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Tensar Information Bulletin
IB/Earthquake_Foundation
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Tensar geogrid foundation solutions in earthquake-susceptible locations

Introduction

This Information Bulletin relates to the use of a Tensar mechanically stabilised layer (Tensar MSL™) incorporating TriAx® geogrid to enhance the performance of compacted gravel foundation layers during earthquake events. Designers are recommended to follow the foundation improvement methodology contained in the New Zealand Ministry of Business, Innovation, Employment (MBIE), Building and Housing information guidelines for building sites assigned to technical category TC2 and TC3, according to New Zealand guidelines(1).These define different foundation classes based on damage potential. ***The content of this bulletin is not intended to replace the need for a qualified geotechnical engineer to carry out site-specific investigations and design.***

Background

The superior behaviour of geogrid reinforced soil structures (walls and slopes) has been proven in several tragic earthquake (EQ) disasters in the past (Kobe, 1996, Chi-Chi, 1999). Reinforced soil structures withstood the seismic events with little permanent deformation and remained serviceable, whereas traditional gravity and cantilever walls collapsed and had to be rebuilt. This proven resistance of reinforced soil structures to earthquake loading is believed to be a result of geogrid/soil interaction which results in a very resilient composite material that behaves in a ductile manner and absorbs earthquake energy while remaining intact.

Tensar geogrids in foundations and pavements provide additional stiffness and resilience to the compacted granular layer thereby offering a better prospect of maintaining integrity during seismic events. Recent incidents in New Zealand (Christchurch, 09/2010, 02/2011 and 06/2011) showed that a geogrid-stabilised granular mattress can also be used very effectively as a foundation solution to mitigate soil liquefaction and associated structural damage to houses. This was confirmed when investigations conducted after the second and third seismic events examined houses that were reconstructed after the first EQ incident. This has led to a more stringent design approach which is referred to in this document.

Over twenty-five years of testing and use of Tensar geogrids in soil foundations to support shallow spread footings has demonstrated that a composite of Tensar geogrid and controlled aggregate fill provides improved performance characteristics. Early geogrid testing by Milligan and Love 1984(2) demonstrated an increase in load spread angle in the Tensar MSL. Further work by Guido et al, 1987(3) provided evidence of increased bearing capacity of a Tensar MSL by a factor of two to three. Adams and Collin 1997(4) established similar improvements in bearing capacity which can be attributed to an increase in shear strength within the Tensar MSL thereby reducing the development of the soil failure. More recently the Building Research Establishment in the United Kingdom(5) carried out full scale plate loading tests with the new Tensar TriAx geogrid to confirm similar improvements in load spread to reduce the vertical stress on the foundation.

The performance of Tensar MSL's incorporating TriAx geogrids has been further investigated through plate loading tests at field sites in Germany(6) along with repeated load triaxial tests, Wayne et al, 2011(7) to obtain improvement in surface modulus and resilient modulus respectively that support the concept of increased stiffness to the Tensar MSL.

Design Method

The New Zealand MBIE issued the Guidance document "Repairing and rebuilding houses affected by the Canterbury earthquakes", December 2012. The information in this Bulletin draws on these documents for guidance relevant to building sites that are classified to meet technical category TC2 and TC3.

Seismic Performance

Three factors will need to be considered for multi-layer Tensar MSL for use as a foundation raft treatment to building foundations under seismic conditions:

- Integrity of the Tensar MSL under vertical accelerations
- Supporting data
- Design considerations

When considering the integrity of a Tensar MSL under vertical accelerations, there is a condition when the raft is carrying a reduced foundation stress from the building. In cases where the vertical acceleration exceeds 1g, the raft can become temporarily 'weightless' as imposed stresses are neutralised. The integrity of the raft in these conditions will benefit from the Tensar geogrid and its ability to hold the composite of geogrid and aggregate together by virtue of the confining mechanism and the built-in residual stress. In the Christchurch 2011 earthquake, the accelerations were predominantly vertical up to 10km from the epicentre and the maximum recorded vertical accelerations were in the region 1.8g to 2.2g – depending on the location.

