

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH  
ROAD RESEARCH LABORATORY

ROAD RESEARCH TECHNICAL PAPER No. 15

# SOIL SURVEY PROCEDURE

ONE SHILLING NET

**THE ROAD RESEARCH LABORATORY** of the Department of Scientific and Industrial Research is a government organization for studying problems that arise in designing, building and maintaining public highways. The primary objectives of the work, which is undertaken in close co-operation with the Ministry of Transport, are to improve the road as a channel for traffic, to reduce the overall costs of construction and maintenance and to promote safety and comfort in travel. The work is organized in two divisions; Materials and Methods of Construction, and Road Safety and Traffic Flow. The principal subjects of study in the former are (a) soils and stones, (b) concrete roads, (c) bituminous surfacings, (d) road plant and machinery. Road safety researches include (a) road layout, (b) surface characteristics, (c) traffic flow and movement control, (d) vehicle characteristics, (e) road user characteristics, (f) accident statistics. The Medical Research Council is collaborating in the work on road user characteristics.

Advice on the conduct of the investigations is given by the Road Research Board and by committees of the Board appointed to deal with specific subjects. Certain parts of the programme are undertaken co-operatively with trade associations who contribute financially to the cost of the work and appoint representatives to joint advisory committees. Special investigations, for which a fee is charged, are undertaken on request in certain cases.

The facilities of the Laboratory, including a reference library, are available to road engineers and others who desire information, and visits may be arranged by appointment. Suggestions regarding problems requiring attention are welcomed. Correspondence should be addressed to the Director of Road Research at the address given below.

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## FOREWORD

**I**N 1946 the Laboratory published, as Road Research Bulletin No. 4, "Soil Survey Procedure and its Application in Road Construction", a brief description of a method of conducting a soil survey, the equipment required for it and the means by which the results could be interpreted.

A new edition is now necessary since the Bulletin series has been discontinued. This is being met by the present Technical Paper, which consists of the original note, revised in certain minor respects, together with some new material. The principal additions are sections dealing with the problem of exploration in gravelly soils and with geophysical methods such as those based on electrical resistivity and seismic soundings. An illustrated description has been included of a simple type of mobile laboratory which is thought to be more in line with the requirements of local authorities than the one described in the earlier edition.

W. H. GLANVILLE,  
*Director of Road Research*

ROAD RESEARCH LABORATORY,  
*November, 1949.*

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# SOIL SURVEY PROCEDURE

## I. INTRODUCTION

### Object and Scope

A soil survey forms an essential part of the preliminary engineering survey for a road and its purpose is to furnish the engineer with information regarding soil and ground-water conditions on which a rational and economic design can be based.

In general, a soil survey involves:—

- (1) The exploration of soil conditions over the site by boring or otherwise, and the preparation of sections\* indicating the nature of the ground.
- (2) The examination and testing of samples of the soil taken from the site and the reduction of the information to engineering recommendations.

Table 1 outlines the significant information that can be obtained from a soil survey to enable the following design requirements to be established:—

- (1) Suitability of the proposed location, both horizontally and vertically.
- (2) Selection of suitable materials for embankments.
- (3) Safe gradients for sides of cuttings and embankments.
- (4) Earthwork quantities, bulking or shrinkage, volume of rock excavation.
- (5) Subsoil and surface drainage requirements.
- (6) Need for treatment of the subgrade and the type of treatment required.
- (7) Thickness of carriageway pavement.
- (8) Suitability of local materials for use in the construction of stabilized bases.

The scope of the recommendations that can be made will depend on the facilities available, which may include:—

- (1) Visual and manual examination alone.
- (2) Standard classification tests in addition to visual and manual examination.
- (3) Detailed investigation of specific soil properties in addition to classification tests.

Only the first two can properly be regarded as an integral part of the soil survey.

Detailed investigations of specific properties vary from soil compaction tests to investigations requiring “undisturbed” samples which are matters for specialists. The conditions revealed by a soil survey indicate, as outlined in Table 1, where further investigations of this type may be profitable.

The only site explorations considered in this paper are those of relatively shallow depth that can be carried out with simple hand-boring equipment without the use of lining tubes. Hand-boring equipment is suitable for most borings required for roads, although in some cases lined borings may have to be used. To assist engineers

\* The following quotation, from “A Treatise on Roads”<sup>(1)†</sup> published in 1833 and said to describe the practice followed by Telford, is of interest in the above connexion:—

“A vertical section should be made, and the nature of the soil or different strata should be shown over which each apparently favourable line passes, to be ascertained by boring; for it is by this means alone that the slopes at which cuttings and embankments will stand can be determined and calculated—.”

If bogs or morasses are to be passed over, the depth of the peat should be ascertained by boring and the general inclination of the country for drainage should be marked.”

† See reference, page 31.

**TABLE I**  
**INFORMATION OBTAINABLE FROM SOIL SURVEY AND ADDITIONAL INVESTIGATIONS**

MAIN DESIGN REQUIREMENTS	PARTICULAR REQUIREMENTS	INFORMATION OBTAINABLE FROM SOIL SURVEY	INFORMATION OBTAINABLE FROM ADDITIONAL INVESTIGATIONS
1 Suitability of selected location	Suitability of horizontal alignment	Data for avoidance of unsuitable ground such as peat, soft clay, areas subject to landslips or rockfalls, or to water-logging in winter.	Shear strength determinations necessary to check designs. Consolidation tests necessary for closer estimates of probable settlement.
	Suitability of vertical alignment	Data for avoidance of high embankments on weak foundations or unstable strata. Data for reduction or avoidance of cuttings in rock or unstable strata. Data for maintenance of formation level at a suitable height above water-table level.	
	Stability of foundations under embankments	Need for further investigation indicated. Possibilities of strengthening the bearing capacity of the subsoil. Indications of probable settlement of pipes and culverts.	
	Stability of rock strata	Visual inspection and preliminary geological information give indications of possible landslips and rock slides.	
2 Selection of materials for embankment construction	Suitability of excavated material for embankment construction	Soil type gives:— (i) Quality of material as filling, probable optimum moisture contents. (ii) Indication of compacted densities. (iii) Suitability for winter construction. (iv) Desirable types of earthwork equipment.	Compaction test necessary to give definite information. In conjunction with density tests information on probable bulking or shrinkage of material.
	Selection of borrow pit sites	Indications of safe slopes in cut and fill.	
3 Earth slopes	Cross-sections of cuttings and embankments	Indications of safe slopes in cut and fill.	In cohesive soils, shear strength of soil required to check designs in doubtful cases.
4 Earthwork quantities	Volume of excavation	Volumes of peat or rock excavation. Allowances for bulking or contraction (these depend on compacted densities, see item (ii) of 2 above).	Compaction tests desirable for more detailed estimates.
5 Drainage	Subsoil drainage	Ground-water studies indicate need for subsoil drainage and location of drains and interceptors. Spacing of drains depends on soil type.	
	Surface drainage	Drainage or diversion of ponds, streams and springs. Location of catch-water drains.	
6 Preparation of subgrade	Need for subgrade treatment and work required	Depends on nature of soil and season in which construction takes place.	
7 Design of pavement	Type and thickness of base	Indications of thickness required given by soil type and wheel loading proposed.	Special investigations needed for closer estimates of required thicknesses.
8 Stabilization	Suitability of local materials for construction of flexible bases	Indications given of practicability of various forms of stabilized construction. (See Table 7.)	Special <i>ad hoc</i> investigations needed for detailed studies.



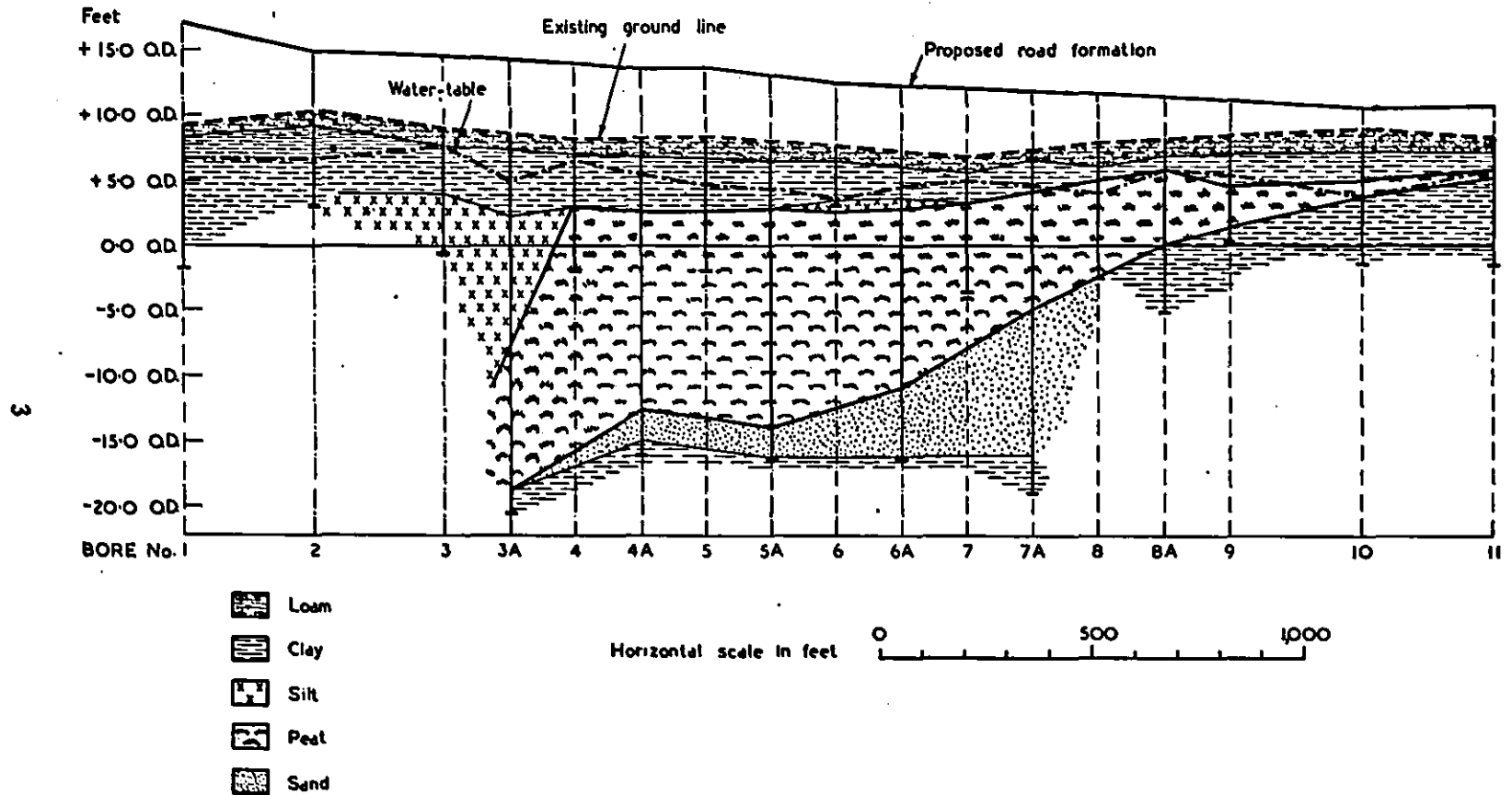


FIG. 1. TYPICAL SOIL PROFILE SHOWING CONCEALED BED OF PEAT

who do not possess soil-testing equipment reference is made to the information obtainable by manual and visual inspection of the samples of soil. So much additional information can be obtained from soil tests, however, that simple laboratories equipped to carry out classification and compaction tests should be available in connexion with all projects of any magnitude. Such laboratories may be set up in a single room or, as mentioned later, a mobile laboratory may be used.

