GEOLOGY AND THE SCIENCE OF EARTHS

authors: V. M. Bezruk and
M. T. Kostriko

CONTENTS

SOURCES:
Geologiya i Gruntovedeniye /Geology and Ground Lore/ 1951

V. M. Bezruk and M. T. Kostriko

GEOLOGY
AND THE SCIENCE OF EARTHS

Released by the Staff Department, GUSHOSDOR, MVD, USSR
as a textbook for highway-mechanical technical schools

D. ORIZDAT

(Publishing house of highway-technical literature for
GUSHOSDOR, MVD, USSR)

Moscow, 1951

CONTENTS

CHAPTER IV. GEOLOGICAL ACTION OF THE EARTH'S INTERNAL FORCES

CHAPTER V. GEOLOGICAL ACTION OF EXOGENOUS FORCES

PART II. THE SCIENCE OF EARTHS

CHAPTER XII. TYPES OF SOIL, THEIR ORIGIN AND GEOGRAPHIC DISTRIBUTION

CHAPTER XIII. GRANULOMETRIC COMPOSITION OF EARTHS

CHAPTER XIV. PHYSICAL PROPERTIES OF EARTHS

CHAPTER XV. AQUEOUS PROPERTIES OF EARTHS

CHAPTER XVI. MECHANICAL PROPERTIES OF EARTHS

PART III

USE OF GEOLOGY AND THE SCIENCE OF EARTHS IN ROAD CONSTRUCTION

CHAPTER XX. EXPLORING AND SEARCHING FOR ROAD CONSTRUCTION MATERIALS

CHAPTER XXI. BASIC METHODS OF ARTIFICIALLY STRENGTHENING EARTHS

CHAPTER VII

BRIEF HISTORY OF THE EARTH'S CRUST AND THE GEOLOGICAL CHART

34. Concept of Geological Age

The processes of creation and destruction of rocks, sometimes extremely slow and eternal, sometimes rapid and abrupt, have gone on throughout the geological history of the Earth, constantly changing the form and composition of the Earth's crust.

Various scientists have calculated that from 3 to 5 billion years have elapsed since the formation of the Earth to the present time. We do not have concrete evidence with which to study the history of the primary stages of the Earth. Scholars assume that in the beginning the Earth was not covered by water. The composition of the atmosphere was considerably different from its present composition. The absence of water, the high temperature of the Earth's surface, and the composition of the atmosphere made impossible the evolution of organic life on the Earth. In the course of time, there arose favorable physico-chemical conditions, and from simple inorganic substances (carbon, nitrogen, hydrogen, etc) hydrocarbons and other more complicated organic substances were formed. Then by a series of successive transformations albuminous substances were formed, and from these arose all living organisms. Evolution of the first albuminous substances over a long period of time led to the formation of different animals and plant life. Geological history begins with this stage in the evolution of the Earth. This study is now possible because of the fossil remains of plants and animals in the masses of sedimentary rocks. The remains have been preserved up to the present day in petrified form. They are solid remnants of former living animals and plants (shells, bones, teeth, skeletons, woods, etc) (Figure 55) or impressions (Figure 56) and are convincing documents on the evolution of life on Earth and its complex geological history.

Figure 55. Petrified cephalopod mollusc -- ammonite in lime

Figure 56. Impression of a fern in clay schist

A special branch of geology, paleontology, is the study of fossilized remains of plant and animal organisms which existed in past geological periods.

Geology and paleontology have played an exceptionally important role in correctly understanding nature from a scientific point of view. The great scientific leader, F. Engels, has pointed out this function of geology. In his book, Dialectics of Nature, he writes: "...geology arose and revealed the presence

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

of geological strata which were formed one after the other and one on top of the other. It revealed the shells and skeletons of dead animals preserved in these strata, the stems, leaves, and traces of plants no longer in existence." This forces us to acknowledge, Engels goes on to say, "that not only does the Earth have a history of its own in time, but so does its surface with the plants and animals which live on it."

Classification and study of fossils and impressions have established the fact that life has developed gradually on the Earth, from the simplest lower forms to the most complex and perfected ones, culminating with the appearance and evolution of man. In determining periods of geological history, we study the animals and plants which were characteristic for each period through the fossils and impressions left in sedimentary rocks. By this method we can divide the whole past history of the Earth's crust into a series of time intervals and also determine the relative age of the sedimentary rocks.

The petrified remains of animals or plants by which the relative age of rocks can be determined are called the leading forms.

The largest interval of time in geological chronology is called an era, and the mass of rocks formed in this time period is known as a group. A further subdivision of eras and groups is given in Table 7.

TABLE 7

	Time Interval	Era	Period	Epoch	Age
Rocks	Series of geological deposits	Group	System	Section	Strata

At the present time the entire history of the Earth's crust is subdivided into the following eras, beginning with the oldest: Archean, Proterozoic, Paleozoic, Mesozoic, and Cenozoic. The divisions into periods with their estimated duration and most characteristic deposits for a given period or era are shown in Table 8.

The depth of the sedimentary rocks varies in the USSR: in Leningrad it reaches 200 meters, in Moscow 1,650 meters, in Syzran' 1,570 meters, in Baku over 4,000 meters, and in the Donets Basin 11,000 meters. Sedimentary rocks often have alternating strata of clay, limestone, sandstone, and other rock. Only by determining the geological age of these rocks is it possible to understand and evaluate these strata.

Frequently, in studying the upper strata of the thicknesses of sedimentary rocks, all the pre-Quaternary stratifications, that is, those formed before the contemporary Quaternary geological period, are grouped under the common term of crust rocks.

TABLE 8

Era (group)	Period (System)	Estimated duration in billions of years	Conventional sign	Chief rocks formed in era or period
Archean	Not subdivided	Over 1500	A_1	Granite, granite-gneiss, schist, marble
Proterozoic	Not subdivided		A_2	
Paleozoic	Cambrian	90	C_m	Clay, conglomerates, sandstone, small quantity of limestone
	Silurian	85	S	Limestone, sandstone, conglomerates, slay, gypsum
	Devonian	40	D	Sandstone, dolomite, clay and sandstone, petroleum and coal
	Carboniferous	75	C	Thick masses of limestone, quartz sandstone, clay, coal, petroleum
	Permian	40	P	Clays and marl, lime sandstone, gypsum, anhydrite, coal
Mesozoic	Triassic	25	T	Sand, sandstone, clay, marl, gypsum, limestone
	Jurassic	25	I	Clay, clayey schist, sand, sandstone, conglomerates, limestone
	Cretaceous	60	C_r	Clayey schist, clay, chalk, limestone, sand, silica, sandstone, conglomerates, coal
Cenozoic	Tertiary	55	(a) Neocene N (b) Pliocene P_g	Sand, clay, sandstone, limestone, conglomerates, petroleum
	Quaternary	1.02	Q	Moraine clay and loam, boulders, pebbles, gravel, sand, loess, sapropelite, peat

35. Evolution of life on the Earth and the Principal Geological Events by Era and Period

Archean and Proterozoic Eras

No sufficiently clear evidence of past life — fossils and impressions — have been discovered in rocks of the Archean era. However, this does not mean that life was not present. It is supposed that life began in the Archean era, but was represented by such simple forms as bacteria, unicellular algae, ringworms, etc, which were either disintegrated completely and left no traces, or left infrequent, barely-perceptible traces, which were destroyed by metamorphic processes. It is possible that at this time organic life still appeared only in the form of extracellular albuminous substances incapable of being preserved for any length of time in a petrified state. Rocks of this era are represented mainly by granite and gneiss.

Detailed study indicates that many gneisses were formed from older sedimentary rocks as a result of metamorphic action. In reality, no sedimentary rocks of the Archean era have been preserved to the present. Rocks of the Archean group constitute that foundation in which are formed later deposits. Only in rare cases do these rocks come up to the surface in the form of ridges, or shelves, of crystallized crust. These are called "shields." In most instances they lie far beneath a mass of later deposits of sedimentary and metamorphic rocks.

In the territory of the Russian lowland, there are two such crystallized shields: the Baltic, or Finno-Scandinavian, and the Ukrainian. The first forms the Kolski Peninsula, Karelia and the neighboring countries of Finland, Sweden, and Norway. It is made up of heavy granular granite, porphyry, gneiss, and quartzite.

The Ukrainian shield is located between the Dnestr and the Dnepr, and further to the southeast extends to the Sea of Azov. It is made up of granite and gneiss, and in places (Ovruch and Krivorozh'e) by quartzite and schist.

Rocks of the Proterozoic occur directly over the crystallized rocks of the Archean era and are made up of gneiss, schist, quartzite, and marble. In the rocks of the Proterozoic group are found indisputable remains of already rather highly developed organisms: algae, rhizopods, radiolaria, sponges, worms, and crustaceans. The Archean and Proterozoic rocks have uneven surfaces and are frequently broken up by the intrusions of the basic magma.

Paleozoic Era

The organic world in the Paleozoic era contains rich and varied forms both on land and in the sea. In the older Cambrian period of this era, simple animals inhabited the sea: sponges, medusae, worms, brachiopods, and arthropods (Figure 57). Among plants, only algae existed at this time.

Figure 57. Trilobite, arthropods

In the following Silurian period, besides the animals already mentioned, there had developed gigantic spiny corals, echinoderms, and cephalopods. The first vertebrates -- the dinoflagellata -- make their appearance in the second half of the Silurian period. (Figure 58)

Figure 58. Armored fish of the Silurian period.

By the end of this period, there appear on dry land moss-like plants, which in the following Devonian period, develop into various sporophytes -- equiseta, club-moss, and fern. The first seed plants appear also.

The living world becomes still more varied in the Devonian age. Fish become more perfected and vary in size and form. Cephalopod molluscs -- ammonites -- appeared (see Figure 55), and land vertebrates appear for the first time.

The next period, the Carboniferous, is characterized by the evolution of rich land vegetation -- ferns, sigillards, lepidodendrons, calamites, and others. They reach huge dimensions and are the basis of coal formation in various localities (Figure 59).

Figure 59. Sigillarids

Spiders, large myriapods, and dragonflies now appear on dry land. One of the leading forms of the Carboniferous age is the shell Productus (Figure 60).

Figure 60. Productus from deposits of the Carboniferous system

In the Permian period, land animals, which now have become more varied, increase in number. Reptiles appear, some of which, such as the Pareyasaur, reach huge dimensions.

During the whole of the Paleozoic era, the sea repeatedly flooded the Russian lowland, leaving vast thicknesses of limestone, clay, gypsum, and other rocks. The oldest sedimentary rocks -- the Cambrian blue clays -- are widely distributed around Leningrad, where they are covered with glacial deposits.

Rocks of the Carboniferous age are extremely widespread in the territory of the USSR. They occur in the Moscow region, in the region of the Central-Volga highlands, in the Donets Basin, and in many other places. Deposits of the Carboniferous system are limestone, quartz sandstone, coarse clay, petroleum, and coal.

These deposits reach depths of 0.4 to 0.5 kilometers in the Moscow region, and 10 kilometers in the Donets Basin.

Deposits of the Permian age, which lie in a wide strip along the west slope of the Ural range, also occur frequently in the Russian lowlands. This system is made up of red clay and marl, limestone, gypsum, anhydrite, and conglomerates. Its average thickness reaches 2,000 meters.

Considerable mountain-forming processes went on during the Carboniferous period east of the Russian plain. They were completed in the Permian period by the creation of the Ural range which continued to undergo many changes throughout its own history.

Mesozoic Era

During the Mesozoic era there was a further evolution of land and sea animals, especially of reptiles, which reached their greatest development in the Jurassic period. Among the reptiles note must be taken of the giant dinosaurs which reached lengths of 26 meters and heights of 5 meters -- the Ceratosaurs, the sea Plesiosaurus and Ichthyosaurus, and also the flying lizards, the Pterosaurs.

In this period for the first time we find birds -- archeopteryx. Besides reptiles, ammonites and belemnites are found in the sea. The latter are the dominant petrified remains of the Jurassic period. Belemnite shells look so much like fingers that they are sometimes referred to as the "devil's fingers." The existence of such devil's fingers in sedimentary rock indicates that it was formed in the Jurassic period.

In the Cretaceous period reptiles gained further supremacy over other animals on land and in the sea. Some of them, the Stegosaurs and the Tyrannosaurs, were exceedingly huge.

Birds in this period continued to perfect their flying apparatus, but they were still far from perfect.

The vegetation changed a great deal in the Cretaceous. At the end of the period appear forms of vegetation which are close to present forms — the monocotyledons and dicotyledons (palms, laurel, willow, birch, oak, maple, and various grasses).

Mountain-forming processes are no longer observed in the Mesozoic era; only the falling and rising of continents as the sea advanced on to the land and then retreated. Because of these ingressions and regressions, the Russian lowlands in many places have great deposits of chalk, silica, limestone, clay, and other rocks of the Triassic, Jurassic, and Cretaceous ages. The northern part of the Ukrainian SSR and the central part of the Don and Volga contain chalk; Bryansk and Penza have beds of silica.

Cenozoic Era

The two periods of this era — the Tertiary and the Quaternary — differ from each other by their duration; the first is very long, the second comparatively short. In the Tertiary period the forms of animals and plants, especially plants, were very much like those at present.

The tropical climate (in Europe) which existed at the beginning of the Tertiary changed to subtropical and then to temperate, and by the end of the period it became moderately cold. The vegetation changed with the climate; subtropical evergreens gradually moved to southern latitudes, and birch, pine, and other species of temperate latitudes became dominant.

The animal world also underwent great changes: the number of reptiles decreased in comparison with the number in the Cretaceous period. Their place was taken by mammals: ungulates, rodents, etc. In the beginning of the period, mammals are still simple of structure; however, by the end of the Tertiary they become more highly organized. Some animals, such as the mastodons, hornless rhinoceros, and the saber-toothed tiger, were of considerable size and far exceeded the size of the modern elephant, rhinoceros, and tiger.

The relief of the globe also changed during the Tertiary period. The formation of the Caucasus and the Crimean folded mountains began at the end of the Cretaceous period, as did the Sikhot-Alin' range in the Far East, which was finally formed in the Tertiary period. The formation of the mountains of Kemchatka, Sakhalin, and the Kurile Islands belong to this period as well.

While mountains formed in the Tertiary period, continents slowly emerged and subsided. The Tertiary sea flooded huge areas of the country, depositing clay, chalk and shell limestone, shell rock, gypsum, and other rocks.

The moderately cold climate of the end of the Tertiary period changed to a cold climate, with the succeeding alternation of the warmer and colder ages of the Quaternary period.

