FEDERAL WORKS AGENCY

UNITED STATES HOUSING AUTHORITY

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S U B - S U R F A C E S O I L I N V E S T I G A T I O N

Technical Material for Information of
Architects and Engineers

(August 1, 1939)

The suggestions in this Bulletin, however, in no way relieve the housing project designer of the responsibility for relating these recommendations to local building code requirements, local practices, and local geological conditions. That this be done is, in fact, the most important recommendation of the Bulletin.

Because project conditions differ so widely no hard and fast rules for conducting thorough sub-surface investigations may be listed. The general suggestions which follow are offered as constructive aid in developing the necessary procedure for a thorough study of these conditions.

PART I

PROCEDURES IN ARRANGING FOR INVESTIGATIONS

1. It is the responsibility of the local housing authority to determine the extent of, and to make arrangements for, the necessary sub-surface soil investigations.

2. Where it is evident that only a limited amount of investigation is necessary, the local authority may request its architect to arrange for and supervise the work, or it may engage an engineer and hire the labor to make the investigation on force account as part of its administrative expenses. Such work should be limited to costs not exceeding one thousand dollars, unless limited to a smaller cost by local law.

3. Where investigations involve costs which probably will exceed one thousand dollars, or a lesser amount in compliance with local law, it is advisable to prepare specifications for the work to be done and request bids from contractors experienced in this class of work. The work should be awarded to the competent and qualified contractor submitting the lowest bid. The services of a competent supervising engineer may be included with the specified work or may be arranged for as a separate contract. The architect's engineer who is to design the foundations should either supervise the soil investigation or should collaborate with the engineer engaged to supervise the work. Copies of all specifications, invitations to bidders and bids for contract work, together with the recommendations of the local authority for award of contract, and copies of the proposed contract agreements, should be submitted to the United States Housing Authority for approval before making an award.

4. All work, either under force account or under contract, must be done according to the provisions in the "Terms and Conditions" of the Loan Contract. Of these provisions, the following should be incorporated in any specification prepared:

Hours of Work.
Wage Rates.
Pay Rolls, Project Data and Records.
Kick-Back Statute and Regulations.

5. Where work is to be executed by contract, unit prices shall be requested with the bids for additions to, or deductions from, the work specified. These are usually requested

per lineal foot for each type of boring. Because the relative cost increases with increase in depth, different unit prices are advisable for open pits, for each succeeding five feet in depth, or some similar increment in depth. This may be determined by the probable necessity for sheeting below certain depths. It is recommended that a minimum amount of work for each type of exploration, usually expressed as a total lineal footage, be guaranteed to the Contractor. The estimated maximum cost, which will not be exceeded without further approval of the United States Housing Authority, should accompany the local housing authority's recommendations for award of a contract.

PART II

DETERMINATION OF EXTENT OF INVESTIGATION

A. Preliminary Investigation Prior to Loan Contract:

1. A preliminary investigation is essential prior to making application for a loan contract and prior to optioning or acquiring a site, to determine that the proposed site will not involve excessive foundation costs, and to justify the preliminary cost estimates which accompany the application. Comparatively favorable sub-surface conditions may often be the decisive factor in the choice of a site. In some instances, tentative sites may be abandoned because investigation reveals unfavorable sub-surface conditions.

2. Much pertinent data for preliminary investigation is obtainable locally without making ground explorations. Local city records and topographical maps are usually accessible. These will indicate probable underlying formations and the geological history of the area. Old records often show whether at some prior date the site included a ravine, swamp, pond or gully, which has subsequently been filled in or covered by alluvial deposits; whether it has been used as a dump; or whether surface conditions have changed in some manner. Geological history will indicate the probable presence of glacial deposits. Old residents in the neighborhood, excavating contractors, and utility companies may be questioned as to their knowledge of the underground conditions and surface changes. Neighboring buildings, as well as those on the site, should be closely inspected for evidences of damage resulting from unequal or excessive settlements, the types of foundations used, and the dry or wet condition of basement or cellar spaces. All such available data should be carefully and thoroughly collected and recorded. These records should be analyzed to determine if some soil exploration on the site is advisable prior to making the application for the loan, or acquisition of the site.

B. Comprehensive Investigation Subsequent to Loan Contract:

1. After a loan contract has been consummated and prior to actual foundation design, a comprehensive investigation should be made. The extent of such investigation depends on many factors, and should be determined by the architect's structural engineer, who will use the data for his design.

2. The soil stratification, at a given location, may be determined in a number of ways. The oldest, and best method is actual excavation of pits, by which the stratification is exposed for examination, and conditions which will be met in actual foundation construction are seen in their true relations. Where great depths or frequent exploration are needed, or where ground water is encountered, borings will probably have to be made. Rod soundings occasionally are used to advantage.

3. (a) Each site is an individual problem, and the proposed number, location, and depth of open pits or borings must be determined from the preliminary data that have been obtained. These may need to be augmented as the exploration proceeds and discloses the necessity for additional information.