It is difficult to give accurate figures of the costs of soil surveys since conditions vary widely but the direct cost (exclusive of travelling) would probably be of the order of £25-50 per mile at the present time where no unusual difficulties are encountered. The cost is therefore very small in comparison with the costs of construction.

### **Outline of Soil Survey**

A typical soil survey usually provides a vertical section or sections showing the nature of the soil in different strata, and it should be made in conjunction with the topographical survey. Such a soil survey can be rapidly carried out by the hand-boring methods described below which, for the same expenditure of time and energy, enable a much more extensive examination of soil conditions to be made than by the digging of trial pits, which becomes costly and laborious if the pits are closely spaced.

Fig. 1 illustrates a typical result of a soil survey and shows the soil profile on a site with a concealed bed of peat covered by 2 to 6 ft of soil. By hand boring it was not possible, with the tools available, to penetrate the peat, the maximum depth of bore being restricted to about 10 ft owing to the repeated collapse of the sides of the holes. Subsidiary borings made on either side of the proposed centre line showed that it was not practicable to avoid the peat by any reasonable deviation. Lined borings were accordingly put down by a boring contractor to ascertain the total thickness of the peat that it would be necessary to remove or displace. It will be noted that to obtain additional information the lined borings, marked "A," were interspersed between the original borings. This example illustrates the insurance value of soil surveys against unforeseen foundation conditions.

## **II. PERSONNEL AND EQUIPMENT**

### **Personnel**

The field work necessary on a soil survey includes taking borings and obtaining typical soil samples. Between 20 and 400 linear feet of boring per mile are usually required on the survey of a trunk road, with 200 linear feet as a general figure. To carry out this work over a length of 2 or 3 miles of road, one engineer and two or three labourers are required. When working far from the base, the labourers may be hired locally, but when working near the base or on a small job it may be more economical to bring experienced men from the base.

### **Equipment**

On most soil surveys a light van is essential to carry the necessary equipment to the site. A 10-cwt. van will usually be sufficient for this purpose since, if the weight of samples becomes too large, some can be forwarded to the laboratory separately.

An alternative procedure is to employ a mobile laboratory, consisting of a 3- to 5-ton lorry or trailer, suitably equipped. Such a laboratory, in addition to being used for the soil survey proper, can also readily be equipped for soil classification

and compaction tests, so that, if required, the whole work can be carried out on the site.

Plate 1 (A and B) illustrates the type of mobile laboratory used by the Road Research Laboratory for a complete soil investigation. It includes equipment for all the laboratory and field tests that are usually carried out and do not require heavy equipment. This type of laboratory is perhaps too elaborate and costly for many local authorities and Plate 2 (A and B) illustrates a simpler type more suitable for such authorities.

If a light van is used, it can conveniently be fitted with racks on the walls to carry surveying instruments and ranging rods, with removable boxes for sample-tins, pegs and other small stores. Boxes about 15-in. cube are suitable for this purpose. The sample tins for the soil should be airtight so that no loss of moisture occurs from any of the samples that may be subsequently required for laboratory tests. Except for gravelly soils, a 1½-lb. sample is sufficient for identification tests and this can be conveniently placed in a 1-lb. lever-lid tin 2½ in. high by 3½ in. in diameter. The larger samples required for more extensive tests need not be stored in airtight tins, but a small part of these samples should be kept airtight for moisture content tests. Typical weights are given in Table 2.

**TABLE 2**  
**SIZE OF SOIL SAMPLE REQUIRED**

PURPOSE OF SAMPLE	SOIL TYPE	MINIMUM WEIGHT OF SAMPLE REQUIRED (LB.)
Soil identification and natural moisture content tests ..	{ Cohesive soils and sands Gravelly soils	1½ 7
Compaction tests .. ..	{ Cohesive soils and sands Gravelly soils	10 20
Soil cement stabilization ..	{ Cohesive soils and sands Gravelly soils	50-100 100-200
Other methods of soil stabilization .. ..	Cohesive soils, sands, and gravelly soils	10-20

On major road construction if samples are taken at vertical intervals of 1 ft 6 in. or 2 ft, or every time the type of soil changes, the number of tins required per mile of road varies between 20 and 100. Rather more are required per mile for a short survey than for a long one. The number of samples required depends on the soil conditions at the site and on the importance of the works proposed.

The type of hand auger that has been found most useful is the post-hole auger of 4- or 5-in. diameter. On stony ground it may be supplemented by a crowbar or a gravel auger, though the latter is seldom satisfactory. For very dry soil or ground below the water-table level an auger with self-closing flaps may be required, but this type is troublesome to use as the flaps are liable to jam. In cohesive soils

### BORING RECORD

Site.....*Greymouth*..... Boring No.....*19*..... Job No..*1234/58*  
 Chainage..*19 + .00*..... Date..*10/2/43*.....  
 Natural Surface Level..*124.6*..... Existing Surface Level..*124.6*.....  
 Formation Level.....*-*..... Water-table Level..*118.1*.....  
 Remarks ..*In an old wood near the bottom of a steep*  
           *bank. 1/2-in. of dead leaves removed before*  
           *boring.*.....

Depth below surface ft      in.	Tin No.	M/C Tin No.	Natural Moisture Content %	Water seeping into hole	Soil Class <sup>n</sup>	Remarks
0    0	136	104	10	—	SF	Dark sandy top soil
1    3	124	98	10	—	SF	Dusty brown cohesive sand
2    0	137	—	—	—	SF	Brown calcareous sand, wetter and plastic.
2    9	113	32	51	—	CH	Hard blue clay, plastic.
5    6	119	—	—	—	CH	Ditto. wetter
6    3	96	169	31	—	SP	Grey-brown mottled sand, very wet, fairly clean.
6    6				Water-table		
7    0	126	—	Water churned up with sample		SP	Clean green sand
7    6	—	—	"	Standing water, sides falling in	SP	Ditto.

FIG. 2. TYPICAL BORING RECORD SHEET

free of stones a corkscrew auger may be used, but the hole produced is of rather small diameter, down which it is difficult to see when measuring the depth of the water-table. A typical hand auger is shown in Plate 3 (A). These augers all need extensions for boring below about 4 ft, the extensions being made of  $\frac{3}{4}$ -in. gas-piping. For convenience, the auger itself and the extensions are made an exact number of feet in length, the auger usually being 4 ft long and the extensions 3 ft. The shaft of the auger and the extensions should be ringed at every foot to facilitate reading the depth at a glance.

For dealing with gravelly soils a power auger is useful. The Ministry of Transport own one such machine which is illustrated in Plate 3 (B). It is hoped to adapt this machine for taking undisturbed samples. This power auger is not of British manufacture and few are available in this country.

Boring records similar to those illustrated in Fig. 2 are required at the rate of five to thirty sheets per mile of road: this allows one sheet per hole and perhaps two sheets for those holes over 10 ft deep.

A list of equipment needed on a large-scale survey is given in Appendix A.

Where conditions make it impossible to carry out the work with the equipment described above, other methods of surveying may be used, details of which are given on pages 10, 11 and 13. The equipment for these methods is generally expensive and the work is usually carried out by specialist firms.

### III. SOIL SURVEY PROCEDURE

The procedure in making a soil survey falls into four main parts:—

- (1) Preliminary work.
- (2) Site reconnaissance.
- (3) Determination of the soil profile and collection of samples.
- (4) Location of water-table.

#### **Preliminary Work**

Before proceeding to the site, the surveyor should first examine any existing information on the geological and soil conditions likely to be met. The 1-in. to 1-mile (and 6-in. to 1-mile if available) Geological Survey Maps and the appropriate Geological Survey Memoirs, particularly the sheet memoirs, will often give useful information. Both solid and drift maps should, if possible, be consulted. The data given include the nature of the underlying rock and superficial deposits as well as the location of any known faults and igneous intrusions. It is also desirable to consult the Geological Survey and Museum as they often have useful unpublished information. In Great Britain soil maps exist for only a few areas, for which they provide useful additional information.

The centre line of the road is set out on the 6-in. to 1-mile Ordnance Map or, if drainage investigations are planned, on the 1/2500 (25-in.) map. The lay-out of the borings should be plotted on one of these maps. If only a strip is to be surveyed, as is usual for a road, a single line of borings along the centre line or a double line offset 50 or 100 ft on each side is usually sufficient, but if a wide area is to be surveyed the best way of covering the ground is probably with a grid. Normally the borings are required at intervals of about 300 ft.

The depth of boring should be 4 to 5 ft below existing ground level when little cut or fill is required. For cuttings, borings should be taken to a similar depth

below formation level, and for deep cuttings it may be necessary to call in boring contractors. For embankments, occasional borings should be taken to a depth of  $1\frac{1}{2}$  to 2 times the height of the embankment, if the presence of soft material is suspected. On all occasions, when a stratum providing a satisfactory foundation of adequate thickness is encountered, boring may be stopped. From the geological information and lay-out of the borings more definite information can be obtained as to the total length of the borings and the number of sample tins required.

### **Site Reconnaissance**

On first visiting the site it is desirable to make a preliminary reconnaissance by walking over the ground, to obtain a broad indication of the work required. When practicable, this site reconnaissance should be made before the main survey party proceeds to the site. Neighbouring quarries, cuttings and escarpments should be inspected. The general topography will often give some indication as to whether the soil conditions are likely to be variable or not. Some indication of the depth of the water-table below the surface can often be obtained from an inspection of streams or ponds, while vegetation such as rushes, cotton-grass or willows indicates that the water-table is near the surface for at least part of the year. Bracken and gorse are usually indications of a well drained soil. Silver birches and pines prefer a sandy soil, while beeches are usually found on clay.

