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Residential Developments on Deep Engineered Fills-Case Study

S. Herath and T.J Holt
A.S. James Pty Ltd, Melbourne, Australia

ABSTRACT: Many residential developments now involve significant geotechnical challenges to structure performance due to the settlement behavior of engineered and non-engineered fills as well as natural compressible soils. The option of shallow footings on deeper fills or sites underlain by soft soils where differential settlement is critical is the preferred approach to mitigate costs of development although it may not be possible in some situations unless ground improvement is carried out. Two case studies are presented as a practical application of performance of shallow footings on such fills: these are a disused brick quarry site located 25 km South East of Melbourne with fill thickness from zero to 15m and the second site located within Maribyrnong river flood plain- 6km from Melbourne CBD with recent controlled fill and historic uncontrolled fill underlain by soft alluvial clays and highly compressible "Coode Island Silt". This paper primarily discusses the monitoring and controlling of settlement to satisfy the slab angular distortion requirements specified in the Australian Standards for Residential slabs and footings, AS 2870-2011 and the construction of infrastructure.

1 INTRODUCTION

Many residential developments now involve significant geotechnical challenges to structure performance due to the settlement behavior of engineered and non-engineered fills as well as natural compressible soils. The option of shallow footings on deeper fills or sites underlain by soft soils where differential settlement is critical is the preferred approach to mitigate costs of development although it may not be possible in some situations unless ground improvement is carried out. Two case studies are presented as a practical application of performance of shallow footings on such fills: these are a disused brick quarry site located 25 km South East of Melbourne with fill thickness from zero to 15m and the second site located within Maribyrnong river flood plain- 6km from Melbourne Central Business District (CBD) with recent controlled fill and historic uncontrolled fill underlain by soft alluvial clays and highly compressible "Coode Island Silt". This paper discusses the following recent case studies where it was possible to adopt shallow foundations with appropriate structural design:

1. Site 1 Former brick quarry site - Scoresby, Melbourne
2. Site 2 Ascot Chase, Ascot Vale- Former Industrial site

Site 1 Former brick quarry site - Scoresby, Melbourne

This site covers approximately 56 hectares and it is planned to construct 1000 dwellings on the site. The site was first developed as a clay quarry and brick operation plant in the early 1960's. After the quarry operations ceased, it was proposed to rehabilitate the quarry pits by filling them for development of the site for residential use. Geologically the site is underlain by residual clays derived from siltstone and sandstone deposits which are of the Devonian age. The residual clays are generally moderately reactive and the depth to rock is often highly variable over short distances.

Site 2 Former Industrial site-Ascot Chase, Ascot Vale

The Ascot Chase site is located within the Maribyrnong river flood plain and it provides storage for flood waters from the Maribyrnong River. It was required to further fill the estate above the flood level. The site had been filled in 1950s under uncontrolled /semi controlled conditions to provide a working platform for the then industrial complex. This historic fill is overlain by recent controlled fill placed in 2008-2013.

Geologically the site is underlain by soft, alluvial clays and highly compressible "Coode Island silts" underlying the fill with further quaternary deposits at depth but less compressible. Advice was required on the earthworks for the areas to be filled with a view to recommending foundation slabs, designing roads and an embankment/dam structure. Given the requirement of shallow footings for the proposed housing structures, minimising the differential settlements due to the fill was critical and strict control over the earthworks was required. The earthworks were carried out under controlled conditions with Level 1 supervision as defined in AS 3798 (Standards Australia, 2007) in accordance with an earthwork specification and settlement monitoring was carried out.

2 DEVELOPMENT ISSUES/IMPLICATIONS

On both sites, the "differential settlement" was the major development issue. At the Scoresby site, the significant fill thickness and variation in fill thickness influenced the differential settlement. In contrast, at the Ascot Chase site, variation in the thickness of the Coode Island Silt mainly contributed to the differential settlement and it was potentially longer term. Confirmation that settlement had reduced to a rate tolerable to the structures would be necessary prior to the development.

3 PERFORMANCE REQUIREMENTS

The suitability of the sites for development after filling depends on the magnitude of the remaining settlement at the time of construction. Whilst the remaining settlement is important, the differential settlement is the most important component and this needed to be within acceptable limits specified in the AS 2870 (Standards Australia, 2011) if that Standard is to be adopted for footing design. As per the performance criteria stipulated in AS 2870 (Standards Australia, 2011), the tolerable limit of differential settlement shall be lesser of the maximum differential deflection values given in the Table 4.1 of AS 2870 (Standards Australia, 2011). Foundation design should limit the maximum differential settlement over a horizontal distance (span) to no more than maximum differential settlement given in this table under serviceability limit state load combinations. Given the type of the proposed housing structures are generally articulated masonry veneer, the criteria for limiting angular distortion was taken as 1/400 or maximum differential deflection of 30mm, which is the safe limit for buildings where cracking is minor.

