

ENGINEERING STANDARD
FOR
SOIL ENGINEERING

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1. SCOPE

This Engineering Standard sets out general rules, procedures and guidelines for planning subsurface explorations, control and supervision of works in such a way to obtain reliable information about engineering properties of soil and rock strata, to produce an economic and safe design.

It also includes the procedures for obtaining essential information about soil properties which are necessary for design of special foundations like piling etc. But it does not include the procedures related to geotechnical design such as grouting, soil improvement etc. Procedures adapted in this Standard are mainly intended to assist those individuals involved in engineering services for petroleum industry projects; as a competent specialist firm in the field of geotechnics and soil mechanics will be engaged to implement and perform the relevant services. Not included in this Standard are:

- Details of laboratory tests, for which adequate references are made to pertinent well known standards.
- Planning and investigation programs for construction materials and quarries.
- Contractual procedures to engage geotechnical contractor or consultant.
- Subsurface investigation procedures pertaining to deep seas and oceans.

2. REFERENCES

In this Standard the following standards and publications are referred to and to the extent specified, form a part of this Standard.

BSI (BRITISH STANDARDS INSTITUTION)

BS 1377: Parts 1 to 9: 1990	"Methods of Tests for Soils for Civil Engineering Purposes"
BS 1881: 1988 Part 124	"Methods for Analysis of Hardened Concrete"
BS 5930: 1981	"Code of Practice for Site Investigations"
BS 6031: 1981	"Code of Practice for Earthworks"
BS 8004: 1986	"Code of Practice for Foundations"

ASTM (AMERICAN SOCIETY FOR TESTING AND MATERIALS)

Vol. 04.08 Soils and Rocks;	"Building Stones; Geotextiles"
ASTM D 653-88	ASTM D 3148-86
ASTM D 341-84	ASTM D 4221-83a
ASTM D 1883-87	ASTM D 4254-83
ASTM D 2167-84	ASTM D 4406-84
ASTM D 2434-74	ASTM D 4525-85
ASTM D 2664-86	ASTM D 4644-87
ASTM D 2850-87	ASTM D 4647-87
ASTM D 2922-81	ASTM D 4767-88
	ASTM D 4829-88

AASHTO (AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS)

Designation M-145-Soil Classification System: 1982

DIN (DEUTSCHES INSTITUTE FOR NORMUNG)

DIN 52104 "Testing of Natural Stone Freeze-Thaw Cyclic Part 1 & 2 Test": 1982

IPS (IRANIAN PETROLEUM STANDARDS)

IPS-C-CE-112 "Earth Works"
IPS-E-CE-140 "Retaining Walls"

ISRM (INTERNATIONAL SOCIETY FOR ROCK MECHANICS)

"Rock Characterization Testing and Monitoring, ISRM Suggested Methods Edited by E.T. Brown 1981"

3. DEFINITIONS AND TERMINOLOGY

Soil and rock mechanics terms are defined in ASTM D653-88, definition of terms related to soil testing is given in BS 1377: Part 1:1990. In addition, the definition of terms used in this Engineering Standard are given hereunder:-

- Dispersive Clays

Clay soils that deflocculate in still water and erode when exposed to a low-velocity flow of water. A clay-pore water system that has a high concentration of sodium ions tends to have high dispersivity.

- Gouge

Soft, pulverized mixture of rock and mineral material found along shear (fault) zones.

- Liquefaction

Loss of strength occurring in saturated cohesionless soil exposed to shock or vibrations when the soil particles momentarily lose contact. The material then behaves as a fluid.

- Relative Density

Term applied to sand deposits to indicate a relative state of compaction compared to the loosest and most dense conditions possible.

- Rock Quality Designation (RQD) Index

Ratio of sum of lengths of core pieces larger than 100 mm to the total core run length percentage wise.

4. UNITS

This Standard is based on International System of Units (SI), except where otherwise specified.

5. GENERAL ASPECTS AND PLANNING OF GROUND INVESTIGATIONS**5.1 Primary Objects of Ground Investigations**

The proper design of civil engineering structures requires adequate knowledge of subsurface conditions at the sites of structures. The objects of ground investigations are to obtain reliable information about subsurface conditions to produce an economic and safe design.

The types of subsurface information required for design include, but are not limited to, the following:

- A real extent, depth, and thickness of each identifiable soil stratum, within a limited depth dependent on the size and nature of the structure.
- Depth to top of rock and the character of the rock.
- Location of groundwater and the presence and magnitude of artesian pressures.
- Engineering properties of the soil and/or rock in situ such as permeability, compressibility, and shear strength.

These information will further be completed by the results of laboratory tests on soil and rock samples so that it will be possible to assess such considerations as bearing capacity and settlement of foundations, stability of slopes in embankments and cuttings, earth pressures on supporting structures and the effect of any chemically aggressive ground conditions.

5.2 Collection and Review of Existing Ground Investigation Data

Before commencing ground investigation, all relevant information should be collected, reviewed and considered together in order to obtain a preliminary conception of the ground conditions and the engineering problems that may be involved. These information include but are not limited to the following:

- topographical maps and aerial photos;
- geological mapping, see 5.3;
- geophysical investigation, see 5.4;
- earlier reports on ground investigations;
- core boxes, logsheets, test pits, trenches, available quarries, etc.;
- information about ground water;
- all other relevant information available.

5.3 Geological Mapping

In cases where the geology is relatively straightforward and the engineering problems are not complex sufficient geological information might have been provided from the existing documents and maps published by geological Survey of Iran (GSI), subject to confirmation by local field work performed by a recognized geological firm.

Where these are insufficiently detailed for any investigation in question it may be necessary to carry out additional geological mapping. For more detailed information refer to Clause 9 of BS 5930: 1981.

5.4 Geophysical Investigations

Geophysical explorations supply information for bedrock profiling, define the limits of granular borrow areas and large organic deposits, and yield a general definition of subsurface conditions including the depth to groundwater. For more detailed information refer to Clause 33 of BS 5930: 1981.

5.5 The Effect of Ground Conditions on the Selection of Methods for Ground Investigation

Ground conditions are determining factors on selection of methods for ground investigation.

Table 1 gives a general guidance for selection of ground investigation techniques depending on ground conditions. For more detailed information refer to Clauses 12.2 to 12.10 of BS 5930: 1981.