A change in the vegetation over quite a small area may indicate an important change in the subsoil or rock formation, such as an igneous intrusion or the presence of alluvial soil. Plate 4 (A) shows how an abrupt change in soil conditions is indicated by a change in vegetation: the growth of daisies on the bank in the foreground stops abruptly where peaty conditions occur in the lower ground in the middle distance. Plate 4 (B) shows how wet soil conditions can affect the growth of vegetation; in winter the water-table rises above the bottom of the valley, which is consequently covered by water-loving plants and grasses, while in summer the water-table drops and the grass becomes parched and brown as shown in the photograph. Brown discolouration of surface water in swiftly flowing streams may denote the presence of peaty soil, though the peat may be outside the site. Geological faults may be indicated by topographical features such as a step in the line of an escarpment, or a valley where the shattered rock has been more rapidly eroded than has the surrounding rock. These places should receive detailed inspection as igneous intrusions may involve rock excavation, while in certain circumstances a fault may also give rise to construction difficulties. Careful note should also be made, especially on sloping clay formations, of any irregularities in the ground that may be due to landslips or lack of stability. They may be indicated by a terraced appearance, and sometimes by the inclination of trees from the vertical.

After the site reconnaissance the preliminary plan of the borings should be revised if necessary. The interval between the borings depends entirely on the nature of the soil encountered and may be as much as 1,000 ft in very uniform ground or as little as 50 ft in quickly changing ground such as glacial deposits.

### **Determination of Soil Profile**

#### *Setting out*

When the layout of the borings has been decided, the position of the holes should be pegged on the ground. Except on moorlands or in very large fields, it is usually sufficiently accurate to mark the positions of the holes by setting ranging rods or

other suitable markers in the hedges on the line of the borings. Only in exceptional cases will the use of a theodolite be necessary.

### *Boring*

As previously mentioned, the post-hole auger is the most useful tool for hand boring. In gravelly soils the gravel auger may be used, but if there are many large stones even this may prove unusable, and it is then best to use the post-hole auger in conjunction with a crowbar. The stones are removed singly by using the crowbar to push them into the lowered auger which has a little soil worked into it to act as a cushion. When the auger is being raised, it may be necessary to hold the stone in position with the crowbar, until it can be reached by hand and thrown out. If these methods fail, it may be necessary to start another hole nearby or to dig down to the obstruction if this is near the surface. If the soil is too dry to be retained in the auger, and no auger with self-closing flaps is available, water may be poured down the hole, but under these conditions samples cannot be taken for moisture content determinations for several feet below the depth at which this procedure was employed. The introduction of water is not recommended except as a last resort. When boring in areas where field drains have been constructed, there is sometimes a danger of mistaking the gravel and stone frequently used for surrounding the pipes for changes in the soil strata.

Beds of peat or soft clay should be completely penetrated and their boundaries located. When rock is encountered it is unnecessary to proceed further, since rock is a satisfactory foundation, but in glaciated areas care should be taken not to confuse boulders with solid rock.

### *Sampling*

At least one sample should be taken from each stratum found in each boring. Samples should be placed in separate sample tins and their nature noted on the boring record. Reliable and experienced labourers can be left to do this on their own, but others may have to be closely supervised unless some such plan as the following is adopted:—Close to the proposed hole, a strip of ground should be cleared and roughly smoothed over, then as the first auger-full of soil is brought up it is laid at one end of this strip, the next load is laid adjacent to it and so on. As each foot of depth is passed a deep scratch is made beside the last auger-load of soil that was brought up. In this way, the engineer can see exactly what soil has been brought up from each part of the hole and can select the samples that he requires. The size of sample necessary for various purposes is given in Table 2 (page 5).

### *Records*

Full and systematic records must be kept of each boring, on boring record sheets (Fig. 2). Part of the boring record is filled in during the survey and part subsequently. The description of the site should give the nature of the ground, e.g. a ploughed field, and should state the depth (if any) of loose leaves or sod removed before boring. The description of the soil should include its colour, texture, consistence, structure, stoniness and a statement as to whether it is highly organic or not. In clays, a mottled colour implies poor drainage, while a blue colour indicates that no oxidation has taken place. Under the heading "texture," a note should be made of the coarseness or fineness of the material; the consistence may be described as hard, stiff or soft, etc. The soil structure will be disturbed by the auger but it may sometimes be discernible from the larger lumps of soil and may be

described, for example, as granular or laminar; the presence of organic matter may be shown by the dark colour and smell of soils containing it. If the soil is so stony that a reasonably representative sample cannot be obtained, a note should be made of the approximate proportion of stone in the soil and the range of sizes found.

### *Gravelly Soils*

In gravelly soils progress with a hand auger will be subject to frequent delays even when a crowbar is also used and it may become necessary to resort to other methods of exploration. The ordinary well-drilling equipment is of little value for this work as the only sample recovered is in the form of a slurry which is unsuitable for soil testing. In cases of this sort a power auger such as is shown in Plate 3 (B) is useful. The machine shown is mounted on a four-wheel-drive lorry and weighs about 9 tons. It can drill holes of from 12 in. to 48 in. in diameter, to a depth of 20 ft. The larger drills are useful when undisturbed samples have to be obtained from a considerable depth as they make a hole large enough to enable someone to go down and obtain the samples, if the soil conditions are such that this is safe.

### **Location of Water-Table**

Should no trace of water be found in the hole at its full depth, it may be backfilled at once, but if water is found or indicated, the hole should be left for 12 to 24 hours for the water to rise to its final level. The most convenient way of measuring the depth to the water level is to lower a levelling staff or a ranging rod until its lower end just touches the water surface. Where depths are too great for this method, a weighted tape can be used.

It occasionally happens that a boring pierces a layer of impervious clay resting on a permeable layer in which the water is under pressure, i.e. there are artesian conditions. These conditions will be shown by the water rising above the level at which it was first found seeping into the hole, and often indicate that special drainage will be required. Under other conditions, the boring may disturb a zone of more than usually permeable soil in which a very rapid flow is taking place. In both these circumstances it would be well to put down another hole nearby as a check.

It is a good plan to plot the information obtained while still on the site to avoid returning to the base with insufficient data.

### **Geophysical methods**

When speed is more important than the accuracy of the information about the types of soil present, geophysical methods can sometimes be used to locate the approximate depth of strata or of the water-table, but specialists must be employed for the work. Both the methods described below are widely used in prospecting but, as far as is known, only the resistivity method has been used on road projects in this country. The seismic method is generally used where information concerning soils or rocks at a considerable depth is required while the resistivity method can be used for shallow depths as well. Both methods have been used to determine depths to solid rock or to the water-table, even when these were shallow.

#### *Seismic method*

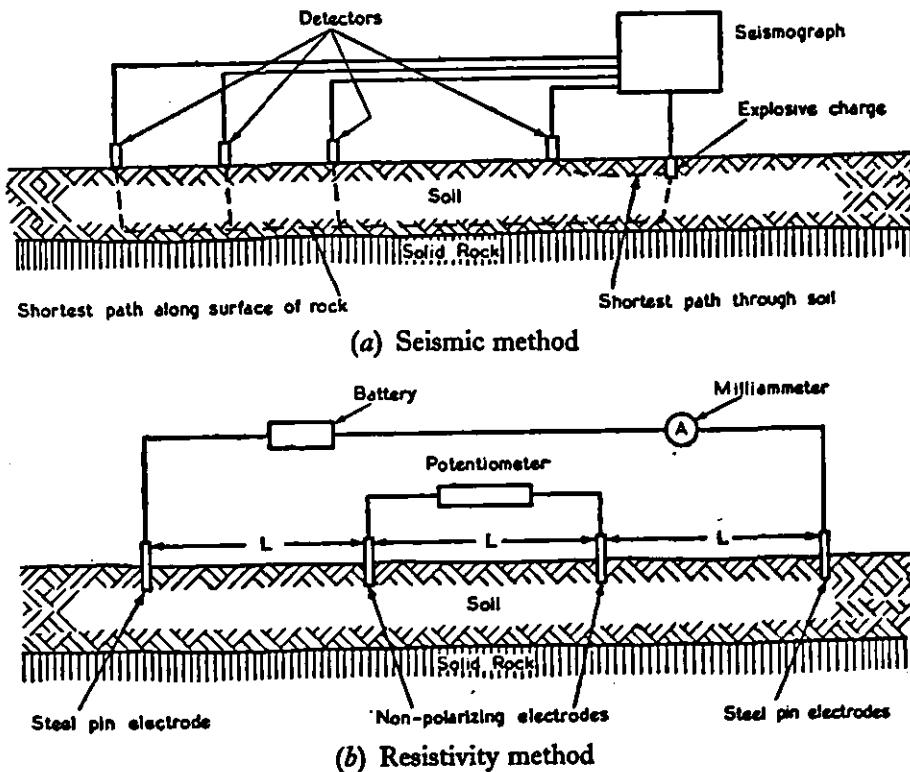
The seismic method depends on the fact that sound and shock waves travel faster in rock than in soil and faster in solid rock than in fissured rock or soil. Fig. 3 (a) illustrates how a shock wave may travel more quickly by penetrating deeply to a stratum of solid rock than by travelling through the soil above it, provided that the



horizontal distance to be travelled is substantially more than twice the thickness of the soil. The shock that first operates the farther detectors is the one which travels down through the soil at such an angle that it is refracted along the surface of the bed-rock below it, and in travelling along this surface is constantly refracted upwards as shown. The speed of the shock wave varies from 1,000 to 20,000 ft/sec. By recording the times taken for the shock wave to be transmitted, both directly through the soil and *via* the surface of the solid rock, from the firing point to each of several detector instruments, the seismograph readings enable the interpreter to determine the depth to solid rock. Ground below the water-table behaves similarly to rock, in that it transmits a shock wave at high speed. It is clear from the foregoing that to obtain a complete picture of subsurface conditions it is desirable to supplement the geophysical measurements with a few borings.

**Resistivity methods**

Of the several electrical methods of surveying, the one most used in road work is the resistivity method illustrated in Fig. 3(b). Two electrodes are set in the ground, their distance apart being of the order of three times the depth to which information



**FIG. 3. GEOPHYSICAL METHODS OF SURVEYING**

is required. Two more electrodes of a non-polarizing type are set in the ground between and in line with the first two, usually at the third points. A current is passed through the ground *via* the outer two electrodes; this may be from a battery, but in districts where electricity is in use it is common to generate an alternating current with a square wave form, so that it can be distinguished from any stray currents in the soil and it is then not necessary to use non-polarizing electrodes.

