HIGHWAY RESEARCH BOARD

Special Report 44

Foundation Exploration

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Special Report 44

Foundation Exploration

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in Earth Masses

1959

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Contents

Foundation Exploration

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Because highway structures such as bridges, fills and pavements, are generally supported on the earth, the character of this support must be explored in order to properly locate and design substructures. Although exploration data should form the basis of an adequate design, its value is emphasized by occasional failures due to lack of careful and complete exploration before design and construction.

Ordinary exploration for pavement design is described in AASHO Method T 86 (1). This report outlines the principles, equipment, and methods of operation involved in explorations of field conditions involved in the design of substructures for bridges and for cuts and fills requiring special consideration.

Exploration, being an investigation of unknown conditions, precludes standardization of procedure since the best method depends upon the conditions which are to be determined. However, certain methods of operation are generally applicable in determining the suitability of a material to support structures or fills, or to support itself in deep cuts or natural slopes. A general plan, plus perseverance and judgment, will provide data needed for design and construction. This report is simply a guide; many special situations will require more detailed study to develop more specific information.

After a description of materials and exploration aims, methods of exploration are presented, concluding with a discussion of a program of work.

SOIL FORMATION

The basic earth materials are rocks which have solidified from molten material (igneous), accumulated in layers or precipitated from solution (sedimentary), or transformed by heat or pressure from preexisting rocks (metamorphic). Rock has a structure due to its method of formation and to distortions after formation.

Weathering at the surface, and chemical action aided by structural weaknesses, gradually transform the rock into residual soil which may be eroded, sorted, abraded, and transported by gravity (talus), wind (loess, sand dune), ice (till, moraine), or water (esker, alluvium, beach, lake deposit).

Figure 1 shows the effect of cracks on the depth of soil over igneous rock and the possible extreme change in soil depth due to dissolving of limestone. Figure 2 shows some variations encountered in transported soils, whereas Figure 3 shows a profile development after deposition of a sedimentary soil.

In time, horizons are formed near the ground surface of residual and transported soils as a function of temperature, precipitation, drainage, slope and organisms. These range from surface accumulations of salts or lime in arid regions to concentrations of clay as deep as several feet in humid regions.

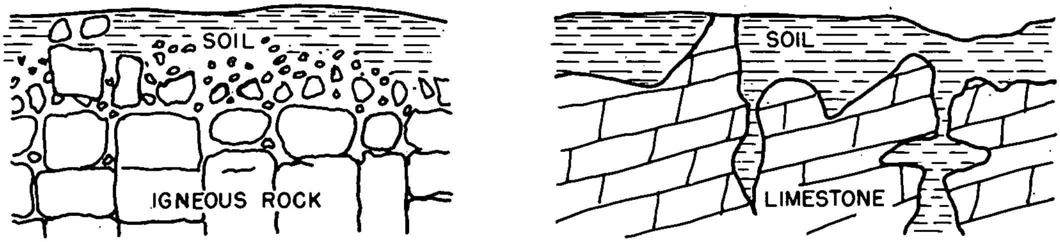


Figure 1. Residual soils.

Groundwater is of great importance to the behavior of foundations; five possible conditions are shown in Figure 4. Groundwater is typically subject to seasonal variations and sometimes to long-time trends.

SOIL IDENTIFICATION

A simple textural terminology (2) is shown in Figure 5.

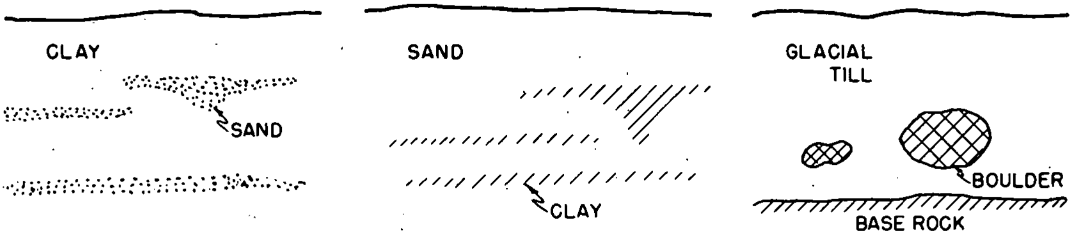
Coarse material should be further described if platy, weak, porous, and whether it softens with submersion overnight in water.

Sand feels gritty and its strength is unaffected by wetting.

Silt is similar to sand but finer so that individual grains cannot be distinguished by eye and is not gritty to ordinary touch. If saturated with water and shaken in the hand, it flows and becomes shiny; if squeezed after shaking, the water disappears—this is dilatancy. When dry, it is easily pulverized.

Clay is a material which is plastic—if wet to a not quite sticky condition, it can be rolled into a thread 1/8 in. in diameter by 3 in. long which can support its weight. When dry, it is hard and, if very plastic, may be polished by rubbing on a smooth surface. Clay is the finest soil material; the plasticity is typically caused by clay minerals—kaolinite, illite and especially montmorillonite.

Table 1 shows the visual identification of soil textures and their related properties—ability to transmit water (permeability), ability to lift water above the water table (capillarity), tendency to decrease in



SAND LENSES CLAY LENSES BOULDERS

Figure 2. Transported soil. (Varying transporting capacity of water causes lenses in soil deposits. Ice transportation mixes soils and may leave boulders above base rock.)

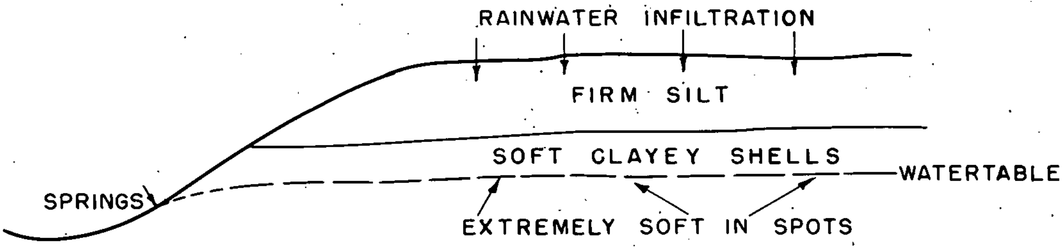


Figure 3. Softening of calcareous soil by solution—Yorktown, Virginia.

volume when dried (shrinkage), tendency to increase in volume when wetted (swelling), strength proportional to confining pressure (friction), strength when unconfined (cohesion), ability to be picked up by running water (erodibility), and ability to be carried by running water (transportability).

The evaluation of the above related properties are typical but subject to wide variation. For instance, sand has low permeability to water under high capillary tension and has no real strength when subjected to water gradients sufficient to float the particles (quicksand). Fissured clay may have a high permeability, and if the clay is extremely wet, it may have very little cohesion.

Organic material may consist of peat which is fibrous, or humus which is black or brown decomposed material which is odorous especially if heated. It reduces plasticity, grittiness, and dry strength of the rest of the soil.

Any exceptional property of the soil should be described—such as shiny flakes of mica, unusual specific gravity, and change of color on exposure. The color in the wet and dry state should be noted as an aid in correlation of strata. Mottling may indicate intermittent submergence.

Chemical properties are often important. Some carbonates may be identified by fizzing when dilute hydrochloric acid or vinegar is applied to

TABLE 1

SOIL IDENTIFICATION

	Sand	Silt	Clay
Grittiness	High	Low	None
Dilation	Low	High	None
Plasticity	None	Low	High
Dry strength	None	Low	High
Permeability	High	Medium	Low
Capillarity	Low	Medium	High
Shrinkage	Low	Medium	High
Swelling	Low	Medium	High
Friction	High	Low	None
Cohesion	None	Low	High
Erodibility	Medium	High	Low
Transportability	Low	Medium	High

the soil. Salt crystals appearing on samples after drying indicates the presence of soluble material. The amount of soluble material may be determined by weight or electrical resistance. Sulfates in the soluble material will cause a white precipitate with barium chloride if the solution is acid. Acidity or alkalinity is indicated by the color resulting from touching pH test paper to the wet soil.

