenous processes, caused by interior forces of the earth such as tectonic, magmatic, metamorphic or hydrothermal ones. These processes are of minor interest for the geotechnical engineer compared to the exogenous processes, connected with activity of external agents such as water, ice, wind, heat, living organisms and, finally, Man himself.

The method of geology is very important to the geotechnical engineer. As stated by Peck (1962), the engineer must know what to observe and how to observe it. The landforms and exposures of sites should be recognized and scrutinized. The geological method consists, first of all, of collecting the facts and evidence based on observations. The geologist, at the time he makes the observations, may not know whether all of them will be pertinent or useful, but he does them in great detail. He maps all geological data collected, studies his map, and forms hypotheses concerning the geological structure and history of the site. All existing data concerning the geological structure and history of development of the region should be taken into consideration. As new geological evidence is obtained the geologist modifies and improves his concept. Thus, the geological method is the transition from details to the whole. The benefits of such an analytical approach are apparent since the geologist tries to understand the existing structure.



The engineering method is opposite. The engineer first constructs a nonexistent machine in his head as a whole and then begins to think over its details. A geotechnical engineer is not only a geologist or an engineer but, rather, both. He must understand the existing geological structure, then create in his head the underground structure to be designed, and foresee the interaction of both structures. It needs mastering the geological and engineering methods both.

#### GEOMECHANICS - SCIENCE OF HIGHER LEVEL

Knowledge of a number of geological sciences even revised for engineering purposes is a necessary but insufficient constituent of the total task. As indicated above, soil mechanics should be supplemented by a science of subsequent higher level equivalent to structural mechanics.

This science is geomechanics. It falls into the technical cycle of sciences as both soil and rock mechanics.

Geomechanics is a comparatively young science. It began to take shape in the 1950's and is now in speedy development (Müller, 1951, 1960). This is a science of a wide range and is far from being mature.

Geomechanics is concerned with study of the mechanisms of geological processes based on laws and principles of continuum mechanics, rheology, soil and rock mechanics, hydraulics, and thermodynamics (Ter-Stepanian, 1967). Conceptually, the mechanism of a natural process is the sequence of intermediate states and conditions of their transition from one state to the other. It involves the in-depth study of the geological processes with due regard to the stress-strain state and time, and is aimed at expressing the results quantitatively. As stated above, geological processes nowadays may be caused by natural factors as well as the result of human influence. Therefore, the state of soil or rock masses and changes of these states may occur due to different natural and technogenetic factors.

Analyses of the mechanism may envelop the whole history of the deposit beginning from its sedimentation or it may be limited by the finite phase beginning only from some reference moment; the analysis is not concerned with changes of composition or fabric only, but the stress state as well. The term "fabric" is used here in the sense put into it by Friedman (1964) and Gerrard (1977), namely as the totality of "all structural and textural features of a rock as manifest in every recognizable rock element from configuration of the crystal lattice of the individual mineral grains up to and including large-scale features which require field investigation."

Many important geological problems such as those which are connected with sedimentation, consolidation, and overconsolidation of deposits, analysis of dislocations and intraformational contortions, study of different types of gravitational movement of earthen

masses on slopes, etc., may be solved successfully with the use of geomechanics.

Let us consider the eventual contribution of geomechanics in the problems of geotechnical engineering; the range of these questions is vast and it may be outlined in part only. No claim to completeness may be made in this rapidly developing field of knowledge. Gudehus (1977) proposed the following classification of boundary value problems in geomechanics, according to thermodynamic criteria. Four categories of problems are distinguished, depending on the rate of dissipation.

1. Equilibrium states (zero rate): elastic, pseudo-elastic and elastic with limit conditions.
2. Stationary processes (constant rate): elastic vibration, potential flow, plastic flow and viscoplastic flow.
3. Stabilizing processes (decreasing rate): transient vibration, diffusion, consolidation, elastic-ideally-plastic deformation, plastic hardening, creep-relaxation and general coupling.
4. Destabilizing processes (increasing rate): plastic collapse, plastic softening, brittle softening and liquefaction.