TABLE 3

SOIL CLASSIFICATION SCHEME (U.S. CORPS OF ENGINEERS)

SOIL TYPE		TYPE PREFIX	NATURE	SUFFIX	DESIGNATION
Coarse-grained soils	Gravel and gravelly	G	Well graded, fairly clean. Well graded, clay binder. Poorly graded, fairly clean. Excess of fines.	W C P F	GW GC GP GF
	Sands and sandy	S	Well graded, fairly clean. Well graded, clay binder. Poorly graded, fairly clean. Excess of fines.	W C P F	SW SC SP SF
Fine-grained soils	Silts, very fine sands, rock flour	M	Low compressibility. Silts, rock flour, clayey fine sands	L	ML
			High compressibility. Micaceous or diatomaceous fine sandy and silty soils.	H	MH
	Clays (inorganic)	C	Low compressibility. Medium plasticity. Sandy and silty clays.	L	CL
			High compressibility. High plasticity. Fat and heavy clays.	H	CH
Clays (organic)	O	Low compressibility. Organic silts.	L	OL	
		High compressibility. Medium high plasticity. Organic clays.	H	OH	
Fibrous organic soils	Peat and other highly organic swamp soils		Very high compressibility.		Pt

TABLE 4. SOIL CLASSIFICATION AND ITS INTERPRETATION

1	2	3	4		5	6	7	8	9	10	11	12	13	14			
			GENERAL IDENTIFICATION														
MAJOR DIVISIONS	SOIL GROUPS AND TYPICAL NAMES	DESIG-NATION	DRY STRENGTH	OTHER RELEVANT FACTORS	OBSERVATIONS AND TESTS RELATING TO MATERIAL IN PLACE	PRINCIPAL CLASSIFICATION TESTS (ON DISTURBED SAMPLES)	VALUE AS FOUNDATION WHEN NOT SUBJECT TO FROST ACTION	POTENTIAL FROST ACTION	SHRINKAGE, EXPANSION, ELASTICITY	DRAINAGE CHARAC-TERISTICS	COMPACTION CHARACTERISTICS AND EQUIPMENT	MAXIMUM DRY DENSITY (lb./cu. ft)* AND VOID RATIO	COMPARABLE GROUPS IN PUBLIC ROADS CLASSIFICATION	THICKNESS OF FLEXIBLE PAVEMENT FOR MAIN PAVEMENT (in.) 10,000-lb. WHEEL LOAD (compacted soils)			
COARSE-GRAINED SOILS	Gravel and gravelly soils	Well graded gravel and gravel-sand mixtures, little or no fines	GW	None	Gradation, grain shape	Dry density, relative compaction, cementation, durability of grains, stratification and drainage characteristics, ground-water conditions	Mechanical analysis	Excellent	None to very slight	Almost none	Excellent	Excellent; tractor	>125 •<0.35	A-3	4		
		Well graded gravel-sand-clay mixtures, excellent binder	GC	Medium to high	Gradation, grain shape, binder exam-wet and dry		Mechanical analysis, liquid and plastic limits on binder	Excellent	Medium	Very slight	Practically impervious	Excellent; sheepsfoot roller	>130 •<0.30	A-1	4		
		Poorly graded gravel and gravel-sand mixtures, little or no fines	GP	None	Gradation, grain shape		Mechanical analysis	Good to excel-lent	None to very slight	Almost none	Excellent	Good; tractor	>115 •<0.45	A-3	4		
		Gravel with fines, very silty gravel, clayey gravel, poorly graded gravel-sand-clay mixtures	GF	Very slight to high	Gradation, grain shape, binder exam-wet and dry		Mechanical analysis, liquid and plastic limits on binder if applicable	Good to excel-lent	Slight to medium	Almost none to slight	Fair to practically impervious	Good, close control essential; pneumatic-tyred roller, tractor	>120 •<0.40	A-2	4-5		
	Sands and sandy soils	Well graded sands and gravelly sands, little or no fines	SW	None	Gradation, grain shape		Mechanical analysis	Excellent to good	None to very slight	Almost none	Excellent	Excellent; tractor	>120 •<0.40	A-3	4-5		
		Well graded sand-clay mixtures, excellent binder	SC	Medium to high	Gradation, grain shape, binder exam-wet and dry		Mechanical analysis, liquid and plastic limits on binder	Excellent to good	Medium	Very slight	Practically impervious	Excellent; sheepsfoot roller	>125 •<0.35	A-1	4-5		
		Poorly graded sands, little or no fines	SP	None	Gradation, grain shape		Mechanical analysis	Fair to good	None to very slight	Almost none	Excellent	Good; tractor	>100 •<0.70	A-3	4-11		
		Sand with fines, very silty sands, clayey sands, poorly graded sand-clay mixtures	SF	Very slight to high	Gradation, grain shape, binder exam-wet and dry		Mechanical analysis, liquid and plastic limits on binder if applicable	Fair to good	Slight to high	Almost none to medium	Fair to practically impervious	Good, close control essential; pneumatic-tyred roller	>105 •<0.60	A-2	4-12		
	FINE-GRAINED SOILS Containing little or no coarse-grained material	Fine-grained soils having low to medium compressibility	Silts (inorganic) and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	Very slight to medium		Examination wet (shaking test and plasticity)	Dry density, relative compaction, water content and consistence, undisturbed and re-moulded stratification, root holes, fissures etc., drainage and ground-water conditions	Mechanical analysis, liquid and plastic limits if applic-able	Fair to poor	Medium to very high	Slight to medium	Fair to poor	Good to poor, close control essential; pneumatic-tyred roller	>100 •<0.70	A-4 A-6 A-7	4-14
			Clays (inorganic) of low to medium plasticity, sandy clays, silty clays, lean clays	CL	Medium to high		Examination in plastic range		Liquid and plastic limits	Fair to poor	Medium to high	Medium	Practically impervious	Fair to good; sheepsfoot roller	>100 •<0.70	A-4 A-6 A-7	7-18
			Organic silts and organic silt-clays of low plasticity	OL	Slight to medium		Examination in plastic range, odour		Liquid and plastic limits from natural conditions and after oven-drying	Poor	Medium to high	Medium to high	Poor	Fair to poor; sheepsfoot roller	>90 •<0.90	A-4 A-7	14-20
		Fine-grained soils having high compressibility	Micaceous or diatomaceous fine sandy and silty soils, elastic silts	MH	Very slight to high		Examination wet (shaking test and plasticity)		Mechanical analysis, liquid and plastic limits if applic-able	Poor	Medium to very high	High	Fair to poor	Poor to very poor	<100 •>0.70	A-5	13 upwards
Clays (inorganic) of high plasticity, fat clays			CH	High	Examination in plastic range	Liquid and plastic limits	Poor to very poor		Medium	High	Practically impervious	Fair to poor; sheepsfoot roller	>90 •<0.90	A-6 A-7	14 upwards		
Organic clays of medium to high plasticity			OH	High	Examination in plastic range, odour	Liquid and plastic limits from natural conditions and after oven-drying	Very poor		Medium	High	Practically impervious	Poor to very poor	<100 •>0.70	A-7 A-7	18 upwards		
Fibrous organic soils with very high compressibility		Peat and other highly organic swamp soils	Pt	Readily identified		Consistence, texture and natural water content			Extremely poor	Slight	Very high	Fair to poor	Compaction not practicable		A-8	14 upwards	

LEGEND FOR GROUP SYMBOLS

C=clay G=gravel L=Low to med. compressibility O=Organic Pt=peat W=well graded  
F=fines H=high compressibility M=Mo. very fine sand, silt, rock flour P=poorly graded S=sand

\* These densities apply only to soils with specific gravities ranging between 2.65 and 2.75

Part of the current is picked up by the intermediate electrodes and the resistance of the circuit is measured by the potentiometer. By increasing the spacing of these electrodes the corresponding depth to which measurements of resistance are taken is increased, and in general the spacing of the central electrodes at which a marked change of resistance is indicated is equal to the depth of the stratum causing it.

A list of further references on geophysical surveys is given on page 31.

#### IV. SOIL CLASSIFICATION AND ITS APPLICATION

##### Scope of Soil Classification

The information obtained from the field work must be reduced to a form in which it can be applied to engineering problems. To permit deductions to be made from a knowledge of the type of soil it is desirable to classify the soil according to some recognized scheme.

##### Selection of Samples for Classification

The first step in classifying the soils from any site is to set out the samples in some logical order, e.g. the samples from each boring can be set in one row with the top sample at the back and the next in front of it, and so on. The soils can then be grouped into a limited number of types, from each of which a few samples representing the extremes and means of grading and consistence etc. should be selected for classification purposes.

##### Classification of Soils

The general scheme of classification recommended is summarized in Table 3 and is described in more detail in Appendix B. In classification an experienced man can do a great deal by manual and visual methods, but it is always desirable to confirm such classification by tests on a limited number of samples. In border-line cases and where only limited experience is available, tests are essential.

The tests employed comprise:—

SOIL TYPES	TESTS
Coarse-grained (non-cohesive) soils	Particle size distribution
Fine-grained (cohesive) soils	Liquid limit
	Plastic limit
	Natural moisture content
	Particle size distribution (subsidiary)
Both types	Compaction and density tests

The results of these tests are applied in the classification scheme (indicated in Appendix B) which permits a number of inferences to be drawn on the lines indicated in Table 4 (facing this page). In all schemes of soil classification, however, the necessity for limiting the number of soil types to obtain a simple and workable scheme involves including soils with quite wide differences in a single group. For this reason it is often possible to devise, on any given site, a more detailed *ad hoc* classification, which may have advantages for certain purposes.

Visual classification was used in the course of an extensive soil survey undertaken to discover the sites for borrow pits that would yield the best sand for making sand

asphalt by the wet-sand process. Fig. 4 represents part of the soil profile mapped from the results of the classification. The five types of sand varied sufficiently in clay content to make certain varieties entirely unusable, and certain others unusable in wet weather. The behaviour of the materials when mixed with bitumen was determined in the laboratory and confirmed on the site. Only types 4 and 5 were usable throughout the year; type 3 was satisfactory in the summer. The desirable sands were therefore types 4 and 5, and the most favourable sites for the borrow pits are between chainages 6,100 and 7,300.

### Interpretation of Soil Classification

The engineering characteristics of soil can be inferred in a general way from its classification. Table 4, taken with slight modifications from a paper by Middlebrooks and Bertram<sup>(2)</sup>, indicates the extent to which the principal properties of the soil may be inferred from the soil type as determined from the classification scheme of Table 3, and gives the ranges of thickness required for flexible pavements to carry a wheel load of 10,000 lb. A minimum thickness of 4 in. is assumed. It must be emphasized that the data given in Table 4 apply strictly to conditions in the U.S.A. and may require some modification when applied in other parts of the world.

Table 5 gives information regarding typical slopes in cuttings of rocks and coarse-grained soils. The safe slopes in fine-grained (cohesive) soils depend on both the shear strength and the height of the cutting embankment. Questions involving the shear strength of the soil necessitate taking into account other factors besides those mentioned in the classification system given in Table 3, since the finer differences in particle size characteristics are of relatively less importance than questions of compactness and consistence. It is relatively easy to determine the unconfined compressive strength, and hence the shear strength, of saturated clay soils. These problems are, therefore, best dealt with in the way outlined below in the section on "Special Investigations".