In the initial short duration phase, the stress is magnified and so it should be a design consideration that bearing capacity needs to be based on the increase in pressure from vertical ground acceleration. Laboratory shaking table research [8,9] on Tensar MSL's shows that initial stiffness of the layer is important to reducing settlement of the foundation. Research under static and cyclic loading does offer evidence of residual stress, where lateral stress is permanently built-in to a Tensar MSL. This phenomenon is seen in laboratory triaxial cell tests where the geogrid creates an effective increase in confining pressure. This state of compression will have a magnitude which may be significant in maintaining the integrity of the Tensar MSL under earthquake-induced loss of vertical effective stress.

Turning to practical full scale supporting data, pressure cells have been used to detect changes in horizontal stress both within and below a Tensar MSL during a field trafficking trial as reported by White et al 2011[10], providing further evidence of the ability of a Tensar MSL to generate increased built-in stresses.

The field research confirms the existence of a significant lateral force, enumerated to be 6kN/m in the specific case considered. It appears to be similar in effect to the passive resistance reported by Koseki [11] for the lateral containment of railway ballast on Japanese railways. The difference being that the use of a Tensar MSL incorporating TriAx geogrids provides a level of internal, omni-spatial and multi-directional restraint rather than an external passive structure.

During the trafficking trial reported by White et al 2011[9], instrumentation was placed near the base of a compacted road base course to measure the horizontal total stress, both as the roller or wheel passed (peak stress) and after the traffic had passed (locked-in stress). Figure 1 shows the total horizontal stress after the wheel had passed, both for the control section, and a section stabilised with TriAx TX160 (Tensar MSL). The data is shown both for the construction phases and the trafficking phases. The base course was built up in two layers of 300mm each. The depth to the pressure cell was 0.45m, so that the vertical total stress was about 10 kPa at that level.