During the centuries of cold climate, glaciers moved down along the Russian lowlands with consequent thaws during the warm interglacial intervals.

With the change in climate came a change in plant and animal forms. The severe cold forced animals and plants of temperate climates to move far to the south. Their place was taken by animals and plants of the tundra. When the climate became warmer they again moved back north, and the animals and plants of the southern latitudes took their places.

In the glacial epoch some animals became adapted to the cold climate. Among these were the mammoths, a group of which is found today in the perpetually frozen ground of Siberia.

The earliest progenitors of man were two-legged, highly developed man-like apes, whose existence is placed at the close of Tertiary. In deposits of the Quaternary age, the remains of an ape-man (pithecanthropus) have been found, the next step in the evolution of man. In the process of development Pithecanthropus cast off his ape-like characteristics and acquired the characteristics of modern man.

of the country, depositing clay, chalk and shell limestone, shell rock, gypsum, and other rocks.

The moderately cold climate of the end of the Tertiary period changed to a cold climate, with the succeeding alternation of the warmer and colder ages of the Quaternary period.

During the centuries of cold climate, glaciers moved down along the Russian lowlands with consequent thaws during the warm interglacial intervals.

With the change in climate came a change in plant and animal forms. The severe cold forced animals and plants of temperate climates to move far to the south. Their place was taken by animals and plants of the tundra. When the climate became warmer they again moved back north, and the animals and plants of the southern latitudes took their places.

In the glacial epoch some animals became adapted to the cold climate. Among these were the mammoths, a group of which is found today in the perpetually frozen ground of Siberia.

The earliest progenitors of man were two-legged, highly developed man-like apes, whose existence is placed at the close of Tertiary. In deposits of the Quaternary age, the remains of an ape-man (pithecanthropus) have been found, the next step in the evolution of man. In the process of development Pithecanthropus cast off his ape-like characteristics and acquired the characteristics of modern man.

In Quaternary time, as a result of the great glaciation, the crust rocks of the Northern and Central parts of the Russian lowlands were covered by extensive thicknesses of glacial formations -- moraine clay, river-glacial sand, sandy loam, and heavy fragmental rocks. At this time loess, quicksand, peat, and other rocks were also formed; these constitute the upper layers of the earth's crust on most surfaces of present continents.

Glacial Deposits in the USSR

In the mountainous regions of the Caucasus, Urals, Pamir, or Altay one can see new and old glacial formations in the mountains and foothill valleys in the form of highly scattered loose rocks. However, these deposits occupy a comparatively small area and are frequently lost among other geological formations -- deluvia, proluvia, and alluvia.

The glacial deposits of the central and northern parts of the USSR are of much greater importance. Their formation is connected with the repeated advance and retreat of glaciers during the glacial epoch. The duration of this epoch is approximately 475,000 years. In the European part of the USSR, there were several freezings which divided inter-glacial periods. There were three or four of these large-scale freezings. A time interval of 25,000 years separates us from the last of these. The Scandinavian mountains and Novaya Zemlya were regions where glaciers accumulated for the movement downward to the Russian lowlands. Down from

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

these mountains upon the wide plains below moved thick masses of ice (up to 1,000 meters) which left extensive geological disruption in their path, destroying mountains, overturning rock, crushing and grinding stones, and transporting huge masses of all kinds of loose materials.

With the change of climatic conditions, the thaws left masses of material along the entire path of the glaciers. Rivers and streams formed from the thaw partially scattered the loose materials of the erosion, but the basic mass was for the most part left untouched. Very frequently, rock waste or beds of gravel are found in thin clay, clay loam, or sand formation.

The southernmost advance of the glaciers in the USSR is approximately a line which goes through Zhitomir, Kiev, Orel, Voronezh, Penza, Kezan', Molotov, and Tyumen', with an extension to Kremenchug and Voroshilovgrad. The glacier reached this limit because of the freezing of the great Dnepr.

The main geological deposits of the glacial epoch can be subdivided into the following types: (a) moraines, (b) fluvial-glacial, (c) deposits of clay loam.

Moraine deposits are widespread in the USSR. They are divided into terminal, ground, interior, and surface moraines. In addition, they are further divided into lower (older freezing) and upper (later freezing) moraines.

Terminal moraines are characterized by the presence of great masses of large fragments (boulders, pebbles, gravel, sand) in the form of lengthened, raised embankments or a particular type of long-stretching hills (kames).

Ground, interior, and surface moraines are characterized by compacted clay or clay loam formations containing pebbles and gravel. The depth of moraine deposits varies from 2 to 100 meters.

Fluvial-glacial deposits are those of rivers formed by glacial thaw. They contain gravel, sand, and pulverized sand formations. Sometimes these deposits occur in more or less even layers, forming plains, and often they are osars or eskers (Figure 61).

1. Sand rubble
2. Sand beds
3. Gravel
4. Morain clay loam

Figure 61. Common type of osar or esker

Covered clay loam most frequently is the product of moraine erosion. It usually occurs in the upper part of the deposit, very close to moraine clay and clay loam, but differing from them in being less compact and composed of larger particles.

Leningrad oblast is a typical region of glacial deposits.

Here once can see terminal moraines with piles of big boulders and compact yellow-blue ground moraine and large strata embankments (eskers and kames), which give the surface a characteristic hilly relief. Here also we find many glacial lakes, a distinctive feature of the whole northwestern region.

At one time, a glacier moved along this area, turning up rocks and leaving deep hollows which filled with water.

In a great many places, areas of glacial deposits are very rich in road construction materials. Localities with terminal moraines (eskers and kames) contain much rock waste, pebbles, gravel and sand -- mixed with clay-dust particles. In the Estonioan SSR, in the Moscow, Kalinin, Kirov, Molotov, and other oblasts, most of the hills contain gravelly sand-rocks with a little rock debris. Some fluvial-glacial formations located close to the terminal moraines also contain gravelly pebble-rocks.

36. The Geological Chart

The geological chart is a topographical chart which shows rock distribution in color.

There are two kinds of geological charts -- charts of crust deposits (rocks) and charts of Quaternary deposits.

The first type of chart shows rocks of the pre-Quaternary age occurring under layers of Quaternary formations. Only when crust rocks are very deep do the charts show Quaternary deposits.

Charts of Quaternary deposits show rocks of the Quaternary age as an almost continuous cover of crust formations. They are divided into glacial deposits, loess, alluvia, etc.

Geological charts of crust deposits are made up principally according to age; that is, the chart shows deposits of any given geological age. Areas with deposits of the Cambrian, Silurian, Devonian ages, etc, are separated without consideration of what rocks are present.

Very frequently, especially in large-scale charts, period deposits (systems) are divided into epoch deposits (sections) and aged deposits (strata).

Areas which have deposits of a given period, epoch, or age are represented on the chart by international letter symbols as indicated in Table 8 and are colored with an appropriate color or striation. The legend of the chart is so constructed that rocks range chronologically from the most recent at the top to the oldest below.

Besides charts based on age, charts are prepared according to lithological character; that is, according to the nature of rock composition. In these charts, areas are divided according to the nature of rock (sandstone, limestone, sand, clay, etc), regardless of geological age.

All types of geological charts are very important in road construction. A familiarity with geological charts gives a good idea of the rocks which occur on the surface and beneath the surface in any locality. If the geological chart is sufficiently detailed and has explanatory notes, a more or less accurate knowledge of the rocks can be ascertained directly from the chart, and sometimes even the condition of the rock beds. This is necessary data for all kinds of construction.

CHAPTER XIV

PHYSICAL PROPERTIES OF EARTHS

To a considerable extent, the basic physical properties of earths indicate whether they are suitable for use as construction materials and as engineering foundations.

The specific gravity and bulk weight, porosity, plasticity, viscosity, swelling, and shrinking are all part of the basic physical properties of earths.

This chapter describes the methods of determining the moisture content of earth as affecting the basic physical properties. Knowledge of moisture content is necessary in determining bulk weight, plasticity, viscosity, swelling, and other properties.

60. Specific Gravity

Specific gravity is the relationship of the weight of the particles of a given volume of absolutely dry earth to the weight of an equal volume of water at a temperature of 4 degrees Centigrade.

Specific gravity is an indication of the mineral composition of earths. For most earths lacking organic material, the specific gravity varies on an average from 2.60 to 2.70

The value of the specific gravity of earth is used in a series of formulas: in calculating porosity, calculating the velocities of falling particles of earth in any medium (Stock's formula), etc.

Testing Procedure

Apparatus and materials necessary: (1) analytic scales, (2) pycnometer, (3) an electric plate or any other heating device, (4) washer, (5) desiccator, (6) thermometer scaled to 150 degrees Centigrade, (7) asbestos sieve, (8) distilled water.

The specific gravity of earths is determined by using a pycnometer equipped with a capillary tube (Figure 87), after the following procedure:

Figure 87. Pycnometer

1. Weigh the pycnometer (weight A) to an accuracy of 0.0002 grams.

2. Pour distilled water into the pycnometer up to the measuring mark and weigh again (weight B).

3. Pour 5 to 10 grams of earth, which has been sifted through a 1 millimeter mesh and dried to a constant weight at 105 degrees Centigrade, into the dry pycnometer and weigh (the weight of the pycnometer with the portion of earth is weight C).

4. Add distilled water to the earth to half the capacity of the pycnometer and boil for 30 minutes.

5. After cooling, pour distilled water into the pycnometer up to the measuring mark, and then weigh the pycnometer with water and earth (weight D).

The specific gravity is calculated according to the following formula:

$$\gamma = \frac{C - A}{C - A + B - D}$$

The specific gravity of some earths and soils varies within the following limits:

Peat	0.50 - 0.80
Black soil containing 10% humus	2.37
Black soil with lower humus content	2.40 - 2.50
Black soil on loess	2.57
Podzolic loam with 3% humus	2.65
Sand	2.65 - 2.67
Sandy loam	2.67 - 2.69
Jurassic clay	2.75

In determining the specific gravity of saline earths and earths containing active colloids, instead of using water for the tests use a neutral liquid such as kerosene or gasolene, etc. Instead of boiling, the air is removed from the earth by use of a vacuum pump. In calculating the specific gravity, correction must be made for the specific gravity of the kerosene or gasolene.

61. Moisture Content of Earth

The moisture content of earth is the quantity of water it contains expressed in a percentage relationship to the weight of dry earth. The moisture of earth is a changeable value and can vary to a great degree. The more finely granulated the earth, the greater is the variation in moisture content. Moisture is an important characteristic of the condition of earth and must be taken into consideration in determining a series of important indexes of the properties of earths: stability under pressure, resistance to displacement, plasticity, viscosity, etc.

Testing Procedure

Moisture content is usually ascertained by a weighing method which determines the loss of weight which results when a portion of earth is dried in the following sequence:

(a) Weigh the weighing bottle

(b) Place a sample of moist earth of 10 to 20 grams into the bottle.

(c) Weigh the bottle with the moist earth.

(d) Place the weighed, uncovered bottle of earth into a desiccator which has been regulated to a heat of 105 degrees Centigrade.

The test sample of earth is allowed to remain in the chamber at 105 degrees Centigrade for 5 hours.

(e) At the end of the drying period, close the bottle, transfer to a dry exsiccator with chlorine ring, and allow to cool to room temperature.

(f) Weigh the cooled bottle of earth.

To dry the earth completely, repeat the sequence after an hour and weigh again.

The difference between the first and second weighings should not exceed 0.2 percent of the weight of the test-sample.

The moisture of the earth is determined according to the formula:

$$W = \frac{P - P_1}{P_1 - P_2} \cdot 100$$

where: W is the moisture content of the earth in percentage relationship to the dry weighed portion;

P is the weight of the bottle of moist earth;

P_1 is the weight of the bottle of dry earth;

P_2 is the weight of the bottle.

Conduct all weighings in moisture determination with analytic chemical weights to an accuracy of 0.01 grams.

For special humidity analysis (determining the molecular moisture capacity, hygroscopic moisture, the humidity effects on rolling limit, etc), decrease the portion of moist earth and weigh 10 grams or less on analytic scales.

62. The Bulk Weight of Earth

The bulk weight is the weight of a unit volume of earth, including mineral particles and spaces (pores) between the particles.

The value of the specific gravity of earth depends upon the mineral and chemical content; the bulk weight depends upon the moisture content and the texture and structure of the earth, that is, on the quantity of pores in the earth. For this reason, the bulk weight of the very same earth, especially of clay, will vary a great deal under different conditions.

Under natural conditions, clayey earths usually have higher porosity than sandy earths and therefore have a lower bulk weight.

Bulk weight can be determined for different states of earth: (a) for earth in natural beds, (b) for filled and loose earth, (c) for earth compacted by different methods.

Determining the Bulk Weight of Air-Dried Earths in the Loose State

Necessary Equipment:

Laboratory rack with collection of holders;

glass or metal funnel for pouring earth, with a capacity of not less than 300 cubic centimeters and an internal tube diameter of approximately 20 millimeters;

graduate with a capacity of 500 to 1000 cubic centimeters;

cup scales of 2 to 5 kilogram capacity with balance.

Arrangement of funnel: in the laboratory rack, fasten the funnel with the aid of the holders into the tube and slip on a perforated cork at the point the funnel enters the cone.

Testing Procedure

1. Pass the sample of air-dried earth, about 1 kilogram in weight, through a strainer with a 10 millimeter mesh.

2. On cup scales, weigh to an accuracy of 1 kilogram a 500 cubic centimeter graduate if the earth is finely granulated, or a 1000 cubic centimeter graduate if the earth contains a large quantity of sand or gravel particles.

3. Through the funnel, fill the weighed cylinder with earth which has previously been strained through a 10 millimeter mesh. The volume of the earth in the graduate must be 500 cubic centimeters if finely granulated or 1000 cubic centimeters if coarsely granulated (containing gravel).

4. Weigh the graduate filled with earth.

5. Bulk weight is determined by the formula:

$$\Delta = \frac{P - P_1}{V}$$

where Δ is the bulk weight;

P is the weight of the graduate and earth;

P_1 is the weight of the empty graduate;

V is the volume of earth in the graduate.

The experiment is repeated for control purposes. Results of repeated experiments should not differ by more than ± 1 percent.

Determining the Bulk Weight of Cohesive Earths with Natural Moisture and Undisturbed Texture

Testing Procedure

1. Place about 100 grams of paraffin into a porcelain pan. Melt the paraffin.

2. Immerse the weighed piece of naturally moist earth of undisturbed texture, 30 to 50 cubic centimeters in volume, by a thread in the melted paraffin for 3 to 5 seconds; then cool in the air. When the paraffin cover has cooled and hardened, immerse the test sample again in the paraffin and again cool in the air. The surface of the paraffin-coated test sample should contain no bubbles; it must be smooth.