5.6 Extent of the Ground Investigation

The extent of the ground investigation is determined by the character and variability of the ground and ground water, the type of project, and the amount of existing information. It is important that the general character and variability of the ground be established before deciding on the basic principles of the design of the works.

For more detailed information about extent of ground investigation refer to Clauses 10.2 to 10.7 of BS 5930, 1981.

TABLE 1 - GENERAL GUIDANCE FOR SELECTION OF GROUND INVESTIGATION METHODS ¹⁾

Method	Geology	Technique	Application in Civil Engineering
Boreholes	Clays, silty clays and peats.	Hand or power auger (single blade or continuous spiral).	Shallow reconnaissance. power operation fast. Limited to non-caving ground except for bellow continuous augers.
	As above, also silts, sands and gravels.	wash boring	Inexpensive equipment. Unsatisfactory for precise investigation.
	As above with occasional cobbles and boulders also decomposed rocks.	Percussion cable tool boring with casing	Standard for soil exploration. Water added below water table to stabilises base of boring. Clean out with auger before core sampling cohesive soils.
	As above and up to moderately weak rocks.	Pneumatic chisel rotary, tricone bit.	Fast, unsatisfactory for precise investigation. Limited to location of hard ground (check for presence of boulders).
	All rocks	Rotary core drilling usually with water flush but mud or air can be used.	Standard for rock exploration. Reliability depends on correct selection of core barrels bits and flush fluid, water table observations difficult.
Pits	Clays and peats	Excavation by hand, power grabs, or augers with support as required.	Direct access gives best opportunity for detailed studies of ground in situ. Presence of stratification and thin clay layers. Depth usually limited by problems of ground water lowering.
	Silts, sands and gravels.	Close timbering, ground water lowering essential below water table.	
	Weak to moderately weak rocks	Hand excavation power grabs or augers with supports as required.	Detailed study of local variations bedding, fissures and joints. Depth usually limited as above.
Trenches	Clays, silts, peats, and sand and gravel above water table.	Excavation usually by machine such as hydraulic powered excavators. Support as required.	Direct access with extended inspection of lateral variations. Exploration of borrow areas.
Adits	All soils and rocks.	Appropriate forms of hand excavation and timbering as for tunnelling.	Established method for detailed exploration of dam abutments and underground structures. Sub-surface exploration of steeply inclined rock strata.

1) Civil Engineering Reference Book, Edited by L.S. Blake London. Butterworth, 1991.

6. SUBSURFACE EXPLORATION

6.1 Excavations and Boreholes

Different methods and procedures are available for subsurface exploration depending on the ground conditions and equipments available, some of the main ones are listed below:

- Shallow trial pits
- Deep trial pits and shafts
- Adits

- Hand auger boring
- Light cable percussion boring
- Mechanical augers
- Rotary drilling
- Wash boring

For detailed information about each of the above mentioned methods refer to Clause 17 of the BS 5930: 1981.

6.2 Sampling

6.2.1 General

Sufficient samples of the right size and type should be taken in order to fully represent the ground being investigated. Samples may be divided into two broad categories i.e., "disturbed" and "undisturbed":-

- A disturbed sample may be defined as one which contains all of the constituents of the in-situ material in proper proportions but which has suffered sufficient disturbance to its structure so that the results of laboratory tests to determine engineering properties such as compressibility, shear strength and permeability would not be properly representative of the material in-situ.
- An undisturbed sample is one obtained with samplers and sampling techniques designed to preserve as closely as possible the natural structure of the material. These samples are suitable for shear, consolidation, and permeability tests of foundation materials.

For definition of sample quality and mass of soil sample required for various laboratory tests refer to Clause 19.2 of BS 5930: 1981.

6.2.2 Sampling techniques

Different types of samplers are available depending on the quality of sample and character of the ground. Some of the main ones are listed below:

- thin-walled open-tube sample,
- split-barrel standard penetration sample,
- thin-walled stationary piston,
- continuous soil,
- rotary core.

For detailed description of the soil sampling techniques refer to Clauses 19.4 to 19.9 of BS 5930: 1981.

6.3 Probing and Penetration Testing

The term "Probing" (synonymous to sounding) represents that method of exploration in which a probe is made to penetrate overburden deposits by means of some kind of loading and record of the resistance to penetration is obtained.

Two distinct types of probe have been developed: one where the probe is driven into the soil by means of some form of hammer blow; the other where the probe is forced into the soil by a static load. For more detailed information refer to Clause 23 of BS 5930: 1981.

6.4 Ground Water

The ground water pressure may vary with time owing to seasonal, tidal, or other causes, and it may be necessary to take measurements over an extended period of time in order that such variations may be investigated.

6.4.1 Methods of determining ground water pressures and level

The selection of a suitable method will largely be determined by the response time.

The time required for a measuring device to indicate the true ground water pressure is known as the response time and depends on the quantity of water required to operate the device, and on the permeability of the ground.

The simplest method of determining the ground water level is by observations in a borehole or excavation that is open or fitted by a perforated tube.

For details of methods and description of various devices refer to Clauses 20.2.2 to 20.2.8 of BS 5930: 1981.

6.4.2 Ground water samples

Care should be taken to ensure that the samples are representative of the water-bearing stratum and that they have not been contaminated or diluted by surface water or water used for boring.

Water samples may deteriorate rapidly and should therefore be tested as soon as possible after sampling.

7. IN-SITU TESTS

7.1 General

In addition to tests which should be performed on samples taken from soil strata and carried to laboratory (see clause 8) it is usually necessary to determine the engineering properties of various strata in-situ.

In-situ tests may be divided into two main categories:

- Tests in boreholes (see 7.2).
- Field tests (see 7.4).

7.2 Tests in Boreholes

Commonly conducted in-situ tests in boreholes may be categorized as follows:

- Standard penetration test (SPT)
- Vane test
- Permeability test
- Packer test
- Plate tests
- Pressuremeter tests

For additional information about test procedures refer to BS 1377: 1990.

7.2.1 Frequency of sampling and testing in boreholes

The frequency of sampling and testing in a borehole depends on the information that is already available about the ground conditions and the technical objectives of the investigation.

In general, the field work will cover three aspects, each of which may require a different sampling and testing programme and may also require phasing of operations. These aspects are as follows:

- a)** The determination of the character and structure of all the strata.
- b)** The determination of the properties of the various strata whose locations have been determined in (a), using techniques for sampling and testing that are normally available in routine ground investigations.