Soil materials are often mixed so that it is necessary to indicate the predominant and modifying properties—thus a material that feels gritty but is predominately plastic would be a sandy clay even though it may actually contain more sand than clay. Using R for stone, G for gravel, S for sand, M for silt, C for clay, and O for organic: a gravelly organic silt might be abbreviated as gMo, lower case indicating the minor component.

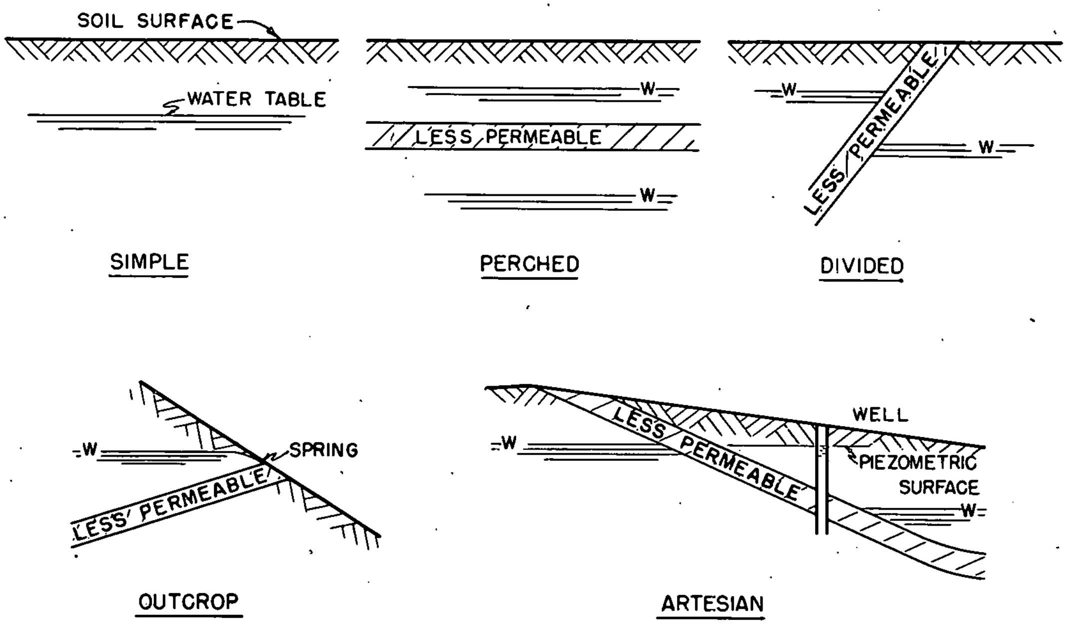


Figure 4. Groundwater conditions. (Water tables are often complex and vary with time. Special methods are required to determine water tables in clay due to long time required to reach equilibrium.)

The physical properties of the whole soil are of chief concern. The purpose of the identification is to give a usable indication of physical action based upon prior experience with materials similarly identified.

Several detailed systems of identification have been published (3), such as the Unified System and the methods of Burmister and AASHO. It is most important that a consistent system be defined and followed.

While soil names should be used on logs and drawings, symbols as shown in Figure 6 may aid in the visual presentation of profiles.

Local terms, if used, should be defined since they may be unknown or have different meanings elsewhere. For instance, in the Great Lakes Region marl is a soft lime deposit, while in the Carolinas marl is a firm limey clay and elsewhere it may be a clayey shell deposit or even impure limestone.

ROUNDED	U. S. STANDARD SIEVE SIZE	ANGULAR
Boulder		Rock Fragment
	12 inch	
Cobble		Rock Fragment
	3 inch	
Coarse Gravel		Coarse Stone
	1 inch	
Medium Gravel		Medium Stone
	3/8 inch	
Fine Gravel		Fine Stone
	No. 10	
	Coarse Sand	
	No. 30	
	Medium Sand	
	No. 60	
	Fine Sand	
	No. 200	
Non-plastic Weak when dry		Plastic if moist Strong when dry
Silt		Clay

Figure 5. Textural terminology.

In the natural state, the thickness and orientation of any stratification of the components should be noted, as well as natural cracks or perforations. The soil should further be described as wet, moist or dry and the consistency given—cemented, dense, firm or loose for sand; hard, firm or soft for clay. Some type of test for resistance to distortion is generally required as described under FIELD TESTS. Typical descriptions are "Hard, fissured, moist blue sandy clay" or "Dense, wet, brown silty sand."

EXPLORATION AIMS

The purpose of exploration is to provide a basis for evaluating the ability of available materials to adequately support the proposed slope or structure both during and after construction. This requires a knowledge of ground water and surface water conditions, the horizontal and vertical location of materials, and their strength, volume change, and permeability.

Bridge piers must be supported on material of sufficient strength and of limited compressibility. Piers in streambeds must also be safe against scour. In addition to streambed material, scour depends on the characteristics of the stream basin, variations in discharge, and drift or ice (4). Sufficient data is required to enable selection of the allowable pressures and the type and location of foundations.

Abutment foundations require consideration of lateral pressure below the abutment as well as directly against it. Figure 7 indicates the high lateral thrust that may be transmitted to deep foundations when fill is placed over soft soil. In addition, settlement of a fill tends to carry the structure down with the fill.

Evaluation of fill materials is required with respect to frost, shrinkage and swelling, and compactability by vibration or otherwise. While some settlement may be tolerated in fill foundations, adequate bearing capacity is required. By careful evaluation of materials and strict control of construction, use can be made of the increased foundation strength accompanying consolidation during construction. Figure 8 indicates the importance of thin seams in determining bearing capacity. Determination of continuity of sand lenses may require field permeability tests. Because of the width of fills, their effect extends to considerable depth. They often cause more stress in deep layers than adjacent structures.

The stability of slopes, either temporary or permanent, often depends upon soil stratification and ground water conditions (5). Particularly important are rises in ground water or sudden removal of flood or impounded waters. The value and practicability of drainage should be evaluated.

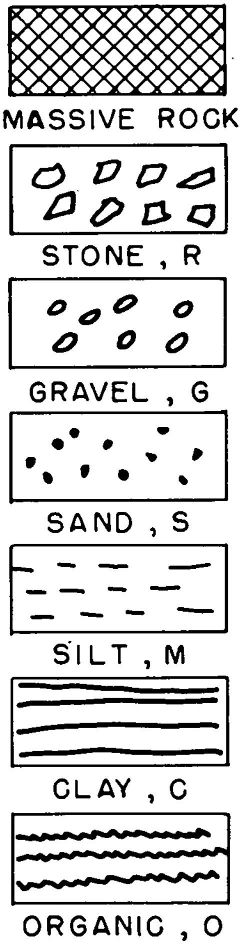


Figure 6. Legend symbols.

The applicability of various methods of deep soil stabilization, as shown in Figure 9, depends upon the stratification and type of materials.

In general, the prevailing condition is to be determined—good or bad.

RECONNAISSANCE

The first step in exploration is the inspection of available data.

Topographic maps show landforms and drainage patterns which may give a clue to the subsurface conditions. A chronologic series of maps may show present trends of erosion or deposition as well as recent changes.

Geologic maps, when available, may show general geology (surficial or bedrock) or depict special studies of oil, ores, gas, clay, groundwater or construction materials. Maps of old shorelines and of bedrock surface contours are available for some areas. Hydrographic maps showing the depths of navigable water are generally available.

Occasionally, records may be obtained for previous borings for structures, wells, or dredging. Collections of such data have been made for a few areas (6).

Agricultural soil survey maps are available for many areas and show the distribution of similar soils to depths of about 6 feet. The most recent reports contain a chapter on engineering applications.