To cool the paraffin-coated test materials, suspend them from the holders by a thin thread or wire.

3. Take a separate test-sample of earth and determine its natural moisture content.

4. Weigh the cooled paraffin-coated material by the difference in weight between the earth and the earth + paraffin determine the weight of the paraffin on the sample by the formula:

$$P = P_2 - P_1$$

where P is the weight of the paraffin on the sample;

P_1 is the weight of the earth;

P_2 is the weight of the paraffin-coated earth.

5. The volume of the paraffin on the sample is calculated according to the formula:

$$V_3 = \frac{P}{0.9}$$

where V_3 is the volume of the paraffin on the sample;

0.9 is the specific gravity of paraffin.

6. Under the raised left pan of the chemical scales, arrange a wooden support in which there has been placed a chemical graduate half filled with water at room temperature. Suspend a wire with a weight in its hooked lower point over the levelly-balanced left cup of the scales. Now level the right pan (Figure 88) with a weight.

Figure 88. Scales for hydrostatic weighing

7. Suspend the prepared paraffin-coated sample on the wire; immerse it in water and determine its weight in water.

Determine the bulk weight of the earth by the formula:

$$\Delta = \frac{P_1}{(P_2 - P_3) - V_3}$$

where P_3 is the weight of the paraffin-coated sample in water.

Repeat the procedure for control purposes.

Determining the Bulk Weight by Use of a Cutting Ring

Under field conditions or when there is a monolithic sample of undisturbed earth in the laboratory, the bulk weight can be determined by using a metal ring (usually steel) with an inside cutting edge.

It is recommended that a ring of 200 to 250 cubic centimeters capacity be used for clay and clay loam, and one of 500 cubic centimeters for sand loam.

The diameter of the ring must be between 2.5 and 3 times larger than its height.

Carefully press the cutting ring into the earth, gradually dislodging the earth from the ~~in~~ outside of the ring.

Trim the ring with a knife and withdraw it; carefully protect the lower and upper surfaces of the earth in the ring.

Weigh the ring and earth to an accuracy of 0.1 grams. The weight of the ring and its volume must have been previously determined.

Knowing the weight and volume of earth in the ring, calculate the bulk weight of the earth by dividing the weight by the volume.

Determining the Bulk Weight of the Solid Portion of Earth

By bulk weight of the solid portion of earth we mean the ratio of the weight of hard particles to the overall volume of naturally moist, undisturbed earth, or to the volume of naturally packed earth.

It is necessary to know the bulk weight of the solid portion of earth in order to determine the density of the structure and other characteristics of a given portion of earth.

To determine the bulk weight of the solid portion of earth, place an average test-sample of earth in a bottle and determine its moisture content.

The bulk weight of the solid portion of the earth is calculated according to the formula:

$$\Delta_C = \frac{\Delta_B}{1 + 0.01\,W}$$

where Δ_C is the bulk weight of the solid portion of earth;

Δ_B is the bulk weight of the moist earth;

W is the moisture content in percent.

Determining the Porosity of Earth

The porosity of earth expresses the relationship of the volume of pores in earth to the total volume of the earth, and can be calculated from the formula:

$$n = \left(1 - \frac{\Delta_C}{\gamma}\right) \cdot 100$$

where n is porosity in percent;

Δ_C is the bulk weight of the solid portion of earth;

γ is the specific gravity of earth.

63. Plasticity of Earths

Depending on the amount of moisture, cohesive earths can be found in various states:

(a) solid, (b) plastic, (c) fluid.

Changes from one state (consistency) of earth to another and changes in moisture content take place rather abruptly and indicate differences in the stability of earths under stress.

For this reason, humidities which correspond to the change of earth from one state to another are used as the most important characteristics of earths.

It is very important to determine the moisture content which corresponds to the change of earth from a solid state to a plastic one, or from a plastic state to a fluid one.

The plasticity of earth is its ability to undergo deformation under outside pressure without rupture of the unified mass, and to preserve its given form when the deformation forces are removed. Cohesive earths possess plasticity only at a definite moisture content: with less moisture the earth becomes solid; with more moisture the earth changes into a fluid state.

To determine the ability of earth to take on a plastic state, determine the moisture content which characterizes the limits of the plastic state: the fluidity limits on the one hand and the rolling limits on the other hand.

The limit of the fluid state is that point at which an earth changes from the plastic state to a semi-liquid fluid. At this point, the cohesion of particles is nearly destroyed because of the free water present because water easily dislodges and disperses earth particles. As a result of this, the adhesion between particles becomes negligible. The stability of earth under stress at the fluid moisture limit is in most cases very slight.

The rolling limit corresponds to the moisture content of earth at the point of change from a solid to a plastic state. When moisture is increased, the earth begins to lower abruptly its stability under stress. The rolling limit corresponds to the level of moisture content at which packed uniform clay and loam practically become impervious to water.

The fluid limit and the rolling limit can be called the upper and lower limits of plasticity.

The plasticity number is used as a basis for describing the fluid limit and the rolling limit.

The plasticity number is the difference between the fluid limit and the rolling limit of earth, and characterizes the degree of plasticity of earth.

Earths which are stable in road foundations or in the heavily-traveled part of dirt roads possess a plasticity number between 1 and 8 inclusive.

By means of the plasticity number, one can judge the amount of clay, the physico-mechanical, and aqueous properties of earth. Increasing the clay content of earth raises the plasticity number.

By comparing data on the natural moisture content of an earth with previously-indicated limits of plasticity, we can express the moisture content by a relative value, in the form of a fraction, with the moisture content of the earth as the numerator and the fluid limit or the rolling limit as the denominator. The relation of the natural moisture content to the fluid limit is called the fluid coefficient. The value of the fluid coefficient describes the state (consistency) of the earth under natural conditions and the degree of its stability under stress.

With normal moisture content equal to, or a little less than, the rolling limit, the earth is very good for working: excavating hollows, filling in, and packing. When the earth changes to a plastic state, it is difficult and even impossible to carry on such operations. In the fluid state, earth loses its stability altogether.

According to the norms for drafting natural industrial foundations and civil buildings (OST 90004-38), earths are classified according to plasticity number. Earths can be divided into the following groups, depending on the value of the plasticity number:

(1) clays with a plasticity number above 17

(2) clay loam with a plasticity number from 7 to 17

(3) sandy loam with a plasticity number under 7

(4) non-plastic sand

Determining Plasticity by the Weighing Method

List of equipment necessary:

(1) Bezruk apparatus for determining the fluid limit

(2) chemical scales with balance

(3) exsiccator with water

(4) spatula

In addition to the above, all equipment necessary to determine the moisture of the earth (desiccator, bottles, etc.).

The Bezruk apparatus for determining fluid limits (this is a modification of the apparatus of V. V. Okhotin): the apparatus (Figure 89) consists of an iron support 1, into which a rod 2 has been inserted; a plate 3, with a depression into which is placed an iron or brass cup 4 of earth, moves freely along the rod.

Figure 89. Apparatus of V. M. Bezruk for determining the fluidity of earths

Prior to the experiment, the cup has been fastened to the plate by means of a rubber ring 5. A rubber strip is attached to soften the blow on the support 1. [Translator's note: There is no number 6 in text to correspond with number 6 of the figure. Assumedly, the rubber strip is number 6.] On the rod 2, at a height of 15 centimeters from the support of the apparatus, screw on a collar; the plate with the cup 4 of earth is raised to this height during the experiment. The iron or brass cup has a diameter of 90 to 95 millimeters and a depth of 25 to 30 millimeters. The weight of the plate and cup is 1 kilogram.

A special metal knife 7 has been provided to make a cut in the sample of earth.

In cross section, the knife has the form of a trapezium with upper base dimensions of 2 millimeters and a lower base of 10 millimeters. The angle formed by the edges must equal 60 degrees.

Preparing the Earth for Analysis

From the earth, which has been pulverized and passed through a 0.5 millimeter mesh, take a sample of about 100 grams. Moisten the sample selected in a porcelain pan and carefully mix until the earth shows signs of plasticity (that is, until the earth acquires the ability to keep the form given it). Place the earth thus prepared into an exsiccator, containing water in its bottom part, for 12 to 20 hours so that the moisture will be spread uniformly throughout. The earth in the exsiccator is used to determine the fluid limit and also the rolling limit.

Determining the Fluid Limit

To determine the fluid limit, pack a 10 millimeter layer of earth in the bottom of the cup of the Bezruk apparatus. With a spatula, level the surface of the earth in the cup. Make a cut through the center of the cup, keeping the knife on the surface.

On the first stroke, sink the knife 2 to three millimeters deep, and in the following cuts slit the earth down to the bottom of the cup. The result must be a depression in the earth, 2 millimeters wide at the bottom of the cup and 10 millimeters at the top, running through the whole layer of earth. Place the cup of cut earth on the plate of the apparatus and fasten with a rubber ring.

Raise the plate 3 with cup along the rod to a height of 15 centimeters, and let it fall freely. Now, observe the condition of the depression in the earth. If the depression does not fill in after the first drop, make a second drop. If after the second drop, the depression is filled in by 1.5 to 2 centimeters at the bottom of the cup, the experiment is considered ended. If no filling-in is noticed after the second drop, moisten the earth in the cup again by adding 5 to 6 drops of water, and after mixing carefully, pack it in the bottom of the cup and repeat the experiment for filling the depression (Figure 90).

At the beginning At the end

Figure 90. Determining the fluid limit

After ascertaining the moisture content, which causes the earth to fill in on the second drop, repeat the experiment; but this time, depress the earth in a direction perpendicular to the first depression. If the earth fills in on the second drop, take a sample from the cup and determine its moisture content by the method previously described.

The moisture content of the earth when it fills in on the second drop is used as the limit of fluidity.

Carry out an experiment for control purposes. Place another portion of moistened earth from the porcelain pan into the cup on the apparatus and repeat the experiment.

Deviation in test results is allowed as follows:

(a) for sandy loam -- not more than 2 percent

(b) for clay loam and clay -- not more than 2.5 percent

Determining the rolling limit

From the moistened earth which has been kept for 12 to 20 hours in the exsiccator, roll a ball 1 centimeter in diameter. Transfer the ball to waxed paper, and on it carefully work the ball into a roll 3 millimeters in diameter.

If the roll of earth does not break up into pieces, mold it again into a ball, and once more roll it out. Repeat the operation until the sample of earth, which has been worked into a roll 3 millimeters in diameter, begins to crumble into separate pieces.

Gather the crumbled pieces of the 3 millimeter roll into a bottle and determine the moisture content of the earth. In order to determine the moisture of earth at the rolling point, it is necessary to have not less than 5 grams of rolled earth in the bottle.

Repeat the experiment for control purposes. Deviation in repeated tests is allowed as follows:

(a) for sandy loam -- not more than 1 percent

(b) for clay loam and clay -- not more than 2 percent

Determining the Plasticity Number

The plasticity number is determined by the difference between moisture contents at the fluid limit and at the rolling limit. Thus, if the moisture at the fluid limit is equal to 40.5 percent and at the rolling limit to 18.7 percent, the plasticity number of the earth sample is $40.5 - 18.7 = 21.8$.

The limits of plasticity and the plasticity number are reliable indexes by which to judge the physical and mechanical properties of earths (resistance to displacement, resistance to vertical stress, ability to increase in volume and become moist, adhesiveness, etc). The fluid limit is very close to the total capillary moisture capacity of the given earth. At this point, earth almost completely loses the ability to resist vertical stress and displacement. With further increase of moisture, earth changes into a fluid state.

The rolling limit is the point at which the earth changes from solid to plastic state. The moisture of earth at this point in most cases coincides with the "optimum moisture content," at which point the earth is subject to maximum compacting with the least pressure applied. Earth at this moisture rolls well for use on thoroughfares; it does not raise dust; it does not possess adhesiveness; it does not form ruts in dirt roads.

64 The Adhesiveness of Earths

Adhesivness is the capacity of earths to adhere to objects when coming into contact with them. Adhesiveness is expressed in grams per square centimeter by measuring the forces necessary to remove the object to which the earth adheres. The property of adhesiveness is characteristic of clays and semi-dusty earths in a moist state. This is extremely unfavorble for road construction. In addition to moisture, other things which influence the amount of adhesiveness are: the granulometric and chemico-mineralogical composition of the earth, the forces which originally caused the object to be pressed to the earth, and the kind of materials to which the earth adheres (glass, wood, metal, etc).

Earths which are most adhesive are saliferous and humus, containing clay and clay loam. Sandy earth has practically no adhesiveness.

The adhesiveness of earth increases with the increase of moisture, but within certain limits. When full moisture capacity is reached, the adhesiveness of earths decreases sharply, and with further increase of moisture, adhesiveness may disappear altogether.

The adhesiveness of earths supplements the characteristics of granulometric composition and plasticity, and is determined for the purpose of establishing the adaptability of earths to the use of road machinery and their suitability for use in the thoroughfare part of dirt roads.

The test for adhesiveness is conducted in the apparatus of Professor V. V. Okhotin (Figure 91).

Figure 91. Okhotin apparatus for determining the adhesiveness of earths

Description of Apparatus

A frame consisting of two stands with a crossbar is set into a wooden board. On the frame are mounted a block and funnel which is filled with shot. A cross brace is placed across the block, on one end of which -- beneath the funnel -- a small bucket is hung, and on the other end hangs a stamp 10 square centimeters in area. The stamp and the bucket must be of equal weight. Test the sensitivity of the apparatus by adding a one gram weight to the bucket. This should cause the bucket to descend. On the board beneath the stamp, arrange a mold for the earth with smoothers.

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

Testing Procedure

1. Pass a dried and pulverized sample of earth through a 0.5 millimeter mesh. Take a 200 gram portion of the sifted earth and moisten it in a porcelain pan to a "working" condition (the earth at this moisture kneads easily, keeps its form, and does not stick to the hands). Record the amount of water added.

2. Place the moistened earth in an exsiccator with water and keep above the water for 18 to 24 hours.

3. At the end of the period, separate the earth and use one portion of the prepared earth to determine the limit of adhesiveness. Determining the limit of adhesiveness is done in the following manner: press a spatula on the earth and then remove it. If no earth adheres to the spatula, add 2 to 3 cubic centimeters of water to the earth. Carefully mix the earth and repeat the experiment by pressing and removing the spatula. Water is added to the earth until no earth adheres to the spatula. Record the amount of water added.

