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Foundations For Low-Cost Housing

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FOUNDATIONS FOR LOW-COST HOUSING

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The function of a foundation is to transmit the weight of the superstructure and live loads imposed on it to the soil at a stress that the soil can withstand. The soil must possess adequate shear strength to prevent a failure by rupture of the soil. This resistance is known as bearing capacity. For design a factor of safety of three is usually allowed for the dead weight of the structure plus the maximum combination of live loads that is likely to act during the life of the structure. In addition, the soil must also be able to withstand the loads without detrimental settlement. The exact amount of settlement that is detrimental is determined by the structural system and its ability to withstand displacements of members and secondly, the use to which the building is to be put. A pin-connected steel structure could withstand large settlements without overstressing the individual columns and beams, whereas the tolerance of a concrete rigid frame structure is much less. Often a value of one inch total settlement is the criteria adopted for allowable settlement of a reinforced concrete building. To design a foundation, a separate bearing capacity analysis and a settlement analysis must be made using two separate soil engineering properties. Often different stress inputs must be used.

If the soil can accept the stresses at a shallow depth without being overstressed or overstressing underlying soils, a shallow foundation is indicated. In some cases, shallow soil layers are weak and compressible, or soils within the zones of stress influence below these shallow soils are weak and compressible. If so, a deep foundation is indicated. Usually, the additional density achieved from the weight of overlying sediments means that soils tend to become stronger and less compressible with depth, but unhappy accidents of geology, such as organic deposits of loose silt or sand prevent this generality from being usable without verification. There are several types of shallow foundations. An individual spread footing is an enlargement of the base of a column so that the column load is "spread" to accomodate the load to the stresses that the soil can withstand. For a wall, the wall footing, an enlargement of the base of the wall is common. Reinforced concrete is the preferred material, but obviously masonry, rubble, or treated wood grillage might also be employed. Another shallow foundation is the mat or raft in which all loads are transmitted to a single well-reinforced concrete surface which covers the plan area of the structure.

Deep foundations include piles, piers, and caissons.

The recent new materials revolution has made few contributions to foundation practice. For shallow foundations, cast-in place concrete is superior to precast prestressed concrete in that laborious hand leveling and cleaning off "high spots" is not required. In the realm of deep foundations, prestressed concrete piling has been used, but most material changes have been evolutionary rather than revolutionary. New construction machinery to excavate for deep foundations has been developed, but largely this is a response to the spiralling cost of labor in technologically advanced countries.

Whether we are dealing with a technologically developed economy or not, deep foundations are expensive, whereas the spread footing-wall footing type is relatively inexpensive. There is a quantum-jump in cost as stresses exceed those that can be carried satisfactorily by a spread footing foundation. This fact of life is well recognized by every foundation engineer. For a one-story warehouse building, an inexpensive foundation can suddenly become the major cost, exceeding that of the superstructure. The obvious solution is to make the structure lightweight or to choose site locations where the soil conditions at shallow depths and within the zone of significant soil stresses are excellent. An example known to the author was when a corporation obtained an option to purchase land to be used as a warehouse with the right to conduct a foundation exploration. The question posed to the foundation engineer was, "Can a simple one-story warehouse be supported on spread foundation footing or are deep foundations required?" The answer was affirmative. Had the answer been negative, the additional cost for a deep foundation, (piles), would have have been tens of thousands of dollars per acre.

Expressed in such a manner, it is plain to see that foundation costs should be ascribed to site costs. An alternate site, costing ten thousand dollars per acre more than the original might have truly been a bargain if it meant the difference in cost between a spread footing foundation and a pile foundation could be saved.

A given site however, might be suitable for a light structure and not for a heavy one. For a given structure the maximum system of loads varies with the geologic soil profile and the settlement criteria. For a given site the use of spread footings may or may not be possible by changing the design from heavy construction (mass concrete, heavy masonry, etc.) to lightweight (steel framing, lightweight curtain walls, etc.). If a standardized design of low cost housing is adopted, some foundation savings may accrue to a lightweight system as opposed to a heavy one. This is one of the advantages of mobile home trailers for invariably their foundation costs are negligible.

The other method to avoid the use of expensive foundations is to select sites with soil conditions that are adequate to support the design loads on shallow foundations. This is done by exploration, sampling and proper interpretation.