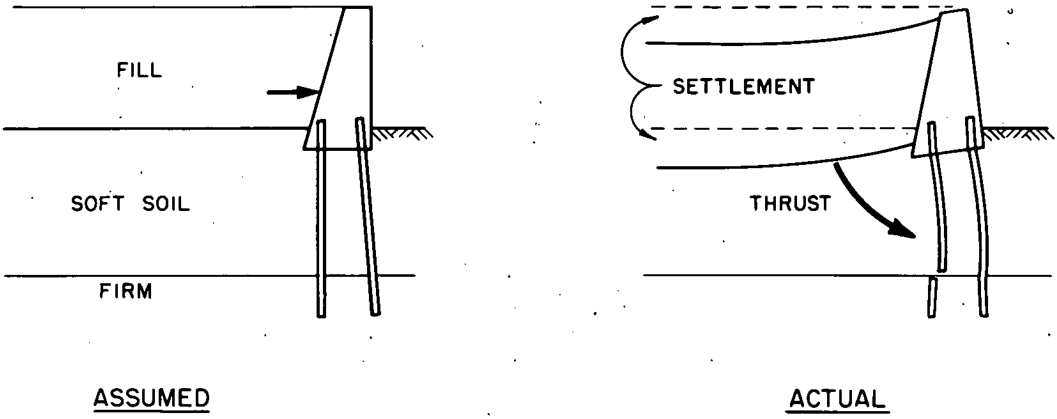


Figure 7. Lateral thrust of surcharged soft soil. (Soft soils under fill loading transmit excessive lateral thrust which may bend or push piles out. Differential consolidation from fill loading may cause abutment to rotate toward fill. Strength and consolidation tests of soil should be made for analysis.)

Aerial photographs are now available for most of the United States, and, when studied as mosaics and stereopairs, reveal landforms, drainage and erosion patterns, and vegetation which often reflect subsurface conditions. They may reveal fault lines, rock structure, stream erosion scars or traces of buried channels.

Hydrologic reports provide data on surface and subsurface water in addition to that inferred from topographic and geologic maps and aerial photographs. Stream gaging records are available for many streams through the U.S. Geological Survey.

Inquiry of local residents, while not always a source of reliable data, may be of help in relation to other sources of information.

Inspection of the site, in conjunction with the evidence described above, is a primary part of reconnaissance. It should include an examina-

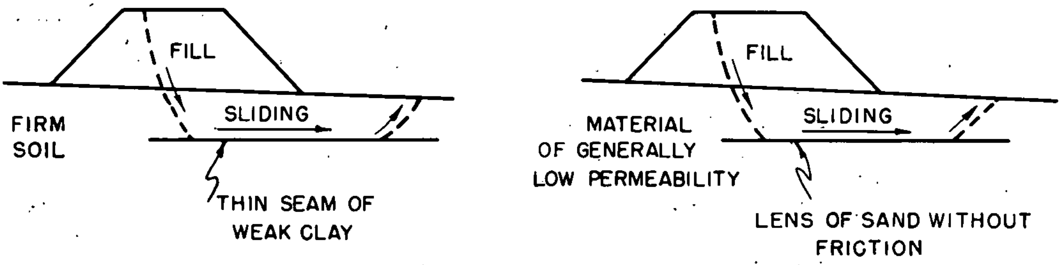


Figure 8. Danger of sliding on thin seams. (Thin seams are sufficient to provide slip surfaces; thorough exploration is needed. Consolidation induced by fill pressure causes intrusive pore pressures in sand lenses which lose frictional strength by reduction of effective compressive stresses. Flatter slopes or drainage is required.)

tion of the local topography and drainage, inspection of existing structures and excavations at and near the site, and search for any evidence of landslides, flooding and desiccation (7). All wet and damp areas at the site in conjunction with vegetation should be given due attention. By streams, factors affecting scour or bank erosion should be noted.

With considerable experience and judgment a reconnaissance investigation may be sufficient for comparison of alternate sites, or it may be used as the basis for further exploration. In some cases such information may be already at hand, while in others, an intensive search may be warranted.

GEOPHYSICS

Various types of geophysical subsurface investigations are available to indicate critical locations for borings and to interpolate between known conditions. The seismic and the resistivity methods are the most applicable to highway investigations. These are quick methods which do not require drilling in themselves; but they must be checked against borings or other known profiles. Depths to soil boundaries can often be determined within 10 percent. Both methods are effective for distinguishing rock or gravel from silt and clay, and wet from dry soil (7).

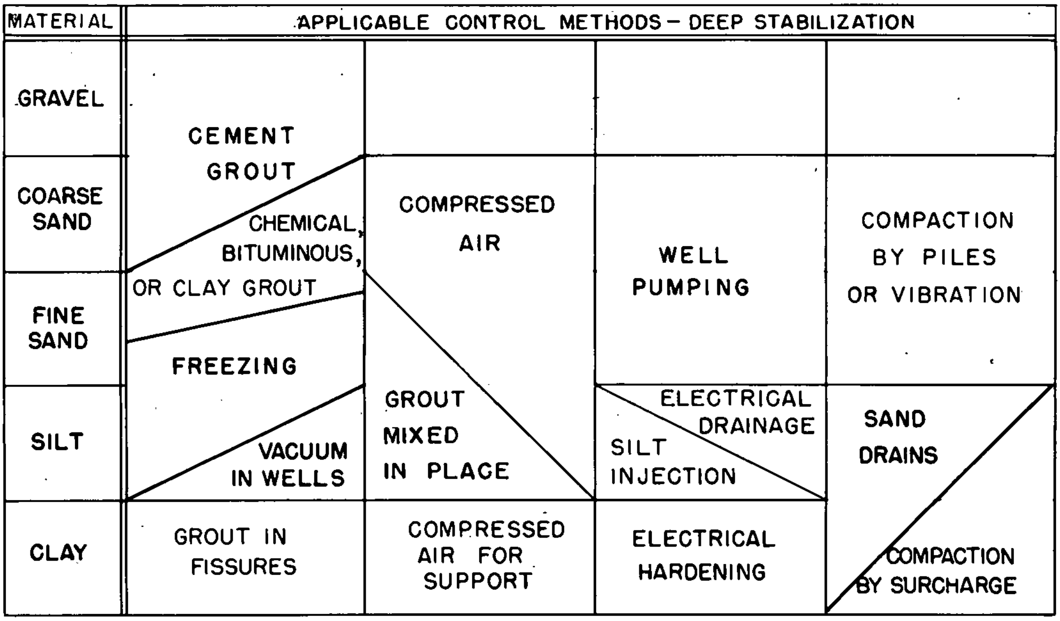
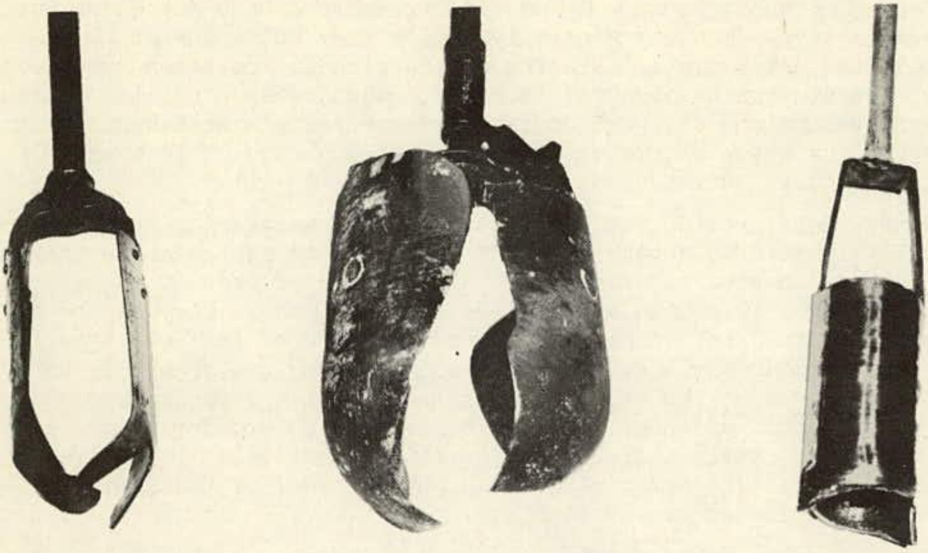


Figure 9. Methods of improving soil. (Troublesome material may be temporarily controlled or permanently improved. Each method is limited to the range of material indicated.)