4. To the second portion of prepared earth, add 4 cubic centimeters of water, less than necessary to obtain the limit of adhesiveness, and carefully mix the earth.

5. Pack a portion of the prepared earth into the mold of the apparatus in such quantity that there will be an excess of earth above the mold.

6. Press the stamp into the mold, which has been supplied with special guides, and by hand or mechanical press, squeeze the stamp. Remove the excess amount of earth pressed out.

7. Arrange the mold in the smoother; to the stamp, join the crossbar with the bucket weighted on the other end, and gradually pour the shot through the funnel into the bucket.

8. When the stamp is removed from the earth, stop the flow of shot and weigh the bucket with the shot. Make a moisture test of the earth in the mold.

9. Free the mold of earth and mix in part of the remaining prepared earth.

10. To this portion of earth add 2 to 3 cubic centimeters of water; carefully mix the earth and again test in the apparatus as indicated in 5, 6, 7, 8, and 9.

11. Continue the testing in the apparatus, increasing the moisture repeatedly until the pull reaches a maximum, and until two or three results are obtained which indicate a decrease in the magnitude of pull.

12. Determine the moisture content in all tests taken.

13. On the basis of the data obtained, compose a table or graph of the relationship of adhesiveness to moisture content and determine the maximum pull in grams per cubic centimeter and

determined the corresponding moisture content of earth.

65. Swelling of Earths

The property of swelling consists in the capacity of earth to increase its volume upon absorbing water. Swelling of earths is explained at the present time by colloidal chemistry. The colloidal particles possess the property of holding (adhering) on their surfaces a considerable amount of the molecular layer of water; this causes the colloidal particles to swell.

Many earths, especially clays, contain various substances in their mass which are in colloidal dispersion. The ability of colloidal particles to swell gives the earth in general the property of increasing its volume when it is dipped into water.

The magnitude of swelling varies for different earths. It depends on the quantity of colloidal substances, their quality, texture, and structure, and the mineral composition of the earth.

As a rule, heavy clay earth with hydrophilic (absorbent) colloidal forms evidences the maximum amount of swelling.

On the other hand, coarse, granulated earths (sand, sandy loam) evidence almost no swelling.

A simple method of determining the swelling of earths is the metering method described on page 200, as developed in the

Experimental Science Road Institute (DORNII). However, this method gives only a relative idea of the swelling of earth, since in carrying out the experiment, the natural structure of the earth is destroyed by pulverizing the earth and subsequently precipitating it in an exceedingly large amount of water. Such test conditions produce exaggerated indications of swelling.

A method which gives a better idea of the natural swelling property of earth has been presented by A. M. Vasilyev.

1. With the aid of a polished cutting ring 1 (Figure 92) 25 millimeters in depth and 58 millimeters in diameter, take a sample of earth of natural texture and moisture. Using the special insert, cut the earth so that the thickness of earth in the ring 1 will equal 1 centimeter.

Figure 92. A. M. Vasilyev's apparatus for determining the swelling of earth

2. Put the brace 2 on the front part of the ring, having previously inserted a disc of filter paper between the earth and the brace. Put the plunger 4 inside the ring.

3. Set the assembled apparatus in a round glass developing dish (crystal pan) after placing a porous plate beneath the apparatus and after filling the space between the porous plate and the lower surface of the earth with the sand filter 3.

4. Set the dish and apparatus on the table 5. Then set the meter, which will measure deformations, in such a position that the stem touches it with the plunger 4. Carefully fasten the cantilever apparatus; this holds the meter by a set screw in the position shown.

Record the initial reading of the meter and allow the capillary water to reach the earth in the ring by carefully pouring the water into the crystal pan up to the level of the porous plate.

6. Make calculations by the meter readings at definite intervals of time.

7. The swelling is expressed in percentage relationship to the initial volume of the test sample. For this, it is necessary to divide by 10 the number of intervals on the scale of the meter which the indicator has passed during the experiment, since the initial depth of the sample of earth is 10 millimeters, and each division on the face of the meter corresponds to a swelling deformation of 0.01 millimeters.

For example, if the indicator on the face of the meter moves 320 spaces during the experiment, the swelling of the earth will be 32 percent.

66. Shrinking of Earths

Shrinking is the capacity of moist earths to decrease their volumes after drying. Therefore, shrinking is the opposite phenomenon of swelling. If the water content in earth decreases as a result of evaporation, the earth changes from a plastic state to a semi-solid state. For cohesive earths, the decrease in volume of earth up to a certain point is equal to the amount of the evaporated water. When the water content in an earth approaches a certain point, which is called the limit of shrinking, the volume of the test sample no longer decreases; however, the evaporation of water continues, and consequently the weight of the sample decreases.

The magnitude of shrinking depends on the quantity and quality of the clay-colloid groups and on the pressure of the coarser groups contained by the earth. Earth with a higher content of clay evidences a greater amount of shrinking. Sandy loam and especially sandy earths are characterized by extremely little shrinking and sometimes do not evidence this property at all.

Linear and mass shrinking are differentiated. The mass shrinking is usually the one determined. The magnitude of the mass shrinking characterizes to a certain extent the content and properties of the clay-colloidal groups in the earth.

The phenomenon of shrinking of moist earth is explained by the very same properties of clay-colloidal substances in the earth that explain the swelling of earth. During swelling, the thickness of the film of water around the earth particles increases; during shrinking, it decreases. Shrinking, like swelling, is partially explained by capillary action.

Determination of mass shrinking, according to the method of A. M. Vasilyev, is done in the following manner:

1. To an average sample of air-dried earth which has been passed through a 0.5 millimeter mesh, add water up to the fluid limit, and leave in an exsiccator with water for 10 to 12 hours.

2. Place moistened earth into a metal cylindrical form 4 to 5 centimeters in diameter and 2 to 3 centimeters in depth, which has previously been smeared with a thin layer of vaseline, and by tapping make sure that the form fills with earth. Smooth off the excess earth along the edges of the form with a steel rule.

3. Dry the earth-filled form first in the air, then after the earth becomes a little firm continue the drying at a temperature of 40 degrees. Continue the final drying of the sample to a constant weighing at 105 degrees.

4. Next, determine the volume of the dried sample and the volume of the form by the method given on page 207.

5. The volume of the shrinking is calculated by the formula:

$$V_y = \frac{V - V_0}{V} \cdot 100\%$$

where V_y is the amount of shrinking
V is the volume of the form

V_o is the volume of the dried sample of earth

According to the data of Professor V. V. Okhotin, the moisture content at the shrinking point is close to the rolling limit of the same earth, but a little lower. Investigations carried on in the DORNII have established that for most cohesive earths, the shrinking limit approximately coincides with the optimum moisture content at the maximum compression point of earth.

CHAPTER XVI

THE MECHANICAL PROPERTIES OF EARTHS

72. The Concept of Stability of Earths under Stress

By stability of earths is meant their capacity of absorbing stresses without forming deformations of compression or dislocation above allowable limits.

The stability of earths is a changeable value and basically depends on the amount of moisture and porosity. The moisture content and porosity in earth, which corresponds to the maximem stability, differ widely for each category of earth and depend upon the source of the earth, its chemico-mineral composition, its granulometric composition, and other characteristics.

Under natural conditions, the total volume of the pores in clayey earths can exceed the volume of the hard skeletal part of the earth, and the number of individual pores can be greater than the number of separate particles. Under the influence of even small stresses, such uncompacted earths evidence a sharp decrease in porosity instead of dislocation or the dislodgement of separate particles in the total mass of the earth. To a considerable extent, the compression of such earths is increased when the earth is moistened. Water, by filling in the pores of the earth, weakens the union between the particles. This strongly decreases the pressure required for bringing earth particles out of a state of equilibrium.

The stability of cohesive clayey earths, with an increase in total volume when more pores are filled with water, is continuously lowered. When all the pores become filled with free water, there is practically no stability at all.

The stability of sandy earths, especially of coarse sands, changes little even when the pores are completely filled with water. Sand possesses little compressibility and does not decrease in volume when dried.

It is necessary to know the characteristics of porosity in order to obtain a correct notion of the degree of stability of an earth.

Porosity of earth is a ratio of the total volume of pores between particles of earth to the total volume of the given earth, including the volume of the pores, expressed in percentage. The porosity of earths depends on their granulometric composition, form, and mutual interrelation of particles; and in saturated earths, in addition, on the magnitude and form of the structural and microstructural fragments.

Earths under natural conditions usually constitute a three-phase system, consisting of : (a) particles of dry earth (the ground skeleton), (b) water, and (c) air. For this reason, pores of the earth are usually filled both with air and with water, and the proportion of water and air often changes.

If the total volume of a given earth is taken as a unit, and that portion occupied by hard particles is designated as m, and the portion made up of pores which can be filled with water and air, by n (Figure 97), we will have the following:

$$1 = m + n \qquad (1)$$

$$n = 1 - m \qquad (2)$$

$$m = 1 - n \qquad (3)$$

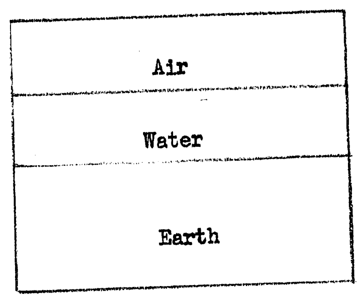

Figure 97. Proportion between the porosity of earths and the volume of earth and its component parts (hard particles, water, and air).

The volume of the hard phase of earth can be calculated if the following are known: the specific gravity of earth γ, and the bulk weight of its hard phase Δ_c using the formula:

$$m = \frac{\Delta_c}{\gamma}$$

Proceeding from this and using equation (2) we find that the volume of the pores in a unit volume of earth equals

$$n = 1 - \frac{\Delta_c}{\gamma} \tag{4}$$

or, expressing the volume of the pores in percent of the total volume of earth, we obtain the value of porosity

$$n\% = \left(1 - \frac{\Delta_c}{\gamma}\right) \cdot 100 \tag{5}$$

The volume occupied by earth is not a constant value. It varies with changes in the internal pressure or under other conditions. Since in a change of the total volume occupied by earth, the volume of the solid phase m does not change, but only the volume of the pores n, in the mechanics of earths it is more suitable to relate the magnitude of porosity to the volume of its solid phase m, than to the total volume of the given earth. The characteristic of porosity thus received is called the relative porosity, or the coefficient of porosity ε and usually is not expressed in percent but in portions of a unit:

$$\varepsilon = \frac{n}{m} \tag{6}$$

or, using equation (3):

$$\varepsilon = \frac{n}{1-n} \tag{7}$$

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

Substituting value n from equation (4), we get

$$\varepsilon = \frac{\gamma - \Delta_c}{\Delta_c} \tag{8}$$

When all the pores of an earth are filled with water, the relative porosity of earth ε characterizes the relationship of earth to the volume of the solid material (skeleton) and is equal to the product of the moisture weight of earth (expressed in portions of a unit) times the specific gravity of earth.

$$\varepsilon = \frac{W \cdot \gamma}{00} \tag{9}$$

73. The Relationship Between Pressure and Porosity

Downward pressure exerted on the earth, under conditions which prevent the earth from expanding laterally beneath the pressure, causes the porosity of the earth to decrease. To a considerable extent, the compressibility of earth depends on the initial porosity of the earth and the magnitude of the pressure applied. The less packed the earth is initially and the greater the magnitude of the compacting stress, the greater will be the extent of compression.

If the relative porosity ε is plotted against the externally applied pressure ρ in right angle coordinates, the result will be a compression curve (Figure 98).

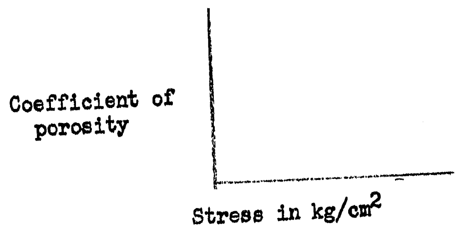

Figure 98. Compression curve

In actual construction with relatively small stresses on the earth, the relationship between the relative porosity and pressure can be considered as linear with enough accuracy for practical purposes. In such such cases, if the pressure on the earth changes from P_1 to P_2, the section of the curve between these points can be used linearly $M_0 - M_1$ without great error. By continuing this straight line to its intersection with the ordinate axis, we find point ε . The following equation can be made for a given linear:

$$\varepsilon = A - aP$$

where ε and P are variable values of the coefficient of porosity and pressure;

A is a constant abstract quantity;

$a = Tg\,\phi$ is the coefficient of compressibility measured in cm^2/g.

From the equation of the linear relationship obtained, it follows that the coefficient of the porosity of earth varies in direct proportion to the pressure exerted on the earth.

This rule is the basis of calculations for determining the value of the settling of earth under structures.

74. The relationship of Moisture to Pressure

The compression curve expresses the relationship between the amount of pressure on the earth and the corresponding porosity; or if all the pores are filled with water, to the moisture content of the earth.

If the earth has been moistened so that all of its pores are filled with water, on applying stress the volume of the pores will decrease; the water which fills the pores will be pressed out. When stress is applied to sandy earth, there is an abrupt decrease in the volume of the pores, since pores in sand are large and water is quickly expelled through them.

If water-saturated clay or clay loam is subjected to pressure, water will run out very slowly from such earth. This means that the compression of such earth, which is connected with the decrease in porosity, will also take a long time. Moreover, the pressure applied to the earth is immediately absorbed by the water in the pores of the earth.

Absorption of the stress by the solid phase is directly proportional to the amount of water expelled from the earth.

When the stress has been completely absorbed by the solid

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

phase of the earth, excess water under pressure stops escaping. Equilibrium is established between the external pressure on the earth and the reaction of the earth particles, which hold a certain quantity of water around themselves in the pores; the settling of the earth ceases. If after this a new stage of stress is applied -- one which exceeds the resisting forces of the earth's skeleton -- the equilibrium previously established is destroyed. Once more the process of expelling the surplus water begins, with the corresponding decrease in porosity of earth, until an accord is established between the pressure and the moisture content (porosity) of the earth.

This dynamic process is well illustrated in the following model (Figure 99).

Figure 99. Schematic drawing showing the relationship of moisture to pressure

A vessel both filled and surrounded by water is closed by a plunger π. The plunger is held in place by a metal spring. Let us suppose that the spring, which bears the stress of the plunger, corresponds to particles of earth; the water in the vessel corresponds to the water contained in the pores of the earth; the outlet a in the vessel corresponds to the pores in the earth through which water can be expelled.

