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THE SUPPORT OF STRUCTURES USING COMPACTED EARTHWORKS MATERIALS

M.W. Frost,
Division of Civil and Structural Engineering,
The School of Property and Construction
The Nottingham Trent University,
UK.

S.P.V. Butler,
Crossfield Consulting Ltd.,
UK.

I. F. Jefferson,
Division of Civil and Structural Engineering,
The School of Property and Construction
The Nottingham Trent University,
UK.

J.R. Greenwood,
Division of Civil and Structural Engineering,
The School of Property and Construction
The Nottingham Trent University,
UK.

ABSTRACT

Where earthworks are required to provide a level construction platform for portal frame warehouse structures it is suggested they can be founded in fill. The use of end product and performance specifications for fill and a change in philosophy for the serviceability of structures will make this approach acceptable.

Keywords: Earthworks Specifications, Portal Frames, Floor Slabs, Sustainability.

1. Introduction

As commercial development is increasingly targeting brown-field and marginal sites, the use of compacted materials to produce level construction platforms is increasing. In such situations where the supporting ground is manufactured, foundations are either constructed to transfer the loads through the engineered material to the in situ soil, or founded upon good quality imported compacted granular materials. In the latter case the performance of the compacted fill is normally assumed from past experience of using similar materials in a similar way. Such an approach inevitably leads to inappropriate use of materials and potentially over design. In addition it precludes the use of marginal or recycled materials in favour of good quality well graded quarried aggregates. Given the current impetus in the UK to use more recycled materials and the impending aggregate tax the use of good quality aggregates as general fill materials will become increasingly uneconomic. Therefore an alternative philosophy which encourages the use of manufactured earthworks for structural support is required.

This paper reviews the specification approaches used for earthworks materials and details the performance parameters required for earthworks materials to perform adequately as supporting strata for structural foundations and ground bearing slabs. It concludes that the use of performance based design and specifications incorporating site compliance testing will facilitate in the long-term the use of a wider range of materials, and increase the use of earthworks for support. However this must be coupled with a more pragmatic view of design serviceability for certain types of structure. This should lead to more economic construction as the need to rely on more expensive forms of foundation will not be necessary on sites where earthworks platforms or construction within existing made ground is required.

2. Sustainable Construction

Sir John Egan's Construction Task Force report, entitled *'Rethinking Construction'* suggests that the construction industry should be able to achieve a 10% reduction in the cost of construction (1). In addition, the report identifies waste minimisation and recycling as areas of potential savings. The subsequent publication of 'A Strategy for more Sustainable Construction' by the DETR further reinforces the need to 'rethink' the management of resources on development sites (2). The report states that 90% of all non-energy minerals extracted in Great Britain are used by the construction industry, some 260M tonnes/year, while 70M tonnes/year of construction and demolition materials are removed to landfill sites. Poor design and planning is identified as the main reason for this dichotomy where similar materials are both consumed and discarded during the same process. In addition to the waste of resources and corresponding environmental impacts of quarrying and landfilling, the cost and pollution associated with the transport of these materials to and from site is significant.

In an attempt to penalise the construction industry for its failure to use available resources, the UK government introduced the Landfill Tax in 1996. In addition, it proposes to introduce an aggregate levy in 2002 to reduce the amount of quarrying. These measures aim to promote re-use and recycling. Thus the use of recycled materials or stabilisation of insitu materials to support structures (where construction platform are required) will become more economic. However the use of such materials in such platforms must be coupled to a geotechnical consideration of their likely performance and appreciation of the implications of this on the structure.

3. The Current Perceptions on the use of Earthworks Support for Structures

There is little published data relating to the long-term performance of foundations within engineered fill. In the UK this may be because few buildings are founded on such materials. This is attributed to the concerns over the performance of such materials which is likely to be related to the types of specification used (see Section 5). For instance the National Building Specification recommends, for foundations in areas of made ground, contractors should excavate down to a natural formation (3).

Various researchers have studied structures on fill and it has been shown, that buildings can be constructed on well-compacted fill with normal foundations (4) and where engineered fill is prohibited as a foundation, this results in some circumstances in gross over-design (5), probably at considerable cost to the client. Surveys have suggested most clients are satisfied with the performance of their structures on engineered fill (6), research in the USA and in Australia report acceptable performance of foundations within fill engineered in accordance with the respective published national standards ((7) and (8)). However, it should be considered that acceptable performance is the result of structural serviceability and not necessarily an indication that conservative design requirements have been met.

4. Performance Requirements of Earthworks Material for Structural Support

There are several properties that materials should possess if they are to be considered suitable for inclusion into engineered earthworks. These materials should be:

- Non-biodegradable.
- Insoluble.
- Easily handled with modern plant.
- Non-hazardous – chemically and physically stable.

