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# Principles of Foundation Design

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Every structure built by man must be supported, at least initially, on the surface of the earth. This simple fact, so obvious that it is all too often overlooked, gives to the art of foundation design an importance that is unique. Since the combination of any particular structure with the characteristics of the site on which it has to be founded is seldom duplicated, there is no convenient set of rules that can be applied with certainty to every foundation design. There are naturally rules for design, but these must always be applied with discretion and with full appreciation of the variations that may be present. It is this ever-necessary exercise of judgement in foundation work that makes its description as an "art" rather than a "science" so especially appropriate.

It is the purpose of this Digest to present a general review of the fundamental principles that must always govern the design of foundations. Previous Digests have dealt with some of the more important but detailed aspects of the subject. Future issues will continue this exposition and will show how the general principles can be applied in the selection of the type of foundation structure to be used in individual cases. The detailed design of large foundations is, naturally, the domain of the expert, but since the success of any superstructure is completely dependent upon its foundation, it is clearly not only desirable but really essential that the designer of the structure to be supported, be he architect or engineer, should be familiar with the general principles governing the design of what is going to carry his superstructure.

This is, again, a "statement of the obvious." To all who have given thought to the matters discussed, most of this Digest will appear to be little more than a succession of such statements. Experience within DBR/NRC has shown, however, that such attention has not always been given to foundations. It is not difficult to understand this neglect, if only because in almost all cases foundations are well hidden beneath the surface of the ground. They are, quite naturally, overlooked as the glory of a towering or beautiful superstructure is appreciated. If a foundation performs as it should, its very success contributes to its neglect.

The resulting anonymity is well known and accepted as inevitable by foundation engineers. It comes up for critical comment only when it has, as is all too often the case, the effect of interfering with the allotment of the necessary funds for the essential preliminary subsurface investigation that must be made before the design of any major foundation structure. In very large buildings, especially those founded upon poor foundation strata, the cost of the substructure can be an appreciable fraction of the total cost of the building, even as high as 25 per cent. Even for quite ordinary buildings, the still appreciable proportion of the total cost that will be spent for that part beneath the ground, coupled with the vital importance of sound foundation design, should dictate no skimping of expenditure upon the necessary preliminary work.

**Terminology**

Terminology in this branch of design is notoriously inexact; semantic accuracy has never, unfortunately, been a hallmark of engineering. "The foundation" is the term often used to describe the structure beneath the surface of the ground. In fact, this term should be restricted to the structural elements that transfer the load from the superstructure to the earth. On the other hand, the material to which the loads from the structure are transmitted, be it soil or rock, should properly be called the foundation bed or stratum. In most cases a plural term will be more accurate because the loads are going to be transmitted far below the material in evidence at the surface.

**Transfer of Load**

That the earth materials to which the loads of a structure are transmitted will react to the stresses imposed upon them is, again, a statement of such obvious logic that some readers may wonder at its being made. It is, however, remarkable how many people will just assume – if asked – that in some undefined way loads simply "disappear" into the ground. Yet a moment's thought will show that at the surface of contact between structure and ground the states of stress must be identical, the bearing pressure exerted by the bridge or building being exactly equal to the developed bearing capacity of the foundation bed.

It follows that not only must the ability of the exposed foundation bed to withstand such a pressure be known with certainty, but also the resistance of the ground well beneath the surface with equal certainty. The load transmitted from the foundation structure can be regarded as gradually "spreading itself" in the ground in all directions. As the distance from the structure increases, the intensity of stress steadily decreases, until eventually it becomes a quite negligible quantity. It is possible to calculate quite accurately the rate at which this state of stress decreases, if one makes certain simplifying but justifiable assumptions. This was first done by the French mathematician Boussinesq. If what is now kown as the "Boussinesq Equation" is worked out for different distances beneath a foundation structure, with the proper assumptions made, a pattern of decrease-of-stress is obtained that can readily be shown by means of a diagram (Figure 1).

It is not surprising that this is known as the "Bulb of Pressure" diagram, this being an obvious description of its shape. It illustrates the distribution of stresses in the ground resulting from two loads of equal magnitude but different width. In each case the large bulb shows the location in the ground where the increase in vertical stress is equal to 1/10 of the pressure applied at the surface. The picture the diagram provides – one that should be visualized whenever a foundation design is being considered – is vital for a full appreciation of what may properly be called the philosophy of foundation design. To many readers it will be familiar. (It has even been used in an earlier Digest.) It is, however, one of those

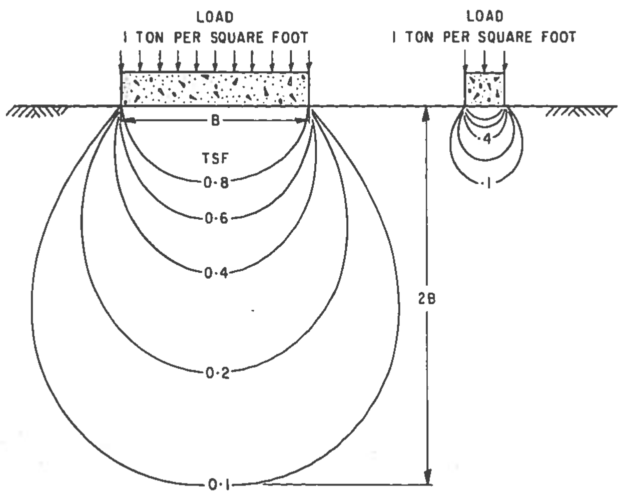


**Figure 1 Lines of equal vertical stress caused by surface loads.**

simple pictures that can never be seen too often, provided only that it does not become so familiar that it is neglected.