This is quite a distinct and comprehensible thermodynamic classification of geomechanics problems. Gudehus points out that the potential flow is relevant for groundwater flow and for electrical or thermal conduction. Among the diffusion processes, unsaturated pore fluid flow, swelling, heat conduction, and electro-osmosis are of interest. As an example of general coupling processes, the case of excavation of a tunnel in involved geological conditions is indicated where several processes proceed simultaneously, such as creep-relaxation, loosening, swelling, temperature changes, and disturbance of electrochemical fields.

As far as creep is concerned, the process is stabilizing in all cases in the first, mobilization phase, and destabilizing in the second, rupture phase. At high shear stresses the process in the rupture phase ends in failure while at intermediate shear stresses it transits into the third, stabilization phase; transition from one phase to the other occurs at mobilization and stabilization limits correspondingly (Ter-Stepanian, 1975).

Fields of application of geomechanics in geotechnical engineering are subdivided according to the process development phases (initial and final phases of loessial soil degradation, depth creep phases before and after sliding in a soil mass bounded by a slope, state of terrain before, during, and after retreat of permafrost, etc.), and the stress state (normal distribution of geostatic pressure, overconsolidated non-lithified clays with easily recoverable strain energy, overconsolidated lithified clay shales with locked-in energy to be recovered after weathering only, rock with residual tectonic stresses, etc.)

Great contributions to geomechanics and related fields of soil mechanics and engineering geology were made during past decades in many countries of the world. In these works the need to study the complicated geological situation and mechanisms of geological processes is emphasized. Investigations of the following writers should be mentioned: L. Bjerrum and T. C. Kenney (1968), M. N. Goldstein (1971-1979), T. W. Lambe and R. V. Whitman (1968), G. A. Leonards (1962), L. Müller (1958, 1968; Müller and Fecker, 1978), R. B. Peck (1969), I. V. Popov (1959), G. Sanglerat (et al., 1980), E. Schultze and H. Muhs (1967), Ye. M. Sergeev (1982), A. W. Skempton (1964), K. Terzaghi (1950), N. A. Tystovich and Z. G. Ter-Martirosian (1981), D. J. Varnes (1978), J. Verdeyen, V. Roisin and J. Nuyens (1971), S. S. Vialov (1978), Yu. K. Zaretsky (1967), Zaruba and Mencl (1976, 1982) and many others. The lecturer is happy that he was fortunate to know personally and work closely for years with some of these prominent scientists on the development of soil mechanics, engineering geology, and geomechanics because there is nothing more inspiring than to participate in the creation of a new, rapidly progressing science!

The international cooperation of scientists in soil mechanics furthered the development of geomechanics. Almost every international or regional conference or symposium on soil mechanics added its contribution into the treasury of knowledge of geomechanics. The papers presented to the International Symposium on Numerical Methods for Soil and Rock Mechanics, held in Karlsruhe in September 1975 (Gudehus, ed., 1977) are of fundamental importance.

Giving their due to profundity of investigations, sophistication of methods, and effective conclusions of theoretical and practical importance contained in the mentioned works, and many others on this subject, the disproportion inherent to some works in geomechanics should be particularly emphasized. The study of geological features ends in a rather early stage with formulation of some idealization embodied in imperfect mathematical models; skilled techniques of analyses with the use of computers are accomplished further, attracting the main attention of the researchers.

This is as if periodical outbursts of mathematized ideas emit from an insufficiently studied geological nucleus supplying the subsequent generation of scientists with ever new, more and more perfect material, adequate to the reality.

It is quite essential to dwell longer upon the features of geological structure and stress history, and extract more information from exploration of sites. Gerrard's (1977) work is a good example of in-depth analysis of soil fabric and stress history aimed at producing mathematical models in applied geomechanics.

## BACK ANALYSES

Complicated or involved geological structure of the terrain makes it difficult and even impossible to produce representative samples for laboratory tests. Studying a great number of samples and determining the average values of the design soil parameters fail in achieving results if the role of weaker layers will be actually greater compared with that which follows from the averaged estimations. Prof. R. B. Peck (1973) has outlined this situation excellently.