Once incorporated into an engineered earthwork the material should have:

- Adequate strength to provide support.
- Low compressibility to prevent excessive settlement (both elastic and permanent).

In theory, any material that fulfils these criteria may be used as an earthworks material. However, availability, quantity and cost will be major factors governing the use of any proposed material. It is therefore considered that materials already present on site are the most desirable materials in terms of cost. Therefore for a sustainable approach, a building project, as with a highway project, should perhaps attempt to achieve an ‘earthworks balance’ by matching the amount of cut and fill, thereby negating the need to import or export materials from site.

5. Earthworks Specification Approaches

The suitability and acceptability of any selected fill material will be controlled by the framework of the contract and specification used for the works. Therefore this will have a significant impact on the nature of materials used and these specification constraints must be considered if earthworks support is to be encouraged. There are three different approaches to the specification of engineered earthworks, (6), a method specification, an end product specification and a performance specification.

5.1 Method specification

This specification approach requires a particular material to be placed and compacted in a certain manner. The contract documentation will indicate that each designated material should be placed to a certain layer thickness and compacted with a given number of passes of nominated plant. The onus is on the designer to specify the correct level of compaction to ensure that a suitably stable earthwork is produced. This is the most common form of earthworks specification used in the UK as the majority of earthworks use the UK Highway Specification (9) which adopts this approach. This highway specification assures performance based on past satisfactory performance of good quality materials constructed in a particular way and is therefore restrictive.

5.2 End product specification

A results (end product) specification is used in the construction of engineered fills where high performance is required but the performance in service is difficult to monitor, for example in the use of clay landfill liners. This form of specification requires a material to be compacted into an acceptable condition. This condition is generally specified as a range of water contents, dry densities and possibly air voids. This ‘acceptability envelope’ is considered by the designer to represent material which is in a condition whereby it will perform satisfactorily. Compliance with such a specification is generally verified by direct measurement of the in situ material properties described above. However density has been shown to be inadequate as an indicator of a materials performance under load as it does not directly assess any of the required performance parameters of the foundation described in Section 4 and can therefore not guarantee performance, however it is a useful parameter to assess relative states, and should play a role in any performance specification approach(10).

5.3 Performance specification

A performance specification stipulates the way in which the earthwork as a whole should act under the conditions likely to be encountered in service. No guidance is given to the choice of materials or the amount of compaction they require. In general it is not the earthwork itself that is required to achieve a given performance but the amount of support that is required by the structural elements of the building. With a performance specification the risk is placed with the contractor to produce an earthwork that will provide this adequate support. The specifier need only ensure that the performance criteria are appropriate for the intended structure and are neither inadequate nor too conservative as to force over-design. Compliance with a performance specification is only truly possible by monitoring the performance and properties of the structure and materials used over their design life, relative to design derived target values of similar properties. Currently such monitoring can usually only give an indication of the short-term performance of the structure by assessing appropriate as constructed fill properties. This approach is gaining credence within the UK highways industry (10), as it will allow innovation and flexibility in terms of materials and construction methods which are restricted in the current method specification approach. Research is still required to allow the evaluation and prediction of long-term performance.

5.4 Appropriate specifications for sustainability

Most building development contracts in the UK are let on a design and build basis with the contractor being responsible for the detailed design of the structure and associated works, including the foundations, and therefore any earthworks that may be required. In design and build the client is merely required to provide a development outline detailing their requirements in terms of end performance. Such an approach should encourage the use of performance/end product specifications rather than methods specification, particular in the light of the drive for sustainable construction, which should encourage the economies achievable with earthworks support and the use of recycled materials. Frequently a preferred foundation solution is stipulated within the contract, and requires the ‘design and build’ contractor to justify any alternative proposal. Consequently there is usually a lack of suitable soils testing information to allow the Contractor to consider fully the use of engineered fill as an alternative design.

A true design and build approach for earthwork must use the latter two specification approaches or a hybrid of both, which will only be suitable to certain types of structure. To facilitate the sue of such specifications and the benefits that will follow clients and designers will be required to reconsider approaches to structural serviceability, and implement measurement of appropriate criteria/material properties in the field, relative to the design target values. This will require a significant geotechnical consideration of the performance of the earthworks at an early stage of the project.

6. Settlements in Fill

To design a structure and its foundations a number of factors must be considered which normally relate to the serviceability requirements of the proposed function of the building. For foundations this is linked to permissible settlements, (either total or differential) or permitted angular distortions. The use of earthworks and compacted fills as support therefore tends to be avoided as concern frequently exists on the properties of any made ground, or the ability to predict its performance relative to the defined serviceability limits.