3.1 Earthwork specification

It was expected that with adequate engineering control over quality and uniformity of fill material and level of compaction, the residual and differential settlements in the fill could be minimised. In order to achieve the performance requirements as per AS 2870 (Standards Australia, 2011), the earthworks specification for both sites was prepared. The specification included removing organic material, stockpiling, sourcing suitable material, testing, mixing/blending, moisture conditioning, placing the fill material, compaction and density testing and surcharging as required.

3.2 Scoresby site

3.2.1 Methodology of earthworks

The Scoresby site was a former brick quarry and was filled to depths varying from 0 to 15m.The fill material was selected to comply with the earthwork specifications. The main types of fill and gradation/plasticity characteristics are summarised in the Table 1 below.

Table 1. Fill material characteristics and placement depth

Fill Type	Placement depth	Maximum particle size (mm)	Plasticity characteristics
Type A	top 1m	50	LL<50%, PI<30%
Type B	between 1and 5m	120	LL<50%, PI<30%
Type C	Below 5m	150	Not specified but LL<70%

Note: LL – Liquid Limit, PI- Plastic Limit

The placement and compaction of fill was carried out to achieve 98% of the Australian Standard Compaction (AS 1289 5.1.1 -2003) at moisture content 85-115% of Standard Optimum Moisture Content (OMC). Field density tests were carried out on each compacted layer. Testing frequency was in accordance with AS 3798 (Standard Australia, 2007) and is one test per 500m^3.The dry density ratio -98% value is higher than that normally specified for residential developments and was chosen to minimise settlements given the depth of fill.

3.2.2 Predicted settlements

It was recognised the main components of settlement characteristics in the Scoresby site comprises the following:

1. Long term creep settlements: settlements due to the thickness of the fill.
2. Settlement/swell due to shrink – swell characteristics.

Due to the restrictions of the plasticity characteristics of the fill material and the control over the moisture content during placement of the fill, the potential for change in volume due to variation of moisture was considered limited and therefore settlement due to "shrink – swell" condition was also limited on this site. Due to the significant thickness of the fill in the majority of areas, long term creep settlement was considered to be applicable to the Scoresby site. Given the strict control over the compaction (98% degree of compaction) only minor creep settlement was expected.

3.2.3 Predicted settlement using laboratory consolidation model

Given the high degree of compaction it was expected that the controlled fill would show "over consolidated" behaviour in the unsaturated state. Generally the soil compaction causes a significant over consolidation effect (Leonards et al 1988). However, it was considered prudent to assess the risk of additional settlement that could occur if the fill is saturated. Although the risk is low because the fill had been in place for several years, it was decided to carry out consolidation tests on saturated samples. Four consolidation tests were carried out on the undisturbed clay fill samples after saturation. Engineering properties of the tested samples are summarised in Table 2.

Table 2. Engineering properties of tested clay fill

Sample No	Depth (m)	m.c %	γ_b	e_0	Cc	Cc/1+e_0
1	3.0	16.7	2.35	0.32	0.08	0.06
2	3.0	22.1	2.04	0.59	0.11	0.07
3	4.0	17.1	1.96	0.59	0.15	0.09
4	7.5	25.2	1.92	0.73	0.09	0.05

Note: m.c- moisture content, γ_b- Bulk density, Cc – Compression index, e_0 – Initial void ratio,

Low compression ratio ($C_c/1+e_0$) values in the range of 0.05- 0.09 were obtained. This indicated that primary consolidation of the fill would be low even if the fill became saturated. Considering the possibility of the total fill being saturated is highly unlikely, the risk of such settlement was considered very low.

3.2.4 Observed settlements

Following completion of the earth filling works, settlement gauges were installed in the deep fill areas to measure the settlement of the fill. The recent monitoring details (September 2014 – approximately after 2 years) indicated negligible settlement (0-2mm) which is within the surveying accuracy. However, these readings did not include settlements that occurred during construction of the fill which was placed before the installation of settlement gauges, however this settlement is already completed and comparatively low given the strict control over the compaction. The long term settlements expected would be of the order of 10-15mm indicating the total settlement would be in the order of 0.05-0.1% of the fill height.