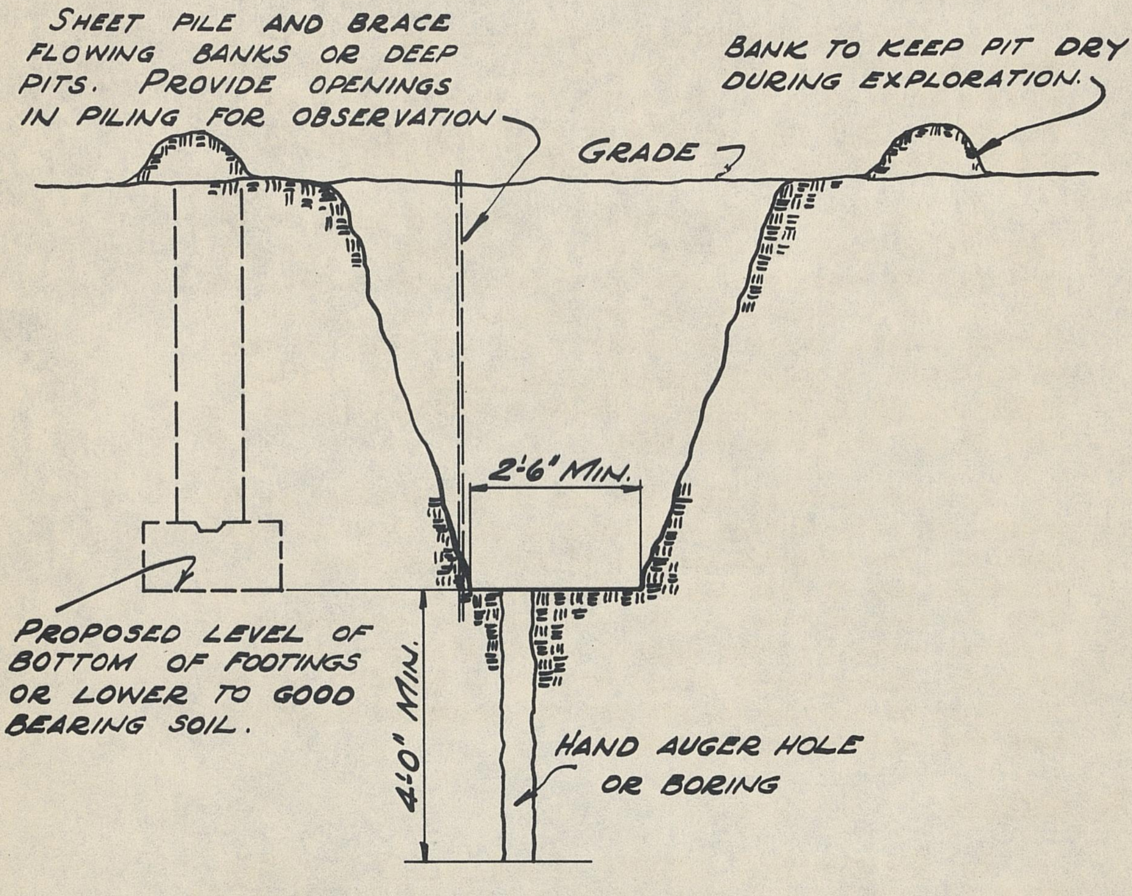
(b) On sites where the preliminary data indicate that favorable bearing soils lie close to the surface, it may prove sufficient to excavate only a few open pits to verify the assumed data. Where the preliminary data or the open pits indicate the presence of top fills or soft grounds, or the presence of questionable underlying strata is indicated or suspected, it is advisable to make a number of borings. These may be few in number, located in well distributed, representative areas of the site, if the sub-surface strata are found to be definitely uniform in character and level. On the other hand, if the evidence indicates varying fills or underlying strata, pockets of unfavorable character, or wide and rapid changes in stratification, a sufficient number of intermediate borings should be taken to determine the extent and variation of such areas. On many sites, borings should be made under each corner of the proposed buildings, and in some instances between corners.

(c) The necessary depths of the borings will be governed by the underlying conditions, but they should extend sufficiently to assure at least four feet of uniform bearing stratum under the footings. Where soft underlying strata are indicated or suspected, a few of the borings should extend to depths 15 feet below the footings. Borings may well be supplemented by a few pits, which are invaluable for gaining complete understanding of the foundation difficulties in unknown sub-surface conditions. Under certain conditions--for example, to determine the approximate contour of a rock stratum within depths of proposed bearing, or the depth of soft ground--sounding bars may be used to augment data disclosed by the pits or borings. The use of sounding bars may be misleading for it is not possible to determine accurately the nature of the material penetrated. By making several soundings within a radius of a few feet, however these instruments will check the presence of a boulder.

4. Where the suitability of a soil for bearing is doubtful, load tests should be made to determine the safe allowable load. Where the necessity for pile or caisson foundations is indicated, load tests are usually specified to be placed on selected piles, after some of the piles in the contract construction work are installed, in order to verify the assumed driving resistance and bearing values. It is not practical to place equipment on the site to drive a few test piles in advance of awarding contract work.

5. It is essential to make accurate observation of ground water levels, and to supplement such observation with information obtained from local sources regarding variations in levels. This is particularly advisable where footings are to rest in clay, or other relatively impermeable strata which will hold water against the foundation walls and the underside of the basement floors, so that necessary drainage and water proofing may be provided in construction of the proposed buildings.

CHART I



TYPICAL OPEN PIT EXPLORATION

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PART III

TYPES OF EXPLORATION

A. Open Pits:

1. Open pit excavations are illustrated in Chart I. Where such pits exceed 8 feet in depth, or lesser depths, in some kinds of soil, the walls of the pits often must be braced. Care must be used in arranging bracing to permit observation of the undisturbed materials.

2. The pits should extend to levels at which it is proposed to place the bottom of the footings. If an unsatisfactory bearing stratum is found at such depths, the pits should be extended, within reason, to satisfactory bearing strata, which are suitable for the proposed type of footings. A minimum four foot thickness of bearing strata should be verified by making a boring into the soil at the bottom of the pit.

3. The material from the pit should be piled as removed, and sufficiently scattered to allow thorough examination. The relative amounts of the various kinds of materials may be more clearly determined in this way than from the exposed sides of the pit, but the hardness and moisture content of the various strata will not be so evident. Arrangements should be made to backfill the excavations as soon as the pit and the excavated materials have been examined and recorded.

B. Borings:

1. The essential function of a boring is to obtain authentic samples and true elevations of the various kinds of soil, including various soft materials, and to permit determination of true ground water levels. This can only be done reliably by the use of dry core boring equipment.

2. Dry core borings utilize a driven casing pipe. Through this a smaller size pipe is driven after the earth within the casing pipe is cleaned out by one of several methods. The smaller pipe is fitted with a valved bottom, which progressively penetrates the undisturbed stratum below the bottom of the casing pipe as the exploration proceeds to the various depths, and a core or slug of the soil in its natural state is collected.