- c) The use of special techniques of sampling and testing in strata where the normally available techniques have given, or may be expected to give, unsatisfactory results.

Table 2 gives a summary about frequency of sampling and testing in boreholes. For detailed information refer to Clauses 22.2 to 22.5 of BS 5930: 1981.

TABLE 2 - FREQUENCY OF SAMPLING AND TESTING IN BOREHOLES ¹⁾

MAIN ASPECTS OF INVESTIGATION	TYPE OF GROUND TO BE INVESTIGATED		
	SAND & GRAVEL	COHESIVE SOILS	ROCK
a) Determination of the character and structure of all strata.	Disturbed samples to be taken from drill tools together with split barrel. Standard penetration tests at about 1 m intervals.	Consecutive drive samples to be taken using 100 mm diameter sampler.	Continuous rotary core sampling should be undertaken and in addition disturbed samples should be taken.
b) Determination of the properties of various strata	At the top of each new stratum and thereafter at 1 m intervals of depth a SPT test should be carried out.	At the top of each new stratum and thereafter at 1.5 m intervals of depth a 100 mm sample should be obtained.	Continuous rotary core sampling should be used.

1) Based on information presented in clause 22.2 to 22.5 of BS 5930:1981.

7.3 Field Tests

The material tested in-situ by a field test is analogous to a laboratory sample, and can be considered as a 'field sample'. The selection and preparation of samples in the field is subject to the same requirements as for laboratory samples, to ensure that they are representative.

Field tests described in this clause generally exclude the tests in boreholes described in Clause 7.2

Commonly conducted field tests may be categorized as follows:

- Pumping tests
- Field density
- In-situ stress measurement
- Bearing tests
- In-situ shear tests
- Large scale field trials

For detailed information refer to Clauses 25 to 31 of BS 5930: 1981.

8. LABORATORY TESTS ON SAMPLES

8.1 General

The samples obtained from the exploration should be tested in a laboratory to assist in the identification of strata and to determine their relevant engineering properties.

The aims of laboratory testing of samples of soil and rock may be summarized as follows:

- a) to identify and classify the samples with a view to making use of past experience with materials of similar geological age, origin and condition;
- b) to obtain soil and rock parameters relevant to the technical objectives of the investigation.

The analysis and use of the laboratory test results are not covered by this Engineering Standard and reference should be made to the appropriate design manuals, textbooks and standards.

8.2 Tests on Soil

The common laboratory tests on soil are given in Table 3, together with references giving details of the methods. In ground investigation, laboratory tests should be considered as supplementary to field tests. In many cases a field test will give more realistic results because of reduced problems of sample disturbance.

8.3 Tests on Rock

Laboratory tests on rock have not reached the same degree of standardization as those on soil; some of the more frequently performed laboratory tests are listed in Table 4.

TABLE 3 - COMMON LABORATORY TESTS ON SOIL

CATEGORY OF TEST	NAME OF TEST	REFERENCE STANDARDS WHERE DETAILS CAN BE FOUND	REMARKS
Soil classification tests	Moisture content	BS 1377: part 2: 1990 Clause 2	Frequently carried out as a part of other soil tests. Read in conjunction with liquid and plastic limits, gives an indication of shear strength of cohesive soil.
	Liquid and plastic limits (Atter berg limits)	BS 1377: part 2: 1990 Clauses 4 & 5	Used to classify cohesive soil and as an aid to classifying the fine fraction of mixed soil.
	Cone penetration limit	BS 1377: part 2: 1990 Clause 4	An alternative method of determining the liquid limit of cohesive soil
	Shrinkage limit	BS 1377: part 2: 1990 Clause 6	The test enables the shrinkage limit of clays to be determined.
	Particle density (specific gravity)	BS 1377: part 2: 1990 Clause 8	Used in conjunction with other tests, such as sedimentation and consolidation. Values commonly range between 2.55 and 2.75, and a more accurate value is required for air voids determination.
	Particle size distribution: a) sieving b) sedimentation	BS 1377: part 2: 1990 Clause 9	Sieving methods give the grading of soil coarser than silt. The proportion passing the finest sieve represents the combined silt and clay can only be determined by means of sedimentation tests.
Soil chemical test	Organic matter	BS 1377: part 3: 1990 Clause 3	Detects the presence of organic matter able to interfere with the hydration of Portland cement in soil: cement pastes.
	Sulphate content of soil and ground water	BS 1377: part 3: 1990 Clause 5	The tests assess the aggressiveness of soil or ground water to buried concrete. (See remarks on test for pH value.)
	pH value	BS 1377: part 3: 1990 Clause 9	To measure the acidity or water. It is usually carried out in conjunction with sulphate content tests. This test and the one above should be performed as soon as possible after the samples have been taken.
	Carbonate content	BS 1377: part 3: 1990	Useful for estimating the chalk content of soils.
	Chloride content	BS 1377: part 3: 1990	The test is used for determination of chloride salt content of soils.
Soil compaction related tests	Dry density/moisture content (proctor test)	BS 1377: part 4: 1990 Clause 3	This test indicates the degree of compaction that can be achieved at different moisture contents.
	Relative density of cohesionless soil	BS 1377: part 4: 1990 Clause 4 ASTM: D4254-83	For cohesionless soils where the proctor curve concept is not applicable the compaction criterion normally used is relative density.