3.2.5 Evaluation and design consideration

The total settlement of 0-2 mm occurred during the monitoring period of 2 years is an indication of satisfactory behaviour of settlements in the longer term. Considering the settlement monitoring results, the differential settlements within a residential lot within the design life is not expected to be more than 30mm. This indicates that the slab angular distortions within the residential lots are within the specified limits given in Table 4.1 of AS 2870 (Standards Australia, 2011).

3.3 Ascot Chase site

3.3.1 Methodology of earthworks

The main development issue at the Ascot Chase site was consolidation settlement of the variably thick soft alluvium clay and Coode Island Silt (CIS) layers up to 12m in depth across the site. Earth filling to design levels as well as the application of surcharge fill in some areas has resulted in large differential settlements. Settlement monitoring continues to be carried out in some areas and has indicated areas of excessive settlements possibly due to a dam or a previous wetland and subsequent filling has caused additional settlements.

Earthworks to raise the ground to design levels commenced in September 2008 and continued until November 2008. Additional surcharge fill equivalent to 15kPa was placed between May 2010 and June 2013 to accelerate the consolidation process. This surcharge simulates the proposed structural load. The approximate fill thickness including the surcharge filling was 0.6-3.5m.

Settlement monitoring plates were installed immediately after the fill placed. These plates were embedded at 1.0m depth below finished fill level with risers.

3.3.2 Observed/predicted settlements

Settlement monitoring as at 30 April 2012 (3.5 years after commencement of filling) recorded total settlement varying from 25-691mm with an average of 159mm. The thickness of CIS layers and applied surcharge contributed to the high settlements. Log–time settlement curves indicated the time for completion of primary consolidation settlement 100-200 days from the commencement of filling followed by secondary consolidation settlement. Further monitoring carried out in November 2013 (5 years after the commencement of filling) revealed negligible settlement showing a "flattening " behaviour of settlement curves with the anticipating remaining secondary settlement generally less than 30mm in most of the areas.

Some areas of the site showed continuing settlement. Detailed settlement analysis based on the thickness of CIS and consolidation parameters was carried out to predict the remaining secondary settlement under the existing surcharge. This resulted settlement varying from 25 to 120mm requiring further surcharge fill. With the application of further surcharge fill, it was aimed to reduce the remaining secondary settlement in order to proceed with the construction, with a final tolerable settlement of 30mm for a design life of 50 years. Fig. 1 presents typical expected behaviour for a period of 100 years.

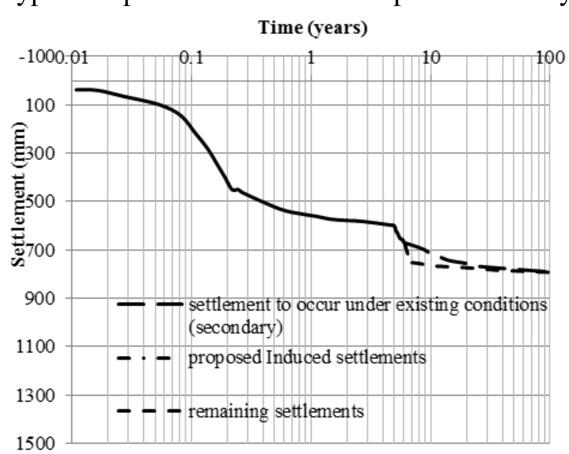

Fig. 1 Typical log time settlement plot for induced settlement, Ascot Chase site

3.3.2 Evaluation and design considerations

Given the potential for excessive differential settlement in some areas, predicted slab angular distortions were not within the specified limits given in AS 2870 (Standards Australia, 2011) for the present conditions. Additional surcharge was used to accelerate the settlement process within the specified time in some areas identified.

At both sites a set of geotechnical guidelines were also made available to make designers and builders aware of settlement issues so that buildings can be designed and constructed to mitigate the long term distress and allow for long term settlements. Some important guidelines are as follows.

1. Use of any foundation type other than a rigid slab system directly on the existing controlled fill is not considered as suitable. A stiffened raft is suitable.

2. Dwelling slab shapes should be kept simple and symmetrical and the loading to the rigid slab made constant. Adequate articulation and limitations on construction type (no suspended slabs) is necessary.

4 CONCLUSIONS

Engineering control over quality and uniformity of fill material and level of compaction significantly limits the residual and differential settlements in a controlled fill. Variable thickness of soft, compressible layers can lead to excessive total/differential settlements necessitating additional ground improvement to satisfy the "tolerable" settlement criteria in order to achieve acceptable limits.

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