3. Wash borings are often utilized for both deep and shallow explorations. Except as a method of cleaning out

the casing pipe for dry core borings, this type of boring is not recommended because samples of the material penetrated cannot be examined in their undisturbed condition. The water used for cleaning out casing pipes makes it impossible to determine moisture content, or to locate accurately ground water levels.

4. Augers are also extensively used for borings. Their satisfactory use is limited to materials which will stay in the helix of the auger until brought to the surface--for example, dry earth, clays, and combinations in which sufficient clay is present to make the material cohesive. It is especially difficult to make these borings in any soil other than clay if water is present, as the water carrying the soil from the surrounding strata will flow into the bore hole. Auger outfits utilizing derrick and hoist have been used for cleaning out the casing pipes for dry core borings. When sand is encountered it often becomes necessary to use a sand pump or water jet. It is usually advisable to start a new hole, when boulders are encountered, although they are sometimes broken up with a chopping bit. Augers are especially adapted to verifying the depth of satisfactory clay, or clay and sand strata at the bottom of open pits. They may also be used for such verification, after excavation for footings, during contract construction work.

C. Rod Soundings:

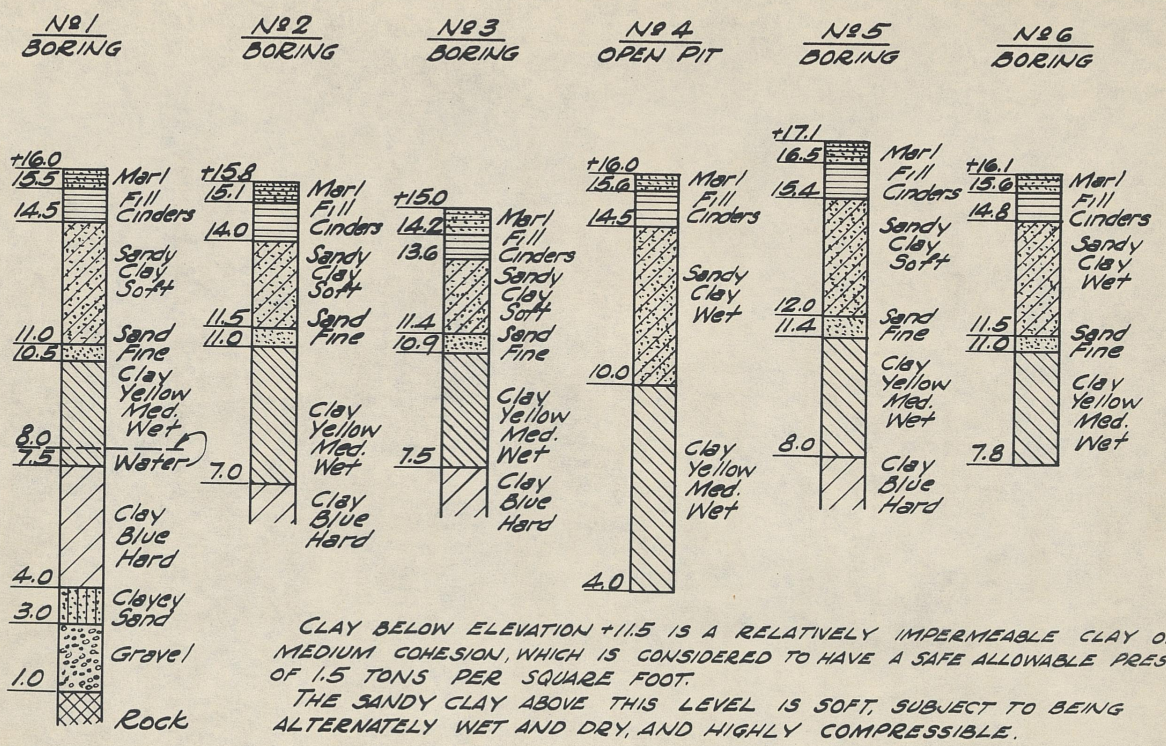
1. Sounding is usually done with bars 5/8 inch to 7/8 inch in diameter, depending on the material to be penetrated. The bottom length usually is pointed and 10 to 12 feet long, to permit it to be churned down 6 to 8 feet by hand. Additional lengths are coupled on and driven with a 10 to 12 pound maul.

2. Samples have been withdrawn by using a short piece of gas pipe on the bottom of the rod, but such samples are necessarily difficult to obtain and are not reliable.

D. Observing Ground Water Levels:

1. Certain representative bore holes should be selected for observation. The observations should extend over a period of at least one week to allow the water to come to equilibrium at its natural level. To permit this, the hole must be covered and protected to prevent surface water from running directly into it.

CHART II



CLAY BELOW ELEVATION +11.5 IS A RELATIVELY IMPERMEABLE CLAY OF MEDIUM COHESION, WHICH IS CONSIDERED TO HAVE A SAFE ALLOWABLE PRESSURE OF 1.5 TONS PER SQUARE FOOT.

THE SANDY CLAY ABOVE THIS LEVEL IS SOFT, SUBJECT TO BEING ALTERNATELY WET AND DRY, AND HIGHLY COMPRESSIBLE.

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TYPICAL LOG OF OPEN PITS AND BORINGS

PART IV

RECORDING AND ANALYSIS OF DATA

A. Field Records and Samples:

1. Careful field records should be kept of all matters and conditions pertinent to the work. These notes should include the elevation of the surface at each pit or boring, the depth at which each stratum is encountered, the kind of material in each stratum, whether the material is hard or soft, whether the material will stand without casing or sheeting, the location and nature of obstructions encountered, and other items that may assist in the interpretation of the earth stratification.

2. Samples of the earth should be obtained at each change of stratum and at each 5 feet in depth of each stratum. As they are taken and before they dry out, samples should be placed in wide mouthed bottles, tightly corked or capped to preserve the original moisture in the material. Gummed labels, on which are printed the location of the boring and the depth or elevation of the stratum, should be placed on each bottle for identification. Every precaution should be taken to make the samples truly representative of the material encountered.