When stress P acts on plunger π, at first all the pressure is absorbed by the water which, because of the pressure created upon it, begins to flow through the outlet a. The greater the size of the outlet, the greater will be the rate of escape from the vessel. The smaller the hole, the more time will be required for the pressure P initially to be felt by the spring. As the stress is transferred to the spring, the pressure upon the water weakens and the water stops escaping from the vessel. The resistance of the spring equalizes the pressure on the plunger. If the stress on the plunger is increased after the spring stops compressing, further escape of water occurs, and a new compression of the spring takes place until a new equilibrium is established between the stress and the resistance of the spring. Analogous phenomena take place in earth when vertical stresses act on it, inasmuch as the compression of the earth skeleton gradually increases its resistance, which equalizes external pressure, and water is expelled from the pores of the earth as the stress is increased.

Decreasing the moisture of the earth, which takes place when stress is exerted, causes a corresponding decrease in the porosity of the earth. Since for water-filled earth the relative porosity is numerically equal to the weight of the moisture multiplied by the specific gravity of earth (Section 72), instead of relative porosity ε , we can plot the weight of the moisture in the earth on the diagram of the porosity-pressure relationship. The diagram of the relationship between the moisture content of earth and pressure is also called the compression curve (Figure 100).

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

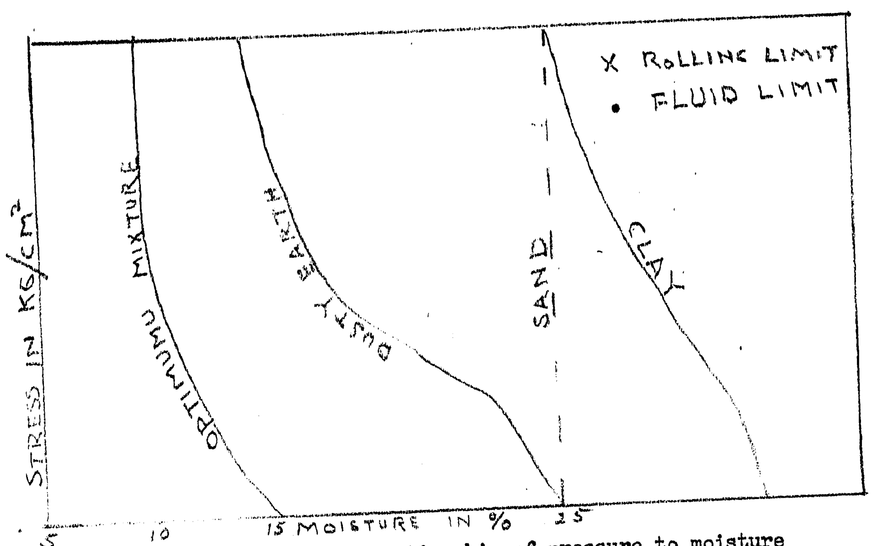

Figure 100. Relationship of pressure to moisture content of earths

Establishing the relationship between moisture of earths and pressure is of great practical significance and describes the change of the properties of earths in foundations of structures — changes which are caused by the action of stress.

75. Friction and Cohesion. Resistance of Earths to displacement

The resistance of earth to displacement is one of its most important characteristics since it is an indication of the stability of earth on the walls of excavations and embankments, and also in foundations of various engineering constructions.

When external stress is applied, tensions can arise in the earth mass causing a reciprocal movement (displacement) of particles;

these movements are of an irreversible plastic character. With increase of stress, deformation of the displacement gradually can take hold of large solid masses of earth, causing the stability of the sides of the earth to be destroyed, and sometimes going so far as to destroy engineering construction. Examples of deformations caused by displacement of earth are shown in Figure 101.

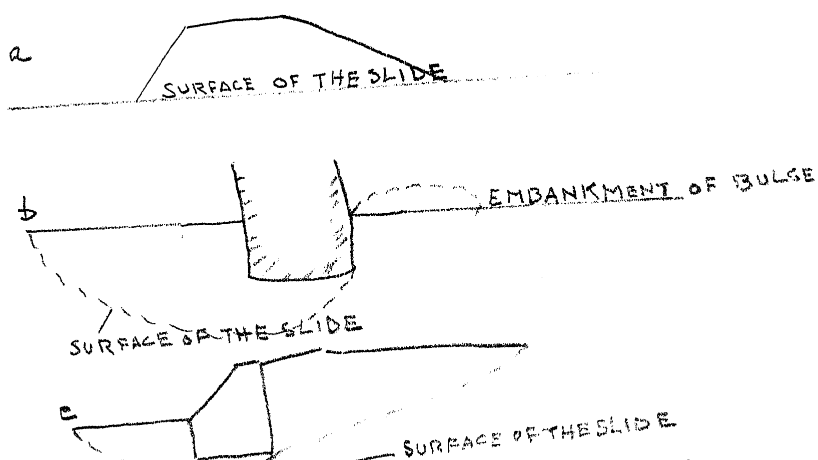

Figure 101. Deformation of the displacement of earth in various constructions: (a) destroying the stability of the side of a sub-grade, (b) bulging of earth from under the support of construction, (c) combined manifestation of deformation of displacement when stability of the slope is destroyed and the earth bulges from the foundation of a supporting wall.

Resistance of earths to displacement depend upon two things: (1) internal friction, and (2) cohesion.

The cause of friction between two bodies is the presence of roughness on their surfaces. When pressure is increased on rubbing bodies, thus bringing them closer together, friction increases between the bodies. In earths, friction arises between separate particles at their point of contact.

When the pores in earths are filled with water, the friction between the particles of earth, especially in clay and clay loam, decreases substantially. Water plays the part of a lubricant. In addition to this, slight particles of earth which are able to swell increase their volume and seem to repel each other, and films of water which are held on the surface of the earth particles by molecular attraction smooth away the roughness of the separate particles or their micrograins. For this reason, there is very little friction in clayey earths when they are moist.

Cohesion, which provides the tenacity of earths, was formerly explained exclusively by the presence of capillary forces in the pores when the mechanics of earths were first investigated. It was believed that when free gravitational water was present in earths, there was the smallest extent of cohesion. As water is removed from earth, concave meniscuses of capillary water are formed. As a result of the binding action of the meniscuses, particles of earth come together and acquire tenacity.

This explanation of the cohesion of earths does not exhaust all the complex phenomena of the interaction between solid particles and the film of water surrounding them. A more acceptable explanation of the tenacity of earths is given in the works of the Soviet scholar, Professor H. M. Gersevanov.

As H. M. Gersevanov points out, the reciprocal attraction of earth particles or their micro-grains is caused by the forces of molecular attraction between the surface of the earth particles and the films of bound water whenever earth particles come together at a distance less than the square of the radius of the action of the molecular forces. In this case, the forces of the molecular attraction of water are equal for both earth particles. On the other hand, the attraction forces of earth particles, which are directed to the water film, tend toward a reciprocal attraction of particles upon each other. In this way, internal forces of reciprocal attraction arise between all earth particles, causing tenacity in the earth. Since in an earth mass the contacting surfaces of particles have a highly diverse direction, the tenacity can be expressed by thorough pressure, which tightens all the particles between themselves. The creation of thorough molecular pressure depends on the density of the earth, which rises when particles come together.

Cohesion between particles or their micro-grains will be greater if there are more contacts between the particles. For this reason, tenacity reaches its highest extent in clay. Tenacity is practically non-existent in pure sand.

Apart from the forces of molecular attraction and capillary pressure in tenacious clay earths, cohesion occurs under the action of natural cements, especially colloidal gels and salts insoluble in water.

The resistance of earth to displacement forces can be expressed by the coefficient of internal friction and cohesion.

By the coefficient of internal friction f is meant the coefficient of the proportion between the vertical compacting pressure and the resistance to displacement, which is caused by internal friction. For a given earth, the coefficient of internal friction f can be considered a constant value. The part of the resistance to displacement caused by forces of friction does not depend on the magnitude of the area to which vertical pressure is applied, but only on the magnitude of the force P. If a graph is constructed showing the relationship of the displacement resistance of earth to the magnitude of vertical pressure upon it, the coefficient of internal friction f can be represented linearly as the tangent of an angle sloping toward the abscissa, which characterizes the rise of the resistance to displacement in proportion to the increase of vertical pressure on the earth:

$$f = \mathrm{Tg}\,\phi$$

where the angle ϕ constitutes the angle of internal friction of the earth (Figure 102).

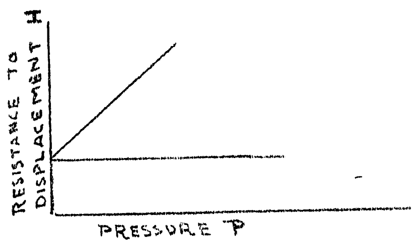

Figure 102. Diagram showing resistance of earth to displacement at different pressures

The value of cohesion c is that part of the resistance to displacement in earth which does not depend on vertical pressure P. Cohesion is measured in kilograms per square centimeter. The part of the general resistance to displacement caused by forces of cohesion depends on the magnitude of the area along which the displacement of earth occurs, and can be expressed as a product of cohesion and the magnitude of the area $C = F_c$.

The coefficient of internal friction and cohesion are very important characteristics used in calculating the resistance of earths to horizontal and vertical forces, as in calculating the stability of supporting walls, sides of embankments or excavations, and other road constructions.

76. Maximum Density and the Optimum Moisture of Earths

When the surface layers of the earth thicknesses occur naturally, they always constitute a three-phase system: solid substance + water + air. The water content and air content in earths are extremely variable, and can range from fractional to large percentages. On the magnitude of the porosity of earth, that is, on the volume which water and air occupy in it, depend the physico-mechanical properties. In road construction -- in the sub-grade, in the surfacings, and in the foundations of the road surfacings -- the greater the stability of the earth, the greater the density or, putting it another way, the smaller the porosity. Depending on how much the pores of the earth are filled with water, the earth can change from a stable condition to an unstable one, and vice versa, taking on a solid, plastic, or fluid consistency.

In examining the conditions of the stability of earths under stress, plastic consistency can be subdivided into hard-plastic and soft-plastic.

Solid and hard-plastic consistencies of earth are caused by the presence physically of bound water, and at hard-plastic consistency, the earth contains a certain amount of free water. A significant lowering of the supporting ability of the earth when changing from the hard-plastic to the soft-plastic consistency is explained by the further increase of the amount of free water.

At the solid consistency, we observe a considerable tenacity (cohesion) of earth -- a property which is very advantageous and valuable when using earth in road surfacings or foundations.

The amount of physically bound and free water in earths can be greatly changed under the influence of climatic and other conditions. Variations in the relative content of these categories of water cause changes in the physico-mechanical properties of earth.

The compacting theory of cohesive earths has been worked out by Professor N. N. Ivanov and Candidate of Technical Science M. Ya. Telegin on the basis of calculating the positive properties of physically bound water.

As a result of their research, it has been established that maximum stability of tenacious earth can be assured only when it is compacted to the maximum density with the "optimum" moisture content corresponding to the given earth.

By "optimum" moisture content of earth is meant the amount of moisture at which one can attain the maximum density, and consequently the minimum porosity, of earth with the least expenditure of work by compacting machinery (rollers, stampers).

The optimum moisture content can vary a little and depends both on the properties of the earth being packed and on the magnitude of the stress which does the compacting (Figure 103).

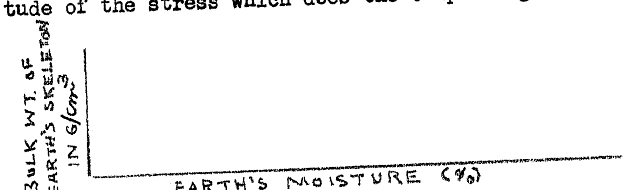

Figure 103. Optimum moisture and maximum density of various earths: (1) moraine clay loam, (2) carbonaceous loess, (3) covered clay, (4) clayey black soil

If the moisture content of earth is gradually increased, keeping the packing forces constant, the density of earth initially becomes greater and reaches a maximum density for each earth at a specific moisture content. Increasing the moisture content further with the same packing conditions causes the density of the earth to be lowered.

The maximum compactness of tenacious earths is approximately reached at a moisture content a little lower than the moisture content at the rolling limit.

Compacting earth at the optimum moisture content to its maximum density is the simplest method of increasing the stability of earth on roads.

However, the density of earth reached later on, when subgrade is used, can be changed under the influence of natural factors -- moisture and temperature. This change is sometimes very slow.

At optimum moisture content, when being compacted by forces of 30 to 40 kilograms per square centimeter (as when a steam roller is used to pack the earth), cohesive earths are at the transition limit from solid to hard-plastic consistency and are capable of withstanding a rather heavy stress (10 to 20 kilograms per square centimeter) without forming any significant deformations. The optimum moisture content assures many advantageous properties of earth when used in road construction. At optimum moisture content, earths excel in tenacity, do not possess adhesiveness and do not form dust.

The optimum moisture content characterizes the critical state of earth. With increase of moisture, free water appears in the earth along with physically bound water, and this causes negative road properties to appear -- low tenacity, swelling, high degree of adhesiveness, and plasticity.

Earth which contains free water first changes to a soft-plastic state, and with further increase of moisture it changes to a fluid state, that is, unstable and poorly suited to road construction.

The optimum moisture content and maximum density is determined in the laboratory to establish the necessary moisture and density of earth for compacting embankments, road foundations, and surfacings.

The apparatus for standard compacting consists of the following units : (1) a beaker base, (2) lower beaker, (3) upper beaker, (4) packer, (5) upright, (6) plate, (7) thrust collar.

The mounting of the apparatus and detailed dimensions are shown in Figure 104.

Sample of earth to
be compacted

Figure 104. Apparatus for standard packing of earth

Procedure of the Experiment

1. Determine the granulometric composition and plasticity of the earth.

2. Pass a sample of earth weighing 3 to 3.5 kilograms through a 5 millimeter mesh and moisten the earth until the moisture content is approximately equal to 50 percent of the rolling limit for cohesive earths and 30 percent of the fluid limit for non-cohesive (non-plastic) earths. Carefully mix the earth and moisten evenly; then determine the moisture content.

3. Weigh the lower beaker of the apparatus with the base to an accuracy of 1 gram.

4. Determine the number of blows necessary to obtain full compactness of the earth. Conduct the compacting of the earth in the form by blows of the descending packing weights, weight of 2.5 kilograms from a height of 30 centimeters. Carry on the compacting in layers by filling in earth to one third the height of the form. At each layer of earth, apply one third the planned number of total blows.

