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The use of Terefil rafts to control static settlement under building loads

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ABSTRACT

Mainmark Terefil is a polymer-modified cementitious grout that is commonly used for void filling, with the potential to be adapted as an alternative liquefaction mitigation raft solution and to minimise static settlements under building loads in low strength soils. Traditional reinforced gravel rafts are frequently used as a stable platform to reduce the effects of liquefaction in future earthquakes for foundation solutions in seismically active areas. A common problem in Christchurch arises when trying to construct gravel rafts where shallow groundwater is present, as this makes excavation and achieving suitable gravel compaction difficult. Furthermore, gravel rafts are unsuitable in areas of very soft soils, where static settlements can occur under static loading due to the compressible nature of these soils. Terefil provides a cost effective, practical solution in such problematic areas whilst still providing sufficient stiffness to provide liquefaction mitigation.

This paper presents a selected case study where a Terefil raft has been used in lieu of traditional gravel rafts. It details key properties of the system, testing undertaken to date to confirm performance, analyses undertaken during the design, and lessons learned during construction observations. The benefits of the system versus traditional gravel rafts are also highlighted.

1 INTRODUCTION

Lightweight cementitious grout such as Mainmark's Terefil is commonly used overseas on various civil projects. Terefil is a lightweight polymer modified cementitious based filler comprising cement, foaming agent and sand that is available with a range of density and strength parameters. Terefil is environmentally inert and complies with the fifty year design life durability requirement as per the New Zealand Building Code. It forms a lightweight, stabilised crust block, providing an effective alternative to gravel rafts.

A commonly used ground improvement solution for MBIE Technical Categorisation 3 (TC3) sites in Christchurch comprises a 1.2m thick reinforced crushed gravel raft, Type G1d as per Section 15.3.10.1 (b) of

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the Ministry of Business, Innovation & Employment (MBIE) Guidance "Repairing and rebuilding houses affected by the Canterbury earthquakes" Version 3, dated December 2012. This solution comprises a 1.2m thick engineered crushed gravel raft, extending 1m beyond the footprint of the structure (from the base of the excavation) and reinforced with two or three layers of geogrid. Reinforced gravel rafts provide a stable platform and reduce the effects of liquefaction, so can be combined with a TC2 type foundation to provide a suitable solution for TC3 sites. Traditional gravel rafts can be difficult to construct in Christchurch, where shallow groundwater is prevalent, making excavation difficult and even requiring dewatering in some cases. Due to the greater stiffness of Terefil, a reduced thickness compared to that of a gravel raft is possible, minimising the depth of excavation required. The installation time is also comparatively reduced. Terefil rafts provide a reduced load when compared to traditional gravel rafts due to their lightweight nature, reducing potential static settlement in areas of soft soil.

Terefil rafts have successfully been designed and constructed for various sites in New Zealand. This paper focuses on a case study in Christchurch with unfavourable ground conditions, where four standalone dwellings founded on Terefil rafts were successfully constructed in 2017. Static settlement modelling using Settle 3D was conducted during the design phase to model predicted static settlement. After the rafts were constructed, laboratory testing was conducted on samples obtained from this site to identify the density, Unconfined Compressive Strength (UCS) and Young's Modulus of the material.

As part of Mainmark's continual internal research and development, additional testing of four different laboratory prepared Terefil mixes have been conducted. The mixes comprised varying densities and were tested in the laboratory to examine the density, strength and stiffness of the mixes and better understand likely performance of different mixes for application in different ground conditions. The preliminary results for mixes comparable to those used at the case study site indicate significantly improved properties compared to the results from the case study.

This paper presents a selected case study where a Terefil raft has been used in lieu of traditional gravel rafts. It details key properties of the system, testing undertaken to date to confirm performance, analyses undertaken during the design, and lessons learned during construction observations. The benefits of the system versus traditional gravel rafts are also highlighted.