B. Preparation of Log:

1. A drawing showing a complete log of the exploration data, as illustrated in Chart II, together with a site plan showing the dimensional location of all pits, borings and soundings, should be carefully prepared. The log should be comprehensive, showing the kind of soil in each stratum, the ground water levels, the surface elevation of the ground and the depth to, or the elevation of, each stratum. Each kind of soil should be adequately described to show whether it is hard or soft, its moisture content, and its relative permeability or capacity to drain free of water. The various soils and their condition should be indicated by symbols and descriptions, as illustrated in Chart II.

C. Analysis of Data:

1. The primary object of the sub-surface investigation is to establish the type of foundation which will result in uniform settlement within reasonable limits, as every soil except rock is compressible. Measurements

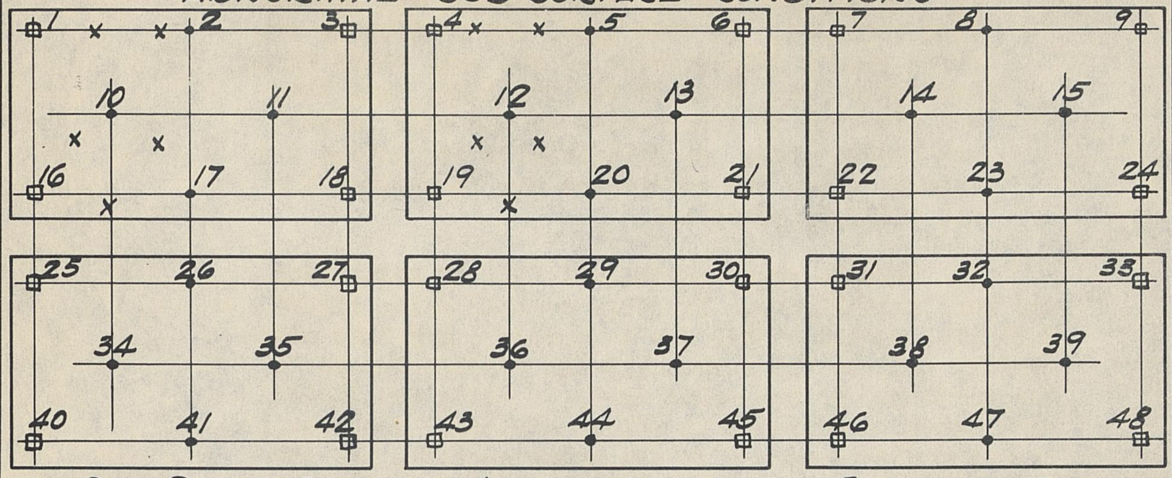
of settlements have shown that absolute equal settlements rarely occur even under like unit loads on many of the common soils. This is evidenced by the frequent appearance of settlement cracks in the masonry walls of existing buildings. In most instances, such cracks have made their appearance years after construction, demonstrating that unequal settlements increased with time. In other instances, cracks have appeared at an early date, and no further cracking has developed. This indicates that non-uniform settlement occurred immediately after the load was applied on the soil, and then ceased almost entirely as the soil became consolidated, with further settlement small and uniform, if at all. Observations further indicate that ends of buildings placed close to adjacent buildings often settle more than ends which are further apart; that center portions of long walls settle more than the corners of the buildings, or the shorter end walls; that interior foundations settle more than exterior walls, and, generally, that settlement is greater near the center of long buildings than near the ends. Some soils near the surface expand and swell when saturated, and shrink and crack open when dry, actually raising and lowering, alternately, entire buildings. In a few instances, portions of a building have heaved upward while other portions settled. Buildings which settle uniformly often settle more than the adjacent surfaces, causing objectionable, and, at times, unsafe relations between floor level and adjacent entrance stoops, porches, or walks, and causing damage to underground utilities extending from the buildings. These evidences indicate the need for a thorough and experienced analysis.

2. Settlement under load is essentially of two different types:

(a) Settlement due mostly to lateral flow of the underlying strata, with little or no consolidation. Characteristic of this type is the fact that the volume of settlement is practically equal to the volume of soil which flows laterally from underneath the building. If due to low permeability of the soil, the consolidation attributed to increased pressures proceeds slowly. The volume displaced by lateral flow represents practically the entire vertical displacement which the building will undergo, at least for a period of many years. If the lateral flow is arrested by driving sheet piling or by similar methods, the settlement will practically stop.

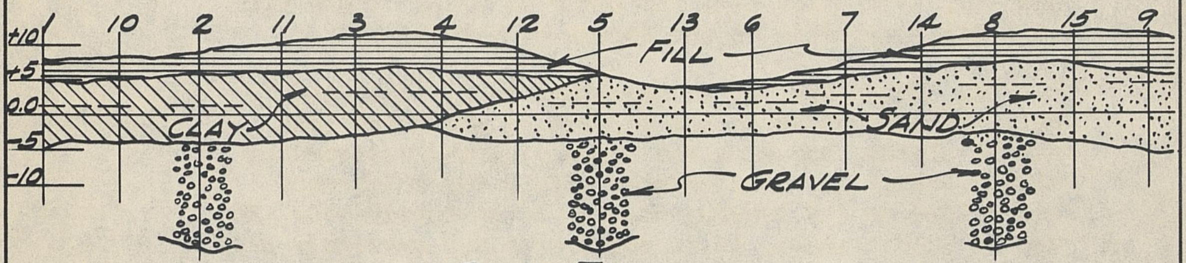
CHART III

ILLUSTRATING CROSS SECTIONAL STUDIES FOR ABNORMAL SUB-SURFACE CONDITIONS



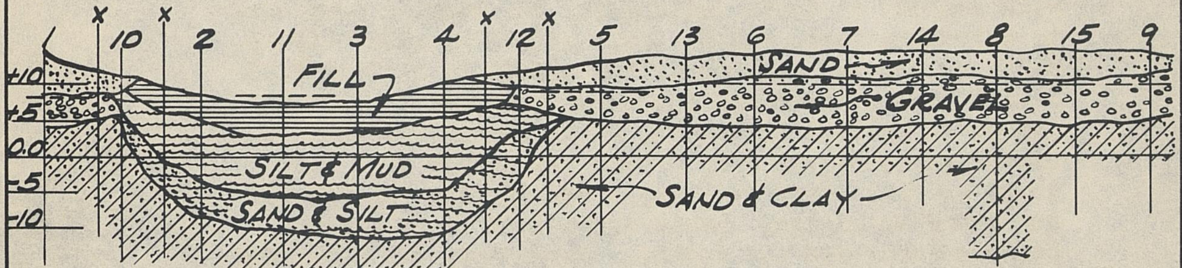
□ = OPEN PITS • = BORINGS X = ADDITIONAL BORINGS ---- = PROPOSED FTG. ELEV.