Exploration is simply the gathering of information of the extent of the soil bodies and their engineering behavior. It follows principles of inference and statistics. It is some-

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times quite foreign to the nature of the architect and structural engineer. Steel is a man-made material with centuries of development, and is generally a rather uniform material. Its properties are given in a handbook. There is no need for the engineer to sample and test each shipment to ascertain design values to be used.

The problem in soils is complicated for there is a great deal of variation in engineering properties within a soil stratum which has at least a color and textural similarity. Even if some reasonable estimate can be made of the properties of the stratum, the extent and dimensions of this stratum are a function of the geologic agent which deposited it. Some deposits by their geologic nature are reasonably extensive and uniform, others have uniformity over only a small area. A four-story apartment house may significantly stress a soil volume approximately equal to the plan area of the building to depth of twenty feet, depending on the exact nature of loads and materials. This may be a volume of soil of several thousand cubic yards. Yet the foundation engineer must assess the range of engineering properties of this soil mass with a boring and sampling program that will recover less than one-millionth of that volume of soil.

Exploration then, includes the boring of a hole and the taking of a sample from the hole. If the soil is cohesive in nature, neither strength nor compressibility can be accurately assessed if the soil sample is disturbed, although rough estimates can be made. Special measures are then required to prevent sample disturbance. Even so, the sample chosen may not have been typical of the soil mass. A thorough sampling program is required, just as the Gallup poll cannot be content to interview just one voter.

For cohesionless sands and silts, the prospect of obtaining undisturbed samples from a borehole are reasonably remote, especially if the sample is to be taken from below the static water table. For this case, the standard penetration tests, a dynamic measure of soil density and resistance to penetration is employed. This penetration resistance correlates with the strength characteristics and compressibility of the soil. The elevation of the water table is also sought from the field exploration.

On-site exploration in underveloped countries poses some problems and opportunities. Expensive rotary drilling equipment used in soils exploration in the U.S. is largely a capital intensive labor-saving device. The methods of the 1930's, the hand-dug test pits, are often as good or better, and obviously more suited to labor-intensive economic societies. The wash-boring rig, uses a simple tripod, a water pump, and perhaps manpower at the end of a rope to propel the 140 pound hammer or to raise and lower the chopping bit. It may seem unsophisticated, but it is an excellent substitute for a mobile rotary drill rig, which could not be economically justified in a labor-rich economy.

Soils are geologic materials, placed or deposited by geologic agents. A soils engineer understands geology therefore a study of geologic reports of an area would give him a picture of the expected nature of the soil deposits and a very general picture of the expected range of soil properties. Almost never would such a report be a sufficient basis for choosing foundation design values, but it is very pertinent to the selection of the soil exploration program.

The interpretation of airphotos by an expert is another valuable method of obtaining general soils information. In the United States it is rarely necessary to have airphoto missions flown. The U.S. Department of Agriculture Agricultural Stabilization and Conservation Service provides coverage of all counties in which there is virtually any agricultural activity. Thus 95% of the area east of the Rocky Mountains is photographed every five to eight years. Much of the other area is photographed by the U.S. Forest Service. The United State Geologic Survey also has extensive coverage of the U.S. For foreign countries, the coverage may not be so thorough, but even old airphotos are generally valuable for soils investigation purposes. Except in the floodplains of major meandering streams and in a few other locations, soil conditions change little over a twenty-year period.

The airphoto is a picture of surface conditions and as such reflects the surface geology and soils. Viewed stereoscopically, a great deal of information may be inferred about the geologic materials and processes which have formed the landscape. The analysis of drainage patterns and gully shapes often serves to detect the granularity of the soil deposit, and often the geologic origion can be inferred. Areas of potential soil problems can often be seen on airphotos where they may be missed on the ground. Area of swamps, marshes, soil with high organic content, sites of former landslides, etc. can be readily detected.

Airphotos should be used as an aid to final interpretation and for the design of an on-site exploration program. But even so, the U.S. Army has had moderately good results in trying to predict the suitability of land for cross-country tank mobility by airphoto means. The soil is often not available for direct test for military reasons.