2 CASE STUDY SITE

A successful case study where a Terefil raft was used at a complex site in Christchurch is outlined in this paper. The site is located in northwest Christchurch which is generally underlain by peat deposits of varying thickness and is bounded by residential dwellings on all sides. The initial site specific geotechnical report encountered non-engineered fill to 1.2m depth atop very soft peat to 2.0m depth, as per Table 1, with the groundwater level at approximately 1.1m depth. Based on the onsite Cone Penetrometer Tests (CPTs) the calculated liquefaction induced vertical settlement for the MBIE 'index' depth of 10m was estimated to be up to 90mm under a Serviceable Limit State (SLS) seismic event and up to 130mm under an Ultimate Limit State (ULS) seismic event, consistent with Technical Categorisation (TC3). The report recommended that all unsuitable material in the upper 2m be removed and replaced with a 2m thick gravel raft. Due to the presence of a shallow groundwater table, soft peat deposits, and proximity to existing adjacent dwellings, and temporary works such as dewatering and shoring to enable construction of the 2m thick gravel raft were uneconomical and presented risk to neighbouring properties.

Settlement calculations were undertaken to ensure that static settlements were controlled, reducing the thickness of the excavated soils; however, some compressible soils remained beneath the Terefil raft. A soil model was established based on the existing site specific geotechnical investigation.

Table 1: Summary of the assumed geotechnical properties adopted for design

Depth to base (m)	Material	Unit weight (kN/m^3)
1.0	Topsoil/fill	17
2.8	Very loose to loose silt (alluvium)	13
4.0	Very soft peat and organic silt (organic soil)	18
7.0	Very loose to medium dense silt and very soft to soft clay (alluvium)	18
19.5+	Loose to medium dense sand (alluvium)	18

An alternative foundation solution comprising a 0.9m thick lightweight Terefil 1000 raft platform was therefore designed to account for the compressible nature of the soils and the high groundwater table. This solution offered reduced loading on the soils, whilst providing a stiff raft, suitable for a TC2 type foundation. The excavation was reduced from 2.0m to 1.1m deep, reducing the earthworks onsite and associated risks and costs when constructing below the groundwater table. The Terefil raft provides a stabilised crust block, reducing the likelihood of total and differential settlements under static and seismic conditions. Terefil 1000 can reach a minimum compressive strength of 1 MPa at 28 days for design densities ranging from 400 kg/m^3 up to 900 kg/m^3. These design parameters were verified with Unconfined Compressive Strength Testing on samples cored out of the slab following curing. The base of the excavation was lined with geotextile and a layer of geogrid reinforcement installed 100mm above the base of the excavation (Figure 1), to provide improved raft behaviour in case of localised loss of support. The site layout of the four units is shown in Figure 2.