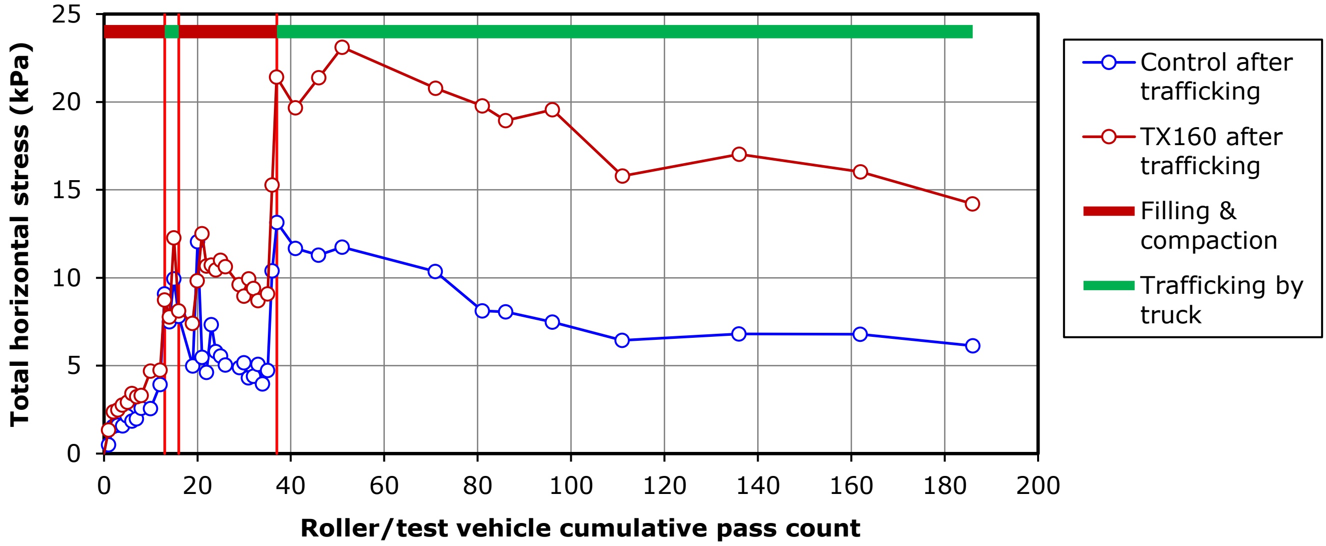


*Figure 1 above shows the residual horizontal stress in the **mechanically stabilised layer** during the construction and test truck trafficking stages (measured after the wheel has passed). This indicates that at the post-compaction stage of the installation, the control section retains a horizontal stress of around 10kPa, while the section incorporating TriAx TX160 there is a retained 'locked-in' stress of 20kPa.*

The 10kPa horizontal stress in the control section indicated in Figure 1 is about twice the active soil pressure that one might expect. This stress tends to be relieved during the subsequent trafficking phase of the test. In comparison, with the TriAx TX160 product the horizontal stress in the Tensar MSL is 'locked-in' at 20kPa but there is a similar subsequent relieving effect. The creation of the Tensar MSL, which includes the compaction stage, appears to account for around 10kPa at mid-depth in the first lift of the base course. If this were an average value over the 600 mm full depth of the construction, this amounts to a confining force of 6kN/m.

Considering, therefore, the 'reduced stress state after the uplift' phase of the Tensar MSL when subjected to the effects of vertical acceleration, the confinement effect can offer additional integrity to the foundation raft during an earthquake event.

The design considerations for a Tensar MSL in the foundation raft should include:

- The minimum thickness, typically 800mm

- The geogrid should be an appropriate grade of TriAx. The isotropic radial stiffness of TriAx allows that alignment is independent from the horizontal acceleration vectors.
- The aggregate is of good quality, likely to be similar in specification to a highway sub-base
- That aggregate compaction is carried out to a suitable performance specification as compaction is an essential component of the installation method.

Geogrid Requirements

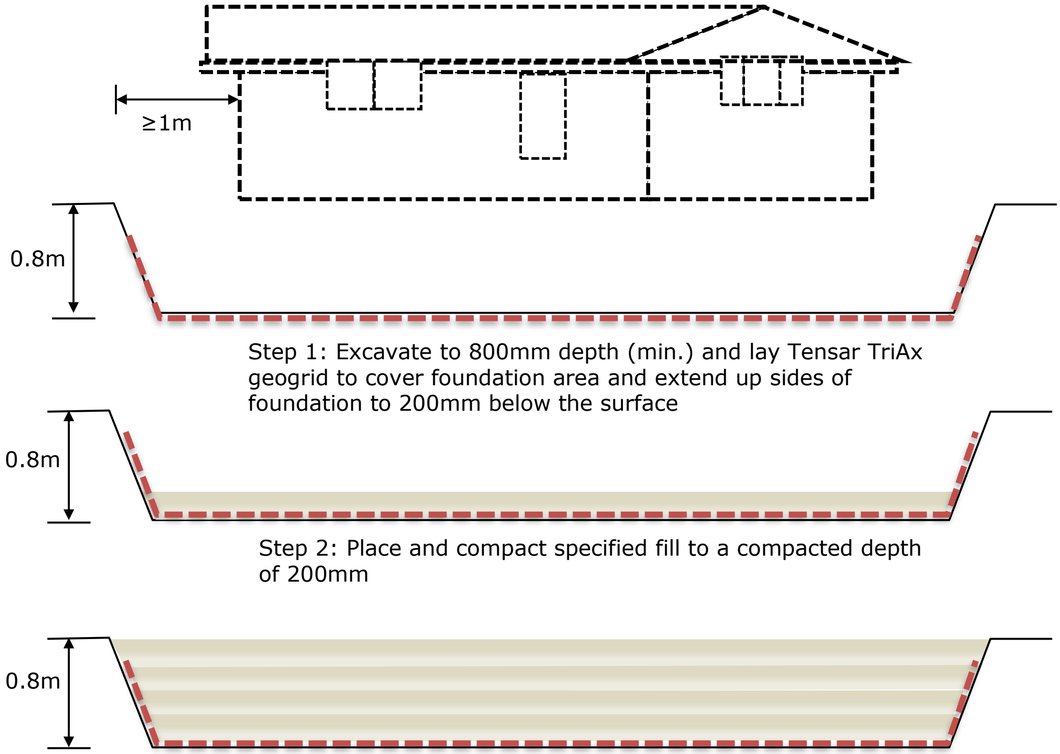
Tensar TriAx geogrid has three principal rib directions of stiffness and these provide near-uniform radial stiffness. This produces a significantly different structure than other geogrid forms and provides near-uniform stiffness through 360 degrees. The near isotropic property of TriAx enables an efficient load distribution in all directions. This is important as the direction of the earthquake loads is not predictable and response needs to be equally available in any direction.