The rate of transmission of shock waves is used in the seismic method. When rock underlies soil, its depth may be indicated by comparing the time required for an impulse to travel through the soil, or down to the rock, then through the rock at a velocity proportional to the square root of its modulus of elasticity, then up through the soil.



IWAN WELL TUBULAR

Figure 10. Hand augers.

The resistivity method utilizes four electrodes equally spaced in a line at the ground surface. The voltage between the inner electrodes is measured while a known direct current is applied to the outer electrodes. From these is calculated a mean electrical resistivity which corresponds roughly to a thickness from the surface to a depth equal to the spacing of the electrodes. By increasing the electrode spacing, change of resistivity with depth is indicated; or, by keeping the spacing constant and moving the whole array along a line, the horizontal variation for a given depth is indicated.

BORINGS

While reconnaissance and geophysical methods are useful to indicate problem areas and general conditions, direct examination of subsurface materials is still required because most maps are general and not specific, old boring or well logs are often not sufficiently refined, cuts and river banks may be masked by eroded or slumped material, seismic methods do not show clay below limestone, and sometimes quite different materials have similar resistivities. These sources of information are useful in selecting location and depths for direct examination and in interpreting data from such examination.

For location and record, points of examination are referenced to reproducible lines and bench marks of known elevation.

Various methods of excavation are used to determine the sequence of strata, observe groundwater conditions, and to obtain representative samples. Disturbed samples may be taken for textural examination and possibly for determination of water content. Undisturbed samples, where an effort is made to preserve the structural properties of the samples as nearly as possible to the field conditions, are required if the structural properties are to be determined by laboratory tests.

Test pits (about 3 ft x 5 ft) provide the most direct method of sub-surface examination. Economy generally limits them to depths of 10 to 20 ft and above the water table. Bracing and barricades are often required for safety. Strata can be observed in place, groundwater conditions at the time are obvious and the best undisturbed samples can be taken. Trenches may be used on steep slopes or where a trenching machine is available. Tunnels are occasionally used.

Hand augers provide the simplest method of excavation but their use is usually limited to depths of about 20 ft and to depths above the water table in non-cohesive materials. However depths of over 60 ft have been reached, using a tripod to stack drill stem sections. They may be screw augers from 1 to 2 in. in diameter or post augers of the Iwan type from 4 to 8 in. in diameter. Extensions 3 to 4 ft long are generally used. Occasional stones may be broken or displaced with a chopping bar and removed with a spoon or tongs. A well auger with no crossbrace can excavate soil with some gravel, while a tubular bit is particularly good for sand (see Figure 10). The material is laid out in order of excavation. Hand-held motorized augers are available.

Power augers with continuous helical flights can drill holes from 8 to 36 in. in diameter to depths of 50 ft or more depending upon the power plant (see Figure 11). When augering continuously, the material is brought to the surface by the rotation of the flight auger. The material from various layers may be mixed and it is difficult to determine the depth from which the soil came. In order to sample a specific depth, the auger is generally lifted; flight connections are designed to facilitate this operation. Helical flights have been constructed with a hollow stem through which a sample may be taken.

A rotary drilling machine with a hydraulic feed and cathead is one of the most versatile types of boring equipment (see Figure 12). It is usually mounted on skids but may be truck-mounted for easily accessible locations. Light machines are available to increase portability in difficult terrain, but the heavier machines are required for large holes. A variety of tools are required to handle different conditions.

The material is loosened with bits turned by means of a drill rod while the cuttings are removed from the hole by means of water under pressure. Where no sample is required 2- to 4-bladed fishtail bits may be used in soil or soft rock while rock roller or other rock cutting bits are required for harder material. In solid rock, hollow coring bits may be used. The standard core diameters for rock drilling are EX, 7/8 in.; AX, 1-7/32 in.; BX, 1-5/8 in.; and NX, 2-1/8 in., larger sizes are available. Corresponding sizes of flush-coupled casing, used

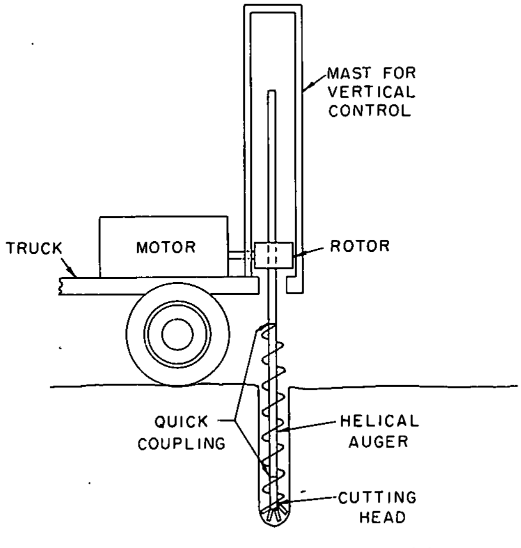


Figure 11. Motor-driven continuous helical auger.

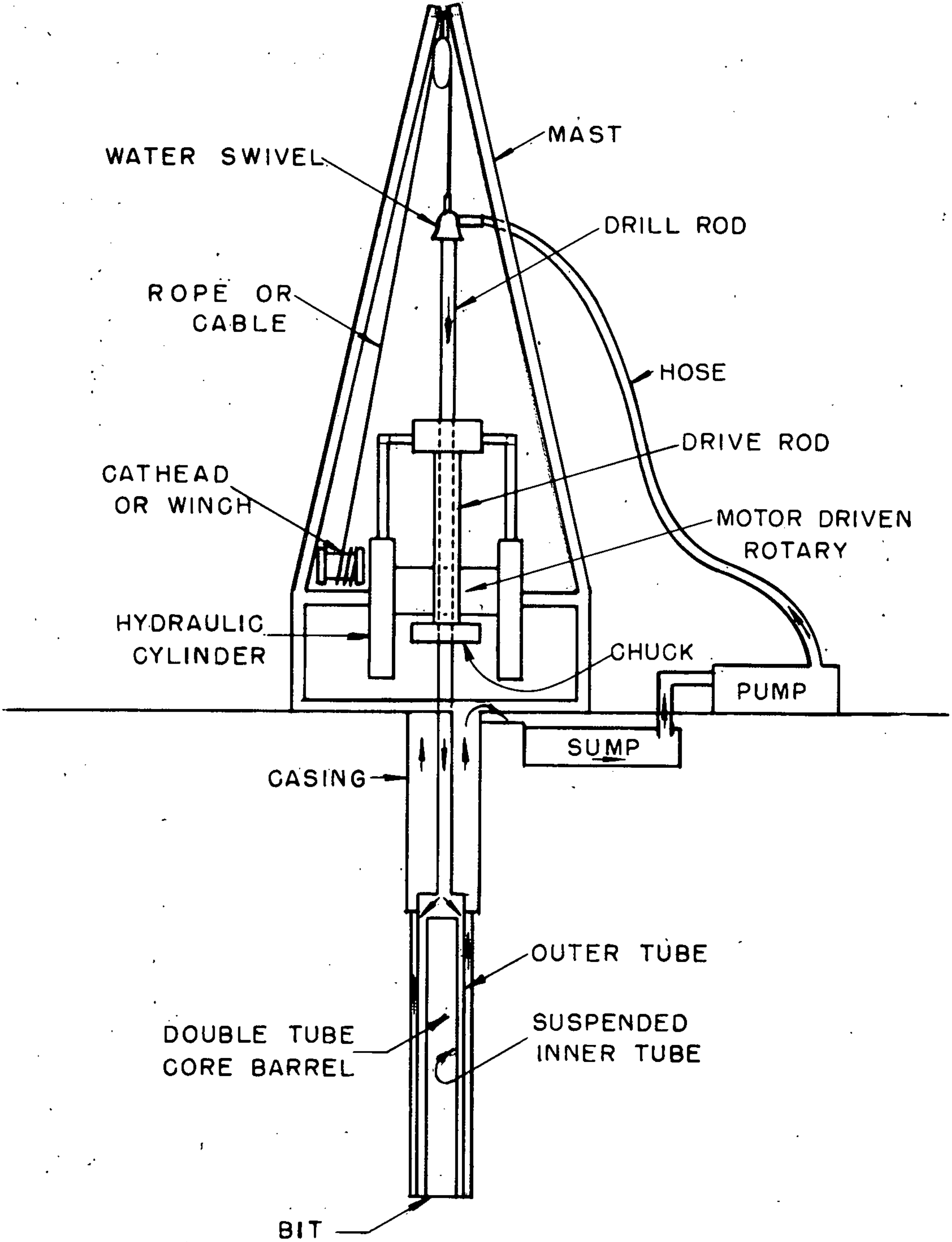


Figure 12. Rotary drilling.