SITE PLAN



CASE I

BORINGS 2,5,8,41,44 & 47 TAKEN TO -20 AND BALANCE OF BORINGS AND PITS TAKEN AT LEAST 4'-0" BELOW PROPOSED FOOTING BOTTOMS. THE CROSS SECTION PLOTTED FROM THIS INFORMATION SHOW THAT THE STRATA FOR AT LEAST 5'-0" BELOW PROPOSED FOOTINGS ARE ADEQUATE FOR SPREAD FOOTINGS. THE FEW DEEP BORINGS SHOW THAT THE LOWER STRATA ARE ALSO RELIABLE. NO FURTHER BORINGS ARE NECESSARY.



CASE II

BORINGS 1, 5 TO 9 INCL. SHOW ADEQUATE BEARING FOR SPREAD FOOTINGS AT BASEMENT LEVEL. 10, 2, 11, 3, 4 AND 12 SHOW THE EXISTANCE OF A FORMER STREAM OR SWAMP NOW FILLED IN. PITS AND BORINGS TO 4'-0" BELOW PROPOSED FOOTINGS DO NOT GIVE ADEQUATE INFORMATION. WHEN SUCH A CONDITION IS FOUND BORINGS SHOULD BE CONTINUED DOWN INTO SATISFACTORY STRATA. ADDITIONAL BORINGS (X) SHOULD BE MADE TO DETERMINE LIMITS OF THE POOR STRATA.

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(b) Settlement due to consolidation and lateral flow combined. In this type, the settlement results from a displacement of the soil which flows laterally from beneath the building, plus that due directly to compression of the soil beneath the loaded area. By artificially preventing the lateral flow, the settlement may be reduced but not entirely prevented.

3. Certain other characteristics of settlement are well established. If soils contain voids filled with air, volume change due to pressure may take place rapidly because the excess air can readily escape to the surface. On the other hand, if voids are filled with water, a decrease in volume obviously requires a corresponding decrease in the water content, and the compression cannot proceed more rapidly than the speed at which the water is squeezed out. The less permeable the soil the more slowly the water escapes and consequently, settlement will not occur at once. There will be a lag, depending on the degree of permeability.

4. Therefore, it is important to picture, not only the soil close to the surface on which the load may be placed, but also the underlying and surrounding strata, which may considerably affect the settlement under load of the bearing stratum being considered. To aid in such studies, it is convenient and extremely useful to draw several cross-sections of the soil strata at intervals across the site, as revealed by the explorations made, interpolating the strata between the explorations, as illustrated in Chart III.

5. In analyzing the logs and site cross-sections, it is important to classify the various soil strata with respect to their suitability for bearing purposes, to allowable load, and to their effect on other strata above or below. Because of the practical minimum size limitations of footings for housing projects which will result in uniform pressures, it is rarely possible to exceed pressures of over 2 tons per square foot for three or four story buildings, and 1½ tons for one and two story buildings. Large variations in relative footing areas are not common. Therefore, the essential determination of soil classification for this type of building may be considerably simplified. It becomes important to know of the presence of soft strata, which will settle excessively under very light loads; the presence of organic matter which will decompose and permit subsidence; the observed relative cohesiveness of the soil or its tendency to flow; the observed

relative permeability of the soil, i. e., its tendency to quickly or slowly drain free of water infiltration. The occurence of hard, firm strata near the surface, suitable for appropriate bearing value at proposed footing elevations, should be analyzed for adequate depth below the proposed bottom of footings, and for the presence of soft underlying strata.

6. Where it is found that firm bearing stratum occurs only at considerable depth below the surface, a condition which makes the use of piles advisable, careful analysis of the strata through which the piles must be driven is required. It has been demonstrated that the value of a pile, driven into very permeable strata such as sandy stone fill, can be reliably determined, when driven according to the "Engineering News" formula. However, for piles driven into soil having very small permeability, such as loam, silt and soft clay, the pile-driving formulae give variable values. For the latter character of soils, the safe allowable load should be determined by making a load test. To determine the proper assumption for a pile foundation design, i. e., type and depth of piles, expert judgment of the soil data obtained is necessary. It will generally not be practical to drive test piles and make test loads on piles driven prior to the foundation design for housing projects. In analyzing the soil data, it is best to distinguish between three different conditions:

(a) Piles will bear on bed rock or a stratum, the bearing capacity of which is equal to or greater than the unit load on the cross section of the pile.

(b) Piles are to transfer the building loads through a very compressible top layer to a less compressible stratum.

(c) Piles will penetrate into a deep deposit, the consistency of which does not appreciably increase with depth.

