Steps in Soil Investigation

Planning

- Collection of Background Information
- Field Reconnaissance

Field work

- Bore-hole Drilling
- Collection of Soil Samples
- Field Tests (SPT, CPT etc.)

Laboratory work

- Laboratory Test on Soil Samples

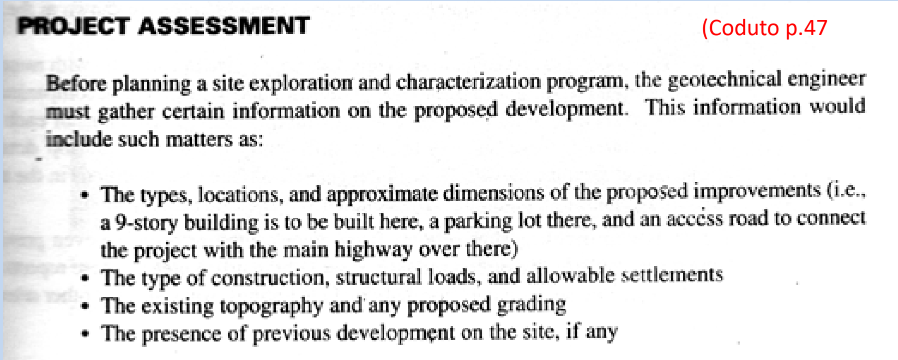
Reporting

- Preparation of Geotechnical Report

Planning of Subsurface exploration progam

Before deciding upon the site exploration program the following are needed:

- Project assessment
- Collection and study of existing information (Literature search)
- Reconnaissance



PROJECT ASSESSMENT

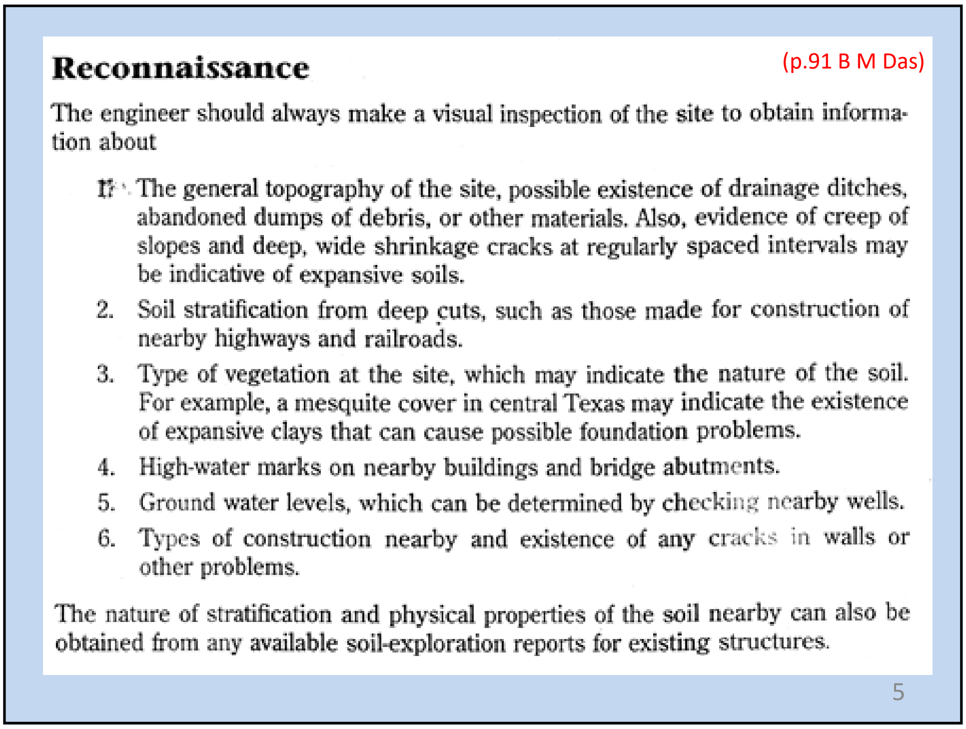
(Coduto p.47

Before planning a site exploration and characterization program, the geotechnical engineer must gather certain information on the proposed development. This information would include such matters as:

- The types, locations, and approximate dimensions of the proposed improvements (i.e., a 9-story building is to be built here, a parking lot there, and an access road to connect the project with the main highway over there)
- The type of construction, structural loads, and allowable settlements
- The existing topography and any proposed grading
- The presence of previous development on the site, if any

Literature search

- Site geology / Geological Maps
- Soil survey reports
- Previous Geotechnical Investigation reports (from same site/ other nearby projects)
- Historical ground water data