(to be continued)

TABLE 3 - (continued)

CATEGORY OF TEST	NAME OF TEST	REFERENCE STANDARDS WHERE DETAILS CAN BE FOUND	REMARKS
Soil strength tests	Triaxial compression: a) Unconsolidated undrained (UU) b) Consolidated undrained (CU) c) Consolidated drained (CD)	ASTM: D2850-87 ASTM: D4767-88 BS 1377: part 8 1990 Clause 8	There are three conditions under which the test may be performed underdrained, drained and consolidated undrained. These conditions are used to evaluate the effect of pore water pressure.
	Unconfined compressive strength	BS 1377: part 7: 1990 Clause 7	This simple test is a rapid substitute for the undrained triaxial test, although it is suitable only for saturated non-fissured cohesive soil.
	Laboratory vane shear	BS 1377: part 7: 1990 Clause 3	For soft clay, an alternative to undrained triaxial test where the preparation of the specimen sometimes has an adverse effect on the measured strength of the soil.
	Direct shear box	BS 1377: part 7: 1990 Clause 4	one of the advantages of this test is that specimens of non-cohesive soil can be more readily prepared than in the triaxial test.
Soil deformation tests	Consolidation: a) one-dimensional consolidation properties (oedo meter test)	BS 1377: part 5: 1990 Clause 3	These tests yield soil parameters from which the amount and time scale of settlements can be calculated. The simple oedometer test is the one in general use and although reasonable assessment of the test, estimates of the time scale have been found to be extremely inaccurate with certain types of soil. This is particularly true of clay soil containing layers and partings of silt and sand, where the horizontal permeability is much greater than the vertical.
	b) triaxial consolidation	BS 1377: part 6: 1990	
	Elastic modulus	BS 1377: part 7: 1990	Values of the elastic modulus of soil can be obtained from the stress/strain curve from undrained triaxial compression with the cell pressure equal to the overburden pressure. Experience, however, shows that the results so obtained are often very much lower than the actual values. It is now generally considered that the plate bearing test of back analysis of existing structures yield more reliable results.
Soil permeability test	Constant head permeability test. Falling head permeability test.	ASTM D2434-74	The constant head test is suited only to soils of permeability roughly within the range 10^{-4} m/s to 10^{-2} m/s. For soils of lower permeability, the falling head test is applicable. For various reasons, laboratory permeability tests often yield results of limited value and in-situ tests are generally thought to yield more reliable data.

(to be continued)

TABLE 3 - (continued)

CATEGORY OF TEST	NAME OF TEST	REFERENCE STANDARDS WHERE DETAILS CAN BE FOUND	REMARKS
Pavement design tests	California bearing ratio (CBR)	ASTM D1883-87	This is an empirical test used in conjunction with the design of flexible pavements. The test can be made either in situ, or in the laboratory.
Soil corrosivity tests	Redox potential	BS 1377: part 3: 1990 Clause 11	The test provides a means of assessing whether a soil is conducive to the activity of sulphate-reducing bacteria which cause corrosion of metals.
Dynamic soil tests	Cyclic load triaxial test cyclic simple shear test	No standard yet available	These tests are used to study the liquefaction characteristics of saturated sands under cyclic load conditions.
Dispersibility test	Dispersive clay soils: a) pinhole test b) double hydrometer test	ASTM D4647-87 ASTM D4221-83a	Dispersive soils cannot be identified by means of conventional soil classification tests, the described tests enable them to be recognized.
Expansion index test	Expansion index test	ASTM D4829-88	The test is used to measure the expansion index of soils

TABLE 4 - COMMON LABROATORY TESTS ON ROCK

CATEGORY OF TEST	NAME OF TEST	REFERENCE STANDARDS WHERE DETAILS CAN BE FOUND	REMARKS
Rock classification tests	Bulk density moisture content porosity	ISRM* : 1981 part 2	These tests give some indication of properties such as compressive strength, modulus of elasticity, seismic wave velocity resistance to weathering and degree of weathering.
	Thin section	ISRM : 1981 part 2	Useful to identity rock type, degree of weathering and gives an indication of stress history.
	Slake-durability	ASTM D4644-82	Useful quality index for testing clay-bearing rocks proposed for construction materials.
	Carbonate content	BS 1881: 1988 part 124	Useful for the identification of chalk, calcereous mudrocks.
	Swelling test	ISRM: 1981 part 2 Clause 3	Gives some indication of moisture sensitivity of rock and possible ranges of induced pressure on tunnel linings.
Dynamic tests	Seismic velocity dynamic modulus		Results may somtimes be useful in extrapolating laboratory and field tests to rock mass behaviour.
Rock strength tests	Uniaxial compression (Brazilian test)	ISRM : 1981 part 2	See remarks on uniaxial compression test.
	Triaxial compression:	ASTM D2664-86	Specimen size limited by strength. It may be possible to in-clude one or more discontinuities in the specimen. Where intact test specimens are tested, upper strength limits are obtained.
	Direct shear box	ISRM : 1981 part 2	Of considerable importance for study of friction on discontinuities. References also cover residual shear atrength. Where joints are filled with gouge,** the properties of the combined gouge joint should be determined under conditions closely simulating those existing in situ.
Rock Deformation tests	Elastic modulus	ASTM D3148-86	Absence of representative discontinuities in the specimen disturbance and unsuitable testing techniques would lead to falsely low values.
	Creep tests: a) Uniaxial b) Triaxial	ASTM D4341-84 ASTM D4406-84	Most meaningful when carried out under multistress conditions.
Rock permeability test	Permeability of rocks by flowing air	ASTM D4525-85	The test determines representative values of the coefficient of permeability of rocks.
Other rock tests	Freeze thaw cyclic test	DIN 52104-1982 part 1 & 2	The test intends to provide information on how a stone behaves when it is subjected to cyclic action of freezing and thawing.
	Los Angeles abrasion test	ISRM : 1981 part 2	The test is used to determine resistance to abrasion of aggregates.

* ISRM = International Society for Rock Mechanics.

** Soft, pulverized mixture of rock and mineral material found along shear (fault) zones.

9. CLASSIFICATION OF SOILS AND ROCKS FOR ENGINEERING PURPOSES

9.1 General

Classification of soils and rocks is an essential factor for effective and clear communication between interested parties in the field of civil engineering.

In this clause different classification systems for soils and rocks are presented.

Among several classification systems introduced by various investigators and organizations, the most universally accepted one for soils, is the Unified Soil Classification System, which was originally developed by Casagrande and adapted by ASTM D-2487-85.

Another soil classification system widely used in the highway construction works, is the AASHTO soil classification system. Both soil classification systems are presented in Tables 6 and 7 respectively in this Engineering Standard.

Although in the field of rock mechanics a standard classification is not yet established. In Clause 9.3 the latest rock classification system under speculation is discussed. In Clause 9.4 Rock Quality Designation (RQD) index is introduced.