to keep the hole clean except in solid rock can be telescoped; thus if NX casing is stopped by an obstruction, BX casing will pass through it. Bits may contain diamonds for hard rock, special metal inserts for soft rock, or simply serrated metal for soil. For extra large holes up to 52 in. in

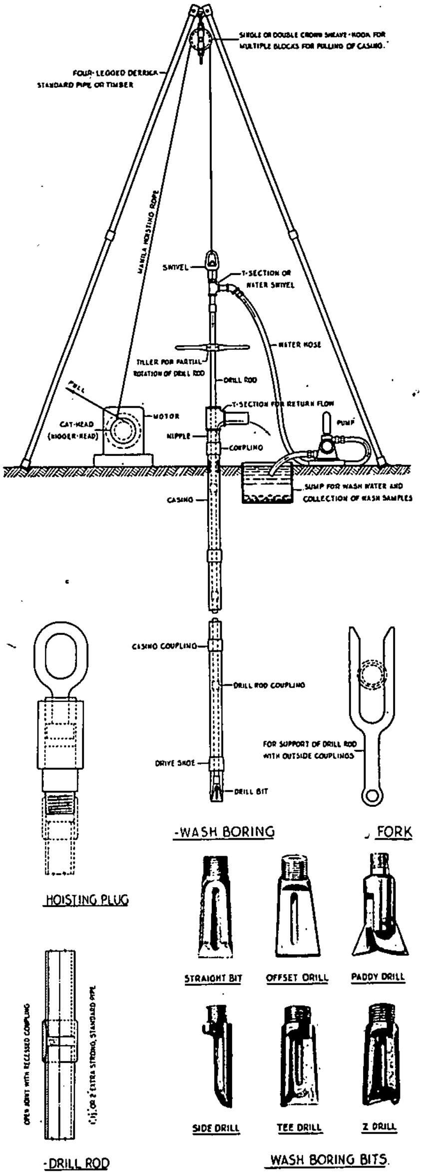


Figure 13. Wash boring rig and tools.

diameter, drilling is done with 3/32 in. chilled shot for hard rock and precrushed shot for soft rock.

In some soils casing may be omitted, particularly if fine clay is added to the water to make a drilling fluid (100 lb bentonite in 350 gal of water). In porous materials this may also be used to help maintain circulation of water, although there is danger of contaminating samples. In cavernous material or loose fragments, grouting may be required before drilling. Freezing has also been used in fragmental material. Individual boulders may be blasted or by-passed by another boring. A thick layer of hard boulders bedded in loose sand and gravel is particularly difficult to penetrate. Sloping holes are sometimes used to get under structures or fast moving water.

Wash boring is a common excavation method for soil but is unsuitable for rock. Casing (in lengths of about 5 ft) is driven and cleaned out by chopping and washing through a hollow bit (see Figure 13). After the casing is cleaned, samples may be taken by driving a tube below the casing. The hole is deepened by driving more casing and repeating the chopping and washing.

SAMPLING

Disturbed samples for classification or compaction tests may be taken from the sides of large excavations, from auger cuttings or by driving a heavy-walled sampler into the bottom of a clean hole, thus providing a "dry" sample. Core retainers may be required to hold clean sand. If the moisture content is desired, a sample must be put in a sealed impervious container, care being taken that it has not gained or lost water. If only an average sample of similar material is desired, several samples may be mixed in the proportions of material they represent or a composite sample may be obtained directly from a pit by excavating a vertical slot of uniform cross-section, the material being collected on a tarpaulin as shown in Figure 14. Samples are put in tightly woven bags, identified and tied securely. The size of sample required depends on the type of material and the proposed use. Twenty-five pounds is generally sufficient except for pavement aggregates. Random oversize aggregate may be discarded after noting the approximate size, quantity, angularity, roughness and strength under a hammer blow.

Undisturbed samples may be required to evaluate the structural properties of the material in its natural condition if it is not obviously satisfactory or obviously unsatisfactory for the intended use. Some disturbance is unavoidable since the stresses are changed by the excavation required to approach the point of sampling, the elasticity of the particles causes expansion, gases may be released from solution, and capillary forces tend to redistribute the water in layered materials. Samples are taken below the casing after it is cleaned out with an auger or side discharge bit to prevent loosening the material to be sampled. The

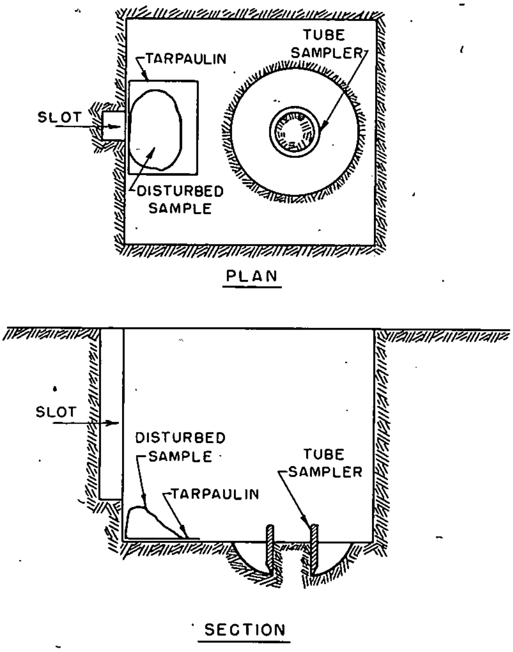


Figure 14. Sampling in pit.