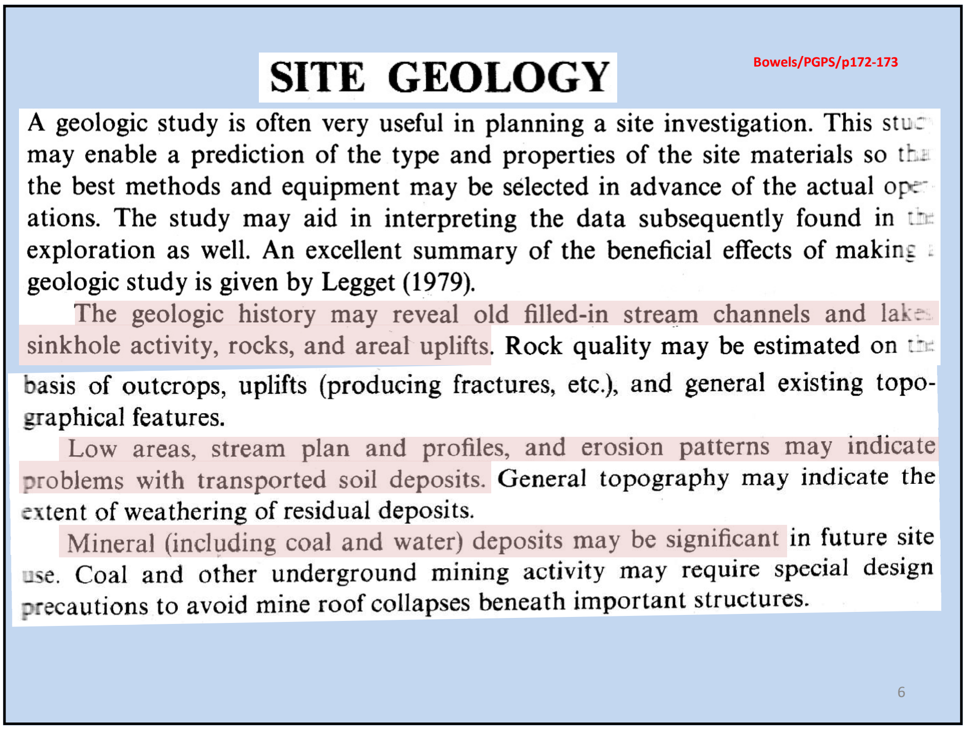
Reconnaissance

(p.91 B M Das)

The engineer should always make a visual inspection of the site to obtain information about

1. The general topography of the site, possible existence of drainage ditches, abandoned dumps of debris, or other materials. Also, evidence of creep of slopes and deep, wide shrinkage cracks at regularly spaced intervals may be indicative of expansive soils.
2. Soil stratification from deep cuts, such as those made for construction of nearby highways and railroads.
3. Type of vegetation at the site, which may indicate the nature of the soil. For example, a mesquite cover in central Texas may indicate the existence of expansive clays that can cause possible foundation problems.
4. High-water marks on nearby buildings and bridge abutments.
5. Ground water levels, which can be determined by checking nearby wells.
6. Types of construction nearby and existence of any cracks in walls or other problems.

The nature of stratification and physical properties of the soil nearby can also be obtained from any available soil-exploration reports for existing structures.



SITE GEOLOGY

Bowels/PGPS/p172-173

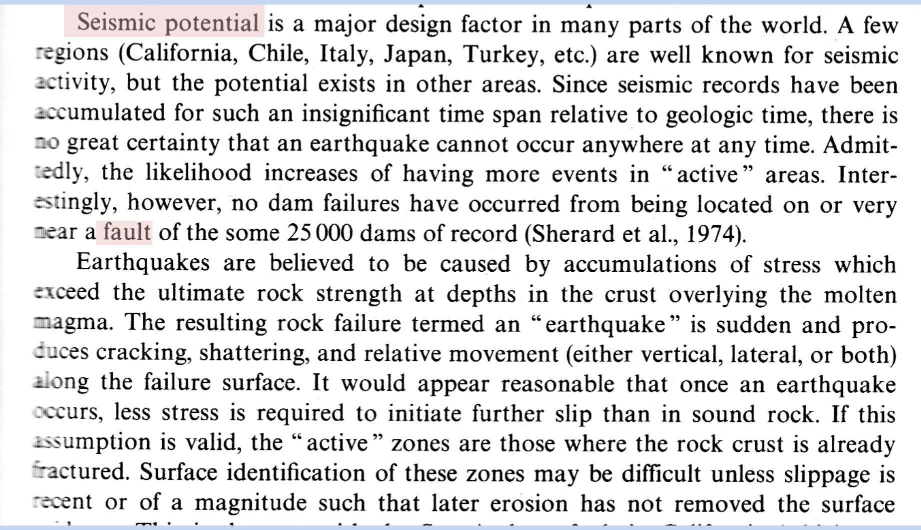
A geologic study is often very useful in planning a site investigation. This stu may enable a prediction of the type and properties of the site materials so th the best methods and equipment may be selected in advance of the actual op ations. The study may aid in interpreting the data subsequently found in th exploration as well. An excellent summary of the beneficial effects of making geologic study is given by Legget (1979).