TABLE 5  
TYPICAL SLOPES IN CUTTINGS

TYPE OF GROUND	TYPICAL SAFE SLOPE FOR EXCAVATIONS
Igneous rocks in sound condition ..	Almost vertical
Slates; schists; hard shales; hard chalk	$\frac{1}{2} : 1$
Thinly bedded limestones and sandstones; mudstones .. ..	$\frac{3}{4} : 1$
Clay shales; friable sandstones ..	$1\frac{1}{2} : 1$
Gravel and sand .. .. .	$2 : 1$
Fine sands .. .. .	$2\frac{1}{2} : 1$
Clays and silts .. .. .	Depends on strength of material and depth of excavation

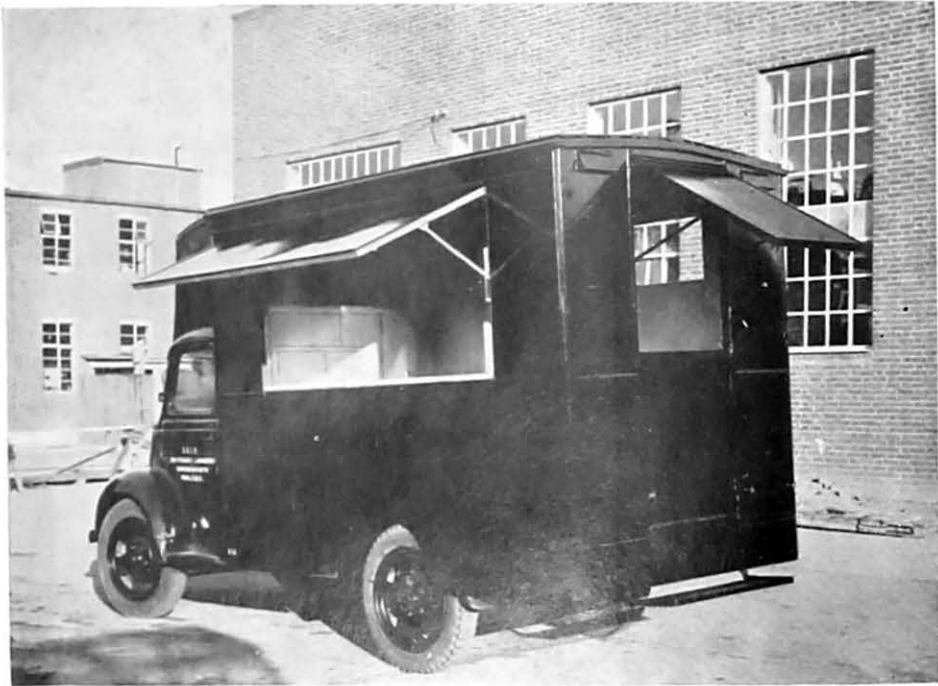
*Note.* The slopes given in this table apply only to strata with more or less horizontal bedding planes. The safe slopes given should not be regarded as applicable in all cases but only as approximate typical values.



(A) MOBILE LABORATORY FOR SOIL TESTING



(B) MOBILE LABORATORY FOR SOIL TESTING: INTERIOR



(A) SMALL MOBILE LABORATORY  
Used for soil survey work and control tests



(B) SMALL MOBILE LABORATORY : INTERIOR

(A) POST-HOLE AUGER  
AND CROWBAR



(B) POWER AUGER  
SUITABLE FOR  
BORING IN  
GRAVELLY SOILS







(A) CHANGE IN SOIL CONDITIONS  
Indicated by change in vegetation



(B) HIGH WINTER WATER-TABLE  
Indicated by parched water-loving grasses in summer

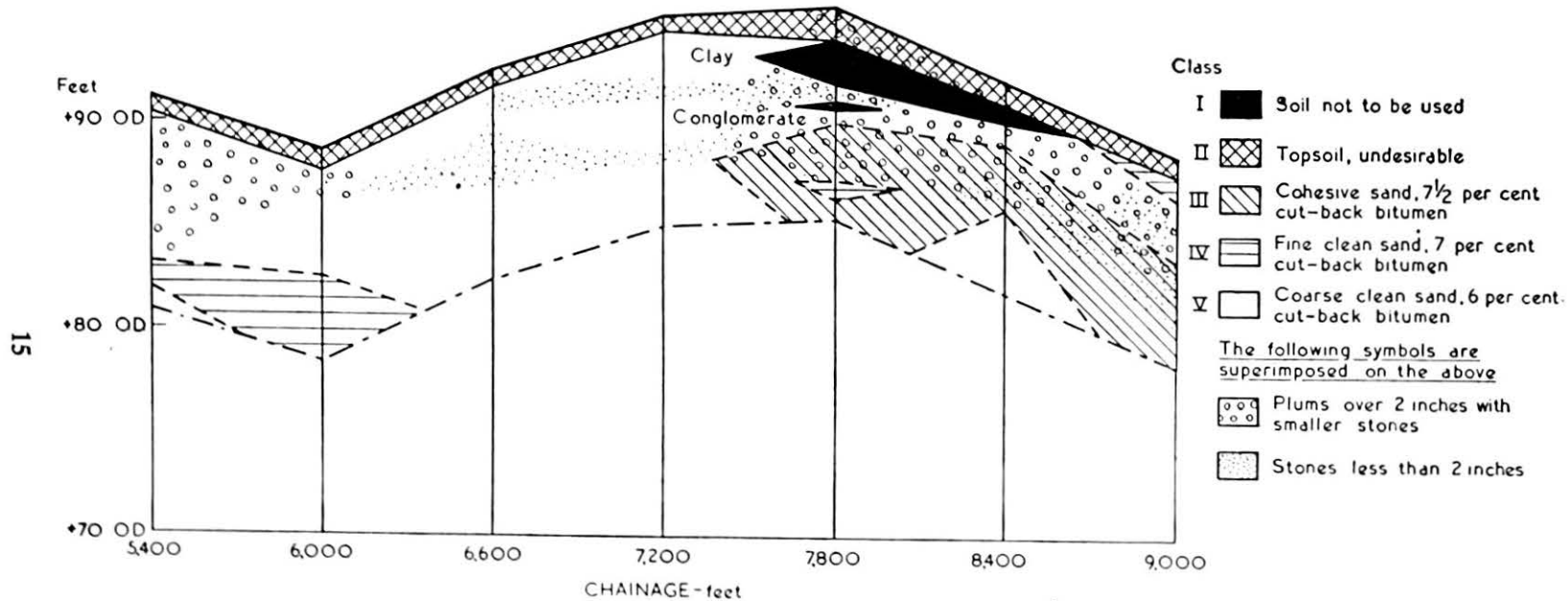


FIG. 4. SOIL PROFILE ILLUSTRATING USE OF VISUAL CLASSIFICATION AS APPLIED TO SANDS FOR BITUMINOUS SURFACING

The bearing capacity of uniform homogeneous soils for structures can be inferred within broad limits from the nature of the soil: Table 6 gives typical values that have been suggested for bearing capacity. Such tables need to be employed with understanding and it is preferable to determine the bearing capacity directly from the shear strength of the soil. This is essential in all cases of difficulty.

TABLE 6

TYPICAL WORKING BEARING PRESSURES FOR STRUCTURAL FOUNDATIONS

MATERIAL	TYPICAL WORKING BEARING PRESSURE (TONS/SQ.FT)
<i>Non-cohesive</i>	
Compact gravel or sand and gravel	5
Loose gravel or sand and gravel ..	3
Compact coarse sand .. ..	4
Loose coarse sand .. .. .	2
Compact fine sand .. .. .	3
Loose fine sand .. .. .	1
<i>Cohesive</i>	
Very stiff boulder clays, clay shales	6
Stiff clays and sandy clays .. ..	4
Firm clays and sandy clays .. ..	2
Soft clays and silts .. .. .	1
Very soft clays and silts and peat ..	not more than $\frac{1}{2}$
Hoggin (compact) .. .. .	6
Hard solid chalk .. .. .	6

Table 7, reproduced with slight amendments from a paper on the use of low-grade aggregates and soils for the construction of bases, <sup>(3)</sup> gives an indication of the value of such materials for use in various stabilization processes.

## V. SPECIAL INVESTIGATIONS

For more precise indications of the behaviour of the soil it is necessary to investigate the specific properties of the soil directly. The scope of such additional investigations is indicated in Table 1. In general, they cover four types of problem:—

(1) Settlement, (2) stability, (3) compaction and (4) design of pavement.

The investigation of the probable settlement of structures on clay foundations involves testing undisturbed samples and requires the use of a fully equipped soil mechanics laboratory. The same applies to stability problems, although the work is considerably simplified when the soil is purely cohesive, since in this case its cohesive strength in shear can be simply determined in the field. Compaction problems are also relatively simple to investigate in the field.

TABLE 7

## SUITABILITY OF MATERIALS FOR BASE CONSTRUCTION IN GREAT BRITAIN

S = Suitable

U = Unsuitable

OS = Occasionally suitable

(subject to confirmation by tests)

STABILIZATION PROCESS	MATERIAL							REMARKS
	CRUSHED ROCK	GRAVEL	GRAVEL WITH SAND AND SILT	SAND	SILTY SAND	LOAM AND SILT	CLAY	
Mechanical—								
(a) without clay binder ..	S	S	S	S	U	U	U	A naturally occurring deposit of type (b) is commonly referred to as "hoggin" in the South of England
(b) with clay* binder ..	S	S	S	S	OS	U	U	
Bituminous—								
(a) cut-back bitumen ..	S	S	S	S	U	U	U	Wet-sand process has been successfully used in Britain. Results have varied in U.S.A. Not very suitable for British use. Wet-sand process with tar has been successfully used in Britain.
(b) bitumen emulsion ..	S	S	U	S	U	U	U	
(c) tar .. ..	S	S	S	S	U	U	U	
Waterproofing methods (including waxed bitumen and resinous admixtures) ..	U	U	S	U	S	S	OS	New processes under development
Portland cement .. ..	S	S when fines added	S	S	S	OS	U	Used increasingly in U.S.A. especially on soils containing little clay
Heat treatment .. ..	U	U	U	U	U	U	S	Not common

\* In American practice, calcium chloride or sodium chloride is sometimes added in small quantities.

In determining in the field the cohesive strength in shear of saturated clay soils, use is made of the fact that the cohesive strength is approximately half the unconfined compressive strength. Small undisturbed samples of clay soils can be obtained, using a simple 1½-in. steel coring tube attached to the ordinary boring equipment. Samples obtained with this tool are tested on the site with an apparatus for determining the unconfined strength of clay soils. This apparatus, which was developed by the Building Research Station and is described elsewhere,<sup>(4)</sup> has proved of value in the investigation of many problems relating to the stability of soil, e.g. in cuttings and embankments on cohesive soils. The methods of calculating the stability of the soil from the data obtained in the investigations, using the circular wedge theory, have been given elsewhere.<sup>(5)</sup>

Investigations of the compaction of soils involve both the determination of the dry density or weight of dry soil per cu.ft as the soil exists *in situ* and a knowledge of the compaction obtainable under standard conditions. The compacted density of soils in the field can readily be measured by such methods as the core-cutter and sand-replacement methods.

The determination of the thickness of pavement required for the carriageway from a knowledge of the nature of the soil is also a matter for special investigation.