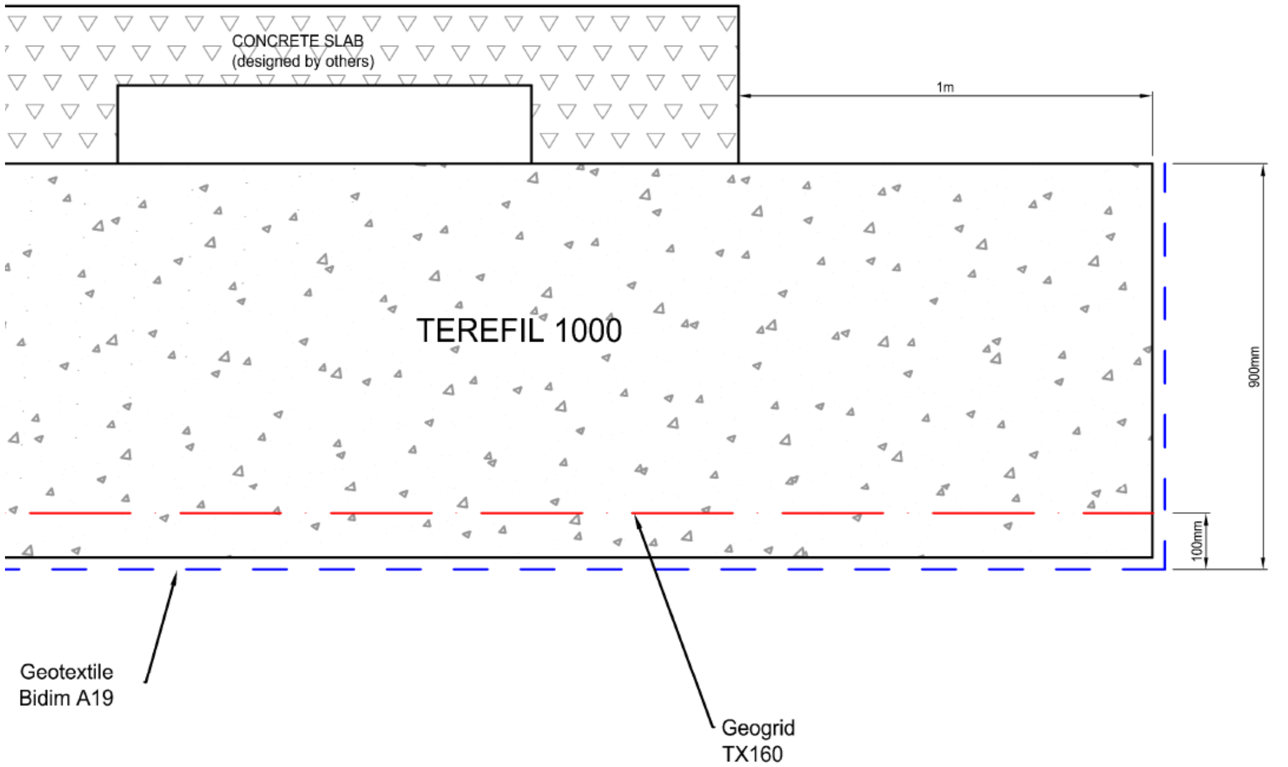

Figure 1: Schematic cross-section of a Terefil raft design

Figure 2: The site layout

3 STATIC SETTLEMENT MODELLING

Static foundation settlements were modelled using ‘Settle 3D’ software by Rocscience. The Boussinesq stress computation method was used. Static settlement modelling was conducted for each of the four units; this paper presents the results from Unit 1. The following construction sequence was modelled: 1.1m deep excavation with a 1m wide buffer zone (Figure 3) and loading from the 0.9m thick Terefil raft and loads for the overlying structure provided by the structural engineer (Figure 4).