Construction Options Following the New Zealand MBIE [1] Guide

1. Enhanced Foundation in TC2

The requirements for foundations for new buildings on sites subject to minor to moderate damage from liquefaction are to follow Table 5.2 and paragraph 5.3. Tensar MSL enhanced raft foundations may be applicable for sites where the ULS bearing capacity > 200kPa. ***The decision on suitability of this approach needs to be determined by a qualified geotechnical engineer.***

For this condition a Tensar MSL may typically comprise one layer of Tensar TriAx geogrid at the base of the excavation extending a minimum of 1m beyond the building foundation line. Well-graded gravels having a maximum particle size <65mm would then be placed and compacted to NZS 4402 as specified by the engineer. No construction traffic should be permitted to travel on the geogrid prior to covering with a layer of gravel fill. An approved nonwoven needle-punched geotextile separator should be considered for subgrade CBR ≤ 3 or where the liquefaction potential exists.



Step 1: Excavate to 800mm depth (min.) and lay Tensar TriAx geogrid to cover foundation area and extend up sides of foundation to 200mm below the surface

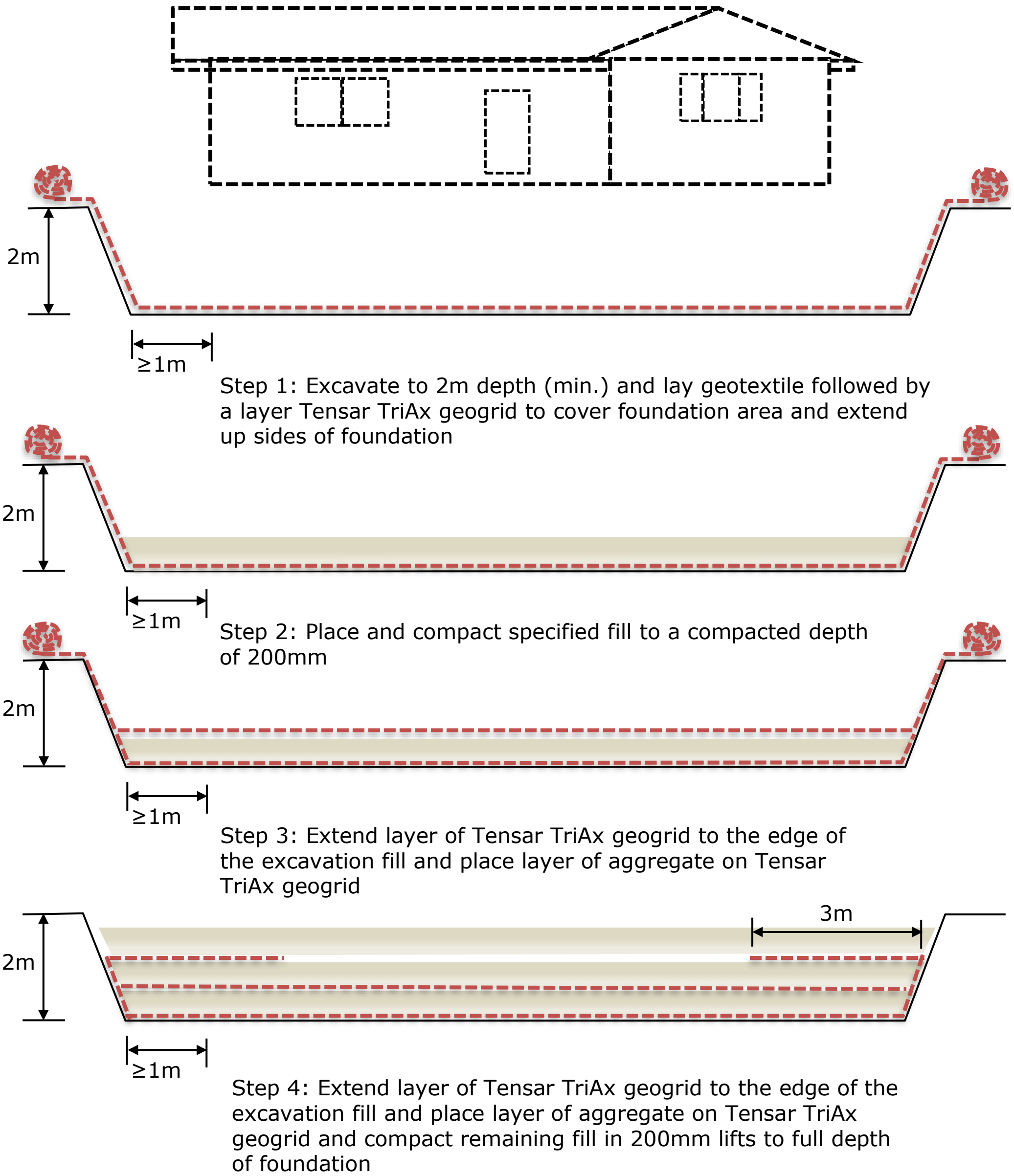
Step 2: Place and compact specified fill to a compacted depth of 200mm