The geologic history may reveal old filled-in stream channels and lake sinkhole activity, rocks, and areal uplifts. Rock quality may be estimated on th basis of outcrops, uplifts (producing fractures, etc.), and general existing topographical features.

Low areas, stream plan and profiles, and erosion patterns may indicate problems with transported soil deposits. General topography may indicate the extent of weathering of residual deposits.

Mineral (including coal and water) deposits may be significant in future site use. Coal and other underground mining activity may require special design precautions to avoid mine roof collapses beneath important structures.

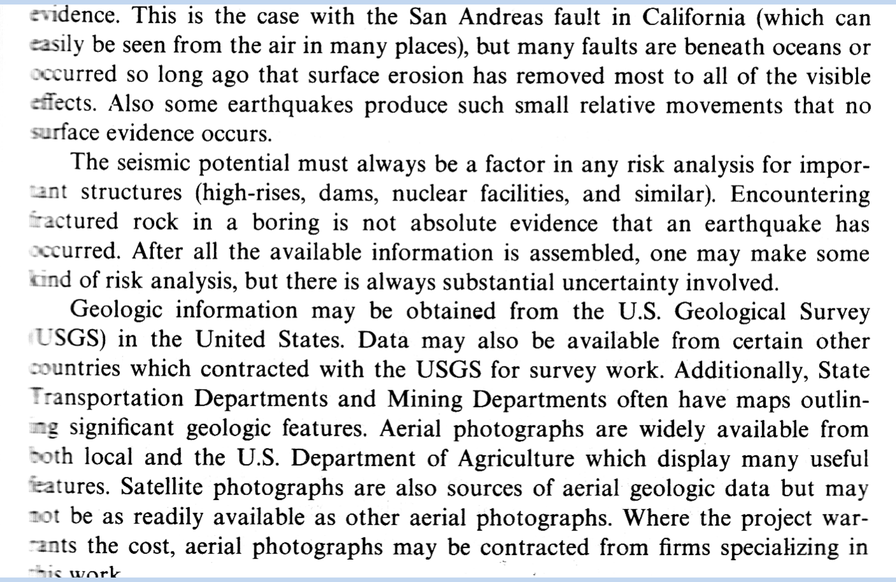
Site Geology........contd.



Seismic potential is a major design factor in many parts of the world. A few regions (California, Chile, Italy, Japan, Turkey, etc.) are well known for seismic activity, but the potential exists in other areas. Since seismic records have been accumulated for such an insignificant time span relative to geologic time, there is no great certainty that an earthquake cannot occur anywhere at any time. Admittedly, the likelihood increases of having more events in "active" areas. Interestingly, however, no dam failures have occurred from being located on or very near a fault of the some 25 000 dams of record (Sherard et al., 1974).

Earthquakes are believed to be caused by accumulations of stress which exceed the ultimate rock strength at depths in the crust overlying the molten magma. The resulting rock failure termed an "earthquake" is sudden and produces cracking, shattering, and relative movement (either vertical, lateral, or both) along the failure surface. It would appear reasonable that once an earthquake occurs, less stress is required to initiate further slip than in sound rock. If this assumption is valid, the "active" zones are those where the rock crust is already fractured. Surface identification of these zones may be difficult unless slippage is recent or of a magnitude such that later erosion has not removed the surface

Site Geology........contd.



evidence. This is the case with the San Andreas fault in California (which can easily be seen from the air in many places), but many faults are beneath oceans or occurred so long ago that surface erosion has removed most to all of the visible effects. Also some earthquakes produce such small relative movements that no surface evidence occurs.

The seismic potential must always be a factor in any risk analysis for important structures (high-rises, dams, nuclear facilities, and similar). Encountering fractured rock in a boring is not absolute evidence that an earthquake has occurred. After all the available information is assembled, one may make some kind of risk analysis, but there is always substantial uncertainty involved.

Geologic information may be obtained from the U.S. Geological Survey (USGS) in the United States. Data may also be available from certain other countries which contracted with the USGS for survey work. Additionally, State Transportation Departments and Mining Departments often have maps outlining significant geologic features. Aerial photographs are widely available from both local and the U.S. Department of Agriculture which display many useful features. Satellite photographs are also sources of aerial geologic data but may not be as readily available as other aerial photographs. Where the project warrants the cost, aerial photographs may be contracted from firms specializing in this work.

