N.N. Maslov

Basic Engineering Geology and Soil Mechanics

Mir Publishers

BASIC ENGINEERING GEOLOGY AND SOIL MECHANICS

Н. Н. Маслов

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Preface

Engineering geology and soil mechanics are disciplines concerned with the study and evaluation of environmental conditions at a purposed site where the designed structure is to be built and where its operating conditions are affected by the surrounding geological features.

By virtue of their subject matter both engineering geology and soil mechanics are general engineering disciplines. For college students specializing in transport technology they may provide a theoretical basis for such applied disciplines as road construction, construction of airfields, and the construction of bridges and tunnels.

The textbook is divided into four parts. Part One deals with elementary general geology. Part Two considers fundamentals of soil science for engineers. Part Three introduces elementary soil mechanics and Part Four, elementary engineering geology. This order of presentation mirrors the fact that the scientific basis of engineering geology is soil engineering and soil mechanics.

Both the theoretical and practical tasks faced by engineering geology can be solved based on natural and historical analysis utilizing field and laboratory investigations which, whenever possible, include physico-mechanical methods along with calculation formulae encompassing soil mechanics.

What makes the subject unique is that the physico-mechanical properties of soils and methods for their determination are studied from the viewpoint of engineering geology. Such an approach is justified by the obvious interconnection of these properties under particular natural conditions. It is important to note that in actual construction work undertaken in this country it is the engineering geological agencies that are fully responsible for studying the above properties and evaluating various design indices.

It was deemed unnecessary to add to the present book the impressive bulk of material of the last decade related to engineering geology and soil mechanics. This would have rendered the present volume excessively large and thus not expedient.

The ultimate goal of the author was to familiarize a beginning civil engineer with methods for solving problems relating to soil mechanics and provide him with information that would be most likely to be of real use to him at the early stages of his engineering career. With this objective in mind the author made it a point to exclude all the data, conclusions and recommendations not verified in practice or of dubious importance, such as those which have not been proven by the nature of the phenomenon or ones that have no appreciable use.

Actual construction work has shown that due to a revolution in engineering methods young engineers should be taught a creative approach to tackling a particular engineering task. Hence the author's determination to make the book more than just a reference book covering a wide range of problems. Instead, he has restricted himself to a presentation of the major problems alone. For this reason, the author has endevoured to consider the theoretical aspects of the disciplines as they relate to practical tasks.

It would be appropriate to point out the great contribution made by Soviet scientists in the development and propagation of concepts bearing on engineering geology and soil mechanics. Credit must first be given to Academician G.O. Graftio who was the first to use and advance the ideas of engineering geology and soil mechanics resulting in the erection of unique engineering structures. Mention should also be made of Academician F.P. Savarensky whose activities did much to establish the Soviet school of engineering geology, connected with such notable men of science as I.M. Gersevanov, M.N. Goldshtein, I.V. Popov, E.M. Sergeev, N.A. Tsytovich and many more.

It is the author's pleasure to emphasize the important role played by my old co-worker, Assistant Professor and Candidate of Science (Geology and Mineralogy) M.F. Kotov in furthering a number of concepts proposed in the book. The author therefore extends sincere thanks to him. The author is also much indebted to Professor M.N. Goldshtein for his advice, assistance and courage in supporting a number of new procedures and theories which have been proposed in the present work.

The staff of the Leningrad Construction Engineering Institute (LISI) headed by Assistant Professor and Candidate of Science S.N. Sotnikov who reviewed the manuscript of the book have provided many useful suggestions and helped better arrange the material and elucidate some concepts outlined in the book. The author is deeply grateful to all of them. He also acknowledges the painstaking efforts undertaken by his constant assistant, Candidate of Science (Geology and Mineralogy) Z.V. Maslova-Pilgunova during the preparation of the manuscript for publication.

N.N. Maslov

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Introduction

The unprecedented large-scale construction of transport facilities being undertaken in this country poses most complicated engineering tasks to the builders, especially with respect to utilization of the vast expanses of Siberia and the Soviet Far East. The putting through of major transport engineering structures and highways in these areas, usually in most inclement conditions, may be, as a rule, justified only on the condition of the efficient and extensive use of findings of engineering geology and soil mechanics.

The proper feasibility study for erecting big structures on any rock such as to rule out accidents is particularly important.