## VI. GROUND-WATER INVESTIGATIONS

The results of ground-water investigations are recorded as:—

- (1) water-table shown on the soil profile.
- (2) water-table contours over the site.
- (3) lines of equal depths to water-table below the surface.

The water-table contours give the general direction of flow of the ground-water and thus indicate the points where, if necessary, this flow is best intercepted. Areas where the ground-water is near the surface usually require subsoil drainage. Water-table investigations are rarely practicable in impervious clay soils in which the free water is present in the fissures in the clay and no true water-table exists.

For ground-water investigations a 25-in. to 1-mile or larger scale map is desirable. If information is to be given on the depths to the water-table, ground contours at 1-ft intervals are required.

To determine the water-table contours, the first step is to plot on the map the positions of the borings with the level, reduced to Ordnance datum, of the water-table beside each point. The water-table contours can then be drawn by connecting points with equal levels. The resulting contours are usually even in shape and show few sudden breaks or irregularities: not infrequently they follow the general lie of the ground although exceptions do occur. Thus a rise in the ground is frequently associated with a rise in the water-table level. Springs, however, will produce marked changes in the shape of the contours.

To obtain lines of equal depth to ground-water, the ground-water contours are superposed on ground level contours as in Fig. 5. The intersections of the two families of contours usually form a series of diamond-shaped areas, as will be seen on the right-hand side of Fig. 5. From the intersections of the two families of curves, points are selected where the differences between ground and water-table levels are constant. For example, take X in the figure where this difference is 2 ft, and join to the nearest intersection where the interval is also 2 ft, i.e. at Y. Continuing in this manner, the line where the ground-water is 2 ft below surface is

gradually developed. The points joined mostly occur diagonally opposite across the diamonds, but care must be taken to see that the correct corners are joined. In general, these lines of constant depth to water-table form irregular closed loops, but frequently the closure is off the edge of the plan concerned. To avoid confusion it will be found convenient to draw each set of contours in a different colour and in the report to give the lines of equal depth to ground-water on a separate drawing.

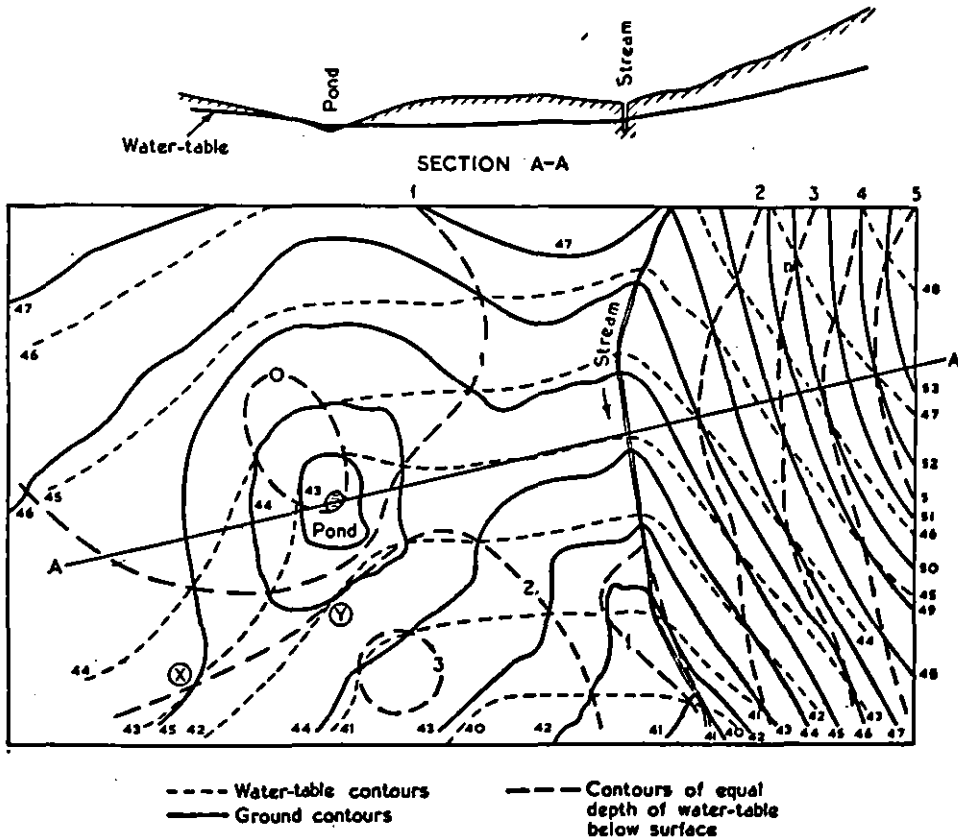
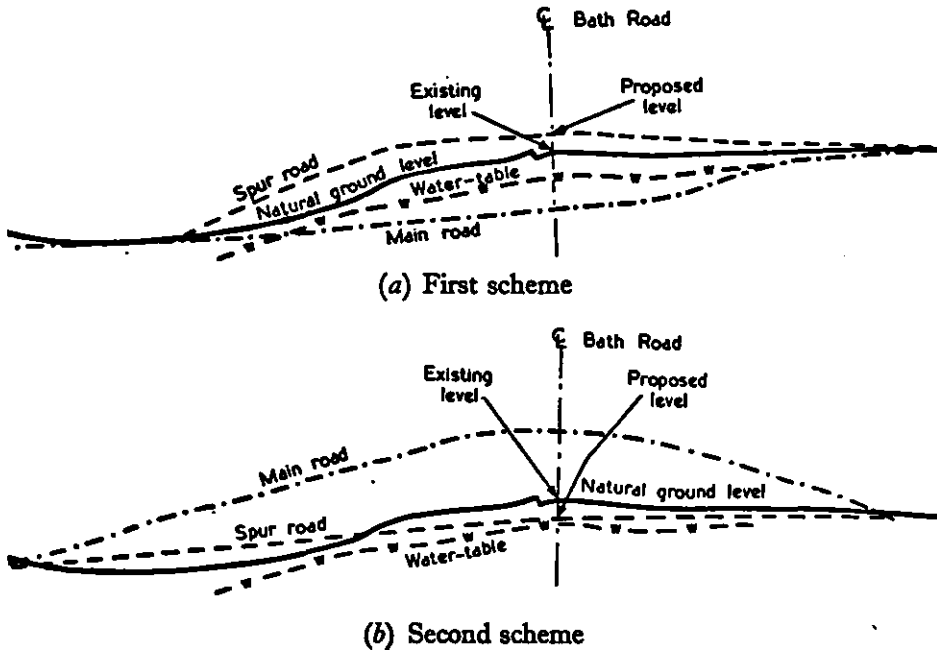


FIG. 5. PLAN SHOWING GROUND AND WATER-TABLE CONTOURS AND CONTOURS OF EQUAL DEPTH OF WATER-TABLE BELOW THE SURFACE

It is also possible, of course, to plot the depths to the ground-water directly from the depths of water in the borings. This method takes no account of the intermediate surface irregularities unless the borings are very numerous or the ground very flat. In practice it is found that the first method affords the easiest way of obtaining the contours of the ground-water.

The actual levels of the ground-water naturally vary with the season, and for this reason it is desirable to carry out the survey when the water-table is at its highest, but whatever the time of year the directions of flow will usually be the same and the areas where the water is nearest the surface will usually be those at which it stands closest to the surface in winter. Where the water is at ground level drainage is obviously necessary, but where the water-table is below ground it is necessary to estimate the height to which it may rise to fix the area that should be drained. The use of the information obtained from ground-water investigations in designing subsoil drainage is outside the scope of the present paper.

An example of the value of such information about the ground-water can be illustrated by the case of a fly-over crossing of the existing Bath Road by a proposed new arterial road, east of Slough (see Fig. 6). A tentative scheme was drawn up in



Scales :—Horizontal : 1 in. to 500 ft ; vertical : 1 in. to 50 ft.

FIG. 6. LONGITUDINAL SECTION ALONG PROPOSED NEW ROAD

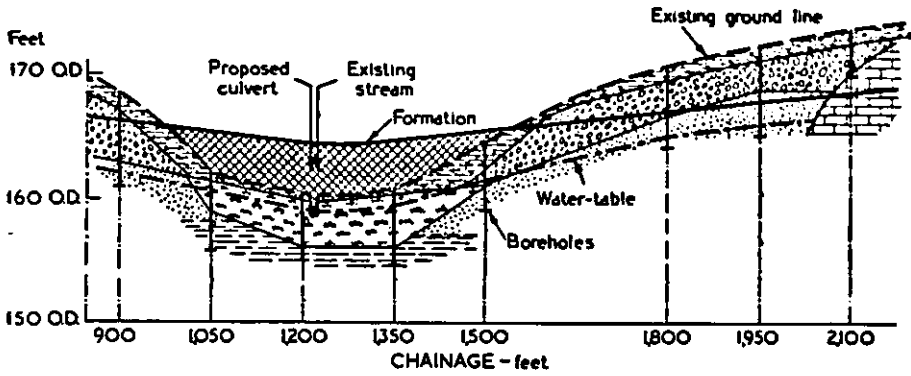
which the existing road was raised a few feet and the new road passed underneath it. In the course of a soil survey of the new road, it was found that the summer (1946) water-table was about 8 ft above the proposed level of the new road at this crossing and that the soil was Thames ballast. This indicated that the scheme would involve heavy expenditure on drainage works, even if it proved practicable, and a second scheme with approximately the same plan was then drawn up in which the existing road was dropped to just above winter water-table level and the new road carried over it.

## VII. PRESENTATION OF INFORMATION

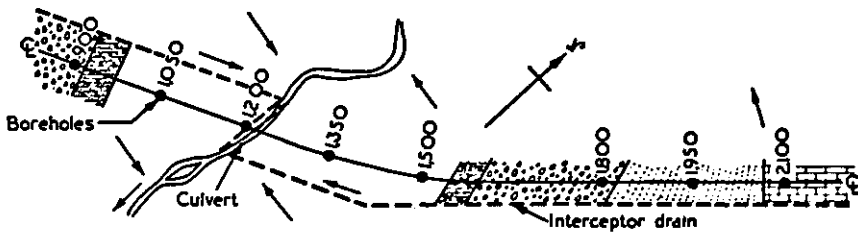
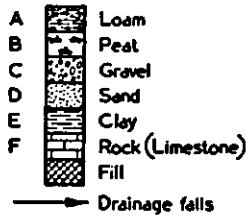
### Soil Profile and Contract Drawings

Recording the information obtained from the borings in suitable form for reports and contract drawings involves drawing a soil profile. For the purpose of a report, it is sometimes advantageous to give the soil profiles, plans and other information on separate sheets, but frequently it may be preferable to incorporate as much information as possible on a single drawing which can then be regarded as a contract drawing.