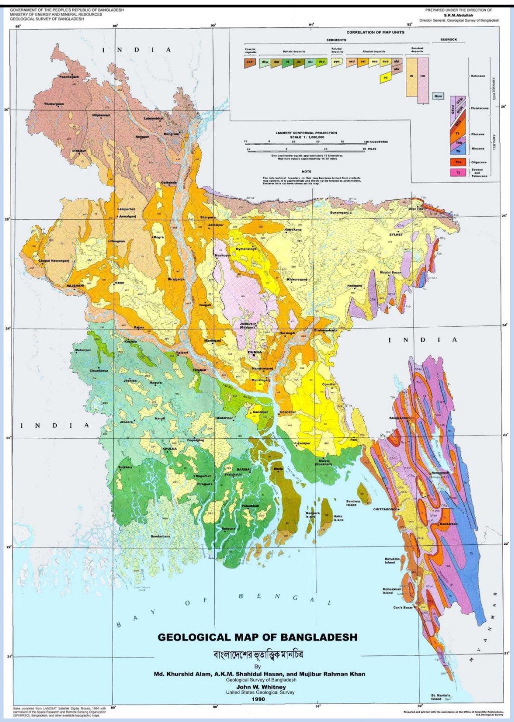
SOIL BORING AND TEST PIT

- **Boring method**
- **Number of boring**
- **Boring Layout**
- **Boring depth**
- **Sampling specifications (interval, type etc.)**

Das/PFE/p.91

Boring depth

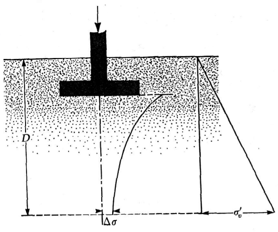
The approximate required minimum depth of the borings should be predetermined. The depth can be changed during the drilling operation, depending on the subsoil encountered. To determine the approximate minimum depth of boring, engineers may use the rules established by the American Society of Civil Engineers (1972):



Considerations for Boring depth

Boring depth……..contd.

1. Determine the net increase of stress, $\Delta\sigma$, under a foundation with a depth as shown in Figure 2.9. (The general equations for estimating stress increase are given in Chapter 4.)
2. Estimate the variation of the vertical effective stress, σ'_v, with depth.
3. Determine the depth, $D = D_1$, at which the stress increase $\Delta\sigma$ is equal to $(\frac{1}{10})q$ (q = estimated net stress on the foundation).
4. Determine the depth, $D = D_2$, at which $\Delta\sigma/\sigma'_v = 0.05$.
5. Unless bedrock is encountered, the smaller of the two depths, D_1 and D_2, just determined is the approximate minimum depth of boring required.



▼ FIGURE 2.9 Determination of the minimum depth of boring

Das/PFE/p.92

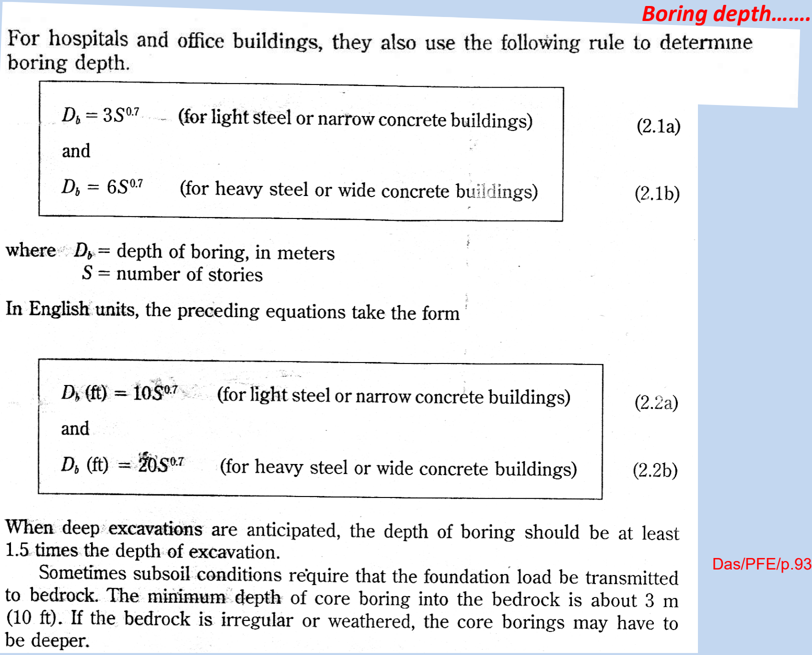
Boring depth……..contd.