Determine the number of blows three or four times, each time changing by 10 or 20 the number of blows given by the weight. With each new number of blows, measure the volume of the compacted earth, and after weighing determine the bulk weight of the earth in the form. Repeat the experiment until the bulk weight of the earth does not vary from the preceding weight by more than 0.3 grams per cubic centimeter. The number of blows necessary for this is taken as the necessary number.

At each new packing, remove the earth from the form, pulverize it, repack into the form, and repeat the experiment, altering the number of blows as indicated above.

5. After establishing the necessary number of blows, repeat the experiment, raising the moisture content of the earth two percent with each repeated trial until the point is reached at which the bulk weight of the earth begins to decrease with further increase of moisture. With each repeated trial, take a sample of earth from the form and determine its moisture content by the weighing method.

6. On the basis of the data obtained, construct a curve showing the relationship between the bulk weight of the skeleton of earth and the moisture content. The peak of the curve defines the greatest bulk weight of the skeleton of the earth, and the corresponding moisture content defines the optimum moisture for the given earth (Figure 105).

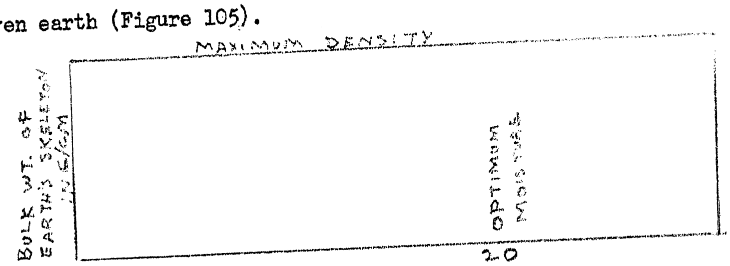

Figure 105. Curve of density (compactness) for clay loam earth

77. The Modulus of Deformation of Earths

Numerous tests conducted in DORNII under the direction of Professor N. N. Ivanov indicate that the durability of road surfacing depends on the amount of sag under the influence of repeated stresses.

The amount of sag of road surfaces depends on the natural hardness of the surfacing and on the resistivity of the earth beneath. According to N. N. Ivanov, the resistivity of earth can be characterized by the value of its modulus of deformation.

The modulus of deformation of earth is similar to the modulus of elasticity, which is used in the resistance of materials, but with this difference: in determining the modulus of deformation, the total deformation of the earth is taken into account — the elastic and the plastic — since even under insignificant stresses, earth has both elastic and residual plastic deformation at the same time.

Under laboratory conditions, the modulus of deformation is determined by pressing a round flat stamp into a sample of earth which has been placed in a special form. This is done with the aid of a hand press and is calculated according to the formula:

$$E = \frac{pD}{l}$$

where E is the modulus of deformation in kilograms per square centimeter;

p is the specific pressure in kilograms per square centimeter;

l is the deformation resulting from pressing in the stamp, in centimeters

D is the diameter of the stamp in centimeters.

CHAPTER XVIII

PERMAFROST REGION

81. General Concepts and Exposition

The permafrost region extends from the White Sea in the West to the Sea of Okhotsk and the Bering Sea in the East. It is called the permafrost region because from the land surface down to a certain depth there is a layer of rocks with negative temperatures. The negative temperature of this mass has been preserved uninterruptedly for a long period, estimated up to a millenium. The permafrost region occupies about 45 percent of the whole territory of the USSR.

The presence of frozen earths in Northern Siberia has been known for more than 300 years. The natives and "state servants" have know about this, and it was also known in Moscow from the reports of these individuals. In 1640, the Lensk governors, P. Golovin and M. Glebov, reported to Moscow that there "the land does not thaw for the year around."

Scientific study of the permafrost region was first begun in Russia. Beginning in 1723, the Russian Academy of Sciences sent an expedition of scholars to study the rocks of the permafrost region.

Investigation of permafrost expanded greatly after the October socialist revolution.

In 1939, under the direction of the existing committee on permafrost, the only Institute of Frost Studies in the world was created in the USSR, with a whole series of permafrost scientific research stations.

Because of the activity of many Soviet frost supervisors, who are also scholars, a new type of scientific frost study has arisen.

82. The Temperature System of Permafrost Rocks

There are three basic layers according to the temperature system of earths in the permafrost region: (a) the active layer, (b) the permafrost layer, and (c) the sub-permafrost layer.

The active layer is the upper layer of earths lying upon the permafrost thicknesses. This layer is characterized by the fact that it freezes in winter and thaws in summer. The activity of plant and animal organisms is concentrated in it, and physical processes of various types take place there.

The depth of the active layer varies a great deal, depending on the geographical locality, the character of the rocks, the depth of the snow cover, vegetation, etc. The shallowest portion of the active layer is found in swamp areas because of the poor heat-conductivity of peat.

The deepest active layer has been observed in sand, gravel, and crushed rocks, especially if they are located on slopes facing south.

In the largest part of the permafrost region, the active layer merges with the permafrost layer during winter, forming the so-called fused permafrost (Figure 114).

Figure 114. Schematic structure of fused permafrost: (1) active layer, (2) permafrost, (3) sub-frost thickness.

In some places where the permafrost rocks are deeply situated such merging does not occur: between the active layer and the permafrost layer lies a thawed layer of varied thickness. This type of frost is called non-merging.

The Permafrost Layer

The depth of the permafrost layer varies widely. It is at a minimum in the southern borderland; in the north, it increases regularly, reaching several hundred meters in isolated places.

The temperature of permafrost rocks ranges from 0 to -13. The lowest temperature is found approximately in the central portion of the permafrost thickness. The temperature system of the active layer and of the permafrost thickness depends on such important factors as climate, vegetation, relief, locality, thickness of snow cover, and works of man. Changes in these factors usually bring about changes in the temperature system throughout the thicknesses of the rocks.

Sometimes a layer of frozen rocks can be interstratified by thawed rocks with positive temperatures. This type of frost is called stratified (Figure 115).

Figure 115. Schematic structure of non-merging stratified frost: (1) active layer, (2) intervening layer with a positive temperature, (3) stratified permafrost, (4) sub-frost layer

The presence of stratified frost is most frequently explained by the circulation of water in the earth at raised temperatures.

Mention must also be made of the presence of layers in the permafrost region which have no permanently frozen rocks at all. These are usually areas at the bottoms of rivers and lakes. However, in the southern part of the permafrost region, layers without frozen rocks are found outside the area of water surfaces. Their presence here is related to the warming effect of the heavy snow cover and other natural conditions which are favorable to the deep thaw of rocks.

The formation of permafrost, from the modern perspective, belongs to the Quaternary period. In evidence of this are the numerous findings of undecomposed corpses of mammoths and rhinoceroses found in the permafrost region. It is evident that the animals mentioned lived and died under conditions approximating those in which they were discovered. It is known that in the Quaternary period, a large cold spell occurred which caused the upper layer of rocks to freeze. As time passed, heat released in radiation by the surface of the land over the world exceeded the heat received from without. As a result, there took place an accumulation of "coldness", an increase in the thickness of the permafrost layer, and a lowering of its temperature.

In several places along the southern boundary of the permafrost region, degradation has been observed; that is, the reserves of "coldness" have decreased. Evidence of this is the increase of the active layer, and a decrease in moss in the permafrost thickness, and a recession of the permafrost toward the north.

The causes of such local degradation of permafrost are, on the one hand, climatic changes, and on the other, the effect of man's activity -- cutting down the forests, clearing the land of brushwood and moss cover, destroying the soil, raising cattle, and various kinds of construction. All these change the temperature system and help lower the reserves of "coldness" in the permafrost thickness.

83. Certain Peculiarities of Frozen Earths

With the lowering of temperature, the water contained in earths freezes, giving it new properties. Ic crystals are formed in the earths which bind the separate rock particles firmly, making the rock monolithic. The degree of tenacity of frozen earths wholly depends on the quantity of water (ice) it contains and on the temperature. Clay and clay loam earths contain the greatest amounts of water. When these rocks freeze in a water-saturated state, they form a bound monolith which is characterized by great durability and is exceptionally difficult to excavate.

At a relatively high temperature (about 0 degrees), water in the pores of clay earths may not freeze; as a result of this phenomenon frozen earth at a negative temperature will be found in a plastic state.

When water is not present, which is sometime observed in sand, the properties of earths show very little change in the transition from plus to minus temperature. The earth, as before, has the properties of a free-flowing body.

In accordance with this, frost is divided into : (a) monolithic, (b) plastic, and (c) dry.

Monolithic frost, which is most prevalent, offers the most difficulty in excavating frozen earths (making hollows, ditches, etc).

The most important peculiarity of frozen water-saturated earths is their low permeability to water. Frozen rocks will hardly allow water to pass through, that is, they are impervious to water. The swamping of the surface layers of the earth and the extensiveness of swamps and peat bogs over a considerable part of the region of permafrost are related to this impermeability of rocks.

When water-saturated earths freeze they swell and the surface rises; when they thaw the surface lowers. The water contained in rocks increases its volume by 9.1 percent when frozen. At the same time, when ice is formed, the general volume of the rocks increase.

Thus, if clay earth has a 50 percent porosity and all the pores are filled with water, the volume of the earth increases by approximately 4.5 percent when it freezes. The earth, which increases in volume, meets the least resistance from above. Therefore, when water-saturated rocks freeze, they rise. Whenever the rocks have room for moisture and are very damp, the rise can be clearly perceptible. Increasing the moisture greatly affects the swelling of earth when frozen. The increase in volume takes place by tightening the capillary and film water in the freezing zone.

The expansion of frozen earth may cause such things as the foundations of buildings to be pushed out or the pilings of wooden bridges or pillars, etc, to do the same.

84 Subterranean Waters in the Permafrost Region

When present in the permafrost region, subterranean waters are principally concentrated above the permafrost thicknesses, but they are also contained within the permafrost layer and the sub-frost layer. In accordance with this, subterranean waters in the permafrost region are divided into three categories: the superfrost, the interfrost, and the subfrost.

The superfrost waters occur above the permafrost layer. This is usually soil water which has accumulated as the result of seepage of rainfall in the summer and its retention on the water-impermeable frost layer.

Even when the permafrost is not deep, superfrost water can freeze completely in the winter, changing to a solid state. This change causes mounds and layers of ice to form and caused the rocks to swell.

In view of the fact that water when frozen increases in volume by 9.1 percent, when the upper part of the water-supplying bed freezes, the water in the lower part of the bed will be found under increased pressure -- the pressure increasing as the depth of freezing increases. Under the effect of the increased pressure, the top layer of frozen earth buckles. In some places, the sag can be very great, taking the form of a mound. Such mounds can reach a height of 3 to 4 meters, and diameters up to 30 or more meters (Figure 116).

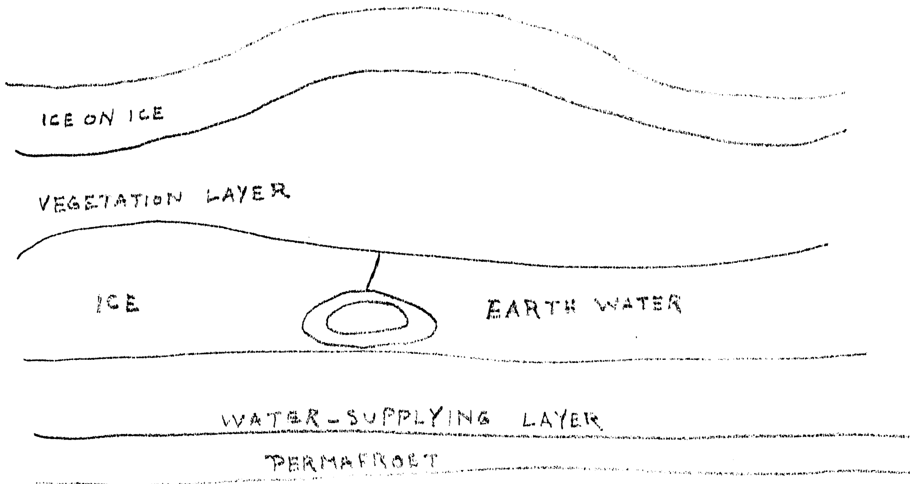

Figure 116. Schematic diagram showing the structure of an ice layer mound

A fissure frequently forms in the central part of the mound; from this water flows and freezes at the surface.

The ice layers formed in this manner are called earth ice-layers (Figure 117), and the mounds are called ice-layer mounds (Figure 118).

Figure 117. An ice layer which did not melt in summer.

Figure 118. A mound which did not melt in summer

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

The interfrost waters are waters of stratified frost. The presence in some localities of courses with positive temperatures, connected with the movement of warm waters, has already been mentioned as occurring in the layer of permafrost rocks.

The interfrost waters can come up to the surface on the sides of hills and mountains or in deep excavations, causing the appearance in winter of the so-called ice-layer springs. Such springs can be utilized for water supply if they are heated deep in the frost zone.

In addition to containing water in a liquid state, permafrost layers contain water in the form of ice. Ice is found in fine crystals and seams, and also in the form of entire beds which are called fossilized or buried ice (Figure 119).

Figure 119. Ice under a small layer of moss in summer

The depth of fossilized ice can reach several scores of meters. When warm temperatures set in and heat penetrates the layers of rocks, shallow layers of fossilized ice thaw, and large and small empty spaces (heat cavities) are formed. When these cavities collapse or settle, various types of depressions are formed on the surface of the earth -- craters, "saucers," "windows," "cave-ins," etc. In a large number of these depressions, a special type of relief is formed -- heat cavities. When buried ices thaw, they replenish the reserves of water and feed lakes.

Subterranean waters circulating in water-supplying rocks beneath the permafrost layer are called subfrost waters. Drilling has established the fact that these water-supplying beds have much water and frequently contain rising water. For these two reasons subfrost waters are possible sources of water supply in the permafrost region.

River Ice Layers

In the permafrost region shallow rivers, as a rule, freeze over in winter. There are a comparatively small number of deep rivers which do not freeze ~~over~~ through, but are covered with a thick layer of ice. These rivers, like subfrost waters, can serve as potential sources of water supply.

When deep rivers freeze through, their profiles decrease, allowing all water to go out. As a result of increased pressure, part of the water flows into the loose sediment on the banks of the river, where in the weakest places it breaks to the surface.

After the water freezes, river ice layers are formed on the surface of the bottom land, sometimes covering large areas.

85. Permafrost and Building Construction

The presence of layers of permafrost rocks creates special problems for erecting above-ground and underground constructions. When constructing automobile roads, bridges, buildings, and other works, one must consider the arrangement of excavations and embankments, the digging of ditches, driving of piles, laying of foundations, etc. With all these aspects of construction, the natural temperature system of rocks changes, as a result of which various phenomena arise which to some extent affect the stability of construction.