The information which should be included on this drawing comprises:—(1) soil profile, (2) plans, (3) typical sections, (4) key to soil types and (5) table of test results on soils. Table 8 indicates in more detail the information that should be included and the scales recommended. Fig. 7 illustrates a drawing of this type. The scale



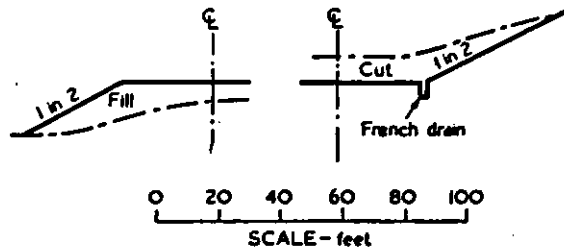
PROFILE ALONG CENTRE LINE OF ROAD



PLAN SHOWING SOIL TYPES EXPOSED AT FORMATION LINE ON CENTRE LINE AND DRAINAGE LAYOUT

SOIL TYPE	C	D	E
Gravel (> 2 mm)%	60	41	0
Sand (2.0-0.06 mm)%	39	55	41
Silt (0.06-0.002 mm)%	1	4	26
Clay (< 0.002 mm)%	0	0	33
Liquid limit	NP	NP	45
Plastic limit	NP	NP	20
Plasticity index	NP	NP	25

NP = Non-plastic



TESTS ON CHIEF TYPES OF SOIL

TYPICAL CROSS-SECTIONS

**NOTES:**

- All topsoil (Type A) is to be preserved and used for soiling at the completion of the work.
- All peaty soil (Type B) is to be cut out and replaced by approved filling.
- All filling is to be spread and rolled in layers not exceeding 9 inches.
- Sand is to be spread 2 inches thick as a sub-base.

**FIG. 7. TYPICAL SOIL SURVEY DRAWING SHOWING ESSENTIAL REQUIREMENTS FOR CONTRACT DRAWING**



**TABLE 8**

**INFORMATION REQUIRED ON SOIL-PROFILE CONTRACT DRAWINGS**

ITEM NO.	ITEM	SCALES OF DRAWING	INFORMATION TO BE SHOWN
1	Soil profile	Horizontal: 1/2500 or 6 in. to 1 mile Vertical: 1 in. to 5-10 ft depending on topography and detail to be shown	<ol style="list-style-type: none"> <li>1. Profile of existing ground surface and of proposed formation level, normally along centre-line of road</li> <li>2. Chainages</li> <li>3. Datum for levels</li> <li>4. Extent of different soils referred to key to soil types (see Item 4)</li> <li>5. Notes on soil types</li> <li>6. Proposed drains</li> <li>7. General notes and recommendations</li> </ol>
2	Plan	Horizontal: 1/2500 or 6 in. to 1 mile	<ol style="list-style-type: none"> <li>1. Outcrops of different soil types at formation level</li> <li>2. Direction of falls of existing ground level</li> <li>3. Proposed drains</li> </ol>
3	Typical sections	Horizontal } Vertical } $\frac{1}{8}$ in. to 1 ft	<ol style="list-style-type: none"> <li>1. Surface and subsoil drains</li> <li>2. Maximum slopes of cuttings and embankments</li> </ol>
4	Key to soil types	—	To present interpretation of soil profile (Item 1) and to be referred to Item 5
5	Table of test results on soils	—	Summary of test results (if any) on different types of soil

TABLE 9

EXAMPLE OF CONCISE METHOD OF REPORTING THE RESULTS OF SOIL TESTS ON TYPICAL SAMPLES

REFERENCE	A.	B.	C.	D.	E.
TEST INFORMATION	TOPSOIL	CLEAN SAND	SILTY SAND	SANDY CLAY	SILTY CLAY
No. of samples tested	2	3	4	3	3
Particle size distribution					
Passing No. 7 B.S. sieve†	100	95-100	92-100	98-100	98-100
Passing No. 25 B.S. sieve	76-78	68-90	64-87	72-89	70-98
Passing No. 72 B.S. sieve	58-59	35-61	40-56	47-65	59-95
Passing No. 200 B.S. sieve	40-42	10-41	19-38	22-50	55-69
Finer than 0.02 mm.	29-31	—	12-38	14-38	42-50
Finer than 0.002 mm.	11-21	—	9-18	10-27	29-45
Gravel: (> 2 mm.)	0	0-5	0-8	0-2	0-2
Sand: (2-0.06 mm.)	58-60	59-87	55-90	49-78	31-43
Silt: (0.06-0.002 mm.)	21-29	10-41	10-20	13-23	10-40
Clay: (<0.002 mm.)	11-21	nil	9-18	10-27	29-45
Soluble in H <sub>2</sub> O <sub>2</sub> (organic matter) (%)	0-8	0	0	0	0
Soluble in HCl (carbonates) (%)	0-4	0-11	2-13	8-19	3-8
Moisture content (above water-table) (%)	13-56	8-15	16-24	21-48	34-55
Liquid limit	36	22*	19*	22-32	46-55
Plastic limit	27	—*	13*	12-17	21-25
Plasticity index	9	—*	4*	10-16	25-34
Soil classification (Table 4)	ML	SF	SF	CL	CH

\* In some samples the soil contained too much sand to permit test results to be obtained.

† For the purpose of soil testing the aperture sizes of the No. 7 and No. 200 B.S. sieves are assumed to be 2 mm. and 0.06 mm. respectively.

of reproduction makes it necessary in this diagram to show only a very short section of profile but in other respects the drawing is complete.

### **Preparation of Report**

It is frequently necessary to present the information obtained in the form of a report, the nature of which depends very much upon circumstances. Reference here will therefore be confined to essential features. The report should begin with a general description of the topography of the site and of the soils encountered with reference to relevant geological information. A plan of the site, on a scale of 6 in. to 1 mile, should be included to indicate the general disposition of the proposed works in relation to the borings taken. As already indicated, the principal information obtained may be presented either on a single drawing which may ultimately serve as a contract drawing or on a number of separate sheets. Salient features of the diagrams should receive detailed mention.

The ground-water investigation (if any) should be described, although the practical inferences will have been embodied on the contract drawings. Reference should be made, if necessary, to the results of special investigations. A summary of the principal recommendations should be given at the head of the report and should cover as far as possible all the appropriate items of Table 1. Unless included in the drawings, the results of identification tests can be given conveniently in tabular form at the end of the report, as indicated in Table 9.

## **VIII. SUMMARY**

The purpose of a soil survey is the exploration of soil and ground-water conditions along the line of a proposed road. Soils occurring in various strata below the surface of the ground are located by sinking borings usually with hand augers. The water-table is determined by allowing water in the boreholes to reach equilibrium. The procedure for making a soil survey is described, and examples of its use are quoted. Details are given of the personnel and equipment required for a survey, and reference is made to tests necessary to identify and classify soils and also to tests to be made in connexion with such problems as the stability and settlement of foundations. Seismic and electrical resistivity methods that have been intensively used in the U.S.A. are described. These are useful where it is necessary to determine rapidly depths of solid rock or water-table.

## APPENDIX A

### LIST OF EQUIPMENT REQUIRED FOR SOIL SURVEYS\*

#### *For Setting out*

A theodolite (can often be omitted)  
1 level (preferably a quickset type)  
1 levelling staff  
1 level book  
1 100-ft steel tape, or 1 100-ft chain and 1 50-ft cloth tape  
12 surveying arrows with pieces of bright cloth tied on as markers  
1 sledge hammer (7-10 lb.)  
6 ranging rods  
1 axe  
1 sickle  
Supply of pegs, painted white at the top

#### *For Boring*

2 or 3 4-in. or 5-in. post-hole augers  
1 2-in. twist auger (A.A.S.H.O. type)<sup>(6)</sup>  
1 crowbar, capable of being connected with the auger extensions  
4 or 6 stillson wrenches (for fitting extensions to augers)  
3 spatulas  
2 spades (for clayey ground)  
2 shovels (for sandy ground)  
2 picks  
Sufficient 3-ft extensions for 2 augers to work at maximum depth  
Supply of sample tins numbered and greased (including tins for large samples)  
Supply of boring record sheets

#### *General*

Boxes about 15-in. cube to carry sample tins  
Sacks (about 3)  
String and rope  
Rags  
Tin of vaseline (for greasing tins and extension joints)  
Bottle of HCl for identifying limestones  
Packing materials  
Pencils  
Chinagraph pencils  
Notebooks  
Squared paper for plotting profiles while on the site  
Set squares  
Scales  
Camera (if large test pits are to be dug)

\* Equipment necessary depends on site conditions and frequently some of the items listed can be omitted.

## APPENDIX B

### SOIL CLASSIFICATION FOR ROAD CONSTRUCTION

#### Objects of Classification

The purpose of soil classification is to provide an accepted and systematic method of describing the various types of soil found in site exploration, which conveys concisely all the essential information.

This procedure has for its objects:—

- (1) To eliminate as far as practicable irrelevant differences in the description of a soil arising from personal idiosyncracies.
- (2) To emphasize the essential engineering characteristics of the soil.
- (3) To assist engineers in appreciating quickly the details of boring records.
- (4) To record the soil data in such a form that published recommendations on design and construction can be readily applied.
- (5) To enable the data in such records to be subsequently applied in the design of other works.

The numerous factors that influence the type of soil make it necessary to sacrifice completeness of description to simplicity. Information given by the type of soil may therefore need to be supplemented by more detailed investigations.

Methods of classification of soil for engineering purposes are in general based on particle size. Gravels, sands, silts and clays constitute the basic divisions of soil types. The first two—the coarse-grained soils—are sometimes referred to as “non-cohesive” and the last two as “cohesive” soils. In addition, peat forms a major division by itself, and it is also desirable to distinguish organic silts and clays from ordinary inorganic soils.

#### Soil Classification for Roads

In classifying soils for use in road construction, the foregoing basic classification requires amplification by subdivision of the main divisions. This is conveniently done in the soil classification scheme used by the U.S. Corps of Engineers,<sup>(2)</sup> which is due to A. Casagrande. In this classification, which is outlined in Table 3 (p. 12), the symbols designating the soil type are immediately indicative of the nature of the soil. Thus gravelly and sandy soils are denoted by the prefixes G and S, silty and clay soils by the prefixes M and C, whilst the prefix O refers to organic silts and clays.

Each of the two divisions of coarse-grained soils is further subdivided into four types, denoted by the following suffixes:—

- |  |    |    |    |    |    |          |
|--|----|----|----|----|----|----------|
| 1. Well graded, fairly clean material              | .. | .. | .. | .. | .. | Suffix W |
| 2. Well graded material with excellent clay binder | .. | .. | .. | .. | .. | ” C      |
| 3. Poorly graded, fairly clean material            | .. | .. | .. | .. | .. | ” P      |
| 4. Material containing an excess of fines          | .. | .. | .. | .. | .. | ” F      |

Well graded soils contain materials of all sizes, but with a predominance of the large sizes, and a poorly graded soil is one with a predominance of a single size. Materials containing an excess of fines include, for example, gravels with an excess of sand and silt.