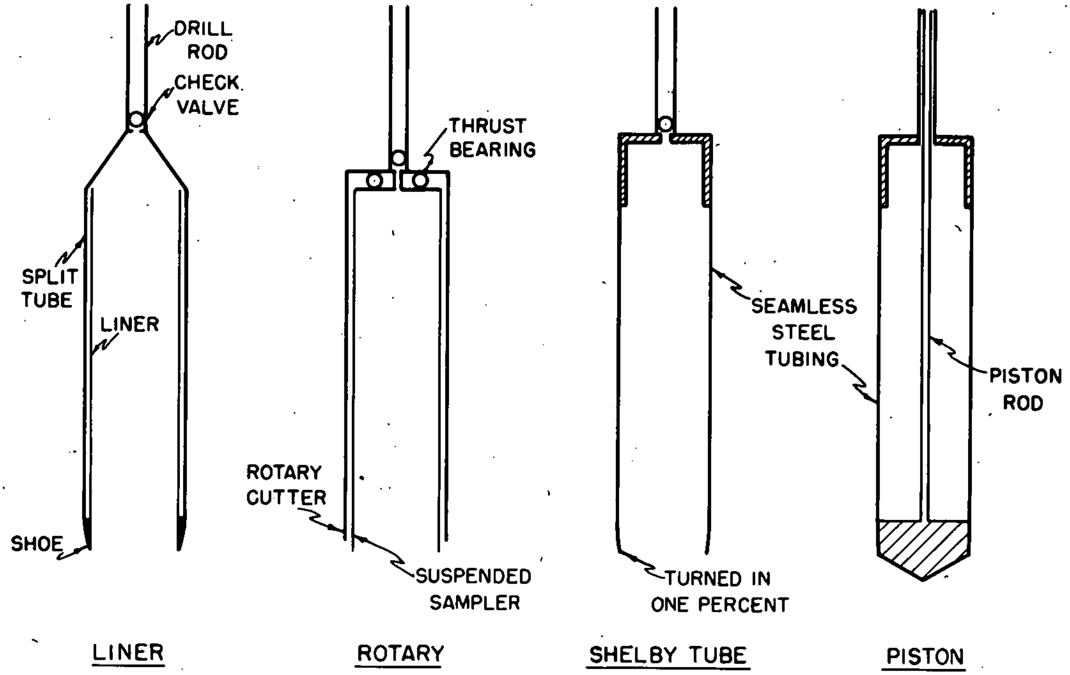
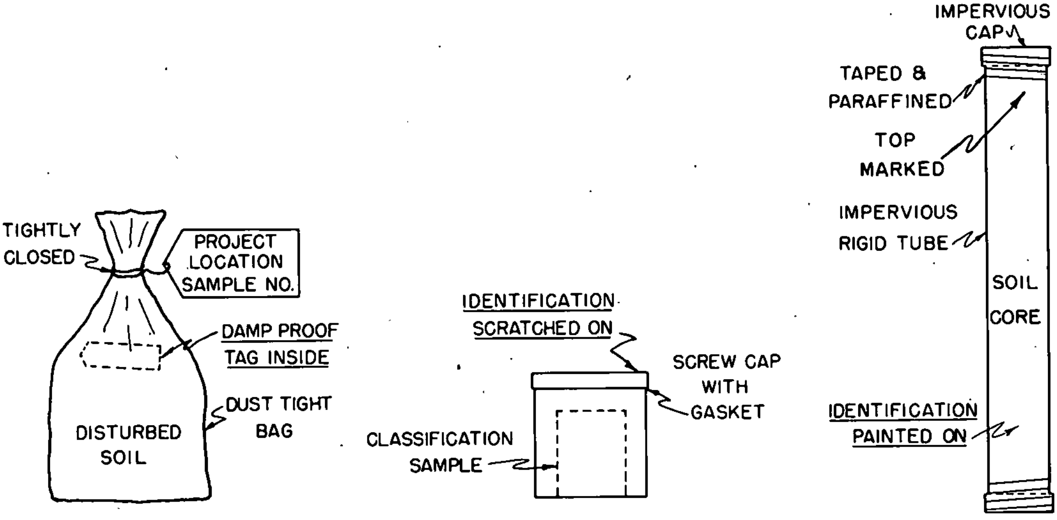


Figure 15. Undisturbed soil samplers. (Undisturbed samples may be required to evaluate soils of uncertain value. For soils not too hard, thin-walled tubing minimizes disturbance. Piston samplers keep disturbed material away from top of sample and with drilling mud can recover sand cores.)



BAG SAMPLE JAR SAMPLE TUBE SAMPLE

Figure 16. Soil samples. (Complete location and permanent identification of samples are essential. Undisturbed samples must be protected from drying and from mechanical shock or extreme temperatures.)

use of thin-walled samplers reduces the remolding of the soil structure and changes in density by minimizing the displacement of material (8). One of the most common samplers is seamless tubing (3) of steel, brass or aluminum, with a sharp cutting edge about one percent smaller in diameter than the inside of the tube (see Figure 15). The length-to-diameter ratio should be limited to about 10. The tube should be cleaned and lightly oiled or lacquered. It is lowered to the soil without resting on it, then forced into the soil, preferably with a continuous rapid thrust. This may be accomplished with block and tackle or hydraulic jack using the casing, anchors or a dead weight as a reaction. Extra wet material at the top of the sample must be removed immediately. Use of a piston sampler, shown in Figure 15, prevents entrance of this material as well as steadying the sampler during penetration and providing a positive seal which helps hold the sample in the tube. In some materials reasonably good samples are obtained by driving the tubes with a drop hammer which is heavy enough to easily overcome the inertia of the drilling rods.

The minimum diameter of the sampler is 1-7/8 in. inside, although 3 in. to 5 in. diameters are preferred, particularly for sampling materials that are sensitive to disturbance. The diameter of the sampler should be at least four times that of the minimum size particle or piece of fissured material to be sampled. Such samples may be taken in holes made by any of the previously described methods. In pits, larger tubes may be used and the material outside the tube may be excavated by hand, as the tube is advanced to trim the sample (Figure 14).

In rock drilling, the core, left after the cuttings are removed by water under pressure, is raised by the wedging action of a core-lifter. A single-tube core barrel is satisfactory for large or uniform cores of sound rock. For small cores or soft rock, a double tube, swivel-type core

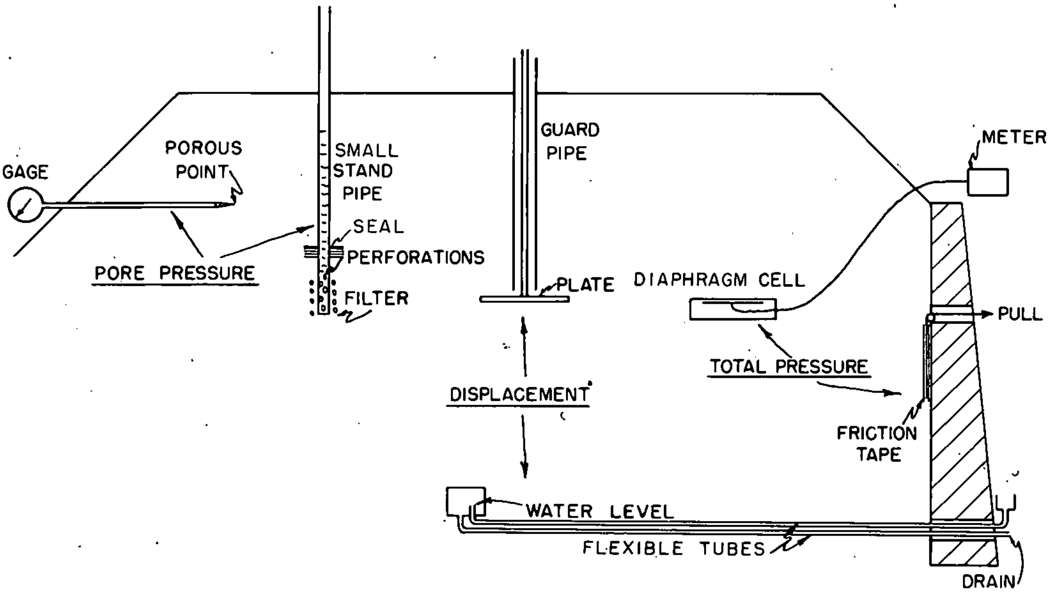


Figure 17. Measurement of field stresses and displacements. (Measurement of pressures and displacements are used to control construction and check designs.)

barrel as shown in Figure 12 is required to protect the sample from torsion and from flowing water. Good core recovery in fractured and mixed material usually requires short runs with large double-tube core barrels and careful control of rotation, vertical feed and water pressure. There is no substitute for skilled operators.

For soil the Denison or rotary core sampler, as shown in Figure 15, is used. The sampling tube extends beyond the cutting tube so that the wash water never comes in contact with the soil core. The thrust bearing at the top of the sampler separates it from the rotation of the outer cutting tube. The Denison sampler is particularly useful in hard and friable soils.

Samples may be taken at prescribed depths, or in special cases continuous sampling may be required where it is essential that thin seams not be overlooked.

Samples that are not tested immediately in the field or discarded after inspection should be sealed against change in moisture with metal caps and paraffin or, preferably, microcrystalline wax. Samples should be protected from freezing or overheating and cushioned against mechanical shock, particularly, if shipped or handled extensively. A positive systematic identification is required, such as project, hole, elevation or depth. The top should be clearly marked (see Figure 16). It is desirable to keep samples upright, especially if they are soft or loose.