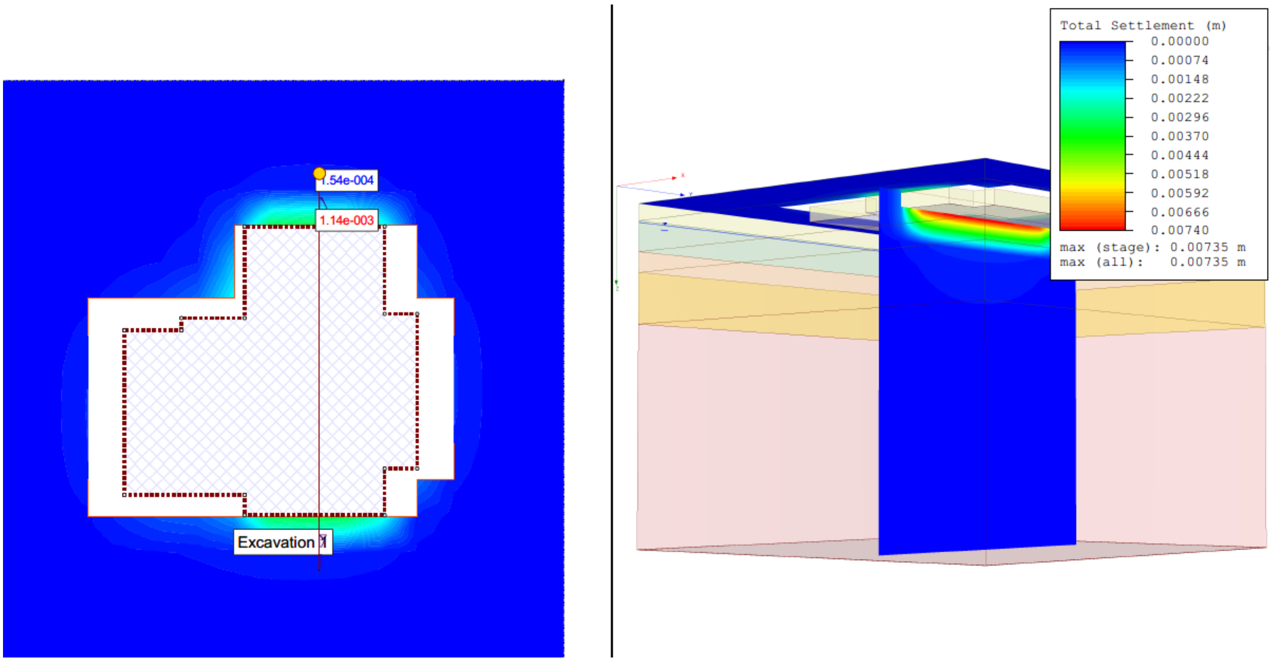

Figure 3: Settle 3D model showing the excavation stage

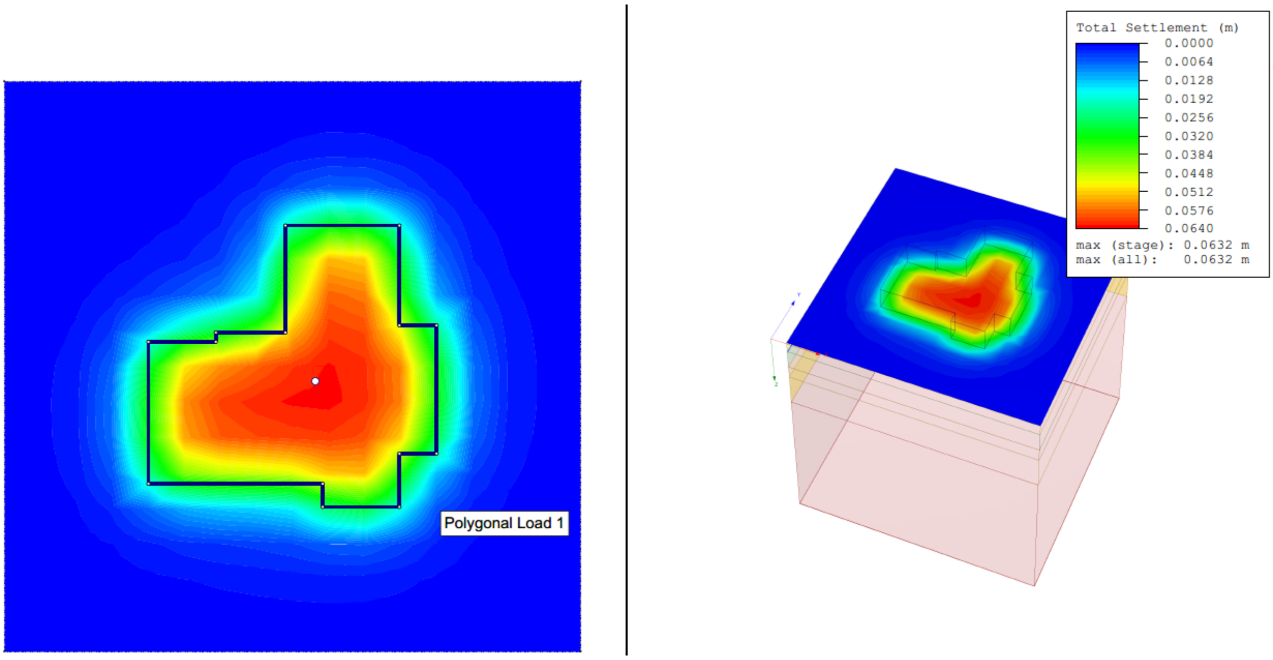

Figure 4: The modelled Terefil raft combined with building loads

Based on the settlement model, the predicted static settlement of the soil under the building loads for Unit 1 without shallow ground improvement was up to 65mm. The predicted static settlement of the soil under the building loads with a 900mm thick lightweight raft was less than 10mm. These calculations were based on conservative values used for the soil model and building loads. Both modelled cases meet the minimum requirement of a differential settlement of 25mm across 6m horizontal distance as per the New Zealand Building Code (1992).

4 CONSTRUCTION AND QUALITY ASSURANCE TESTING

At the case study site, four Terefil rafts were successfully constructed in under five days, as shown in Figures 5 – 8. Firstly, a 1.1m deep excavation with a 1m buffer zone was excavated and lined with geotextile. The first 0.1m of Terefil was installed, then a layer of geogrid, followed by the remaining 0.8m of Terefil.

Figure 5: Preparing the excavation

Figure 6: Terefil raft installation


Figure 7: Completed Terefil raft


Figure 8: Formwork placed over the Terefil raft

Laboratory testing was undertaken on Terefil samples, after a minimum curing time of 28 days, from each of the four building platforms at the site to confirm the density, strength and stiffness. A summary of the results are as follows:

- The density of the samples ranged from 690kg/m^3 to 960kg/m^3, with an average of 758 kg/m^3. Although the actual densities were variable, they were generally less than the design densities providing additional confidence of the settlement performance of the foundation system.
- Maximum compressive strength values ranged from 926kPa to 1603kPa were measured, with average values greater than 1000kPa (1MPa).
- Young's Modulus ranged from 137.1MPa to 586.7MPa, with an average of 304MPa.
- Construction was successful and met the minimum requirements of the brief.