9.2 Soil Classification

9.2.1 Unified soil classifications system

In the Unified Soil Classification System, all soils are classified into 15 groups, each group being designated by two letters. These letters are abbreviations of certain soil characteristics as follows:

G-Gravel	O-Organic
S-Sand	W-Well-graded
M-Nonplastic or low-plasticity fines	P-Poorly graded
C-Plastic fines	L-Low liquid limit
Pt-Peat, humus, swamp soils	H-High liquid limit

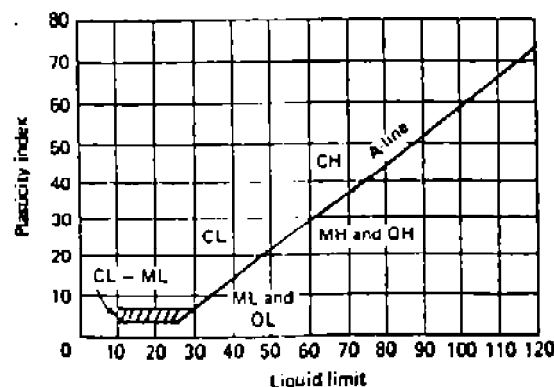
The classification, is further based on the results of laboratory tests of particle-size characteristics, liquid limit, and plasticity index. The essentials of system are given in Table 5. For further detailed information see ASTM D-2487-85.

9.2.2 AASHTO soil classification system

Another system widely used in highway construction works is the AASHTO (American Association of State Highway and Transportation Officials) classification system. In this system classification is based upon results obtained from the laboratory tests of mechanical analyses, liquid limit, and plasticity index. Soil classification can be obtained by using Table 6. For further details refer to AASHTO Designation M-145.

TABLE 5 - UNIFIED SOIL CLASSIFICATION SYSTEM

Major division	Group Symbols	Typical Names	Classification Criteria
Coarse-grained soils More than 50% retained on No. 200 sieve	Gravels	GW Well-graded gravels and gravel-sand mixtures, little or no fines	$C_u = D_{60}/D_{10}$ Greater than 4
		GP Poorly-graded gravels and gravel-sand mixtures, little or no fines	$C_u = \frac{D_{60}^{1/2}}{D_{10} + D_{30}}$ Between 1 and 3
		GM Silty gravels, gravel-sand-silt mixtures	Not meeting both criteria for GW
		GC Clayey gravels, gravel-sand-clay mixtures	Atterberg limits plot below "A" line or plasticity index less than 4
	Sands	SW Well-graded sands and gravelly sands, little or no fines	$C_u = D_{60}/D_{10}$ Greater than 6
		SP Poorly-graded sands and gravelly sands, little or no fines	$C_u = \frac{D_{60}^{1/2}}{D_{10} + D_{30}}$ Between 1 and 3
		SM Silty sands, sand-silt mixtures	Not meeting both criteria for SW
		SC Clayey sands, sand-clay mixtures	Atterberg limits plot below "A" line or plasticity index less than 4
	Sands and Clays	ML Inorganic silts, very fine sands, rock flour, silty or clayey fine sands	Check plasticity chart
		CL Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
		OL Organic silts and organic silty clays of low plasticity	
		MH Inorganic silts, fine sands or silty sands, silty clays or silts, elastic silts	
Fine-grained soils 50% or more passes No. 200 sieve	Sands and Clays	CH Inorganic clays of high plasticity, fat clays	Check plasticity chart
		OH Organic clays of medium to high plasticity	
	Highly organic soils	Pt Peat, muck and other highly organic soils	Fibrous organic matter, will char, burn, or glow



Plasticity chart for the classification of fine-grained soils.
Tests made on fraction finer than No. 40 sieve.

TABLE 6 - AASHTO SOIL CLASSIFICATION SYSTEM

General Classification ^a	Granular Materials (35 percent or less passing No. 200)							Silt-Clay Materials (more than 35 percent passing No. 200)				
Group Classification	A.2		A.3	A.2				A.4	A.5	A.6	A.7	
	A.1.a	A.1.b		A.2.4	A.2.5	A.2.6	A.2.7				A.7.5	A.7.6
Sieve analysis percent passing:												
No. 10	50 max											
No. 40	30 max	50 max	51 min									
No. 200	15 max	25 max	10 max	35 max	35 max	35 max	35 max	33 min	36 min	36 min	36 min	
Characteristics of fraction parsing No. 40:												
Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min	
Plasticity index		6 max	N.P. ^b	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min	
Usual types of significant constituent materials	Stone fragments gravel and sand		Fine sand	Silty or clayey gravel and sand					Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor				
^a Classification procedure: With required test data in mind, proceed from left to right in chart: correct group will be found by process of elimination. The first group from the left consistent with the test data is the correct classification. The A.7 group is subdivided into A.7.5 or A.7.6 depending on the plastic limit For PL < 30, the classification is A.7.6: for PL> 30, A.7.5.												
^b N.P. denotes nonplastic.												

9.3 Rock Classification

As mentioned in Clause 9.1 a standard rock classification system is not yet established by known international organizations. Attempts have been made, however, to introduce a Unified Rock Classification System (URCS) by ASTM STP 984-1988. The URCS consists of four fundamental physical properties: 1) weathering, 2) strength, 3) discontinuities and 4) density. A general assessment of rock performance is then based on a grouping of the four key elements to aid in making engineering judgments. These individual properties are estimated in the field with the use of a hand lens, a 0.5 kg ballpeen hammer, a spring-loaded "fish" scale and a bucket of water. Each property is divided into five ratings which convey uniform meaning to engineering geologists, design engineers, inspectors and all other interested parties.

Tables 8 and 9 represent the basic elements for classification of rocks according to this system. For further detailed information refer to "Rock Classification Systems for Engineering Purposes", ASTM, STP 984, 1988.