Similar bulbs can be drawn for any other percentage of the unit load upon the foundation bed. They will increase in size as the distance from the structure increases, and with increase in size will indicate a steadily decreasing intensity of stress. Beneath the centre of a structure in the supporting strata the intensity of stress in the material of the ground decreases rapidly at first and then more slowly. Not until a depth of about *twice the width of the foundation structure* has been reached, however, will the increase of stress in the ground from the load transmitted to it by the structure be reduced to 1/10 of the applied pressure.

**Philosophy of Design**

It is the purpose of the foundation design to ensure that loads from the structure and any earth fills associated with it are transmitted safely to the ground in such a way that the finished structure will perform as intended. This means not only that the foundation beds will not fail when the full load comes upon them, but also that the settlement of the structure (and almost all structures settle to some degree) will not be excessive and be as calculated in advance so that the necessary precautions can be taken in superstructure design.

A common error in design is the failure to take into account the loads added to the ground by even small earth fills on the site. Two or 3 feet of fill may equal the weight of the structure and serious settlement may be caused by the combined load.

The loads to be transmitted to the foundation beds must be known with reasonable accuracy in advance of design. Equally important, also in advance of design, is the necessity for knowing the exact character of the supporting foundation beds to a depth of at least twice the width of the anticipated foundation structure, and preferably deeper than this. When both loads and foundation bed characteristics are known, it is the task of the foundation engineer not only to devise a foundation that will give the desired result but also one that can be constructed safely and economically. These are the determining factors in the choice usually available among various types of foundations, a choice that will be discussed in the next Digest.

**Subsurface Investigation**

Reference to the Bulb of Pressure diagram will make clear at a glance why subsurface investigation is so fundamental a part of foundation design. If soil or rock is to be subjected to appreciable stress from a load imposed on an overlying surface, it is essential that its nature be known. CBD 29 deals with the methods that can be used for such investigations. They are, in general, relatively simple and relatively inexpensive. To be fully effective they must be carried out by expert operators, of whom there are many throughout Canada. Equally important is the necessity for expert supervision by personnel trained in such work. No two sites are ever the same and the unexpected has always to be anticipated. A three-dimensional viewpoint has to be applied to the interpretation of all results obtained from a "one-dimensional" borehole. And a full appreciation of Geology, with special reference to the particular site, is a basic requirement.

Unless the designing architect or engineer is fully aware of the importance to his superstructure design of the information about the site conditions to be obtained in this way and gives it proper recognition in the design process, the work may not receive the attention it deserves. And incorrect subsurface information can be much worse than no information at all. "Messing about with mud" (as one has heard it described) at an undeveloped site, using unusual-looking equipment — some of it working unseen beneath the surface — may seem to have little to do with the aesthetic delight of designing a slender roof structure. Both, however, are essential parts of the design process and of equal importance.

It might be thought that such attention to subsurface conditions is of importance only for large structures. It is just as important, though much easier to obtain, with the smallest structure. Quite recently, the writers learned of a small residential development where all the pleasant houses had to be vacated for some weeks because they had been built on filled ground. Subsurface conditions had not been investigated, and it happened that the fill contained organic material that led to the formation of methane gas. When this seeped into the basements, it quickly created a very real danger.

This is just another of the hazards that can develop from building on filled ground without adequate subsurface investigation. A less serious, but equally inconvenient situation, arose in a new housing development on an old garbage dump. In this case putrified ground water penetrated foundation walls, giving off a sickening odour in the house as it evaporated.

Some of the more remarkable cases of foundation movements of light structures occur as a result of seasonal volume changes in the subsoil. These may be caused by drying and shrinking due to vegetation, to swelling of certain clay minerals following excessive wetting, or to heaving by freezing or settlement by thawing. Freezing and thawing must be considered a hazard both during and after construction.

For large buildings or small, therefore, subsurface conditions *must* be known with certainty in advance of design.

**Groundwater**

As all who have ever looked at an excavation will know, subsurface conditions can vary greatly in relatively short distances. Especially is this true in Canada, so much of the area of which is now covered with glacial deposits. There is, however, a still further complication in the art of foundation design: water is usually present beneath the ground surface whenever the ground consists of soil. (Water can be present in solid rock also, but rarely in a way that causes foundation problems.) Groundwater is the name given to subsurface water, a name that may conceal the fact that almost all such water has come to its present position by seeping into the ground from the surface. It is, therefore, almost always in a dynamic state and is not stagnant. It is probably moving laterally, though slowly. It will almost certainly vary in level throughout the twelve months of the year. Not only may it complicate the design process, but it will certainly affect construction methods if its level is interfered with by the building operation. So important is groundwater in foundation work that it will be the subject of a separate future Digest.

**Building Regulations**

The skeptical reader may think that the emphasis in this Digest is misplaced, because local building regulations – and the National Building Code of Canada – give all the information necessary for foundation design; and that all one has to do is follow the requirements of such documents. A careful reading of the Code or local building by-laws, however, should show that such views are not professionally tenable. Even for the smallest buildings, simple tests, knowledge of site conditions, or accurate knowledge of foundation practice on an *adjacent* site is required. For all but such small buildings, the approach herein recommended is implicit in all good Codes. Regulations are mainly for the guidance of local building officials – giving them authority to insist on the proper approach to design rather than providing a guide to easy design.

**Conclusion**

The design of a foundation is an integral part of the design of a structure. Less interesting to the architect or structural engineer than his normal work of designing superstructures, it is of equal importance and is essential to the success of the total design. Neglect of a proper approach to foundation design, or foolish limitation of funds for necessary subsurface exploration, can lead to disaster. It will almost certainly lead to that extra cost for the completed structure that redounds so adversely on the public appreciation of the design professions. Details of the design can and should be left to the expert. All architects and all structural engineers should, however, have a general knowledge of the fundamentals of foundation design if their confidence in the entire project is to be complete.

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