FIELD TESTS

The most common field test of the soil is measurement of its resistance to penetration of the sampler. A proposed standard penetration resistance (3) is the number of blows of a 140-lb hammer dropped 30 in. required to cause a split-barrel sampler, 2 in. outside diameter and 1-3/8 in. inside diameter to penetrate the soil 1 ft (from 6 to 18 in.). Firm sand will require from 10 to 30 blows, loose sand less and dense sand more. The number of blows is approximately proportional to the cross-sectional area of the sampler and inversely proportional to the product of hammer weight and height of drop. With experience, penetration values, adjusted for depth, may be used in design (9). The consistency of clay is better classified by unconfined compressive strength which can be determined in the field—1,000 to 2,000 lb per sq ft for firm clay, less for soft clay, and more for hard clay. Tests are required in each stratum and every 2½ or 5 ft.

Various cones are also used either with static loads or under hammer blows. Rods or rails can be used to measure penetration resistances between bore holes if the results are correlated with data from the bore holes. In soft cohesive materials a direct shear test can be made by forcing a rod equipped with four vertical vanes below the bottom of the drill hole and measuring the force required to rotate it (10). The vane is especially useful in soft to firm clays which are easily disturbed.

In addition to noting any loss or gain of water during drilling, the water level in the boring is noted after flushing and bailing the hole and partly or totally removing the casing. In sand 24 hours may be sufficient for equilibrium; in silt and clay special piezometers to minimize the flow of water, as shown in Figure 17, are required (11). In addition to pore pressure, Figure 17 shows devices for measuring displacement (12) and total pressure (13), which may be required for design, construction control, or to check on performance after construction.

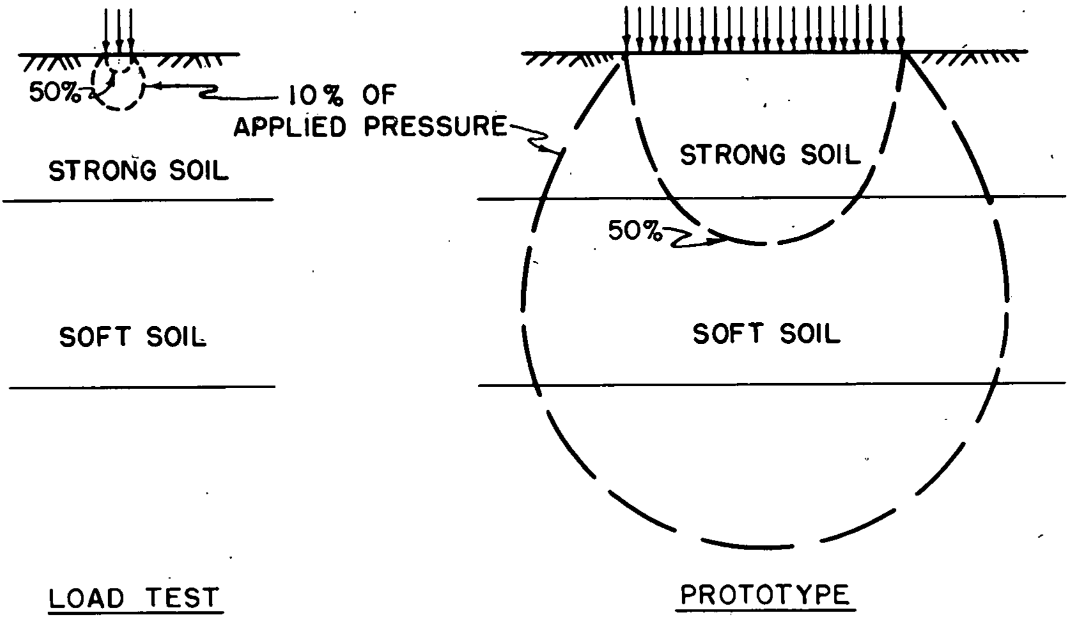


Figure 18. Problem of small scale bearing test. (Small scale bearing tests affect limited depths. They fail to disclose deep soft layers or long-time settlements. An insignificant 0.001 in. settlement each day becomes 3.6 in. in 10 yr.)

Large plate bearing tests (3) may be used after borings have located the critical materials. There is danger of placing such tests on the wrong layers (see Figure 18). At a depth of twice the loaded width, the transmitted stress is only 10 percent of the applied stress. The slow consolidation of silt or clay is not measured in ordinary bearing tests and must be determined from laboratory tests which can be made on several samples from different depths and locations. Bearing tests are particularly useful on granular materials for which undisturbed samples are difficult to obtain. For piles, especially those depending on friction, bearing or pulling tests (3) adjusted for group action are used.

Field permeability tests are often required because of the difficulty of integrating the permeability of samples to the permeability of stratified material. They require considerable care in performance and analysis (12). Pumped wells are used for mass measurements while bore hole tests can be used to test the permeability or continuity of individual strata (see Figure 19). It is especially difficult to obtain representative tests of the permeability of fissured or randomly varved material.

LOGGING

Drill operation is a trade requiring experience and mechanical aptitude and is not a job for engineers. The driller should conscientiously aim for quality of information rather than footage. On the other hand, supervision and interpretation of drilling operations is a job for an experienced and practical materials engineer and should not be left to the driller. While exploration may represent only a small part of the project cost, inadequacy of data may be disastrous.

A complete and concise log of drilling operation should be systematically kept; a sample form is shown in Figure 20. A chronological record should be kept of size and resistance of casing, method of advancing hole, size, resistance and penetration of sampler, recovery of sample, and loss or gain of water. Water records should include procedure, casing position and date; seasonal records may be required. The reason for abandoning any hole should be included together with its complete log.

In rock drilling, the record should include size and type of core barrel and bit, rate of drilling, recovery and cause of sample loss, with data on cavities, fractures or clay content as indicated by cuttings, vibrations and sound of drilling and loss of water. The core should be described as to type of rock with its hardness and structure. The limits of each material should be recorded.

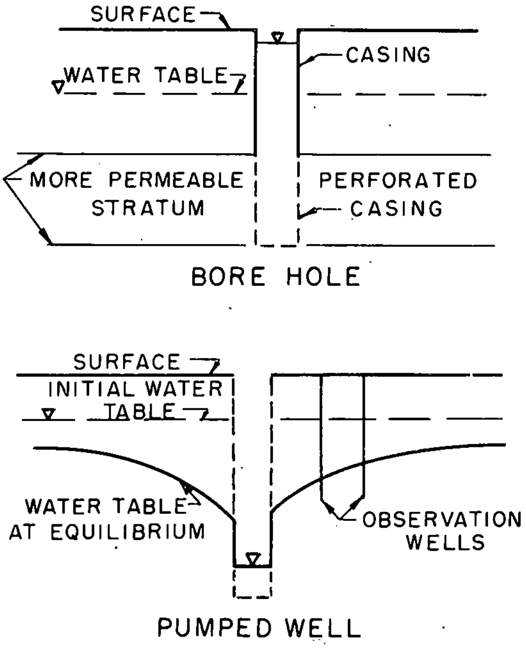


Figure 19. Field permeability test.

The logs should be checked by the engineer as developed to review the progress of work and to plan further exploration as required.

All essential information should be plotted to scale for visual inspection (see Figure 21) and comparison. Care must be taken in interpreting a set of boring logs as they give no assurance of what is below or between the borings (see Figure 22). If the possible variations between borings is too large, more exploration is required. A minimum of three borings not in a line is required to measure the dip of a stratum. Data on water content, plasticity, grading and structural test results may be added. After use in design and construction, the records should be filed for future reference.

FIELD LOG - SUBSURFACE EXPLORATION

JOB NO. ______ NAME ____________________ BORING NO. ______
LOCATION __________________________ Sheet ____ of ____
Inspector ______________ Coordinates ______________
Driller ______________ Reference Elev. ________ Datum ________
Work Started ________ Drill ________ Angle ________ Direction ________
Work Finished ________ Ground Water: Depth ________ Date ________

Date & Time	Depth (Ft.)		Description of Operation - Remarks -	Sample No.	Blows on Sampler	Recovery (Ft.)	Symbol	Description of Material
	From	To						

Figure 20.

PROGRAM

The program of exploration may develop progressively from reconnaissance to site selection, to preliminary design, to final design, to construction. One set of borings will sometimes suffice for all phases. Additional borings are often required to obtain more details of an indicated problem, to check final locations, or to take undisturbed samples for laboratory tests (3) (see Figure 23) from areas shown to be critical by preliminary borings and the proposed design.