TABLE 7 - BASIC ELEMENTS OF THE UNIFIED ROCK CLASSIFICATION SYSTEM

DEGREE OF WEATHERING

REPRESENTATIVE		ALTERED	WEATHERED			
			> GRAVEL SIZE		< SAND SIZE	
Micro Fresh State (MFS) A	Visually Fresh State (VFS) B	Stained State (STS) C	Partly Decomposed State (PDS) D		Completely Decomposed State (CDS) E	
UNIT WEIGHT RELATIVE ABSORPTION		COMPARE TO FRESH STATE	NON- PLASTIC	PLASTIC	NON- PLASTIC	PLASTIC

ESTIMATED STRENGTH

REACTION TO IMPACT OF 0.5 kg BALLPEEN HAMMER				REMOLDING
"Rebounds" (Elastic) (RQ) A	"pits" (Tensional) (PQ) B	"Dents" (Compression) (DQ) C	"Craters" (Shears) (CQ) D	Moldable (Friable) (MQ) E
> 103 Mpa (g)	55-103 Mpa	21-55 Mpa	7-21 Mpa	< 7 Mpa

(1) Strength Estimated by Soil Mechanics Techniques

(2) Approximate Unconfined Compressive Strength

DISCONTINUITIES

VERY LOW PERMEABILITY			MAY TRANSMIT WATER	
Solid (Random Breakage) (SRB) A	Solid (Preferred Breakage) (SPB) B	Solid (Latent Planes of Separation) (LPS) C	Nonintersecting Open Planes (2-D) D	Intersecting Open Planes (3-D) E
			ATTITUDE	INTERLOCK

UNIT WEIGHT

Greater Than 2.55 g/cc A	2.40-2.55 g/cc B	2.25-2.40 g/cc C	2.10-2.25 g/cc D	less Than 2.10 g/cc E
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Note:

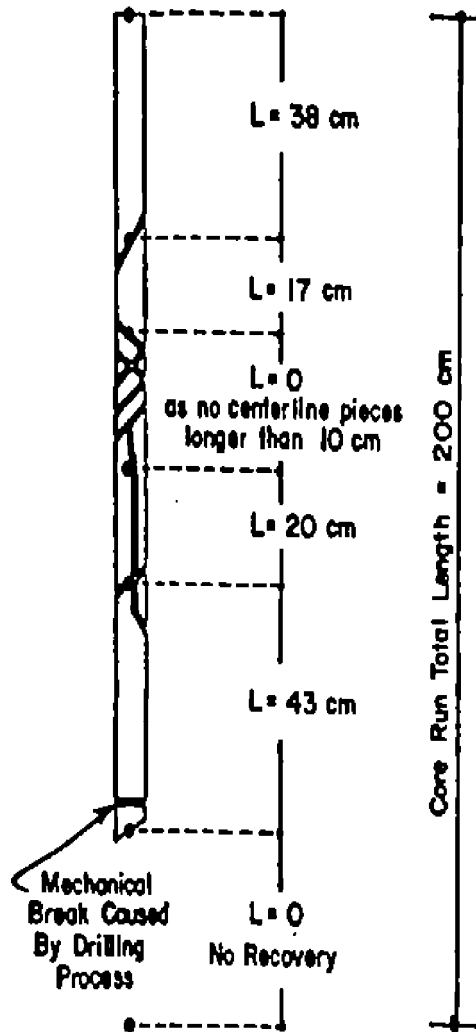
For definition of terms used in Table 7 refer to Table 8.

TABLE 8 - NOTATIONS FOR UNIFIED ROCK CLASSIFICATION SYSTEM

CATEGORY SYMBOL	ABBREVIATION	MEANING
DEGREE OF WEATHERING ELEMENT		
A	MFS	Micro Fresh State (determined by hand lens)
B	VFS	Visual Fresh State
C	STS	Stained State
D	PDS	Partly Decomposed State
E	CDS	Completely decomposed State
STRENGTH ESTIMATE ELEMENT		
A	RQ	Rebound reaction to hammer blow
B	PQ	Pits with hammer blow
C	DQ	Dents with hammer blow
D	CQ	Craters with hammer blow
E	MBL	Can be remolded with finger pressure
PLANAR AND LINEAR ELEMENTS		
A	SRB	Solid with random breakage
B	SPB	Solid with preferred breakage
C	LPS	Latent Planes of separation
D	2-D	Planes of separation in two dimensions
E	3-D	Planes of separation in three dimensions
UNIT WEIGHT ELEMENT		
A	> 2.55	Greater than 2.55 Mg/m ³
B	2.40-2.55	2.40-2.55 Mg/m ³
C	2.25-2.40	2.25-2.40 Mg/m ³
D	2.10-2.25	2.10-2.25 Mg/m ³
E	<2.10	Less than 2.10 Mg/m ³

9.4 Rock Quality Designation (RQD) Index

The Rock Quality Designation (RQD) index, is a simple and rapid measure to assess the quality of rock in the bore-holes. Procedure for measurement and calculation of RQD index is shown in Fig. 1.



$$RQD = \frac{\sum \text{Length of Core Pieces} \geq 10 \text{ cm}}{\text{Total Core Run Length}} \times 100\%$$

$$RQD = \frac{38+17+20+43}{200} \times 100\%$$

$$RQD = 59 \% \text{ (FAIR)}$$

RQD (Rock Quality Designation)	Description of Rock Quality
0 - 25 %	Very Poor
25 - 50 %	Poor
50 - 75 %	Fair
75 - 90 %	Good
90-100 %	Excellent

PROCEDURE FOR MEASUREMENT AND CALCULATION OF RQD INDEX

Fig. 1

10. AGGRESSIVE GROUND AND GROUND WATERS

Some types of ground have a corrosive action on metals, particularly on cast iron, owing to electrolytic or other chemical or bacteriological factors. In industrial areas, corrosive action may arise from industrial waste products that have been dumped on the site.

Laboratory tests to assess the aggressiveness of the ground and ground water against Portland cement concrete include determination of pH value and sulphate content, see soil chemical tests in Table 3.

11. GROUND INVESTIGATION OVER INLAND SHALLOW WATERS

For design of civil engineering projects, it may be necessary to obtain information about ground conditions under water, in this clause of the Engineering Standard special problems encountered in this respect is discussed. It should be noted that the ground investigation over water, discussed here, is restricted to those inland waters with a maximum depth of 5 to 10 meters and not under influence of tidal effects.

Geophysical techniques are also used to augment the information obtained from borings, or as a preliminary investigation before putting down borings.

The scope of the work, including the methods of boring, sampling and in-situ testing, requires careful consideration depending on the particular difficulties of the site. When working over water it is essential that due consideration be given to safety requirements and the regulations of governmental departments and other authorities.

For detailed information refer to clause 14 of BS 5930: 1981.

APPENDICES

APPENDIX A*

INVESTIGATION OF LIQUEFACTION POTENTIAL

A.1 General

Liquefaction may be defined as loss of strength occurring in saturated cohesionless soils exposed to shock or vibrations when the soil particles momentarily lose contact and the material then behaves as a fluid, resulting in settlements and tilting of structures.