Step 3: Place and compact specified fill to full depth of foundation

2. Shallow Foundation Treatment in TC3

This method applies to sites where the potential for significant damage from liquefaction has been identified by the geotechnical engineer and the formation of a well compacted raft of soil to a depth of 2m below the house foundation is considered necessary. The methodology utilises a Tensar MSL comprising multiple layers of Tensar TriAx geogrid placed between 200mm layers of compacted fill that can achieve a minimum density >95% standard compaction.

Tensar TriAx geogrid is laid in 200mm lifts extending a minimum of 1m beyond the building foundation line and extending up the side of the excavation to allow for a 3m return. Approved well-graded sands or gravels having a maximum particle size <65mm would then be placed and compacted to NZS 4402 as specified by the engineer. No construction traffic should be permitted to travel on the geogrid prior to covering with a layer of gravel fill. An approved nonwoven geotextile separator should be considered. ***The decision on suitability of this approach needs to be determined by a qualified geotechnical engineer.***



2. Areas of Lateral Spread

Specific design from a qualified geotechnical engineer is required in zones where foundations are to be subject to lateral spread. The solution may involve the use of Tensar uniaxial geogrids to resist the calculated horizontal forces. Designers should refer to Table C15.4 on page 64 of Appendix C to the MBIE Guidance Document.

Construction

Geogrid installation is a straight forward construction method which does not require specialist skills. See Tensar Construction Sequence ref CS/TriAx.

Performance in Recent New Zealand Earthquake

Several foundations which had been constructed on a Tensar MSL geogrid stabilised granular mattress following the 09/2010 event were investigated after the 02/2011 EQ and showed no sign of failure, while nearby buildings showed up to 700mm settlement and up to 500mm horizontal movement. The buildings resting on the Tensar MSL foundations however, showed only 40-50mm of movement and no failures or cracks in the superstructure. Only minor refurbishment was required for the buildings to be fully usable.

The builder of this structure with a Tensar MSL foundation in Huxley, reported no liquefaction from the Christchurch earthquake despite major liquefaction problems found in nearby structures.

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