If the preceding rules are used, the depths of boring for a building with a width of 30.5 m (100 ft) will be approximately the following, according to Sowers and Sowers (1970):

No. of stories	Boring depth
1	3.5 m (11 ft)
2	6 m (20 ft)
3	10 m (33 ft)
4	16 m (53 ft)
5	24 m (79 ft)

Das/PFE/p.92

Boring depth……..contd.



For hospitals and office buildings, they also use the following rule to determine boring depth.

$$D_b = 3S^{0.7} \quad \text{(for light steel or narrow concrete buildings)} \qquad (2.1a)$$

and

$$D_b = 6S^{0.7} \quad \text{(for heavy steel or wide concrete buildings)} \qquad (2.1b)$$

where D_b = depth of boring, in meters
S = number of stories

In English units, the preceding equations take the form

$$D_b\,(\text{ft}) = 10S^{0.7} \quad \text{(for light steel or narrow concrete buildings)} \qquad (2.2a)$$

and

$$D_b\,(\text{ft}) = 20S^{0.7} \quad \text{(for heavy steel or wide concrete buildings)} \qquad (2.2b)$$

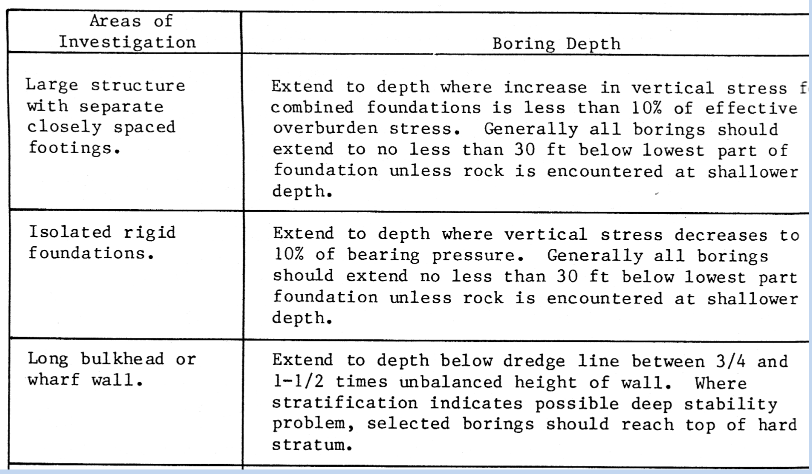
When deep excavations are anticipated, the depth of boring should be at least 1.5 times the depth of excavation.

Sometimes subsoil conditions require that the foundation load be transmitted to bedrock. The minimum depth of core boring into the bedrock is about 3 m (10 ft). If the bedrock is irregular or weathered, the core borings may have to be deeper.

Das/PFE/p.93

Boring depth……..contd.

Guidelines for boring depths according to NAVFAC DM 7.1, 1982



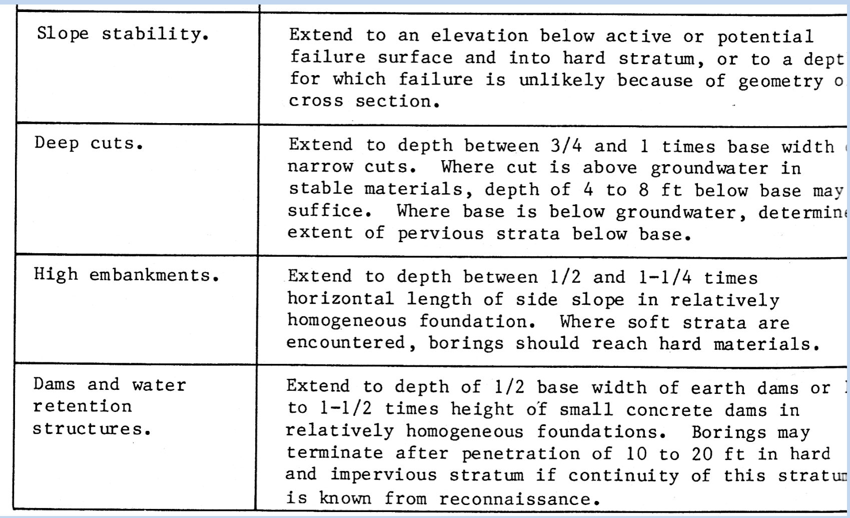
Areas of Investigation	Boring Depth
Large structure with separate closely spaced footings.	Extend to depth where increase in vertical stress f combined foundations is less than 10% of effective overburden stress. Generally all borings should extend to no less than 30 ft below lowest part of foundation unless rock is encountered at shallower depth.
Isolated rigid foundations.	Extend to depth where vertical stress decreases to 10% of bearing pressure. Generally all borings should extend no less than 30 ft below lowest part foundation unless rock is encountered at shallower depth.
Long bulkhead or wharf wall.	Extend to depth below dredge line between 3/4 and 1-1/2 times unbalanced height of wall. Where stratification indicates possible deep stability problem, selected borings should reach top of hard stratum.