It is therefore very important to investigate liquefaction potential of soils especially in earthquake prone areas. In this Appendix general methods of liquefaction potential investigations are discussed.

A.2 Prediction of the Effects of Soil Conditions on Liquefaction Potential

From a practical point of view, the evaluation of the liquefaction potential of soil deposits at proposed construction sites is one of the most challenging problems facing the soil engineer working in seismically active regions of the world. Procedures used for making such evaluations are as follows:

A.3 Use of Past Experience

Past experience of the conditions under which liquefaction has occurred in previous earthquakes will always be one of the most useful guides to the probable performance of other soil deposits. However, the limited extent of this experience at the present time and the limited number of well-defined case studies makes it extremely desirable to supplement this experience by appropriate analyses and test procedures whenever possible.

*** The material of this appendix is mainly based on the information obtained from: Foundation Engineering Handbook by H.F. Winterkorn and H.Y. Fang 1991.**

A.4 Use of Standard Blasting Tests

This procedure involves the use of a standard blasting test to evaluate the liquefaction potential of sands in the field. For a sand deposit 8 to 10 m thick, a charge of 5 kg of ammonite is exploded in the ground at a depth of 4.5 m and the resulting settlements of the ground surface are determined within a radius of 5 m from the explosion. Where the average settlement in this zone is less than 80 to 100 mm and the ratio of settlements from successive shots is less than about 0.6, it is considered that there is no need to provide measures against liquefaction of the soil.

A.5 Use of Ground Response Analyses and Laboratory Test Procedures

A procedure which has been applied with some success to analyze the liquefaction of soils involves the use of ground response analyses to determine the stresses induced in a soil deposit during any given earthquake and the comparison of these stresses with those observed to cause failure in laboratory cyclic load tests. Such an approach involves the following steps:

- 1)** Assess the magnitude of the ground motions likely to be developed in the base rock at the site under investigation; this assessment should involve the entire time history of the base motion throughout the period of the earthquake.
- 2)** Determine the response of the overlying soils to the base motion, assuming that the deformations of the soils are caused primarily by the vertical propagation of shear waves as a result of the base motions. Such an analysis would permit the computation of the shear stresses, and their variation with time, at different depths in the soil deposits.

- 3)** Idealize the shear stress history at the various depths to determine the significant number of stress cycles and the equivalent uniform cyclic shear stress developed at each level.
- 4)** Determine, by means of cyclic load tests on representative samples of sand from the site, the cyclic shear stress required to cause liquefaction of the sand in the significant number of stress cycles.
- 5)** Compare the magnitude of equivalent cyclic stress developed at any depth with the cyclic stress causing liquefaction for the conditions existing at that depth to determine whether or not liquefaction will occur.

It is of course necessary to make appropriate corrections to the laboratory test data before using it in step (5) of the analyses.

This procedure provides a means for considering the effects of the amplitude and time history of the earthquake ground motions, the in-situ characteristics of the soils, the variation of overburden pressure with depth and the position of the water table. Different ground response analyses or laboratory test data may readily be incorporated in the procedure depending on the judgment and experience of the soil engineer involved.

APPENDIX B

DISPERSIVE AND EXPANSIVE CLAYS

In this Appendix special soil categories are discussed, namely: dispersive and expansive clays

B.1 Dispersive Clays

Fine-grained soils that will deflocculate in still water and erode if exposed to low-velocity water are termed dispersive clays. Ordinary clays typically do not erode in the presence of water unless the flow velocity is relatively high (e.g., more than 0.9 to 1.2 m/sec).

Susceptibility of clays to dispersion has been found to be related to the presence of cations (sodium, calcium, magnesium, potassium) in the soil pore water.

The erodibility of dispersive clay can be reduced through the use of hydrated lime or aluminum sulfate admixtures, 1-2 percent by weight. Where core zones of dams must be constructed of dispersive clays, soil transition-filter zones that border the dispersed clay can be designed to control erosion and seal concentrated leaks. The use of geofabrics (geotextiles) can also be investigated as an erosion control.

B.2 Testing for Dispersive Clay

Dispersive soils cannot be identified by means of conventional soil classification test, so when it is indispensable to use these kind of soils, special tests should be conducted to identify dispersibility properties of soils under consideration. In Table 3 two types of such tests is presented and reference is made to relevant ASTM standards. A brief description follows:

B.2.1 Pinhole test

The test soil is compacted, and distilled water is then made to flow through a one-mm-diameter hole in the sample. The test can be set up in the permeameter apparatus used for permeability determinations, using pea gravel filters at the ends of the test sample. With a dispersive clay, the hole erodes and the flowing water discharge is colored, whereas for a nondispersive soil the hole does not enlarge and the water discharge remains clear. For further details refer to ASTM-D4647-87.

B.2.2 Double hydrometer test

This procedure compares the percentage of soil sample particles smaller than 0.005 mm as determined by a conventional hydrometer analysis (where a deflocculating agent is used and the soil sample is mechanically agitated prior to test) and as determined when a similar sample is exposed to a plain distilled water environment without being agitated, whence

$$\% \text{ dispersion} = \frac{\% \text{ finer than 0.005 mm in plain water test}}{\% \text{ finer than 0.005 mm in conventional hydrometer test}}$$

A percentage dispersion greater than 35 percent is used to indicate a dispersive clay soil.

For further information refer to ASTM-D4221-83a.

B.3 Expansive Clay

Some clay soils are prone to large volume changes which are directly related to changes in water content, shrinking in dry seasons and swelling in wet seasons or when otherwise in the presence of water. Such soils are termed "expansive clays" or "swelling clays". Clays including the montmorillonite mineral are particularly noted for their high volume

change characteristic. The expansive force of a swelling montmorillonite clay can lift pavements and light structures. A common construction practice in areas where expansive clays exist is to keep the soil beneath a structure stable by providing protection against changes in the moisture content. Additives that provide a source of calcium, such as lime or lime materials, have also been used to stabilize expansive clays.

B.4 Testing for Expansive Clays

In all cases where extensive swelling damage of soils may be expected, it is necessary to conduct tests on soil samples for identification and characterization of expansive soils.

For measuring expansion index of such soils refer to ASTM-D4829-88.

APPENDIX C SLOPE STABILITY

C.1 General

In this part of the Engineering Standard, stability of man-made slopes (cuttings and embankments) is discussed.