We use the historical method when dealing with natural phenomena. This directly applies to scientific investigations in the field of engineering geology and soil mechanics. Among these, to cite an example, is a theory of successive phases of tectonic inactivity and orogenesis in the formation and development of the earth's crust.

Any structure to be erected, including a transport facility, must possess proper stability and strength. Moreover, it should meet special deformability requirements. A structure being designed must concurrently satisfy the following conditions: it should be built at lowest possible costs in terms of money, manpower and time.

In order to successfully deal with all these problems, when designing a structure, it is necessary to determine and take into account the environmental conditions under which it will be constructed. These, notably, should include soils and rocks that will support the structure; their composition, state and properties and also the mode of their occurrence, thickness of individual layers, jointing of the hard rock mass etc.

The mode of occurrence of subsurface water and its regime in the soil mass being explored are an important component of the problem in hand. Yet the data on these separate items cannot aid in solving the entire problem. What proves of exceptional and sometimes crucial significance is the behaviour of soils and rocks under the effect of the weight of the structure being built, of the forces applied and the states of stress that appear in the soil mass.

In addition, a structure to be built may frequently be under the deleterious effect of one or more natural geological processes or phenomena known as geodynamic. These include, first and foremost, seismic phenomena (earthquakes), landslides and landfalls, collapses induced by the caving of the roofs of subterraneous voids etc.

The negative effect of the above phenomena on the structure in question may be avoided or lessened by taking requisite protective measures (active control). On the other hand it may prove in many cases better to apply simpler and cheaper methods of tackling the problem. For example, we can site the centre line of a bridge at other than a hazardous section of the bank of a river (passive control). Such a solution, however, can be effective if the phenomena in hand have been studied in advance and their likely influence on the structure being designed has been established.

Engineering geology, as a science and an applied discipline, studies general natural phenomena that must be taken into consideration when it is desired to design, build and operate an engineering structure, and geological processes and phenomena likely to affect adversely the structure concerned and interfere with the normal conditions of its operation.

The subject of engineering geology as an applied discipline includes a variety of problems most diversified in contents and important in essence. The natural conditions that obtain at a given job can be fully understood only after all the regularities of the particular geological processes and features have been determined and investigated.

These regularities can be referred to four principal types.

The first regularity suggests that the engineering and geological conditions of construction and operation of a structure are governed by the nature of the soils and rocks involved, their properties, mode of occurrence, subsurface water regime and also by the pattern and conditions of the likely effect of geodynamic processes and phenomena.

The second regularity suggests that the character and intensity of the occurrence of one or another geological process and phenomenon is determined by the peculiar features of the structure of the earth as a cosmic body. These primarily are: (1) the presence of a relatively thin hard outer shell of the terrestrial globe called *the crust* made up of rocks; (2) the occurrence in the inner reaches of the earth of complex processes that are responsible for the thermal and special physico-chemical regime of the earth's interior and for the processes that take place in the earth's crust by virtue of the latter's comparatively small thickness; (3) the effect of the external processes and phenomena associated with the activity of the atmosphere and surface waters on the crust-forming rocks and the earth's relief.

The third regularity consists in that the engineering geological properties of soils and rocks are determined by their composition, state and their structural and textural features.

The fourth regularity suggests that the composition and state of the rocks and soils, their structural and textural features and mode of occurrence are governed by the nature of the parent materials from which they originated, by origination conditions (*genesis*) and environment (*facies*) and by the character of the subsequent transformations of the particular rock or soil due to one or another geological (geodynamic) process and phenomenon.

As to soil mechanics, it is a science concerned with the conditions that lead to the disturbance of the strength and stability of structures and with the behaviour of the soil mass underlying engineering structures under the effect of forces acting on these. Conclusions from soil mechanics rely on the data furnished by engineering geological investigations. This discipline develops the array of mechanical and mathematical data for evaluating the stability and strength of soils and their deformations generally taking into account the time factor.

In fact, soil mechanics necessarily operates with ideal soils and rocks and uses approximate calculation formulae. The actual behaviour and properties of soils and rocks are much more diversified and complex than can be described by mathematical relationships. That is why in each particular job the conclusions from soil mechanics must be corrected by allowing for the actual natural conditions that can be studied by the methods of engineering geology. Thus the needed intimate connection between the two disciplines will be achieved.