Table 7 / p.7.1-70

Naval Facilities Engineering Command

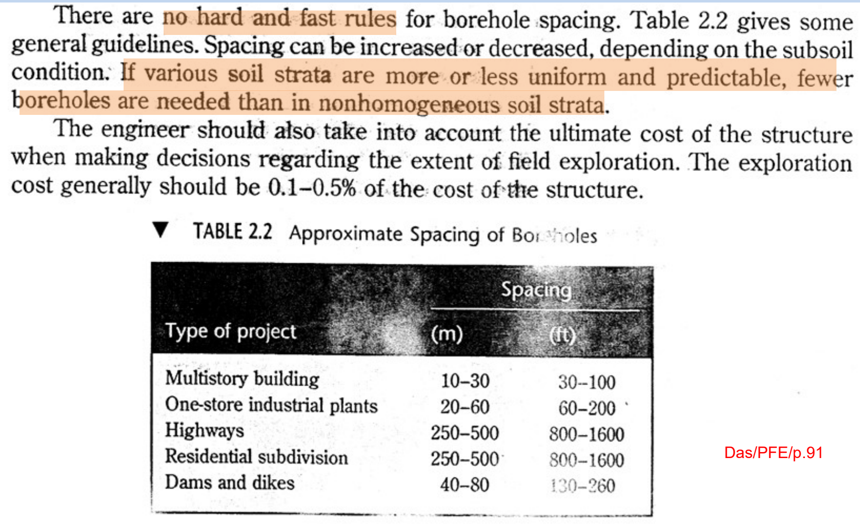
Boring depth……..contd.

Guidelines for boring depths according to NAVFAC DM 7.1, 1982



Slope stability.	Extend to an elevation below active or potential failure surface and into hard stratum, or to a dept for which failure is unlikely because of geometry o cross section.
Deep cuts.	Extend to depth between 3/4 and 1 times base width narrow cuts. Where cut is above groundwater in stable materials, depth of 4 to 8 ft below base may suffice. Where base is below groundwater, determin extent of pervious strata below base.
High embankments.	Extend to depth between 1/2 and 1-1/4 times horizontal length of side slope in relatively homogeneous foundation. Where soft strata are encountered, borings should reach hard materials.
Dams and water retention structures.	Extend to depth of 1/2 base width of earth dams or to 1-1/2 times height of small concrete dams in relatively homogeneous foundations. Borings may terminate after penetration of 10 to 20 ft in hard and impervious stratum if continuity of this stratum is known from reconnaissance.

Number of Boring / Borehole spacing



There are no hard and fast rules for borehole spacing. Table 2.2 gives some general guidelines. Spacing can be increased or decreased, depending on the subsoil condition. If various soil strata are more or less uniform and predictable, fewer boreholes are needed than in nonhomogeneous soil strata.

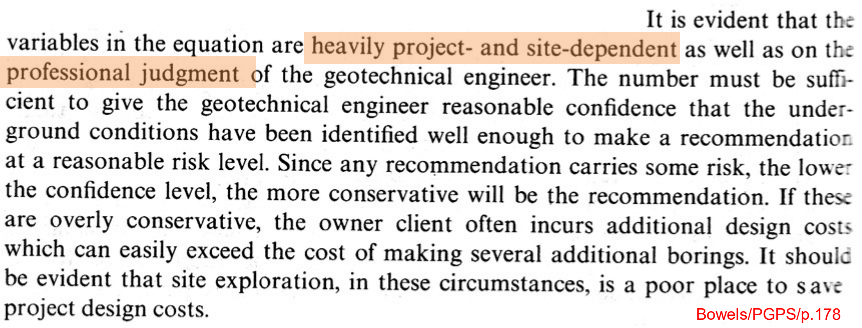
The engineer should also take into account the ultimate cost of the structure when making decisions regarding the extent of field exploration. The exploration cost generally should be 0.1–0.5% of the cost of the structure.