Back analyses allow us to obtain generalized geotechnical soil characteristics taking into account adequately the whole geological situation. Back analyses proved their effectiveness by solution of stability problems. In performing the back analyses of failed slopes it is possible to derive the field values of the peak and residual shear strength of soils and to use these values further for determining the stability degree of slopes situated in the same geological and hydrogeological conditions.

These data are free from limitations imposed on laboratory tests by small size of samples, structure and stress state disturbance by sampling, and neglecting the hydrogeological conditions. In respect to problems of slope deformability the possibility of obtaining the field values of two main rheological parameters - the creep limit and the viscosity coefficient - was shown (Ter-Stepanian and Simonian, 1978). It is possible in principle to apply back analyses to other types of deformation as well, such as consolidation, swelling, etc.

## OBSERVATIONAL METHOD AND MONITORING

In principle, the observational method is the most logical way to deal with multifactor processes proceeding in nature which can not be expressed strictly in the form of mathematical equations. If one has to change the course of such processes or affect them in some way he must consider, make a plan of actions, try them, and see what comes out. If it corresponds to his predictions he continues to act in the same direction, and if not he changes the plan. As a matter of fact, the whole of medicine is based on this principle. This is a most ancient mode of thinking and is not to be attributed to anybody.

Successful use of this method during construction of the hydroelectric plant Svir-3 in the USSR was reported by Graftio (1936). The method was briefly outlined in 1948 by Terzaghi and Peck (1948). The lecturer proposed to use this method in 1957 for landslide control (Ter-Stepanian, 1957, 1973). Numerous cases of effective application of the observational method were analyzed in classical papers by Terzaghi (1961a) and Peck (1969); I shall not dwell upon these well known works. In carrying out observations, a great deal of help may be rendered by papers presented to the Symposium organized by the British Geotechnical Society, held in 1973 (Field

Instrumentation, 1974), and by a book edited by Goldstein (1970).

Despite its great advantages the observational method did not gain sufficient recognition and application in geotechnical engineering. The principle "investigate, design, and construct" inherent traditionally to civil engineering continues to dominate in the field of geotechnical engineering. Dr. Ruth D. Terzaghi stated in her preface to translation into Russian of the paper "Past and Future of Applied Soil Mechanics," by K. Terzaghi: "That principle, still more honored in the breach than in the observance" (Shakespeare's "Hamlet") might well be expressed by a paraphrase of Socrates' aphorism "an unexamined profession is not worth practicing." (Terzaghi, 1973).

It makes sense to analyze the difference between the geologist's and engineer's approaches to solve their problems. The engineering approach is well known. When a civil engineer designs some structure, e.g. a bridge, he must take into account the most unfavorable combination of operating conditions, in the present instance, passage of two heavy oncoming trains traveling at great velocity, with a lateral wind. This is justified since each of these factors and their combination are quite real.

The state of things in geotechnical engineering is completely different; not real unfavorable factors and their combination, but uncertainties regarding the geological structure and combination of their influences actually exist. They may or may not be - all depends on the success of engineering geological exploration and the correctness of the geological conception. These uncertainties may be fraught with real danger for the structure, but may be quite harmless. Therefore, considering the real existence of these dangers in geotechnical engineering, the more so does the most unfavorable combination of these factors lead to expensive decisions.

The observational method is a good alternative but it needs a certain flexibility of the structural design. Not the most unfavorable combination of geological conditions, but the most reasonable and probable one following from analysis of the whole geological situation should be used as the basis for the structural design. The design should be drawn up so that amendments could be introduced, if necessary, depending on soil behavior. A system of relevant instrumentation should be installed and regular observations carried out to estimate the soil response to changes of the stress state, hydrogeological conditions, etc. (Peck, 1969).