Preliminary design is often based upon a few borings providing 2-in. samples for moisture, density and identification tests. Final design may require intermediate borings and 3- or 4-in. undisturbed samples for shear and consolidation analysis. Exploration should be extended to the point where its cost approaches the probable cost of remaining uncertainties in terms of failure, delays or change orders.

An early determination of the type of foundation is desirable. If piles are to be driven to a firm layer, higher layers may not require testing except near abutments and to determine their effect on pile driving. For spread footings, 20 ft of good bearing material (45 standard blows or 8 kips per sq ft compressive strength) may in a particular case, be a sufficient raft over weaker material if consolidation is not excessive.

Boring location is often controlled by the predetermined line of the highway. Where the line is not set or conditions are found to be intolerable, exploration of several lines is often desirable. It is well, whenever feasible, to keep borings out of tunnel or cofferdam cross-sections in order not to cause extra leakage.

The number of borings required depends on previous information and what is found as boring progresses. Where areas of general similarity are recognized from topography, geology or airphotos, the number of borings can be minimized and their location made more advantageous. When sufficient local experience is at hand borings may not be required for small structures such as culverts. For short bridges, a minimum of 2 or 3 borings is generally

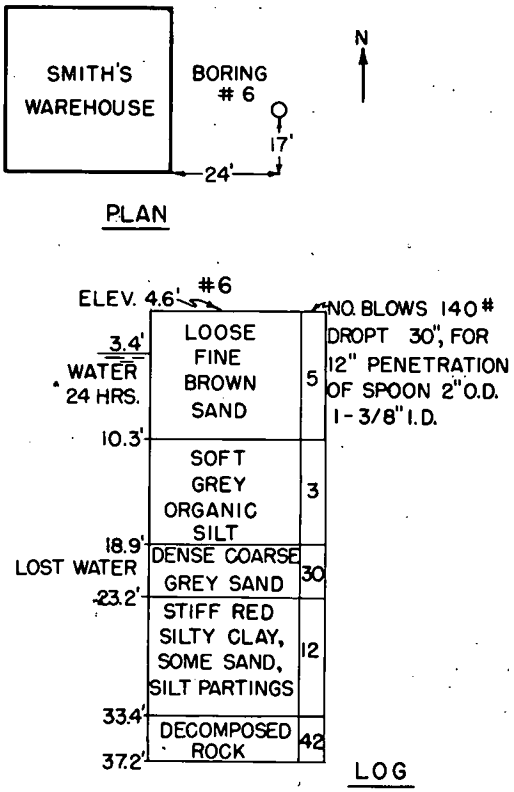
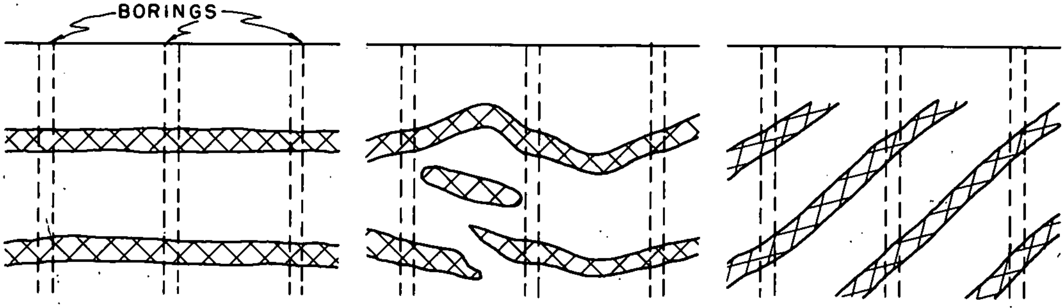


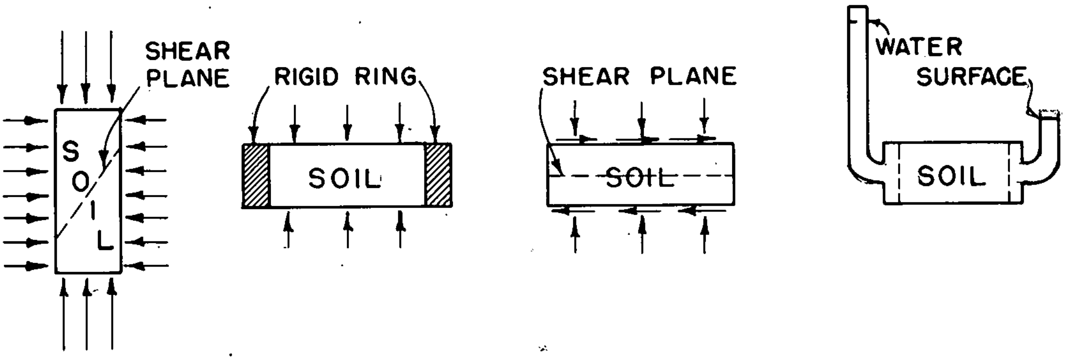
Figure 21. Typical boring. (Carefully made borings should determine boundaries of strata and groundwater conditions and recover whole samples of each layer. Penetration resistances of sampler in undisturbed material are valuable in indicating consistency of clay and compactness of sand.)



USUAL INTERPRETATION

OTHER POSSIBLE CONDITIONS

Figure 22. Boring interpretation. (Borings show only what is in each hole: three identical borings do not guarantee uniform stratification. Three borings not in line is often a minimum requirement.)



TRIAXIAL CONSOLIDATION DIRECT SHEAR PERMEABILITY

Figure 23. Laboratory tests can give precise structural properties of samples. Accuracy of design is often limited by uncertainty of field situation and representativeness of samples.

sufficient to indicate consistency of conditions. For a 1,000-ft river crossing, five preliminary small diameter borings at 250-ft spacings may indicate the best location for piers but leave a question as to whether a clay layer may be used for support. Subsequent larger diameter borings at each pier and abutment location including undisturbed samples of the clay may provide more specific design data. Single borings at each pier or borings at diagonal corners may be indicated depending on the consistency of stratification.

For long trestles or fills, borings spaced at 100-ft intervals staggered across the line may be used for average conditions. Spacing may be increased to 400 ft for uniform conditions or decreased to 25 ft for nonuniform conditions. For trestles over uniform material, borings at every second or third bent may be sufficient. For critical slopes in cut or fill, three borings—at the middle of the slope, beyond the top, and beyond the toe—will provide a basis for analysis or further exploration. A general investigation followed by detailed study of critical areas is generally most efficient.

One boring should extend to a stratum below which it is known no poor material exists. One boring to rock is common if it is not over 100 ft deep. For foundations on rock, coring for 5 to 10 ft is required to evaluate the material and to be sure it is not a boulder. In general borings should not be stopped in soft material.

In homogeneous material, a depth of boring equal to twice the width of footing or twice the fill or cut height is generally sufficient, providing good bearing is found. However, a very weak layer at any depth may be important. Boring to a depth at which the applied stress is not over 1/10 the original soil stress is usually sufficient. It is desired to find a means of support and to eliminate the possibility of adverse conditions being left undetected. It is particularly important to look out for soft material underlying hard material which may be caused by gravel wash over a marsh or delta, surface drying of clay, artesian pressures from below, or weathered shale below thin beds of limestone or sandstone.

The method of exploration depends upon the problem, several may be used on one job. Augers are quick where applicable. Pits may be required in broken and mixed materials. Wash borings are applicable to most conditions except rock. Rock drills are required in many areas to insure penetration to and through all soft strata. While drilling gives accurate data at points, geophysical methods tend to average out irregularities. Observations recorded during and after construction should be tied into the previous exploration.

If exploration is done by contract, specifications should cover the quality of work with general limits for location and depth of borings. Whether by contract or the owner, the exploration must be controlled by an experienced professional engineer who can develop the program as data is obtained. When borings are contracted, payment is usually based on a lump sum for moving on and cleaning up the site, with unit prices per foot of each size hole in soil and in rock and a price for each undisturbed soil sample.

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