Part One

Elementary General Geology

Chapter 1

The Earth as a Cosmic Body. Tectonics

Sec. 1.1. General Facts on the Structure of the Globe

The appearance, occurrence conditions and construction properties of a rock or soil are governed by the character of the original products or rocks and by the conditions of their formation and subsequent action of consolidation, weathering, cementation and others. For this reason, the most reasonable pathway for studying the above aspects of evaluation of rocks and soils in terms of engineering geology is to gain an insight in the conditions of their origination and the agents acting on these rocks and soils that are directly connected with the earth's life.

The life of the planet Earth is determined by the following principal factors: (1) the presence of a solidified layer enveloping the globe said to be *the earth's crust* (*lithosphere*) composed of hard rocks; (2) the relatively small thickness and rigidity of the earth's crust; (3) complex processes are at work in the earth's bowels, beneath the crust, that determine the thermal and physico-chemical regime of the earth's interior; (4) the action of various physico-chemical processes related to the atmospheric activities on the crust-forming rocks and the earth's relief.

The age of the earth as a planet is now estimated to be 4.5 to 5 billion years. The earth's radius is about 6400 km. On the other hand, the thickness of the crust, according to geophysical findings, in particular, from the speed of propagation of seismic waves passing through the mass of the globe, does not exceed 30 to 40 km. In the Soviet Union (Cola Peninsula) and the USA attempts are being made to directly determine the crust's thickness by sinking superdeep boreholes. Thus, by 1980 the depth of a borehole reached some 10 km.

Such a thin shell, in practical terms, is unable to offer any appreciable resistance to various deformations that have been acting on the globe. The crust is being passively deformed in response to the deformations of the earth itself due to the processes and phenomena that occur in its interior which are termed *endogenic*.

At greater depths the pressure in the earth's interior and hence the temperature constantly rise to attain as much as 5 000 °C. The central part of the earth forms what is known as a core (inner and outer). The core is about 3 000 km in diameter. The pressure there presumably attains 3.0 to 3.5 million at (0.3 to 0.35 million MPa).

As is known, the specific density of the globe as a whole, equal to 5.5, by far exceeds the bulk density of rocks (2.5 to 2.8) that compose the crust. It is only in the crust's lower strata that its value increases. Therefore the density of the globe's central part is expected to be much greater and amounts to 12, that is, close to the unit density of iron (Fe) and nickel (Ni). These figures are substantiated by geophysical evidence as well.

The above circumstance led, at one time, to an assumption that the core is composed of heavier elements (Ni, Fe, Mg) and, due to the great pressures and heat there, the material in the inner reaches of the earth is in a specific overheated elastic state of plastic viscosity. It has been by now established that the core lets pass longitudinal seismic vibrations (P-waves) and is impregnable to transverse vibrations (S-waves). This fact permits belief that the material forming the earth's core, at least, its outer shell, the inner core remaining hard, is in a specific overheated liquid state.

The mantle that encloses the core is very great in thickness and represents an intermediate zone between the core and the crust. According to the speed of propagation of seismic waves the mantle divides into *an upper* and *a lower mantle*. The chemical composition of the mantle is supposed to correspond to a well-known rock, basalt, which is in a less dense state in the upper mantle where Si, Fe, and Mg prevail that passes in the lower mantle to a denser state where Fe, Mg, Ni occur. It is there that catastrophic earthquakes originate.

Sec. 1.2. The Structure of the Earth's Crust

The zone above the mantle is *the crust* or *lithosphere*. The lithosphere, in turn, divides into the upper granite belt where Si, Al, and Fe (sial) predominate, and the lower basalt belt. The oceanic crust differs from the continental in that it is thinner and lacks the upper granite layer.

The external layers of the earth's crust are composed by *sedimentary rocks* (e.g. clays, sandstones, limestones) formed by decomposition and disintegration, largely, of magmatic rocks 4 to 10 km in thickness. These rocks are underlain by what are known as *metamorphic rocks* (shales, gneisses, marble etc.) 5 to 10 km thick. These are rocks that originate from magmatic and sedimentary rocks transformed by the action of high temperatures and pressures inherent to orogenesis and volcanism. The mass of metamorphic rocks together with the granite layer provide *the crystalline foundation* of the continents.

These are the oldest of known rocks whose age is well over 3 billion years. Occasionally the rocks of the crystalline foundation may outcrop at the earth surface. Such areas are called *shields*. We know the Ukranian