However many structures could be successfully founded upon constructed ground if appropriate consideration of their fitness for purpose and the function required of the ground is considered.

The settlement of foundations placed within engineered fill is the sum of four separate components, (4):

- Elastic deflection of foundation and fill under applied load.
- Consolidation of engineered fill due to foundation load.

- Consolidation of underlying natural ground due to weight of fill and structure.
- Secondary settlement of all materials (creep)

It should be noted that of these only the second is likely to produce appreciable differential settlement unless there is a significant variation in fill thickness or formation compressibility across the footprint of the structure. Elastic deformation generally occurs during construction thereby limiting the damaging effect of the movement on the superstructure. However consideration of potential collapse settlements of the fill must also be made

Values of constrained modulus, compression due to foundation loading (elastic and consolidation), and creep compression, due to the self-weight of the fill, for poorly compacted earthworks materials (based on observed performance and laboratory testing) are summarised in Table 1 (11, 12, and 13).

Table 1. Typical Settlement Parameters for Various Engineered Fills

	Constrained Modulus (kN/m^3)	Creep Rate (%)
Sandy gravel fill	50000	0.1
Sandstone fill	12000	0.1
Colliery spoil fill	6000	0.2
Clay fill	5000	0.2

If consideration of these fill settlement properties relative to the purpose of the structure is made then the appropriateness of the structural form for founding in fill can be assessed.

7. Appropriate Structures to be Founded on Fill

Multileveled structures, (such as office blocks/city centre buildings) where high column loads and low distortions are required, are unlikely to be suited to the use of earthworks for foundation support. Large traditional housing developments are suited to founding on earthworks, (and this is increasingly occurring), however, the foundation requirements for new-build housing are controlled by the scheme insurers who are unlikely to accept the perceived risk associated with shallow foundations in recently placed fill. Where the purpose of the structure is not to provide support to other floors but to act as an enclosure such as large portal frame industrial warehousing, where the serviceability requirements for the structures are not so stringent as for multilevel structures, foundations on earthworks are a viable option.

Such warehouse structures are increasingly being constructed on brownfield sites or marginal land. Such sites include the reuse of industrial land (which is frequently pre-existing made ground from previous reuse), or marginal sites with poor supporting soils where increasing land prices have now made their development economic under current construction practice. It is possible that an earthworks support performance type approach, reusing fill and waste materials, could make these sites more viable, as foundation costs on made ground could be less and contamination could be contained by an appropriately engineered earthworks platform.

Typically the cost of the foundations and ground supported floor slabs for warehouses is a significant proportion of the total construction cost of such buildings. Frequently more onerous performance is required from the ground floor slab it self than of the structure, where “super flatness” is required to allow the satisfactory operation of narrow isle high level racking, or where the floor forms the base for any internal structures such as offices. Industrial floors are generally required to settle with an angular distortion of no more than 1mm in 300mm and 3mm in 1500mm for super-flat floors despite being subject to point loads of up to 200kN (14). This suggests that in some circumstances it is the floor that requires greater support than the superstructure, and these are currently more likely to be founded on made ground.

8. Consideration of Structural Form for Foundations on Earthworks

Modern commercial warehouse and light industrial buildings generally comprise sheet clad portal-frames. Often low perimeter walls of brick or concrete blocks are provided. The loads from the roof and cladding are transferred to the frame producing a series of column loads carried through to the foundations. The intervening masonry walls bear on strip footings between the column foundations. The form of foundations for these elements placed within engineered fill must be dictated by the sensitivity of the structure to movement, the applied loads and the anticipated performance of the fill.

Typical column loads for steel portal frame buildings are between 200kN and 800kN suggesting that foundation pressures of less than 100kN/m^2 can be achieved without excessive pad sizes. The data in Table 1 suggest that a 2m by 2m footing imposing a bearing pressure of 100kN/m^2 on to a clay fill earthwork 5m high will suffer approximately 40mm of settlement due to foundation loading and a further 10mm of creep settlement. Although this total settlement of 50mm may be considered excessive, it should be noted that a majority of the foundation loading settlement will occur as the load is applied suggesting that potentially damaging post-construction settlements are likely to be less than 25mm. In addition, total differential settlement is likely to be of the order of 25mm (1:280 over 7m) with a post-construction differential settlement of less than 15mm (1:500).

With the possible exception of any masonry elements, portal frame structures are relatively flexible and can suffer considerable distortion, whilst remaining serviceable. For steel portal frame buildings it is considered that individual pads may generally be utilised below columns. Masonry walls will require a shallow reinforced footing stiff enough to minimise cracking within the wall. In addition, the walls and columns should be separated by movement joints to allow differential settlements between them. For structures with heavily loaded columns or where masonry is the main component of the walls, stiffer beam foundations running below successive columns may be more appropriate. Beam foundations may also be appropriate where fill quality is variable, since this allows column and wall loads to be redistributed away from soft spots.

