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Please note

Structures must sometimes be erected on sites where material has been placed as fill over the original ground surface. The presence of the fill may be well known in the locality, but on occasion it may be revealed only after subsurface exploration has been carried out. To the normal problems of foundation design and construction, then, several complications are added if buildings have to be founded on it. Should building proceed in ignorance of the fact that the site does consist of fill and it is therefore not taken into account, the consequences can be serious indeed. There are, unfortunately, all too many cases of this on record. Even when fill has been known to be the foundation material, its true character has not always been recognized and subsequent troubles have been serious.

Very little has been written on this rather specialized aspect of foundation design. Although the proportion of structures in Canada that are founded on fill is small, the number of inquiries on this subject coming to the Division of Building Research suggests that a study of the subject and a review of associated problems may be useful. This Digest presents such a review and includes also a brief explanation of the entirely satisfactory performance of structures built on fill that has been properly placed. The latter part of the Digest confirms that, except in the most exceptional cases, there is no objection to building on fill. Whenever a site that contains any fill has to be used, however, the project demands an unusually careful investigation.

Character of Fill

The use of depressions such as disused quarries and abandoned excavations for the disposal of waste material in areas of developed land will be familiar to all readers. Unless rigid control over such dumping operations is exercised, the fill material will be heterogeneous in the extreme. There always seem to be people who will deposit garbage at the nearest possible location regardless of public amenity. The disposal of discarded automobiles, also, is a problem delightfully solved if there is an old quarry into which to drop the ancient machine on a dark night. These seemingly absurd references are made deliberately to remind readers that fill may contain almost anything. The writer even found part of an old bedstead in the fill from which he once had to make a garden. It must, therefore, be realized that one can take nothing for granted in dealing with fill unless one is absolutely certain that it has all been placed with selected material under strict control.

Even when the character of the material deposited in areas to be filled is so controlled, it is rare that the method of deposition can be regulated. Usually good fill such as sand, gravel or clay is deposited by end dumping from trucks. Gradually, as more fill is dumped and as loaded trucks pass over the newly placed fill, it will take on a reasonably solid appearance. It will, however, be far from properly compacted. In comparison with the state of the same soil in its natural undisturbed condition, it will be "unconsolidated" material liable to further consolidation either with time or when subjected to loads. Structures will, therefore, settle on fill unless the appropriate measures to prevent this are taken in design and construction.

In the older cities of Europe, and in a few parts of North America, some areas may be covered with fill consisting of rubble (broken masonry) that has accumulated from the repeated destruction of old buildings. Prague in Czechoslovakia, for example, has been an urban area for over one thousand years and in some parts of the city miscellaneous fill material extends to depths of up to 8 metres (26 feet). Even more remarkable is the city of Warsaw, now happily rebuilt after its total demolition during the course of the Second World War. Polish engineers, in explaining the phenomenal reconstruction of their city, say (almost with a smile) that it is today about 2 metres higher than it was before the war -- since the rebuilding was carried out on the fill provided by the rubble from the destruction of the pre-war city. These are extreme examples, but they are a useful reminder that even in Canada building sites in mid-city areas may be covered by fill from previous buildings.

The most serious aspect of the varied character of the material that may be found underlying building sites on fill is that organic material such as domestic garbage may be buried in the fill. There are other less obvious sources of organic matter. Although solid when deposited, it will deteriorate with time, and will in all probability generate gaseous products of decomposition, notably methane, which is not only offensive but also an explosion hazard. With modern and well accepted procedures for sanitary land-fill refuse disposal, this will be an increasing feature of filled land. At the same time, however, land reclaimed by sanitary fill methods is almost always scheduled for use as open parkland where the hazards noted - being always limited in extent - will be of no serious consequence. It is only when methane, for example, is trapped in enclosed spaces such as basements that the hazard becomes so serious that it must be eliminated.

Some industrial processes result in large quantities of waste material that must be disposed of as fill. Many Canadians are familiar with night views of the slag heaps at Sudbury. Refining processes at aluminum works produce large quantities of red waste that is usually deposited in special sludge reservoirs. These and similar processes may also yield solid material that can form what appears to be acceptable solid fill. The origin of all such industrial fill must always be determined since its chemical composition may be significant.

Recommended Practice

Whenever a building site is known to have fill material beneath it, it is most important that the necessity for a detailed sub-surface investigation be accepted, despite all the "local information" that may be provided. There are no general rules for the design of foundations on filled ground; every case must be considered separately, and the exact character of the entire site, to a suitable depth, must be determined. Only then can foundation designs be considered unless the preliminary investigations show that the site cannot be safely used at all for the intended purpose.

This extreme case may arise should extensive deposits of organic material be discovered by the sub-surface investigation. The decay of domestic wastes is one possible source, but even if good fill has been placed over old swamp deposits (muskegs) the same danger may exist. Nothing will stop the natural chemical process of disintegration. If the presence of methane is liable to create a hazard, as it will if there are to be any enclosed parts of the structures below ground, then either the site will have to be abandoned or, if it is economically possible, all the fill must be removed and the original ground used as the foundation stratum.