The fine-grained soils, including the organic clays, are classified on a different basis and each of the three divisions is further divided into two groups of high and low compressibility denoted by the suffixes H and L respectively.

Highly compressible clays are those which, owing to the presence of certain constituents (mica or diatoms) or to the fineness of grain and high relative moisture content, have a relatively loose grain structure and can be considerably compressed under load. The classification of the fine-grained soils is made on the basis of the index tests (liquid and plastic limits) from the chart given in Fig. 8.

An older soil classification scheme is that of the U.S. Public Roads Administration, <sup>(7)</sup> originally proposed in 1929, in which the soil is classified on the basis of grain size and index tests into eight main groups, designated A-1 to A-8 respectively. In its practical outcome the scheme is very similar to that given in Table 3 and the following equivalents may be noted:—

U.S. Public Roads Administration Classification	U.S. Corps of Engineers' Classification (Table 3)
A-1	GC, SC
A-2	GF, SF
A-3	GW, GP, SW, SP
A-4 and A-5	ML, MH
A-6	CL, OL
A-7	CH, OH
A-8	Pt

The U.S. Public Roads Administration classification makes use, in addition to the liquid and plastic limit tests, of the shrinkage limit test which distinguishes elastic micaceous clays and clays containing diatomaceous particles from ordinary plastic clays. So far as Great Britain is concerned, however, clays of this type appear to be rare.

The scheme given in Table 3 has the following advantages over the Public Roads Administration classification:—

1. The classification has a more strictly logical basis and is more readily followed and applied by non-specialists.
2. The designation of the soil type is immediately indicative of its nature.
3. The classification is more detailed (15 soil types are given in place of 8), but the amount of testing required is less.
4. Classification of a given soil by either method will result in similar inferences being drawn, but the larger number of soil groups obtained by the U.S. Corps of Engineers' method enables somewhat greater precision to be achieved.
5. Greater use is made of characteristics that can be inferred by visual and manual examination.

In adopting the U.S. Corps of Engineers' classification, it is recognized that experience in the use of soil classification in this country is limited and that some modifications may be found necessary as experience accumulates.

### Field Identification

Most coarse-grained soils are easy to identify by inspection. Clean gravel is readily identified from the size of its constituent particles. Coarse and medium sands are also readily identifiable by visual inspection but very fine sands are sometimes mistaken for silts. To assist identification in cases of doubt, samples should be dried. Dried samples exhibit no cohesion and the grain size can be inferred to some extent from the gritty feel of the material.

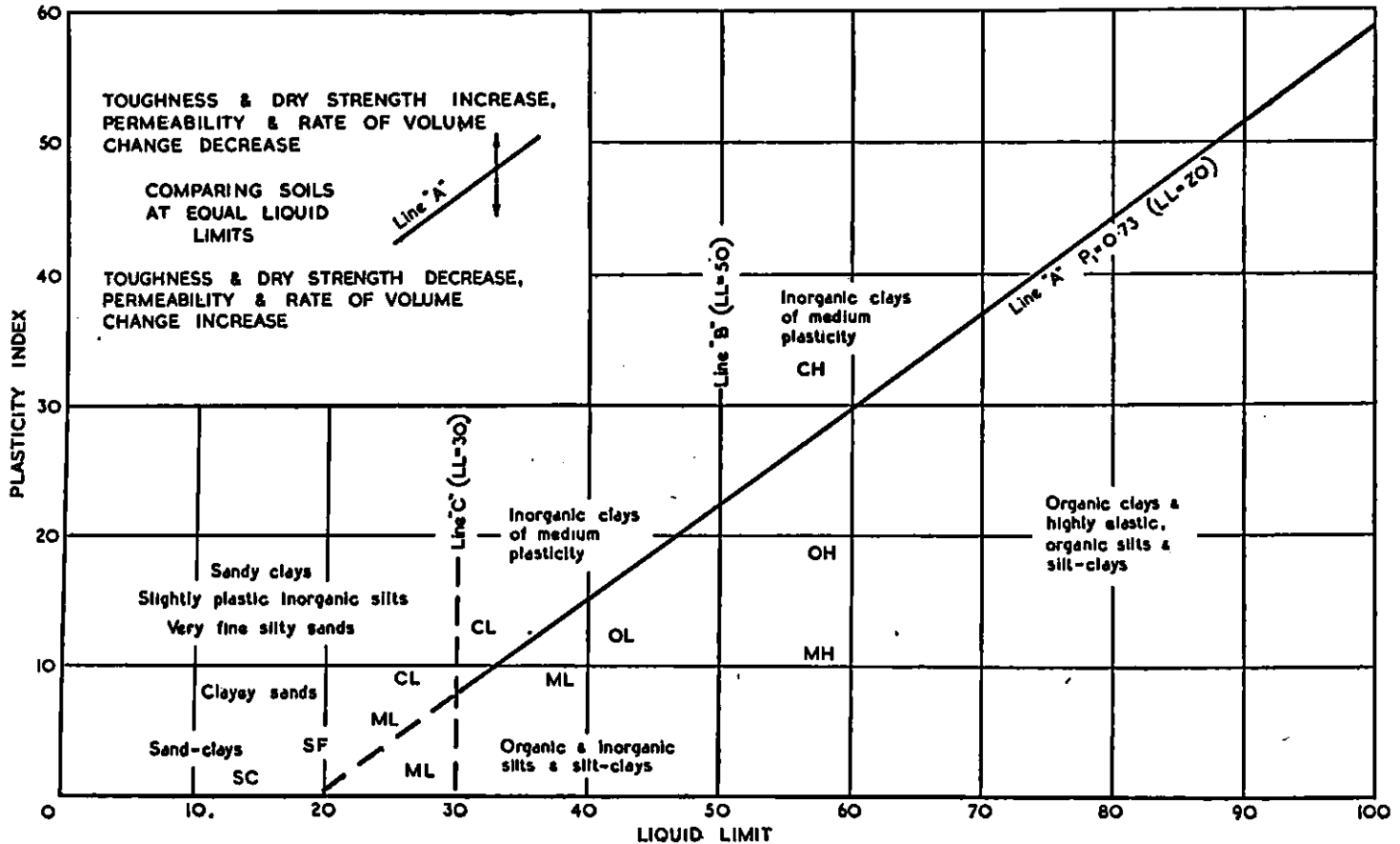


FIG. 8. PLASTICITY CHART FOR SOIL CLASSIFICATION

Small quantities of silty or clayey material in gravels and sands can be identified by rubbing moist soil against the palm of the hand and then wiping off all grains of visible size. The remaining material is then examined. Another method is to shake the material up with water in a glass jar and to examine the layers of sediment.

Various methods are also available for the examination of cohesive soils. It is first necessary to distinguish silts from finer-grained soils. This may be done by preparing a pat of wet soil, adding water if necessary. In the case of inorganic silts, shaking the pat in the hand will cause moisture to appear at the surface, but squeezing causes the surface to appear to dry.

It is also useful to examine samples after drying. Typical inorganic silts show little or no cohesion when dry, but have a smooth feel in contrast to the grittiness of fine sand, for which they are sometimes mistaken.

It is also possible to obtain indications as to the fineness of cohesive soils by rubbing a film of wet soil between finger and thumb. Clays, and especially very fine-grained clays, have a characteristically greasy feel. Silts feel harsher to the touch. Another method of distinguishing between silt and clay soils is to dry a pat on a tin lid over a fire. Clays shrink much more than silts under such conditions and consequently show much wider cracks.

Peats and peaty soils can be readily identified from their dark chocolate colour and the presence of fibrous organic material. Organic silts and clays, however, present more difficulty, as the organic material is frequently finely divided and not visible to the naked eye. In many cases such soils possess a characteristic odour which in doubtful cases can be intensified by rapid heating. Such materials are not infrequently blackish in colour, but colour is by no means a sure guide. When in the plastic range they also feel more spongy than corresponding inorganic clays.

### **Laboratory Identification**

Soil classification tests are required when it is desired to distinguish between types of soils that cannot be readily distinguished visually or manually. The tests are of two types, namely:—

- (1) Particle size distribution (mechanical analysis), a combination of sieving and sedimentation (applicable to soils covering the entire range of particle size).
- (2) Index tests (confined to that portion of cohesive soils passing a No 36 B.S. sieve), by means of which the type of soil is inferred from the moisture content at various standard consistences.

These tests have been standardized by the British Standards Institution<sup>(6)</sup> and in the United States by the American Association of State Highway Officials and by the American Society for Testing Materials. No attempt will therefore be made to describe them in detail.

The notion of particle size distribution (mechanical analysis) is a fairly straightforward one, calling for little general comment. The results are expressed on a graph indicating the cumulative percentage passing any given size. It is also possible to classify into grades defined as "sand," "silt" and "clay" as indicated in Fig. 7 and Table 9 (p. 23).

The identification of the coarse-grained soils is made from the results of sieve analysis. For this purpose it is desirable to have a complete particle size distribution curve, and to study the shape of curve.

Index tests, as already mentioned, can be made only on fine-grained soils. Briefly, the "liquid limit" of a soil is that moisture content at which the soil is sufficiently fluid to flow a specified amount when lightly jarred 25 times on a standard apparatus.



It marks the transition between the fluid and the plastic conditions. The "plastic limit" is that moisture content at which a thread of soil can be rolled without breaking until it is only  $\frac{1}{8}$  in. in diameter. It marks the lower limit of moisture content at which the soil can still be regarded as plastic.

The difference between the liquid and plastic limits, which is termed the "plasticity index" of the soil, indicates the increase of moisture content required for the soil to change from a firm to a very soft condition. It is found to increase directly with the percentage of the "clay" portion of the soil (particles smaller than 0.002 mm.) but for a given "clay" content the plasticity index depends upon the nature of the clay minerals and is greatly affected by the presence of organic or micaceous particles.

The liquid and plastic limits are therefore interpreted by plotting the liquid limit against the plasticity index (defined as the difference between the liquid and plastic limits). The soil is then classified according to the zone in which the point lies, using the diagram given in Fig. 8. Typical inorganic clay will generally be above line A. A liquid limit of 50 (line B) is taken as the dividing line between clays of relatively low compressibility (CL) and clays of relatively high compressibility (CH). Silty and fine sandy soils having some plasticity (ML) and organic silts (OL) will generally lie below line A and to the left of line B. Organic clays (OH) and micaceous or diatomaceous silty soils (MH) will be below line A but to the right of line B.

The limits of inorganic silty soils (ML and MH) and organic silty and clay soils (OL, OH) when plotted in Fig. 8 overlap to such an extent that no line of demarcation can be drawn. Visual and manual inspection, however, serve to distinguish between the two types. The liquid and plastic limits of organic clays as determined from oven-dried samples are also much smaller than the limits of the same soil that has not been oven-dried. Oven-drying of an inorganic soil will result only in small changes in the index properties of the soil.

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