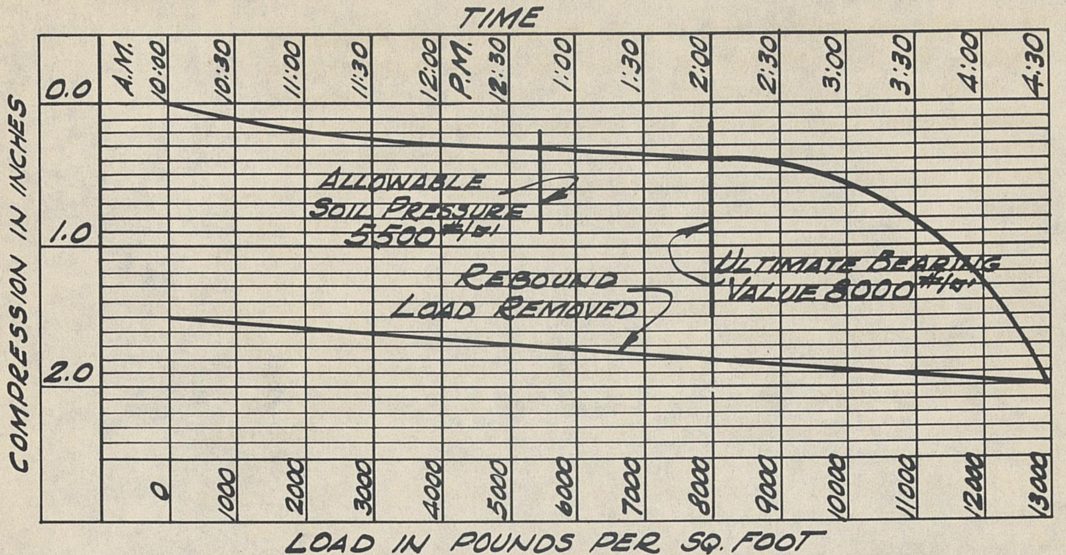
Condition (a) needs no discussion. In condition (b) the feebly resistent top layer may or may not be made more compact by the pile driving. If the surface of the deposit subsides when piles are driven through a top layer, such as one composed of very fine-grain, saturated sand, it may safely be assumed that the pile driving reduces the volume of voids, which, in turn, increases the bearing power and decreases the compressibility of the deposit. In contrast, when piles are driven into a deposit, such as one composed of soft wet clay, the surface rises between the piles, sometimes as much as several inches. This indicates that the volume of voids of the material remains practically unchanged and the pile driving produces no consolidation of the material. In the first case, the piles will increase the bearing capacity of the top layer and will need to penetrate the underlying stiffer bottom layer only a short distance. In the second case, the pile must penetrate the lower stratum sufficiently to develop a bearing capacity great enough to support the load without much aid from the upper stratum. A large group of piles in such strata may act as a unit and subside with the compressibility of the soft top layer, if not extended sufficiently into the stiffer layer below. A single pile, however, may be sustained by both the bearing in the stiffer sub-stratum and the friction on the pile in the soft top layer. Under condition (c), the proper length of the piles should be greater than the width of the structure to be supported, so that the piles will reduce the intensity of the maximum pressure near the surface and shift the zone of maximum stress from the surface to levels near the lower ends of the piles. If the length of the piles is less than the width of the building, the pressure reducing effect of the piles is very small, for the short piles become an integral part of the compressible soil. Under this soil condition, the knowledge of the safe load of an individual pile represents only a minor part of the information required for depicting the behavior of the foundation as a whole.

D. Allowable Load:

1. The allowable load, as herein used, is regarded as a safe function of the settlement of a selected soil, whereas the bearing capacity is the ultimate load the soil will bear, with satisfactory settlement. A determination of the allowable load and the bearing capacity, as herein defined, implies that a load test should be made on the soil or pile. The necessity for determining the allowable load by load test is a matter which the engineer in charge of the investigation must determine. In many instances, the data will confirm conditions for which safe allowable load values are locally known and commonly used with satisfactory results. Whenever there is any doubt as to a safe allowable load, a load test should be made.

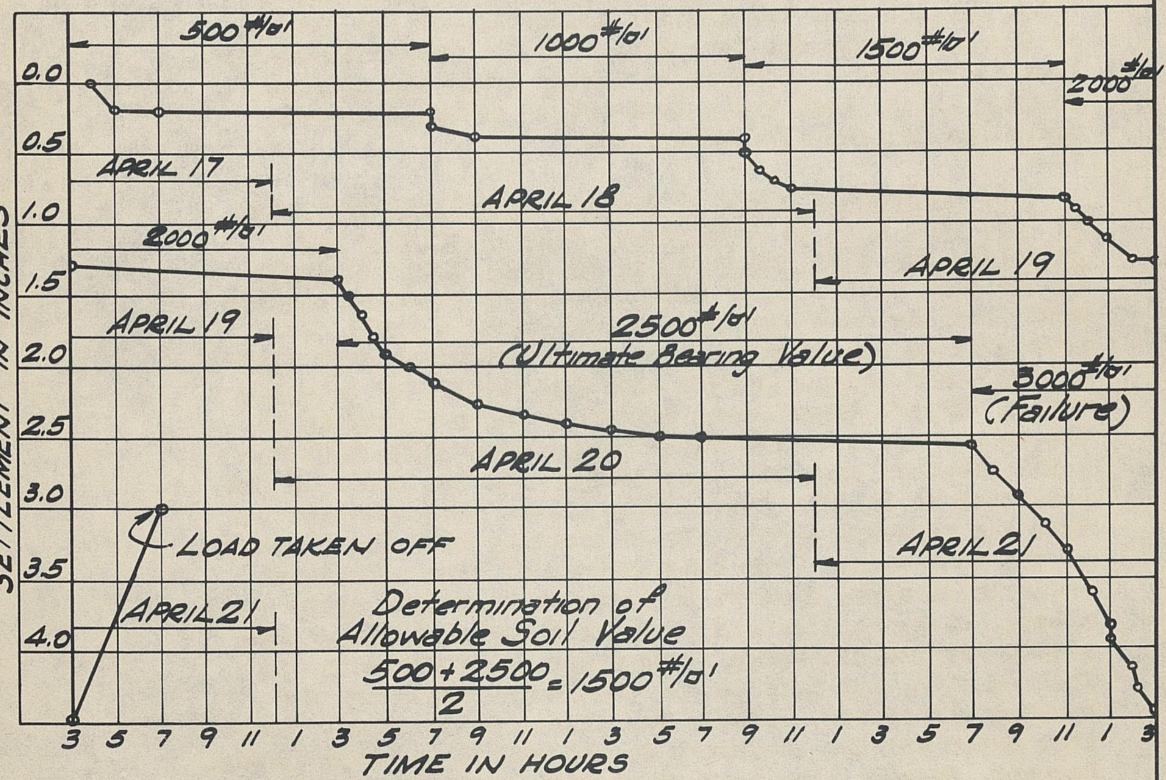
2. It is believed that the limit of allowable load should be approximately 1/2 of the value shown by a compression diagram between the point where the soil