9. Floor Slabs Founded on Earthworks

As described above frequently the most onerous design aspect of commercial developments is often the floor slab, and the failure of such slabs is normally defined by serviceability criteria to ensure fitness for purpose. Slabs are designed based on leg loads from high bay racking, trafficking and loads from internal structures and can be in excess of 200kN (14). However, it is the floor, and not the fill that is subject to these loads with the floor redistributing the point loads to a more uniformly distributed load within the underlying strata.

The design of the slab is based on limiting the deflection, and tensile cracking of the slab. The performance of the slab is therefore determined by the stiffness, resistance to deformation of the foundations, and strength, and resistance to cracking of the slab itself. Finite difference analysis of a typical industrial floor slab (15), suggests that a series of 120kN leg loads at 1.5m centres bearing on to a 150mm thick slab induces a relatively uniform bearing pressure of 60kN/m^2 on to an underlying clay subgrade, whilst maintaining slab deflections within acceptable limits permitted by the current codes (16).

However the floor thickness depends to a limited extent on the stiffness of the underlying soil, the grade of concrete, notably the provision of a high performance sub-base tend to have a more significant effect. This is related to the contrast in stiffness between the floor and the subgrade being greater than any potential stiffness variation in the subgrade itself. Design guidance for concrete industrial floors indicates that there is little benefit, in terms of slab thickness, from having a granular subgrade rather than a clay subgrade other than for short-term construction expediency (16). In addition, the use of an unbound granular sub-base also has little effect on the slab thickness. By contrast the use of stabilisation of in situ materials to provide a high performance lean concrete bound sub-base may reduce the required thickness significantly.

This suggests that under current design floor slabs may be supported on relatively low stiffness fill if a cement bound sub-base material is provided immediately below the floor slab. It is clear that the use of a high performance sub-base in the upper layers of an earthwork otherwise constructed of site-won material would be much more cost effective that attempting to construct the entire platform from imported granular material. However additional factors such as dynamic loading of joints and evenness and consistency of support are now being considered important (17, 18 and 19) for which adequate foundation stiffness to depth will play a larger role.

Where subgrade support or settlements may be critical small changes to the slab design to improve its tensile strength and stiffness could be implemented to distribute stresses further, such as a slightly enhanced concrete strength, slightly thicker slabs or additional reinforcement (particularly beneath internal structures).

The stiffness of the earthworks fill therefore has little influence on the current design methods for floor slab. However, as with the foundations for the superstructure, settlement of the fill due to compression under applied load and creep can affect the performance. Therefore the quality of the earthworks fill should be maintained so as to avoid the potential for differential settlement within the fill distorting the floor slab. Hence, for this approach to be fully acceptable a series of in situ performance testing actually measuring the performance parameters defined above has been proposed to assess consistency of foundation support in an attempt to guard against differential settlements, (19). However it must also be considered that for a full performance specification approach measurement of appropriate material properties at design stage will also be necessary (19).

Consequently it is considered using current design, that the choice of any bulk fill material required below the slab should be driven by the availability of cost effective earthworks materials rather than the perceived requirement for high stiffness. An economic choice can then be made between the use of high performance or conventional sub-base with a thin, high performance slab or a thicker, low-grade slab respectively.

10. Conclusions

Large buildings are rarely founded on made ground and fill materials due to concerns over likely settlements. Where fill is used foundations are taken to depth or high quality quarried materials are used for support. Such an approach will become increasing uneconomic due to taxation to encourage sustainable construction.

Earthworks for supporting layers are normally constructed in the UK using a method specification adopted from the highway industry. This approach is restrictive to the use of insitu or recycled materials as the requirements of the specification are too prescriptive.

The use of design and build specifications for structures should define acceptable structural performance, for a sustainable approach corresponding earthworks specifications should allow the widest range of stable materials to be used. End product/performance type specification approaches are required to fully enable this freedom to be introduced.

For end product or performance specifications to be successful for founding earthworks an increased geotechnical engineering input will be required at design stage coupled with a detailed consideration of structural serviceability. For such specifications to be truly successful they must assess the required physical parameters of the materials over the life of the structure, both at design stage and in service. Research is required to fully assess the long-term behaviour.

Portal framed warehouse type structures are considered most suitable for founding within earthworks, as settlements will not be so critical. Settlements within an appropriately engineered fill have been assessed, and earthworks can be designed to give settlements within acceptable limits. An engineered fill will also save costs on the floor slab foundations using current design philosophies.

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