Stability of slopes discussed here is mainly by adopting engineering measures i.e.; by providing adequate factors of safety so that the designed slopes are stable per se in different loading conditions. Structural considerations like retaining walls, surface protections, etc., are discussed in IPS Standard E-CE-140 "Retaining Walls".

Temporary supports to excavations are described in IPS-C-CE-112 "Earthworks".

C.2 Design of Stable Slopes in Cuttings

C.2.1 Factors governing the stability

Factors governing the stability of cutting slopes may be categorized as follows:

- Materials: Soils and rocks
- Parameters of soil and rock masses which are important in the assessment of slope stability
- Structure and fabric of soils and rocks
- Surface and subsurface water
- Time effects
- Other factors such as surcharge on slopes and seismic effects.

Detailed description of the above mentioned factors are given in Clauses 6.2.1 to 6.2.6 of BS 6031: 1981.

C.2.2 Methods of slope stability analyses

C.2.2.1 Limit-equilibrium methods

There are numerous methods currently available for performing slope stability analyses. The majority of these may be categorized as limited equilibrium methods.

Depending upon the type of soils and rocks, homogeneity, presence of water and type of failure surface, the limit equilibrium methods may be divided into the following main categories:

- a) Planar slides
- b) Wedge failures
- c) Circular rotational slides
- d) Non-circular rotational slides

Clauses 6.4.2.1 to 6.4.2.4 of BS-6031: 1981 give brief description of the methods together with basic equations and the relevant nomenclature. In Table C.1 a summary of slope stability analyses by limit-equilibrium methods is presented.

C.2.2.2 Other methods

In addition to the above mentioned methods, in some special cases, other methods like stress analysis and physical models may be used for stability analysis of soil and rock slopes. For further details refer to Clause 6.4.3 and 6.4.4 of BS 6031: 1981.

**TABLE C.1 - SUMMARY OF SLOPE STABILITY ANALYSES BY
LIMIT-EQUILIBRIUM METHODS ¹⁾**

TYPE OF FAILURE	METHOD	ASSUMPTIONS	ORIGINATOR'S NAME
Planar Slides	Infinite slope Culmann	Constant slope with unlimited extent. Planar failure surface intercepting toe of slope.	Taylor (1948) Culmann (1866)
Wedge failures	Wedge or wedges	Sliding block or blocks with lateral forces.	Hoek and Bray (1977) Seed and Sultan (1967) Morgenstern (1968)
Circular rotational slides	Slices	Lateral forces on each side of slice are equal.	Fellenius (1936)
	Friction circle	Resultant acting on rupture are tangential to a concentric circle of radius $R \sin \phi$.	Taylor (1948)
	Bishop	Total force system acting on sides of slice considered.	Bishop (1955)
	Modified Bishop Spencer	Total force system simplified. Interslice forces parallel.	Bishop (1955) Spencer (1967)
Non-circular rotational slides	Morgenstern and price	Based on complete Bishop force system.	Morgenstern and Price (1965)
	Janbu	Allows for interslice forces.	Janbu (1954)

1) Reference: Geotechnical Engineering analysis and evaluation by R.E.HUNT, McGRAW-HILL, 1986.

C.2.3 Design considerations and assessment of safety

C.2.3.1 Safety factors

Suitable values of safety factors in a particular case can only be arrived at after a careful study of all the relevant factors and the exercise of sound engineering judgment. These factors include the complexity of the soil conditions, the adequacy of the site investigation, the certainty with which the design parameters, e.g., shear strength and ground water pressures, represent the actual in-situ conditions, the length of time over which stability has to be assured, the likelihood of unfavourable changes in ground water regime, surface profile or other factors taking place in the future and the likely speed of movement and consequences of any failures.

The risks of failure in shear of the earthworks are assessed by calculating a safety factor which is defined as the ratio of the available shear strength of the soil to the strength required to maintain equilibrium. This approach is known as the limit-equilibrium method (see subclause C.2.2.1).

Current practice would suggest that for first-time slides with a good standard of investigation, a safety factor between 1.3 and 1.4 should be designed for.

For critical slopes adjacent to roads or important installations a factor of safety of 1.5 is preferred.

In case of transient loadings (e.g., earthquake) the factor of safety may be reduced to 1.1.

C.2.3.2 Design considerations

In addition to the stability analysis of cutting slopes (Clause C.2.2), several design considerations should be regarded, these items may be categorized as follows:

- Slope profile, including slope angles, berms, space for debris, etc.
- Influence of construction procedures on slope stability.
- Drainage.

Details of the above mentioned items are described in Clauses 6.5.2 to 6.5.4 of BS 6031: 1981.

C.3 Design of Stable Slope for Embankments

C.3.1 General factors affecting the design of embankments

The cross section of an embankment is determined by the required functional width at the top, the height above ground level and the profile of the side slopes. At the base, sufficient land should be reserved for the location of any necessary drains and services at the toes of the slopes and any other ancillary purposes such as landscaping, including tree or hedge planting. The cross section may also be governed by the stability of the ground on which the embankment is to be constructed, particularly if this is sidelong ground.

Where sufficient width of land is not available to accommodate the full width of the base of the embankment, the provision of earth-retaining structures has to be considered. Types of earth-retaining structure are described in IPS-E-CE-140 "Retaining Walls".

C.3.2 Stability of embankment slopes

Calculation of the stability of the embankment should be undertaken using the methods of analysis described in C.2.2. In some instances, it may be desirable to analyse embankment deformations using, for example, finite element methods, to determine whether deformation is acceptable.

An assessment is necessary to check the ability of the foundation material to carry the required superimposed load without shear failure or unacceptable deformations. The factors governing the behaviour of soils and rocks in cuttings (see C.2.1) generally apply also to their behaviour as foundation materials for embankments. If the site contains geological features such as faults or slip surfaces resulting from previous movements, due regard should be taken of these during the evaluation of the stability of the embankment.

Techniques are available for improving the strength properties of fill and foundation materials, and these are described in IPS-E-CE-120 "Foundations" and IPS-E-CE-140 "Retaining Walls".

Safety factors mentioned in C.2.3.1 is also valid for embankment slopes. In design of water retaining embankments attention should be paid to the effect of additional pore water pressures developed in case of rapid drawdown.