CHART IV



COMPRESSION DIAGRAM

TYPICAL FOR UNIFORM APPLICATION OF LOAD



TIME SETTLEMENT CURVE

SEE PAGES 15, 16, 18

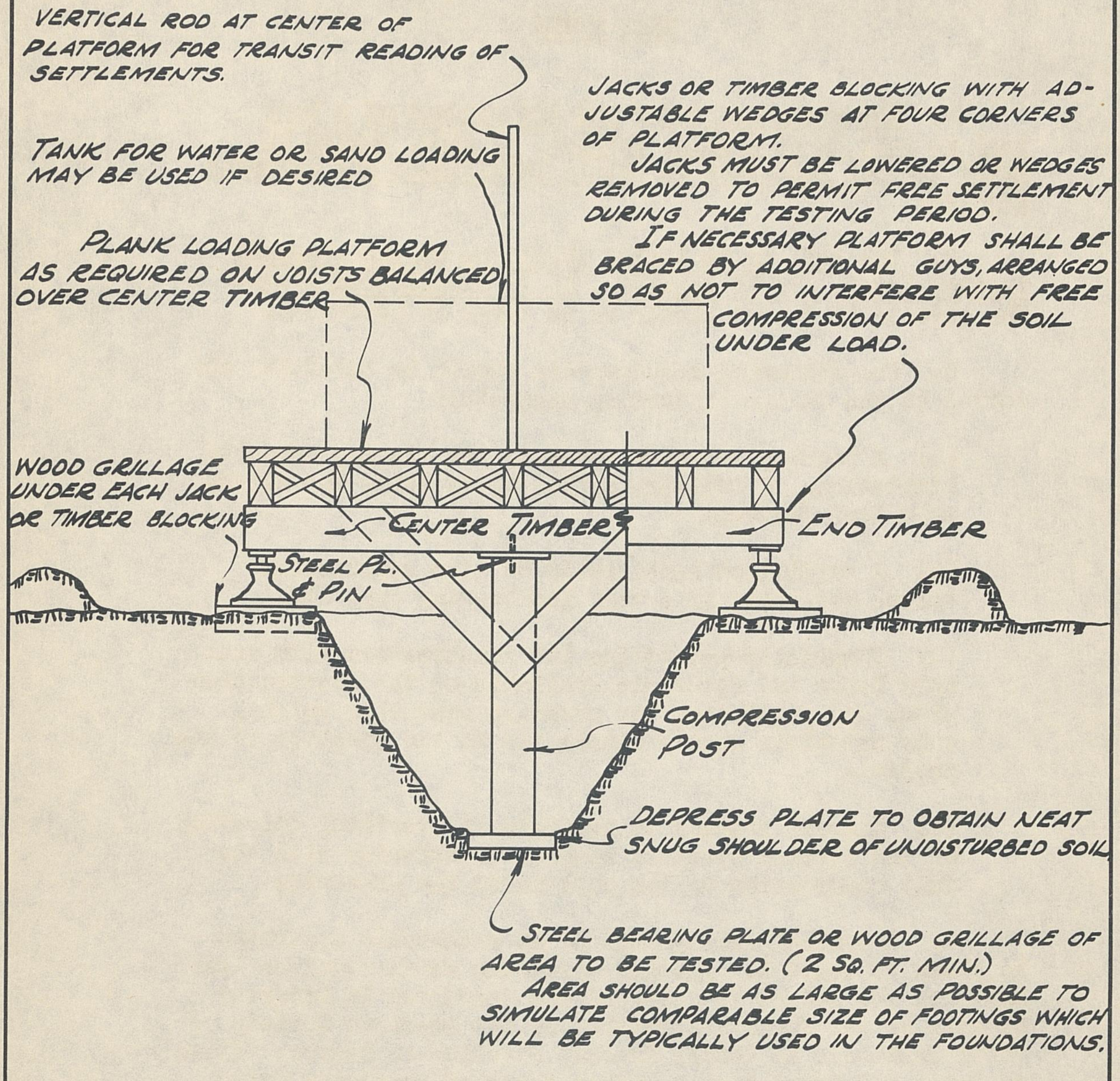
is merely compacted and the point where displacement begins, as illustrated by Chart IV. The compression by continuous application of load in any homogeneous soil, where there is not an excess of water causing a more or less viscous condition, is illustrated by a fairly regular form of compression curve. Such a curve shows a relatively large compression at the beginning of the load application, which diminishes rapidly as the load is applied. Then a considerable increase of load occurs with a fairly regular compression until, finally, rapid breakdown occurs, as displacement or crushing of the grains of the soil takes place. Even on piles in soft wet grounds, where the piles are held or aided by friction, the same form of compression curve is obtained. The allowable load is also often determined from a Time Settlement Curve, as illustrated in Chart IV. This curve results from plotting the settlement as each increment of load is allowed to cause pressure, until no additional appreciable settlement occurs for a period of approximately 12 hours before additional load is added. The allowable load should be limited to approximately 1/2 of the value where continued settlement occurs after application of additional load, disregarding any settlement which results from the initial compacting of the surface of the soil under the test area. If a specific allowable load is desired to conform to design loads and minimum footing sizes, load tests need not be extended beyond twice the desired allowable load.