The possibility to introduce promptly changes in the design is the most important condition and the vulnerable side when using the observational method in geotechnical engineering; it is connected with great personal responsibility. The geotechnical engineer in charge of a big project must have the necessary knowledge, be entitled, and have means to make changes in the design if the geological situation requires that. In a number of cases there must be no delay in

performing the decisions. The case of constructing the largest Tarbela earth dam across the Indus River in Pakistan in extremely difficult geological conditions is a good example of using the observational method (Lowe, 1978, 1982). A 145 m high dam was built on thick alluvium deposits (more than 212 m) where the layers of thin sand alternate with "openwork" cobble gravel. An impervious blanket, 1800 m wide and 1.0 to 1.5 m thick, was made in order to protect against seepage deformation and to diminish leakage; a large number of instruments were installed for monitoring the behavior of the dam and its foundation. Cracks and about 600 sinkholes ranging from less than 1 to about 10 m in diameter formed in the impervious blanket after initial filling. The increased seepage was accommodated as a result of barge dumping of impervious material over sinkholes, natural deposition of silt from reservoir waters, and natural healing of cracks; the underseepage has been halved. Clarifying the geological structure features with a necessary accuracy would require detailed exploration, probably at least 50 times larger than for the same dam in a normal geological situation (Stapledon, 1976).

#### FORECASTING GEOLOGICAL HAZARDS

Geological hazards are distinguished according to the nature of forces that cause them. There are differentiated exogenous hazards (avalanches, landslides, falls, lahars, mudflows, and floods) caused by action of external geological agents (water, ice, wind, solar heat) and endogenous hazards (earthquakes, tsunamis, volcano eruptions) caused by action of internal geological agents (tectonic stresses, the earth's internal heat). Some geological hazards may be brought about by the same causes and, therefore, they occur simultaneously; for example, Cyclone Alison devastated the east shore at Kaikoura, South Island, New Zealand, in March 1975, and produced landslides, avalanches, floods, and erosion (Bell, 1976). Landslides can cause earthquakes, floods, tsunamis, and giant waves, and they may have resulted from earthquakes, floods, volcanic activity, deforestation, and large waves; D. H. Radbruch-Hall and D. J. Varnes (1976) give numerous examples of such interaction. Geological hazards cause alarming losses of life and property all over the world (Arnould, 1976). Man influences all exogenous processes and may be responsible for generating some shallow earthquakes.

Investigating the causes of geological hazards or their forecasting is beyond the scope of geotechnical engineers, but they must understand the importance of these problems and draw into their solution high rank geologists and engineering geologists. The geotechnical engineers require knowledge of not only the immediate consequences of changes introduced but the remote ones too, not only the danger for the structure to be constructed but for the environment as well. The importance of these problems and their correction solution is felt even now and it will be quite evident in the coming century.

In principle, no one geological hazard proceeds suddenly, they all have some preparatory period.

The only difference is that in some cases this preparatory period is long and easily observable (majority of landslides), in other cases it is too short (landslides in highly sensitive marine silty clays, avalanches, lahars, mudflows). In a third kind of cases the preparatory period is long but observations are difficult (falls, earthquakes, volcano eruptions). Nevertheless, the existence of the preparatory period, especially when it is long, offers considerable scope for forecasting and combating these hazards. In the final analysis all depends on investigating the mechanics of the phenomenon in detail based on precise measurement of the effects, on working out the theory of the process explaining adequately its manifestations, on formulating and calculating the necessary means of influence and, finally, on the technical means Man has at his disposal.

The first great success in studying and combating geological hazards was achieved with landslides; its history is well known. Studying the landslide mechanism was of decisive significance. The same work should be done in reference to other geological hazards such as mudflows, falls, lahars, and so on. It is possible in principle to combat even shallow earthquakes by water injection or a series of deep blasts in the seismic focus aimed at successive discharge of accumulated tectonic stresses in the form of weak impacts producing a trigger effect. One must know only where and when such weak earthquakes should be provoked. Certainly serious investigation into the natural process of accumulating and discharging the tectonic stresses should precede such actions. However, the solution of this problem is a matter of time only.

#### COMMENTS ON THE DISCUSSION TOPICS

The Organizing Committee proposed the following problems for discussion sessions:

- a. Slope Stability Problems;
- b. Geological Aspects in Earth Dam Engineering;
- c. Problems in Areas with Special Geologic Conditions (Loess, Permafrost, Arid Regions, etc.)