In working the ground, one first of all runs into the difficulty of handling the monolithic frozen rocks and having to use explosives to loosen them, or having to thaw them with the aid of "torches" or steam. Excavation slopes in frozen rocks thaw out after the first winter and float around when supersaturated with water.

In winter, hollows are the places where most frequently ground and ice-layer springs and swelling occur. For these reasons, in seeking routes for automobile roads, deep hollows are to be avoided. The routes should be projected along the southern slopes of hills or along the high, raised terraces of rivers. High places are usually less humid, and afford good drainage for surface and ground water.

The least favorable place for laying a road is swampy or mossy tundra flatlands, the mari. At shallow depths these areas contain permafrost layers with large deposits of pure ice in the form of seams and streaks. In building embankments in the mari, frozen earths and ice melt. This can cause the embankments to buckle.

It is difficult to lay roads in areas with heat cavities. Here, besides the difficulty in working the ground because of all kinds of pockets, there is still the danger of forming new depressions in the process of building the roads, and later on in the process of using the roads.

Therefore, in deciding upon routes for automobile roads, more than the routine geological inspection should be made. There should be, in addition, boring and drilling for determining the depth of the stratum containing permafrost rocks, and for establishing presence of heat cavities and buried ice. This procedure should be followed for the entire route.

In those sections of roads where high embankments are built, changes occur in the temperature system.

The limit of the permafrost thickness under the embankment is raised upwards, gradually becoming the core of the embankment. When the marginal portion of the embankment thaws in the spring, the sides slip down along the frozen earth of the core. Dust rocks are most subject to this slide phenomenon, but under conditions of heavy moisture, even clay loam and sandy loam rocks will slide.

In road construction, the possibility must be considered of river, spring, or ground ice-layers forming in the vicinity of the road, since these layers render the normal use of roads difficult, destroy wooden bridges, and waterpipes.

Deformations of buildings -- buckling, bulging, formation of fissures in the foundations -- are frequent phenomena occurring in the permafrost region.

When negative temperatures are maintained, frozen rocks remain firm and provide a good base for foundations of buildings and supports of bridges. In case of thaw, however, their capacity to withstand external pressure is considerably decreased as a result of the moisture. This is especially characteristic of dust and clay loam earths, which possess a large moisture-retaining capacity.

The foundations of buildings and supports of bridges during winter freeze to the moist earths. As a result, the construction rises (or bulges) whenever the earth freezes. Depending on the nature of the earths, the degree of their moisture, and the type of foundation, the bulge will take various dimensions. With the most unfavorable combination (dust earths, much moisture, deep freezing) the bulge can reach several scores of centimeters.

From what has been stated, it is evident that in carrying on different kinds of engineering construction in the permafrost region, a whole series of peculiarities arise — defects which can shorten the period of service, make extra repair necessary, and lower the utilization value of the construction.

CHAPTER XXI

BASIC METHODS OF ARTIFICIALLY STRENGTHENING EARTHS

96. General Information

The use of earths as local road construction materials at the present time in the Soviet Union is based on the practical experience gained in constructing many hundreds of road surfacings and foundations.

At the present time, the use of earth as material for the construction of road surfacings and foundations is very important. If earth can be used, there is no need to transport large quantities of stone and sand materials from other places for this purpose.

As a result of many research projects conducted by Professor M. M. Filatov, V. V. Okhotin, and others, effective and economical methods of constructing roads have been developed; these are based on the use of earths as the primary construction material for road surfacings and foundations.

In using established methods of artificially strengthening earths, road surfacings and foundations can be made which fulfill the engineering requirements for modern automobile roads. Using local earths for construction materials is very profitable from the economic point of view, since the earth serves as the cheapest and most accessible material and is not difficult to transport or to work.

The various methods of artificially strengthening earths are often collected under the general term of earth stabilization. The artifical strengthening of earths constitutes the totality of all technical and construction measures for assuring the stability of earths when cohesiveness is increased in both wet and dry states.

After being strengthened, earths are usually able to withstand the considerable stresses which occur when vehicles pass over them, and do not develop any noticeable deformations. Such earths are characterized by high cohesiveness in both dry and water-saturated states, by insignificant swelling, and low moisture retention. The degree to which these properties are expressed can vary widely, and depends on the methods of treating earths and on the properties of the earth being treated.

When binding materials are added to the earth, complex physico-chemical and chemical interactions take place between the earth and the binding materials. This results in a fundamental improvement of the physico-mechanical properties of an earth. However, the optimum effect of such treatment can be expected only when the binding material is carefully and evenly distributed in the quantity needed, and subsequently packed throughout the whole mass of the treated earth.

TABLE 20

EARTH-STRENGTHENING METHODS USED IN ROAD CONSTRUCTION

No P/P	Strengthening Method	Materials for Treatment	Earths Recommended for Treatment
I	Granulometric admixture	Crushed stone, gravel, cinders, sand, clay, clay loam	Clay, clay loam, dust, sand
II	Organic binding materials	Solid and liquid asphalts, mazut, petroleum, oil, tars; asphalt and tar emulsions	Sand, sandy loam, dust, clay
III	Inorganic binding materials	Portland cement, slag-Portland cement, clay-slag and lime-slag cements; flaked, ground, and slaked limes; quicklime	Sand, sand loam, dust, clay loam, clay
IV	Soluble salts Salt solutions	Calcium chloride Magnesium chloride Sodium chloride	Sandy loam, dust
V	Heat treatment	Local fuel (wood, brushwood, etc)	Clay, clay loam
VI	Compound strengthening	Granulometric admixture + organic binders Granulometric Admixture + inorganic binders Granulometric admixture + hygroscopic salts Organic binders + inorganic binders Baking or heating + organic binders	Clay, clay loam, dust

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

At the present time many methods of treating earth which increase stability in the roads have been developed. These methods for strengthening earths have acquired wide usage. Table 20 shows a list of the methods used in road construction.

Each of the methods indicated in Table 20 for strengthening earths has its own peculiarities with relation to its effectiveness in raising the stability of earth used in the road and with relation to the kind of working required.

97. Earth Mixtures of Optimum Granulometric Composition

The reason for unsatisfactory working characteristics of earths used in the thoroughfare part of roads is the substantial loss of stability when their moisture content changes. When wet, sandy earths possess satisfactory stability, but when dry, they lack cohesiveness. Friability appears. On the other hand, clay earths lose stability and cohesiveness when very moist; in a dry condition they possess much cohesiveness.

As far back as the 1860's, Russian engineers worked out a theoretical and practical means of artificially strengthening earths so as to make them stable in the thoroughfare part of earth roads by mixing sand or gravel with clay earth.

In a book by E. Golovachev, "On the Construction of Earth Roads and Their Relation to Railroads for Developing the Productivity of Russia," published in Kiev in 1870, practical instructions are given for obtaining stability with a bed of "dirt concrete", consisting of a mixture of local earth, sand, and gravel or crushed rock.

Numerous field observations on road conditions in the past 20 to 30 years in the Soviet Union and in other countries indicate that with a known proportion of sand, dust, and clay particles in the earth, the earth acquires sufficient stability. Such earth has come to be known as the optimum earth.

In optimum earth, sand particles serve as the skeleton; this absorbs the main part of external forces whenever the earth is very moist. Clay particles, on the other hand, render the greatest stability of the mixture during dry spells. Clay particles, evenly distributed throughout the entire mass of the earth, serve as a natural cementing substance which binds the coarser particles into a single whole.

Dust particles of the earth occupy an intermediate place because of their properties.

In the composition of optimum earth, dust particles serve as fill material since -- because of their small size -- they are distributed in the pores formed among the coarser particles in the given earth. Dust particles permit the external friction of the earth to be increased.

When calculating the proportion of the various particles according to their coarseness, it is also necessary to consider local climatic conditions and the distribution of traffic along

along the road throughout the course of a year, for these have a substantial effect on the composition of the optimum earth, that is, whether the traffic occurs mostly in the summer (dry season) or in spring and autumn (rainy seasons).

The chemical and mineral composition and the degree of dispersion of the clay-colloid groups also affect the composition necessary for the optimum earth. The binding properties of these groups, depending on their physico-chemical state, can be very different.

Investigations of M. M. Filatov indicate that the binding capacities of soils containing organic colloids (humus) are more than 1.5 higher than those with mineral colloid particles. When earth contains displaced positively charged ions of sodium, the binding properties of dry clay particles increase greatly.

It follows that the granulometric composition of the optimum earth can vary within known limits, and the selection of any composition of optimum earth will depend both on the properties of the earth and on local climatic conditions.

As a result of the work of V. V. Okhotin and I. I. Ivanov, it has been established that the greatest stability of optimum mixtures is obtained by selecting mixtures of separate granulometric groups which assure the greatest porosity.

The highest porosity of a mixture is achieved by observing the following rules:

(1) Assure a careful selection and mixture of separate granulometric fractions in the composition of the optimum earth for increasing internal friction and tenacity.

(2) Assure mechanical compacting of the earth to the maximum density with the corresponding optimum moisture.

The compositions of optimum earths were checked by numerous experiments on the construction of earth roads in various regions of the Union. These compositions followed the Technical Specifications of the Gushosdor of the NKVD of the USSR, 1938, for constructing automobile roads and bridges, and are shown in Table 21. (Following page)

As can be seen from Table 21, the local climatic conditions and the coarse quality of the skeleton have a substantial effect on the relative content of the various fractions.

In all cases, preference must be given to mixtures with a coarse granular skeleton, since the latter offers the greatest stability for the optimum earth. If fine sand (particles from 0.25 to 0.05 millimeter) is present in the optimum mixture in quantities greater than provided in Table 21, such earth will lose its supporting ability when moisture is increased.

It should be noted that no matter how well the optimum mixture is selected, it cannot develop its innate stability without proper compacting at the corresponding optimum moisture.

For this reason, when stabilizing earths by granulometric

TABLE 21

COMPOSITION OF THE OPTIMUM SAND-CLAY MIXTURES

Dimension of Fractions in millimeters	Content of the Fractions in Percent			
	Zone of Normal and insufficient moisture		Zone of excess moisture	
	Type A_1	Type A_2	Type B_1	Type B_2
2—0.25	45—60	20—45	45—70	25—45
0.25—0.05	10—20	20—40	15—30	25—55
0.05—0.005	15-35	15—35	15—25	15—25
under 0.005	6—12	8—14	3—8	8—10

doses, special attention is paid not only to the selection and insertion of granulometric doeses, but also to the maximum packing of the mixture at optimum moisture.

98. Strengthening Earths With Organic Binding Materials

The most effective method of strengthening earths, and one which has received wide usage in making surfacings and foundations in road and airport construction, consists of treatment with organic binding materials -- asphalts, liquid asphalt, tars, and emulsions. In addition, organic binding materials mixed with earth are widely used to make various water-permeable layers in the sub-grade of the road and in other constructions out of earth.

Numerous observations of surfacings made from earths which have been treated with organic binding materials indicate that the best results come from treating earths of the podzolic and black soil zones with asphalt and tar. Treating saliferous earths, alkaline soil, and saline soil give negative results. In saliferous earths, the organic binding material can be washed out of the treated layer and can penetrate to the deepest layers.

So far as the granulometric composition is concerned, the best results with the least quantities of binding material come from sand loam and dust earths. Especially good results, with the use of a minimum amount of binding material, are obtained in treating earths of the optimum granulometric composition.

Any method of strengthening earth with binding materials will be effective only if the following procedure is observed:

(a) using the binding material in a quantity sufficient to change the properties of the earth being treated;

(b) distributing the binding material evenly in the mass of earth being treated; this assures the fullest interaction of the earth with the binding materials;

(c) carefully packing the mixture treated to the desired density.

In conducting the operations indicated -- diffusing the binding material, mixing and packing the mixture -- water which is in the earth undergoing treatment is of utmost importance. Water may have different effects on the properties of the binding material.

Interaction of Earths with Organic Binding Materials

Theoretical research on the interaction of fine granular earths with organic binding materials was first carried out by M. M. Filatov and his students.

According to the views of M. M. Filatov, the interaction of earth with organic binding materials basically embraces three phenomena:

(1) absorption of certain component parts of the binding material by the surfaces of the thinly-dispersed particles;

(2) cementing of the separate particles and lumps of earth by the binding material;

(3) mechanical filling of the earth pores by the binding material.

Through the work of M. M. Filatov and B. B. Tolstopyatov, it has been established that earths treated with asphalt (or tar) materials have a lumpy-cellular structure, formed as a result of the uneven distribution of the binding substances in the earth mass and the presence of closed micropores filled with air.

The binding substances, as microscopic observations show, are spread out in the mass of the earth, enveloping for the most part clay lumps, on the surface of which are formed special clay-asphalt combinations. The result is a monolithic mass of earth, cemented by films, in some instances forming a thin net, in others forming flaky accumulations out of the clay-asphalt substances. Earths strengthened with inorganic binding materials -- cement, lime, silicates (Figure 141) -- have a similar structure.

Figure 141. Microstructure of black soil strengthened with 10 percent lime. Light areas: lime earth skeleton. Dark areas: micrograins of black soil. Earths strengthened with asphalt, tar, or cement give a similar picture.

So far as the physico-chemical interaction of earth with binding materials is concerned, different results have been observed in treating various types of earths with organic binding materials. As a rule, treating black soil which possesses a well-expressed and firm structure and contains interchanged calcium gives good results with little use of binding material. On the other hand, alkaline soils, which contain interchanged sodium, with the same granulometric composition, are difficult to treat, and even with much use of the binder give very poor results.

Physico-Mechanical Properties of Earths Treated with Organic Binding Materials

As a result of treating earths with organic binding materials, fundamental changes occur which favorably affect their stability for purposes of road construction:

(1) When the asphalt dosage is increased, the resistance to compression of tenacious earths, tested in a water-saturated state, is considerably increased. However, the durability of the water-saturated sample increases only as high as the known "optimum" content of the binder. After this level is passed, resistance to compression is markedly lowered.

(2) In testing samples by impress of a cone stamp, using the method proposed by A. I. Lysikhina, the depth of impress decreases down to a known limit (the optimum of the binder) when the asphalt dosage is increased. When the asphalt content is further

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

Impression depth
of stamp in mm

Percent of asphalt

Figure 142. Impression depth of cone in relation to asphalt content

(3) Earths treated with organic binding materials do not become soft from moisture; that is, they do not disintegrate when in water over a long period, and they have a low coefficient of swelling. Clay earths will acquire this characteristic if dosed with 8 to 10 percent of binder; sand loam and dust need 4 to 8 percent.