▼ **TABLE 2.2** Approximate Spacing of Boreholes

Type of project	Spacing (m)	Spacing (ft)
Multistory building	10–30	30–100
One-store industrial plants	20–60	60–200
Highways	250–500	800–1600
Residential subdivision	250–500	800–1600
Dams and dikes	40–80	130–260

Das/PFE/p.91

Number of Boring / Borehole spacing…..contd



It is evident that the variables in the equation are heavily project- and site-dependent as well as on the professional judgment of the geotechnical engineer. The number must be sufficient to give the geotechnical engineer reasonable confidence that the underground conditions have been identified well enough to make a recommendation at a reasonable risk level. Since any recommendation carries some risk, the lower the confidence level, the more conservative will be the recommendation. If these are overly conservative, the owner client often incurs additional design costs which can easily exceed the cost of making several additional borings. It should be evident that site exploration, in these circumstances, is a poor place to save project design costs.

Bowels/PGPS/p.178

(Thumb rule) For residential buildings app. 1 borehole per katha (720 sft ≈ 67 sqm).
Number may be increased if these borings show great variability in the sub-soil profile.

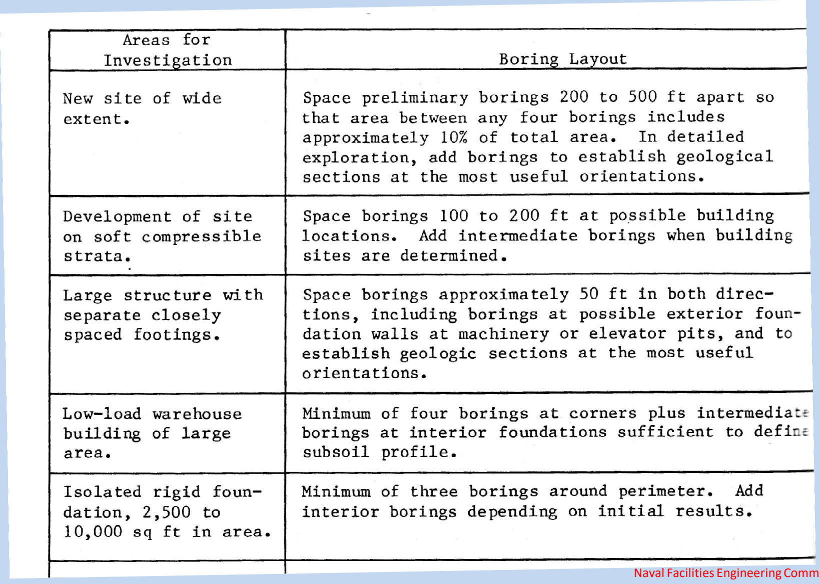
Boring Location / Layout

Bowels/PGPS/p.177

- Boring location is subjective; hard & fast rules are not possible
- Locations generally depends on site topography and/or proposed location of structure.
- Confidence is subjective in nature and thus for a project where one geotechnical engineer accepts three or four borings, some other may require six or eight.
- Some design codes provide broad guidelines.

Boring layout….contd.

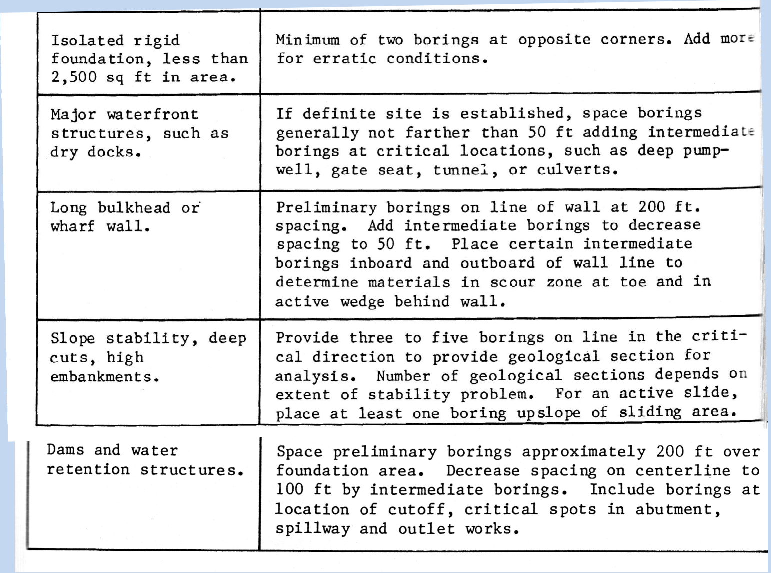
Guidelines for boring layout according to NAVFAC DM 7.1, 1982



Areas for Investigation	Boring Layout
New site of wide extent.	Space preliminary borings 200 to 500 ft apart so that area between any four borings includes approximately 10% of total area. In detailed exploration, add borings to establish geological sections at the most useful orientations.
Development of site on soft compressible strata.	Space borings 100 to 200 ft at possible building locations. Add intermediate borings when building sites are determined.
Large structure with separate closely spaced footings.	Space borings approximately 50 ft in both directions, including borings at possible exterior foundation walls at machinery or elevator pits, and to establish geologic sections at the most useful orientations.
Low-load warehouse building of large area.	Minimum of four borings at corners plus intermediate borings at interior foundations sufficient to define subsoil profile.
Isolated rigid foundation, 2,500 to 10,000 sq ft in area.	Minimum of three borings around perimeter. Add interior borings depending on initial results.