Agricultural soils survey reports, where available, are an excellent source of information. Recent United States County Surveys are extremely detailed and even have a section describing the engineering soil properties. Even if this section is not present, the agronomist routinely performs several tests which are of use to the engineer, viz. Atterberg Limits and grain-size analysis of the soils. In the broad sense, some soil types and classifications reflect certain geologic parent materials and this knowledge is an aid to the foundation engineer.

The full extent of the required exploration program may unfold only as the various preliminary surveys and as the on-site programs provide data. Beyond a certain amount, the information becomes redundant, up to this point the design is too risky. No rules of thumb can guide the architect, structural engineer, or owner as to how much information is necessary. There is no substitute for a trustworthy competant foundation engineer. Often when severe money limitations are placed on the foundation engineer the response is that the engineer provides a larger factor of safety, which is, after all, a margin of error. If this means a difference between the possible use of spread footings and the use of piling, the price for the lack of information may be indeed high. There is no low-cost exploration, only intelligent exploration.

For individual housing units, sometimes overdesign is cheaper than an engineered foundation. This is often done for foundations for U.S. housing. For mass housing this could be dangerous. For individual custom-built homes, if one foundation was not adequate it might take a period of weeks or months to determine, and subsequent construction could use more conservative designs. For mass housing, if a soils problem exists, many houses would experience the distress. A general site exploration coupled with some simple on-site tests as the foundation is excavated, could be an acceptable compromise.

There is a strong tendency to standardize designs for a low cost housing project. Often, in order to use a standard plan a great deal of site grading is required. Often buildings are placed entirely on embankment fill, or what is even more critical, part of a building is placed on natural ground and part on fill.

Architects and design engineers are now beginning to appreciate that embankment fill is an engineering material and proper control of the compaction procedure can result in a strong reasonably incompressible engineering material.

However, the dead weight of this properly constructed embankment fill can cause major problems to the natural soil below. Five feet of fill, weighing 130 pounds per cubic foot will result in soil stresses greater than those imposed by most three-story buildings. These stresses are imposed over large areas, thus the natural soil is significantly stressed to a substantial depth. Bearing capacity failures of underlying soils due to the weight of an embankment have been documented by Peck (1954). Perhaps even more serious are the settlements caused by such stresses. If the soil is cohesive, such as a clay or organic silt material, the settlements will not occur immediately, but rather over a period of months, years, or decades. The time is controlled by that required for water to migrate from the stressed soil. The settlements may not be significant until after the construction of the building. Then the building may be racked by the settlements that occur, which are never uniform.

Often such a problem can be the result of a failure in communication between architect and soils engineer. The original plot plan requires little excavation, and the soils engineer proceeds with his investigation and design recommendations. A few footings are on shallow fills. Then discoveries are made, the plot plan is changed and deeper fills are required. The footings do not stress the fill material to a greater degree so the soils engineer is not called upon to change his design. But now the weight of the fill stresses the natural ground to a much greater degree and a problem is born.

The author is familiar with a case that illustrates the dangers of stresses applied by embankments. A series of rowhouse apartments, two stories high, were constructed. In part of the site, up to sixteen feet of embankment fill was required to achieve the desired grade. The underlying natural ground included a deposit of compressible organic clay, several feet in thickness. Even though the one apartment house was placed on piles to distribute the foundation loads below the organic layer, the weight of the embankment caused the organic layer to flow plastically, elongating the apartment building and opening tension cracks in the structural concrete of the building. At present, it is still not known whether these movements are continuing, and whether the building can be safely occupied.

All of the problems that are inherent in foundations for low cost housing cannot be catalogued in one paper. Some of the obvious problems are inherent in the general idea of economy and a limited budget. A low cost site often is an invitation for a high-cost foundation. A low cost foundation exploration is often an invitation to a high cost increase in factor of safety. There is no substitute for an adequate soil exploration; however intelligent planning can result in greater efficiency.

Test pits and other high labor input exploration methods are an excellent substitute in countries where labor is cheap and foreign exchange is lacking to buy expensive exploration equipment.

Deep embankments, even where compaction is well-engineered and supervised, by their very weight alone, impose very high stresses on the natural subsoil beneath the embankment. Bearing capacity failures and excessive settlements from this cause should be foreseen and prevented.

REFERENCES

Peck, R. B. (1954) "Failure Induced by Weight of Fill." Proc. Am. Railway Engr. Assoc., Vol. 55, pp. 645-649.