(4) Striking-stress and stamp-impress tests characterize an earth which has been treated with organic binding materials as an elastic system, capable of receiving considerable stress without noticeable residual deformations.

Earths can be divided into the following series on the basis of their granulometric composition and the effectiveness of treatment with binding materials:

Sandy-gravel and coarse-sandy optimum mixtures > Sand loam and dust earths > Clay loam > Clay earths (which are difficult to treat and use large amounts of binder)

The physico-mechanical properties of treated earths to a considerable degree are predetermined by their granulometric composition. However, the original type of earth and the physico-chemical condition of its clay-colloid fractions play a very essential role also.

Earths (soils) can be divided according to type into the following series, based on the degree of effectiveness and suitability for treatment:

Black soil > Woody and podzolic soils > Chestnut soils > Saliferous and alkaline soils (conditionally suitable for treatment) > Saline and swampy soils (unsuitable for treatment)

As a result of research projects carried on in the DORNII by A. I. Lysikhina, the most productive use is the method of treating earths with liquid asphalts by mixing them on the road (A. I. Lysikhina. The treatment of earths and gravel roads with liquid asphalt. DORIZDAT GUSHOSDORA NKVD, 1942.).

99. Strengthening Earths with Inorganic Binding Materials

The experience gained in road and airport construction during the last 10 to 12 years shows that cement and lime can be successfully used to strengthen earths. Portland cement especially is very effective in strengthening earth.

At the present time, the fact can be considered as firmly established that cement and lime have a favorable and lengthy effect on the physico-mechanical properties of earths of the most diverse origins and granulometric compositions. Only in rare instances does the physico-chemical state of the earth have a negative effect on the binding properties of cement or lime.

The Physico-Chemical Interaction of Earth and Cement

The high binding capacity of cement is explained by the chemical disintegration of cement when interacting with water (hydrolysis) and by the consequent separation of the durable insoluble compounds of hydrosilicates and hydroaluminates which form solid connections between the earth particles. When the hydrosilicates and hydroaluminates are separated, water is chemically bound, making up the compounds (hydration).

In treating earth with cement, hydrolysis and hydration, as well as other chemical reactions, will be accelerated, or on the contrary, retarded, depending on the chemical and mineral content of the cement and on the nature of the earth and its physico-chemical state at the time it is treated.

In strengthening turf-podzolic soils with cement (especially of the humus sort), the process of hydrolysis and the hardening of the cement will be retarded under the action of acid agents. As a result the cemented earth will not be very firm.

In strengthening carbonaceous earths, carbonaceous loess for example, when calcium ions are present in the solution, the processes of hydrolysis and hardening of the cement will be more intense. In this case, the cemented earth will be very firm.

The presence in the earth of interchanged calcium, which is able to form a firm microstructure (in black soil), also is a factor which favorably affects the firmness of the earth.

The absence in earths of water soluble salts (sodium sulfate, magnesium sulfate) detracts from the firmness of the cemented earth to a considerable extent.

The firmness of cemented earth is found to be greatly dependent on the properties of the cement and the properties of the earth being strengthened.

The physico-mechanical properties of earths which are treated with cement are very different from the original properties of untreated earths. This is illustrated in Table 22.

TABLE 22

LIMIT OF DURABILITY ON COMPRESSION, AND THE MOISTURE CAPACITY OF CEMENTED EARTH AFTER KEEPING A SAMPLE IN WATER FOR 6 MONTHS

No	Description of Mixtures	Dosage of Cement in % of wt. of earth	Full moisture capacity of sample after 6 months in water		Limit of durability on compression for water-saturated samples in kg/cm^2
			% of wt. of earth	% of volume	
1	Covered non-carbonaceous clay + Portland cement, Type 400	6	17.8	31.9	63
2.	The same as No 1	10	18.7	33.5	79
3.	The same as No 1	14	18.1	32.6	108
4.	Clayey black soil A_1 + Portland cement, type 400	6	26.8	4.13	15
5.	The same as No 4	10	24.1	38.8	26
6.	The same as No 4	14	23.8	38.3	31
7.	Podzolic light clay loam A_2 + Portland cement, type 400	6	20.1	35.6	5
8.	The same as No 7	10	20.3	35.9	8
9.	The same as No 7	14	20.1	35.6	45
10.	Heavy sand loam with optimum granulometric composition + Portland cement, type 400	6	9.1	18.6	29
11.	The same as No 10	10	7.8	15.9	99
12.	The same as No 10	14	6.8	13.7	147

TABLE 22

LIMIT OF DURABILITY ON COMPRESSION, AND THE MOISTURE CAPACITY OF CEMENTED EARTH AFTER KEEPING A SAMPLE IN WATER FOR 6 MONTHS

No	Description of Mixtures	Dosage of Cement in % of wt. of earth	Full moisture capacity of sample after 6 months in water		Limit of durability on compression for water-saturated samples in kg/cm^2
			% of wt. of earth	% of volume	
1	Covered non-carbonaceous clay + Portland cement, Type 400	6	17.8	31.9	63
2.	The same as No 1	10	18.7	33.5	79
3.	The same as No 1	14	18.1	32.6	108
4.	Clayey black soil A_1 + Portland cement, type 400	6	26.8	4.13	15
5.	The same as No 4	10	24.1	38.8	26
6.	The same as No 4	14	23.8	38.3	31
7.	Podzolic light clay loam A_2 + Portland cement, type 400	6	20.1	35.6	5
8.	The same as No 7	10	20.3	35.9	8
9.	The same as No 7	14	20.1	35.6	45
10.	Heavy sand loam with optimum granulometric composition + Portland cement, type 400	6	9.1	18.6	29
11.	The same as No 10	10	7.8	15.9	99
12.	The same as No 10	14	6.8	13.7	147

Untreated earths, when tested for water softening, decompose after 10 to 30 minutes; however, the same earths, when treated with the proper amount of cement, acquire stability in water and possess sufficient mechanical durability even after being saturated with water for 6 months.

When the dosage of cement is increased gradually in earths which have been previously treated with cement, they increase their mechanical durability and stability in water. With small doses of the binder, the cemented earth is a relatively plastic (semi-rigid) material, and with a 12 to 14 percent or greater cement content, the cemented earth possesses the properties of a rigid non-plastic material, which differentiates it very much from earths which have been treated with organic binding materials (Figure 143).

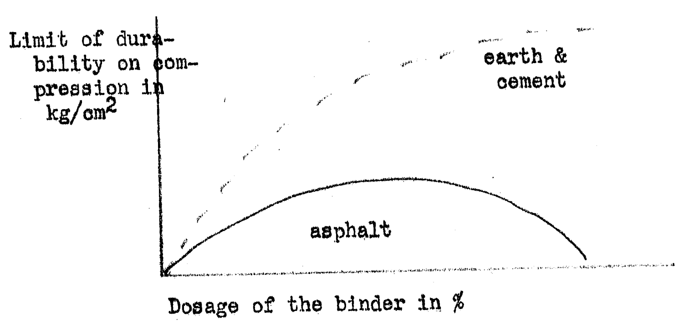

Figure 143. Relation of the compression durability limit to dosage and the properties of the binding material

Compound Strengthening of Earth

Despite ~~the~~ their high mechanical durability and stability in water, earths which have been treated with cement possess a large moisture capacity and residual porosity, which are without doubt negative properties of this material.

When earth is given a compound treatment of cement and asphalt emulsions, two processes are combined which reciprocally complement each other, and which assure that the treated earth gains the properties it lacked initially: the treated earth does not permit water to go through, and it does not become wet (hydrophobic quality). It should be noted that the quantity of cement used is slightly reduced.

For cement to harden and for hydration to take place, it is necessary to have a certain moisture content in the earth being treated. On the other hand, removal of water is necessary for asphalt to disintegrate and be removed, thus giving hydrophobic properties to the earth.

In this way cement, by taking water from the emulsion, facilitates its disintegration and creates favorable conditions for the assertion of the binding properties of asphalt; by absorbing water which existed in the asphalt emulsion, cement particles receive the water necessary for carrying on the processes of hardening and hydrating the cement under optimum conditions. Conditions are thereby assured for the maximum use of the binding properties of both asphalt and cement.

Basic Productivity Requirements and Production of Work in Treating Earths with Cement

As experience accumulated in recent years demonstrates, in order to obtain good results in constructing cemented earth surfacings or foundations, it is necessary to observe a set of basic rules. Durability, stability in weather of all sorts, and resistance to wear of this type of surfacings and foundations are qualities that depend on the following basic procedure:

(a) Put enough cement into the earth to make sure the mixture hardens to the planned durability with an even distribution of the cement throughout the mass of the earth to be treated.

(b) Have the proper (optimum) amount of water in the treated earth during the period when the cement-earth mixture is packed and is hardening.

(c) Pack the cement-earth to the established maximum density, maintaining optimum moisture in the mixture during the packing period.

100. Strengthening Earths with Lime

Lime as well as Portland cement can be used for strengthening earths. It can be put into the earth in slaked and unslaked form.

Strengthening earth with lime has much in common with treatment of earths with cement. However, the properties of lime bring about certain peculiarities in the properties of the earth-lime mixtures and in the sequence of their preparation and packing into surfacings or foundations.

Lime, like cement, makes earth stable in water and raises its mechanical durability in a moist condition; however, the durability of earth which has been strengthened with lime is lower than when treated with cement.

When strengthening earth with lime (just as with cement) mix carefully and moisten and then pack the mixture to the maximum density.

The process of hardening lime begins initially with the evaporation of water and the crystallization of calcium hydroxide. In the course of time, part of the calcium hydroxide is subject to the action of the carbon dioxide of the air and turns to calcium carbonate (carbonization takes place).

$$Ca\,(OH)_2 + CO_2 = CaCO_3 + H_2O$$

Another part of the calcium hydroxide interacts with silicate compounds of the earth to be treated. This causes new cementing substances to appear, and these strengthen the mass of earth. These processes develop in the course of time because of

Declassified in Part - Sanitized Copy Approved for Release 2012/04/20 : CIA-RDP82-00039R000200050010-4

the fact that the durability of the strengthened earth increases.

Because of the great surface of clay and clay loam soils, a physico-chemical phenomenon connected with the interchange of the absorbed cations takes place in addition to the purely chemical reactions. This happens both with lime and cement. Differing from treating earth with cement, lime will successfully strengthen semi-swampy, podzolic, and saliferous and alkaline earths.

101. Strengthening Earths with Hygroscopic Salts

The stability of earth surfacings and foundations is explained by the presence of the internal friction and cohesion inherent in the separate granulometric fractions of the earth. The internal friction characteristic of the sand and gravel fractions maintains stability of the earth under excess moisture conditions of wet weather. When the weather is dry, the disturbance of the earth surface is prevented by the presence of clay fractions which give tenacity to the earth. So that this tenacity will not weaken, it is necessary that the moisture content of the earth not exceed the rolling limit of the earth.

In order to maintain optimum moisture of the earth, salt stabilization can be provided by adding hygroscopic salts — calcium chloride, sodium chloride, magnesium chloride, etc.

Earths treated with hygroscopic salts draw water vapor from the air and possess little evaporating ability. Consequently, such earth can retain the moisture it receives over a comparatively long period.

It is enough to indicate that calcium chloride under average weather conditions absorbs a quantity of moisture which exceeds its own weight by 4 or 5 times.

The best way to pack the mixture of calcium chloride or sodium into the earth is to let the traffic over the road do it over a period of time. By assuring maximum packing of the earth's surface, we decrease its deterioration and increase its stability during the moist periods by permitting a small amount of moisture to penetrate to the dense treated layer.

The properties of earths which have been treated with salts have already been enumerated; to repeat: maximum density is attained, the rate of deterioration is lowered, dust does not form in dry seasons, great stability is acquired during the moist periods because the covering is practically impervious to water — all these qualities are basically the result of the physical properties of the water distributed in the earth in the form of thin films adhering to the surface of the earth particles by molecular attraction. Water in such a state possesses higher adhesiveness and greater surface tension; it has a lower freezing point and very little evaporation.

The properties of film water enumerated as advantages in road construction appear at the optimum moisture of earths. At the optimum moisture of earth, the water in it plays the part of a binder. The optimum moisture in untreated earth is a short-lived and very unstable phenomenon, but when hygroscopic salts are added at the optimum moisture state, the life of the earth increases greatly.

102. Thermal Treatment of Earths

The road-construction properties of clay and clay loam earths can be fundamentally changed and improved by hear treatment.

As a result of the work of professors P. A. Zemyatchinskiy, M. M. Filatov, and others, it has been established that the improvement of the road properties of clay earths is caused by the fact that temperature, which acts on clay or clay loam for a long period of time, brings about deep changes in its nature; the earth loses its chemically and physically bound water, loses plasticity and adhesiveness. When particles cake, the earth will not become soft in water and acquires physico-mechanical properties very different from those which were evident before baking. Its tenacity is increased; its swelling is lost.

Depending on the temperature and how long it lasts, heat treatment can be divided into the following types:

(1) Warming or thermal dehydration

(2) Baking

(3) Clinker firing

Warming or Thermal Dehydration

This is the initial stage of baking and operates when the earth is under the influence of a comparatively low temperature on the order of 300 to 500 degrees Centigrade. Most of the clay minerals composing the earth (kaolin, montmorillonite, micas, etc) dehydrate at this temperature; organic compounds are destroyed. As a result of initial heating, earths lose some properties that are detrimental to road construction (lower plasticity and adhesiveness), and they acquire and maintain for some time partial stability in water.

Baking

This takes place at temperatures from 600 to 800 degrees Centigrade and is a subsequent stage to warming.

As a result of baking, the earth not only does not dehydrate, but undergoes fundamental changes in its properties and composition. Baked clays and clay loams completely lose adhesiveness and plasticity, do not swell, and do not soften when moist. They are turned to stone, although a relatively weak rock, which is characterized by temporary resistance to pressure of approximately 80 to 120 kilograms per square centimeter. These changes occur after baking because of the clinkering of mineral substances, converting the earth into a monolithic mass.

Clinker Firing

With further increase of temperature to 1100 degrees Centigrade and higher, the earth begins not only to clinker but also to partially melt. The fused mass of the most easily melted minerals fills the free pores. As a result of this process, a dense artificial stone material, called clinker, is obtained when the mass cools.

The mechanical durability of the clinker is usually very high, and as a rule it exceeds 600 kilograms per square centimeter.

Clinker firing is done in special plants; here the clinker is prepared in the form of block rubble which serves to make highly durable road surfacings.