One can not overestimate the importance of these problems. Almost each international and regional conference on soil mechanics and foundation engineering considers these problems. Even a brief review of the present state of these problems will require much time. I shall dwell here upon the geological aspects only.

Slope stability and landslides are inverse problems. From the viewpoint of geology, landslides are a normal element of denudation. However, natural landslides in developed countries occur at present very rarely; the great majority of them are caused by Man's unreasonable activity. Landslides are stimulated by a tendency to consider them as sudden, unexpected phenomena, which is convenient for those who are responsible for the failure. The same tendency may be seen

even in some textbooks and case histories which deal mainly with the final stage of the landslide formation and description of the failure but not the long-term depth creep phase. Medicine would have little success if its main attention was drawn to last hours of human life and to post-mortem examinations.

The present state of knowledge of landslide mechanisms is enough to forecast and to prevent many types of landslides. Saito (1969, 1979) succeeded in forecasting the Tabakayama landslide with an error of 6 minutes only! Still more important is preventing landslides. Early recognition of landslides in the depth creep phase and correct remedial measures using the observational method will diminish considerably the damage caused by landslides.

Another problem concerning slope stability is the side effect. Plane (two-dimensional) problems are considered in calculations of slope stability while failed earth masses actually have limited width. Three-dimensional analyses of sliding bodies are advantageous since slip resistance of such bodies will obviously be higher. Studying the relation between the shape of the sliding body and the character of stratification is important from the geological viewpoint.

The problem of progressive failure deserves special attention. Bjerrum's (1967) concept is well known. Slope failures in overconsolidated plastic clays and clay shales are preceded by development of a continuous sliding surface whereby the shear strength is progressively reduced from the peak to the residual value. One of the conditions of this process is the existence of "sufficient amount of recoverable strain energy to produce the necessary expansion of the clay in the direction of sliding to strain the clay in the zone of failure." This process is of great importance for clay shales with strong diagenetic bonds where the locked-in strain energy is liberated by decay of bonds due to weathering.

Another mechanism was brought up by the lecturer. Distortion in a wide creep zone proceeds during the depth creep phase. In the course of time, the strains in marginal less stressed parts of the creep zone decelerate (stabilization) while in central, more stressed parts, they accelerate (total rupture). Thus, creep is concentrated in a narrow strip attached to the potential sliding surface and progressive failure develops (Ter-Stepanian, 1984). The course of progressive failure depends on the ratio between the peak and residual shear strength of the soil.

Depending on soil type, various other mechanisms of progressive failure may exist. Extensive inclinometric observations and rheological experiments are needed for clarifying the special features of this process.

Finally, the problem of the role of discontinuities of different origin (geologic, tectonic, weathering), such as bedding, jointing, fissuring, schistosity, slackening, etc., which affects the stability of natural and cutting slopes is of interest, especially if these discontinuities are oriented.

The following topics for discussion during the first session are proposed:

- (1) Creep of slopes. Investigations and their interpretation.
- (2) Side effects in landslides (three-dimensional analysis). Investigation and calculation methods.
- (3) Progressive failure. Analysis of conceptions: development of continuous sliding surface by liberating the recoverable strain energy, transition from depth creep phase to failure, etc.
- (4) Effects of oriented discontinuities on the stability of slopes.

Earth dam engineering is a rather vast problem. It contains two groups of questions. The first group belongs to the dams proper where an engineer is less concerned with the geology since he can select the material for the core, embankments, etc., and design the dam cross-section according to specifications. Thus, he is free from limitations owing to the geologic uncertainties. The second group of questions belongs to the dam abutments and foundations where the existing geological conditions and uncertainties are of decisive importance. Most of the above-mentioned falls exactly into this group of questions.

Ascertaining the geological conditions of a dam site and forecasting the probable mechanism of geological processes after filling the water reservoir is a very difficult and responsible task. One has to imagine the future behavior of the dam and analyze a number of possible mechanisms. Much easier, although not preferable, are the cases of dam failure analyses. Dam failures may be considered as full-scale experiments, where the mechanism of the process should be established and verified. Even this work is not easy.