5 ADDITIONAL TESTING

The durability of the foamed concrete product was proven by laboratory testing undertaken by University of Dundee (2006). Strength and density of twenty cubes 150mm in dimension were tested, along with the following durability properties: water percolation, alkali silica reaction, cyclic wetting and drying, and protein identification. The samples remained stable following these tests; therefore, the product is considered to be environmentally inert. This study highlighted deviation in the design and measured density of the samples.

As part of Mainmark's research and development, additional testing has been undertaken on four different mixes of Terefil with varied cement and sand contents to verify the assumed design parameters for the different mixes and potential for other applications especially in lieu of engineered gravel rafts for mitigation of liquefaction induced differential settlements. Representative samples for each mix design with varying increments of foaming agent added to the mixes was made in cylindrical moulds 200mm long and 100mm in diameter. The mixes were then cured for 28 days, before testing the density and capping of the samples using the following methods NZS 3112:1986, Pt 3 Section 5 and NZS 3112:1986, Pt 2 Section 4 (amendment No2, 2000), respectively. The water content was tested in accordance with Standard NZS 4402:1986 Test 2.1. The UCS Tests were carried out in accordance with Standard NZS 4402:1986 Test 6.3.1, which involved loading the samples in the UCS device and measuring the strain until the samples failed, at which point the maximum stress (peak strength) was recorded. The results from the different mixes are presented in Table 2.

Table 2: Summary of the test results of the laboratory prepared Terefil samples

			Mix 1 – average values		
Density (kg/m³)	620	675	830	920	1210
Strength (MPa)	1.075	1.384	1.982	2.718	7.381
Young's Modulus (MPa)	404.6	500.3	642.5	1130.4	2048.4
			Mix 2 – average values		
Density (kg/m³)	705	855	925	1105	1590
Strength (MPa)	0.710	1.589	1.9563	3.140	9.875
Young's Modulus (MPa)	216.0	452.2	697.1	968.0	1021.0
			Mix 3 – average values		
Density (kg/m³)	795	970	1225	1440	2180
Strength (MPa)	0.628	1.678	2.515	6.527	34.860
Young's Modulus (MPa)	131.6	426.9	792.1	1930.1	6694.3
			Mix 4 – average values		
Density (kg/m³)	1045	1270	1515	1705	2175
Strength (MPa)	1.468	1.985	3.727	7.051	19.541
Young's Modulus (MPa)	414	597.7	983.7	1567.8	2996.5

The results show the following:

- All the low density mixes tested exhibited high strength and stiffness.
- The stiffness is greater than that of comparable gravel rafts.
- Properties of the comparable mix to that used at the case study are higher than obtained from the case study.
- The densities were less variable than that of the case study.

6 CONCLUSIONS

Terefil is a highly effective alternative to traditional gravel rafts in challenging sites around Christchurch. It can be designed to meet a range of density and strength requirements, while offering a lightweight solution compared to alternative products. Terefil rafts can be installed in a few days, does not require compaction and is a self-levelling product.

Terefil rafts have successfully been design and constructed for complex sites, liquefaction prone sites with soft soils and shallow ground water conditions. Settlement modelling has proven significantly reduced static settlement compared with traditional gravel rafts. The density, UCS and Young's Modulus properties of the material have been validated with laboratory testing.

6.1 Lessons Learned

When working with Terefil, the following should be noted:

- Variability between the design densities and the measured densities were encountered from site samples.
- It is important that the Terefil is periodically wet down following installation to minimise potential shrinkage.

6.2 Further Works

Additional testing should be conducted to validate the long-term performance of density, strength and Young's Modulus over time.

It is possible to extend the application of Terefil rafts to liquefaction mitigation, similar to a traditional reinforced gravel raft as recommended in the MBIE Module 5A Guidelines in certain ground conditions for residential development in Christchurch. Such application will open opportunities for a versatile, cost effective system that could be used where a traditional shallow foundation system is not practical. Numerical modelling should be conducted to verify the performance of Terefil rafts under seismic loading to validate the use of Terefil rafts to mitigate liquefaction potential.

7 ACKNOWLEDGEMENTS

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