The possible presence of organic material is but one of the reasons why test boring must be carried out much more extensively on filled sites than is usually the case. Natural soil strata are themselves variable enough to necessitate closely-spaced test borings for all major structures to ensure as accurate knowledge of subsurface conditions as possible before foundation structures are designed. It is impossible to guarantee any uniformity in fill material. It is almost certain that its texture will be variable if only because of the way in which most fill is deposited. Accordingly, a carefully planned program of test boring must be carried out, starting with strategically placed holes that will give first a general picture of the extent of the fill. Subsequent holes can then be located between the key holes so as to give a steadily unfolding picture of the character and extent of the underlying material and of the location of the original ground surface and soil conditions.

If groundwater is found in any holes, even more precautions must be taken because it may be trapped in pockets between fill of varying character. It may thus conceal the real composition of some of the material. Every effort must be made to obtain good samples of the fill material, especially when it is water-logged, so that it can be studied carefully and its properties determined in the laboratory. Even test drilling must be carefully conducted since if methane is encountered it may be under slight pressure. As any groundwater encountered may have been contaminated by material in the fill, samples must be tested for chemical properties to ensure that it will not prove injurious to any foundation structure.

Samples of the fill material must also be carefully examined, even in apparently "good solid" material such as industrial slag. There are, for example, some types of slag other than blast furnace slag that expand slowly when exposed to heat and moisture. This has already caused serious foundation trouble in at least one location in Canada. Nothing must be taken for granted about artificial material that is found in place beneath a site on which building is planned.

Once the presence of fill material has been determined then its properties must be investigated. This will involve laboratory testing if preliminary study suggests that it will be worth while. If, however, as will often he the case, the depth of fill is not great, an obvious and desirable course will be to neglect the fill as a foundation bed and investigate the characteristics of the underlying soil with the idea of founding the building upon it. This will be possible with the use of concrete piers, caissons, or piles if the original soil conditions are suitable for piles as foundation units. It will be realized that the chemical character of the fill and of any groundwater must be known with certainty so that there will be no possibility of deterioration of the foundation units after the building has been erected.

It may be desirable to use the fill itself as bearing material if it is deep or the loads to be supported are not large. In this case, a test boring *must* be put down at the location of every column if loads are to be transmitted through columns and suitable footings to ensure that the bearing conditions are known with certainty. Estimates can be made of the safe bearing capacity of the material once its character is known. The bearing capacities to be used in design must be determined with caution not only to keep settlement within reasonable limits, but to ensure a minimum of differential settlement between foundation units since the uniformity of the fill can never be assumed. If the structure is such that loads can be carried by concrete slabs either at or just below grade, bearing pressures must again be held to duly conservative limits. It will rarely be economical to consider pre-loading a filled site, but this possibility should not be forgotten even though it can be implemented only with the aid of expert advice.

Many fine structures have been built on filled ground despite all the hazards. In almost all cases, their success has been the result of careful preliminary investigation -- not forgetting an element of good luck in a few cases in earlier days when foundation design was not so well developed as it is today. All the expenditure of time, money and effort in the investigation of a building site on filled ground should be regarded as the best insurance policy; if the site can be used at all, it is possible, with care, to avoid all dangers and achieve a foundation design that will serve well.

Controlled Fill

When it is possible to control the selection of fill material and its placement for the general filling of a site or even for minor levelling of an undulating surface, modern soil techniques can readily eliminate the hazards present with uncontrolled fill. A finished excavation or building site can then be obtained that will be just as satisfactory as the original ground or even better. As more and more excavation has to be disposed of in urban areas and poorer building sites have to be used with the spread of urban development, there is a steadily increasing need to recognize and use this sound handling of fill material.

Back-fill material should be selected to duplicate as closely as possible the material that has been removed. When excavated material has to be used as fill, its properties should be carefully predetermined so that it can be placed in the best possible manner. When a site has to be levelled and fill can be specially selected, soil with desirable compaction characteristics that will blend well with the soil already on the site should be obtained if possible.

The site to be filled should be prepared by removing all surface material, to preserve its valuable agricultural properties. Beyond this, natural ground should not be disturbed. Every care must be taken that the traffic of earth-moving equipment does not cause the original soil more than a minimum of disturbance. As explained in earlier Digests, the fill material must then be deposited in thin layers so that it may be compacted by suitable mobile equipment and brought to a density consistent with its moisture content and compaction characteristics. This means strict field control at the source of the fill material and at the location of placing, such field inspection being a particularly important feature of modern soil engineering.

When these precautions are taken, it is possible to place soil -- fill, but controlled fill -- so that it has predictable characteristics and can be used with confidence as a foundation material for even quite heavy loads and structures. Modern practice with embankments is well known; the state of California, for example, has several highway fills over 90 feet high upon which roads were paved shortly after the fills were finished. Not so well known is the use of exactly similar techniques for the levelling of the sites of many notable industrial plants. These include at least one major part of a large atomic complex in the United States, part of which is on natural ground and part on compacted fill with eminently satisfactory performance.

Building on fill, therefore, is a challenging operation in foundation engineering. If it is always remembered that no two filled sites are the same and that varying conditions over a filled site make unusually careful sub-surface investigation essential, foundations can be designed that will give satisfactory performance on all but the most exceptional sites.