The case of the Teton dam failure, which occurred on June 5, 1976, may serve as a good illustration. R. B. Peck (1980) stated that the dam had been designed and constructed under the supervision of an organization which was among the most authoritative and experienced in the world. Geological conditions of the dam site after failure were investigated by the Interior Review Group including engineering geologists R. L. Schuster and D. J. Varnes (Failure of Teton Dam, 1977). The dam site was studied by the Independent Panel to Review the Cause of Failure, including A. Casagrande, R. Peck, and W. Chadwick (1981). A retrospective review of the failure and its mechanism was made by H. B. Seed and J. M. Duncan (1982). Reconsideration of the initiating mechanism was reported by G. A. Leonards and L. W. Davidson (1984).

All of these names are among the most prominent ones; nevertheless, there is no single standpoint concerning the failure mechanism. It is almost impossible to enlist such high rank experts in ordinary cases when it is not the failure that is to be analyzed but much more difficult problems - the behavior of the dam, its stability, and performance

are to be considered. Therefore, the lessons from the Teton dam failure case pointed out in the quoted papers are of great value. These are the principle of "multiple lines of defense," advocated by K. Terzaghi and A. Casagrande, instrumentation to monitor the performance of earth dams to detect the malfunctioning at an early stage, and remedial actions to prevent failure, etc.

The following topics for discussion during the second session are proposed:

- (1) Risk of erosion in the subgrade under high hydraulic gradients. Investigations and their interpretation.
- (2) Stability of dam abutments and adjacent areas. Investigations and monitoring.
- (3) Soluble rocks (limestone, gypsum, salt) under dams at varying depths. General evaluation. Design and safety concept.
- (4) Soil and rock of changeable strength and deformation behavior in the foundation, e.g. overconsolidated clays. Suitability of such soils and rocks as embankment and core material.
- (5) Disintegration of rocks. Suitability of disintegrated rocks as embankment material.

Areas with special geologic conditions such as loess, permafrost, arid regions, etc., bring forward still more problems in comparison with earth dams. These problems are enormous; they will attract the attention of our science for a long time. Some aspects of this vast problem were illuminated in the general report by G. D. Aitchison (1973), presented to the Moscow Conference on Soil Mechanics. It is expedient to select topics for discussion during the third session, according to the submitted papers. The following considerations are aimed at clearing up the general strategy in this question.

Having very different properties and composition, the soils in areas with special geologic conditions have one common distinguishing feature; they all were formed precisely in these conditions and, hence, their physical properties and geologic conditions of the areas are connected functionally. With the change of the environmental conditions these soils change as well. Developing the areas with special types of soils, Man changes their hydrogeological or thermal conditions, affects their degradation and, thus, causes detrimental deformation and damage of engineering structures. Therefore, the general strategy when dealing with such soils is to avoid changes in the environment. Naturally, it is impossible to avoid that fully, but all of Man's engineering actions should be thought out well. It is essential to take into account not only the immediate effect but the remote consequences also. One must bear in mind that all the changes that Man introduces in areas with special geologic conditions are of irreversible nature.

It is wrong to see only the negative sides

of areas with special geologic conditions, they may have useful features too; in some cases, such areas ought to be preserved. "Enormous territories of maritime lowlands in northern Siberia with elevations of 20 to 30 m above sea level remain as dry land owing to permafrost. If the permafrost that contains 50-60% of ice particles and has thickness measured by several hundreds of meters will thaw, a part of the dry land will subside below sea level while the higher areas will turn into impassable bogs" (Sergeev, 1982). Draining the upland moors affects adversely the hydrogeological and climatic conditions, feeding the rivers deteriorates, the fertility of drained soils falls. Deformation of collapsible loessial soils is a serious problem: It leads to subsidences in zones of irrigation channels, breakage of canals on slopes, formation of underground cavities, rising of the groundwater level, secondary salinization, etc.

The following general topic is proposed for discussion during the third session: Geotechnical engineering aimed at controlling the collapse of loessial soils, preservation of the permafrost, conservation of the upland moors, controlling landslides on shores of large water reservoirs, etc.

Geological aspects in geotechnical engineering are still poorly explored fields of investigation promising fundamental progress when engineers will master them.

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