3. Allowable loads or bearing capacities indicated by load test must be interpreted with experience and judgment, and with reference to the soil data obtained. It has been conclusively demonstrated by repeated experiment that the unit bearing capacity under a small test area will be considerably more than that which will ultimately occur under a larger area for relatively cohesive soils. Expert technicians differ in their theory as to the causes and relative variations. Some claim that the total pressure varies in accordance with the ratio of the perimeter to the diameter, while others have demonstrated that the pressure varies almost directly with the diameter of the test area. Over long periods of time settlement under large areas appears to increase more than under small areas. Close application of these theories would necessitate varying allowable loads under every variation in footing size, but this is not considered necessary for housing structures, because the sizes of the normal footings under any one structure do not vary to a large degree. However, where a load test is applied over a test area of one or two square feet and the resulting bearing capacity is utilized to determine the allowable load under

areas of ten square feet or more, a considerable error may result. It is preferable to make the load test on an area closely approximating the proposed footing areas. Where this is not practical, adjustments must be made to the bearing capacities obtained under small test areas for soils that are relatively cohesive.

4. Where the engineer in charge of an investigation has not had sufficient experience with conditions disclosed to enable him to confidently determine a safe allowable load, he should obtain the services of a consultant on soil mechanics and analysis who has had experience with such conditions.

CHART V



TYPICAL ARRANGEMENT OF APPARATUS
FOR LOAD TESTS ON SOIL

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PART V

LOAD TESTS

1. The preparations for and the conduct of a load test on soil or on a pile, caisson, or pier, should be given careful attention to obtain intelligent and reliable results.

2. The soil to be tested should be at the proposed footing level, and if possible, in an undisturbed state. The area to be tested should be as large as practical.

3. The following requirements should be carefully observed in the design of testing apparatus:

(a) A testing capacity equal to the bearing capacity limitations of ordinary soils, or to twice the allowable load desired.

(b) A sufficient sensitivity to give compression values for soils of a very low bearing capacity.

(c) Simplicity permitting its construction with ordinary labor and materials available on the construction site, and requiring, for pressure producing weight, only materials easily obtainable in the locality of the project.

(d) Lateral bracing to maintain the vertical direction of the applied pressure without interfering with the full compression of the soil under the pressure.

4. A typical arrangement of an acceptable apparatus is shown in Chart V. Another apparatus which requires less material for weight is detailed and discussed in Progress Reports of the Special Committee of the American Society of Civil Engineers to Codify Present Practice on Bearing Values of Soils for Foundations. Other types of apparatus using hydraulic jacks or pile driving rigs have been successfully used for load tests.

5. In the conduct of the test it is important to follow a procedure of loading the apparatus in small increments and measuring the resultant compression of the soil after each increment of the load has been placed. After each increment of load is placed and the compression has assumed a normal rate, an interval of at least 12 hours should elapse before the next increment is placed. The initial compression immediately following the application of the load will generally

be accelerated by the impact and rate of loading, which may give an erroneous initial reading. The compression should be measured immediately after each increment of load has been applied, and after each period of rest before the next increment is added. After the final increment of load has been applied, a period of at least 48 hours should elapse before the load is removed. The compression should be measured each 24 hours after the final load application, unless an increasing rate of settlement, indicating failure, is noted. The rebound after removal of the load should also be measured. A chart of the compression for each application of load should be prepared, showing the rate of compression and the rebound, as illustrated in Chart IV.

PART VI

APPLICATION OF DATA TO FOUNDATION DESIGN

1. The selection of the proper type of foundations bears a basic relationship to a complete analysis of the sub-surface soil investigation. Settlement which would be considered excessive near the surface of the ground, due to underlying strata of uncertain behavior may be satisfactory for an undisturbed stratum overlying stiff and feebly compressible strata. Settlement for a single pile may be entirely erroneous for a large cluster of piles. Settlement for a small test area may be an entirely unsafe value for a large footing or a continuous raft mat foundation.

2. Where the sub-surface conditions reveal the need to extend spread footings to slightly greater depths than those ordinarily required for frost protection, it is necessary to determine the relative economy of continuous foundation walls or grade beams supported on piers. The relative difficulties of excavation, requirements for sheeting and bracing and the removal of ground water, as well as the presence of existing basements, cisterns, abandoned cesspools, manholes, or other underground voids, fills, utilities, etc., all have a direct bearing on this determination.

3. Where rock is encountered at varying elevations, it is essential to decide if all of the footings or foundations should extend to rock bearing, or if portions of the footings should rest on earth, with sand cushions used over the rock to equalize the relative compressibility. For this condition it is again advisable to study the economy of continuous foundation walls as compared to grade beams and piers. The necessity for removal of rock must be determined and the probable amount of such removal estimated. The probable slope of the surface of the rock and the probable occurrence of fissures and intervening veins of soft strata should be considered.

4. Under varying sub-surface conditions, it may be advisable to use two or more different types of foundations beneath some buildings, although this condition should be avoided as much as possible. Thus, one end of a building may be on piles and the other end on rock or earth. Also, adjacent buildings may be judiciously placed on different types of foundations. For such conditions it is essential to determine where the change in type of foundations should occur. Expansion joints should be provided in the superstructure at each change under a building, and the final location of the building may need to be adjusted to suit the sub-surface conditions.

5. For conditions of design which will require footings at varying levels, for example, deep basements at only portions of the buildings, or stepped floor levels, due to a sloping topography it may be necessary to place footings at varying elevations. The effects of placing the loads on the soil at such varying elevations should be carefully analyzed for the comparative effect on compressibility of the soils. Also, the effects of spreading the loads from varying levels above to underlying strata, and the possibility of the strata sliding or flowing must be studied. Additional data may be necessary to make the proper design.

6. Because of the practical limits to which investigation prior to design must be kept, it is probable that the foundation design may not completely suit the sub-surface conditions. However, the investigation should serve to assure a proper type of foundation which will be subject to minimum adjustment during construction. Actual excavation for the foundation should be closely inspected, and checked for verification of the assumptions made for the foundation designs. In this way proper adjustments can be expeditiously made to obtain assurance of uniform compressibility and resulting settlements, and to avoid serious delays.

Nathan Straus

NATHAN STRAUS,
Administrator.

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