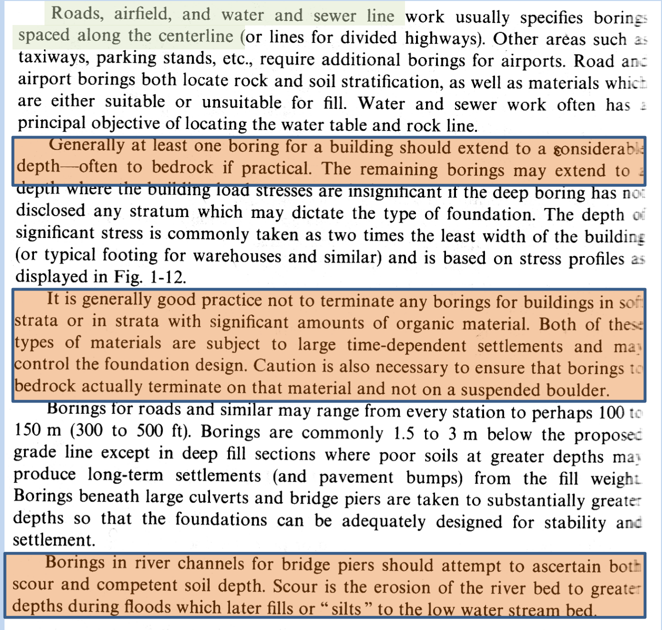
Naval Facilities Engineering Command

Boring layout….contd.



Isolated rigid foundation, less than 2,500 sq ft in area.	Minimum of two borings at opposite corners. Add more for erratic conditions.
Major waterfront structures, such as dry docks.	If definite site is established, space borings generally not farther than 50 ft adding intermediate borings at critical locations, such as deep pumpwell, gate seat, tunnel, or culverts.
Long bulkhead or wharf wall.	Preliminary borings on line of wall at 200 ft. spacing. Add intermediate borings to decrease spacing to 50 ft. Place certain intermediate borings inboard and outboard of wall line to determine materials in scour zone at toe and in active wedge behind wall.
Slope stability, deep cuts, high embankments.	Provide three to five borings on line in the critical direction to provide geological section for analysis. Number of geological sections depends on extent of stability problem. For an active slide, place at least one boring upslope of sliding area.
Dams and water retention structures.	Space preliminary borings approximately 200 ft over foundation area. Decrease spacing on centerline to 100 ft by intermediate borings. Include borings at location of cutoff, critical spots in abutment, spillway and outlet works.

Boring layout….contd.



Roads, airfield, and water and sewer line work usually specifies borings spaced along the centerline (or lines for divided highways). Other areas such as taxiways, parking stands, etc., require additional borings for airports. Road and airport borings both locate rock and soil stratification, as well as materials which are either suitable or unsuitable for fill. Water and sewer work often has a principal objective of locating the water table and rock line.

Generally at least one boring for a building should extend to a considerable depth—often to bedrock if practical. The remaining borings may extend to a depth where the building load stresses are insignificant if the deep boring has not disclosed any stratum which may dictate the type of foundation. The depth of significant stress is commonly taken as two times the least width of the building (or typical footing for warehouses and similar) and is based on stress profiles as displayed in Fig. 1-12.

It is generally good practice not to terminate any borings for buildings in soft strata or in strata with significant amounts of organic material. Both of these types of materials are subject to large time-dependent settlements and may control the foundation design. Caution is also necessary to ensure that borings to bedrock actually terminate on that material and not on a suspended boulder.

Borings for roads and similar may range from every station to perhaps 100 to 150 m (300 to 500 ft). Borings are commonly 1.5 to 3 m below the proposed grade line except in deep fill sections where poor soils at greater depths may produce long-term settlements (and pavement bumps) from the fill weight. Borings beneath large culverts and bridge piers are taken to substantially greater depths so that the foundations can be adequately designed for stability and settlement.

Borings in river channels for bridge piers should attempt to ascertain both scour and competent soil depth. Scour is the erosion of the river bed to greater depths during floods which later fills or " silts " to the low water stream bed.

Bowels/PGPS/p.178