University of Southern Queensland

Faculty of Engineering & Surveying

Interaction of Recycled Concrete and Geogrid Reinforcement Material 14m High Reinforced Earth Wall

A dissertation submitted by

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in fulfilment of the requirements of

Courses ENG4111 and 4112 Research Project

towards the degree of

BACHELOR OF ENGINEERING (Civil)

OCTOBER 2008

Abstract

Townsville's former General Hospital site is undergoing a major redevelopment that includes the construction of twelve elevated, level residential allotments with commanding views across Cleveland Bay towards Magnetic Island. To achieve the above development objectives, a large quantity of fill is required and most importantly will need to be retained to construct the allotments. Numerous methods of retainment were investigated and the reinforced earth option was discovered to be the most feasible.

A recycled concrete fill material, crushed to 100 mm minus, was proposed to be used in the reinforced earth structure. This material was a result of the demolition of numerous buildings from within the site. External advice suggested that the 100 mm minus material would not integrate sufficiently with the reinforcement (Tensar Geogrid) and would need to be crushed further to a 75 mm minus material. This would help to provide enough resistance to achieve the correct pullout characteristics of the reinforcement.

The objective is to create a testing apparatus that makes it possible to test the interaction of the Tensar Geogrid reinforcement with the various gradings of crushed recycled concrete material. These tests can then be analysed to confirm interaction calculations and the design of the reinforced earth structure.

A plywood box is constructed to allow the compaction of various grades of crushed concrete within. A similar grade of Tensar grid is used for each test and located centrally within the material. The reinforcement material extrudes from the box allowing a force to be applied. A load gauge records the pullout force applied to pull the Tensar grid from the apparatus.

The results from the individual tests undertaken are analysed against calculations made for the various types of material. The results are then compared against each other to indicate the ability of interaction and performance under load.

Preliminary analysis indicates that failure strength is similar for all tests undertaken, however the rate of failure gives a good indication of the interaction characteristics of the materials.

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Acknowledgments

I would like to acknowledge and thank my external Supervisor, Mr Henry Fracchia, for his guidance and invaluable contribution throughout this entire project.

I would also like to acknowledge the support of Geofabrics (Australasia) Pty Ltd, and their assistance in providing the Tensar Geogrid material for the project testing.

My appreciation is extended to Mr David Miller, for his invaluable time and assistance with the formation of the testing apparatus used during this project.

To Mr Aaron Gibson and Express Crane Trucks for his time, efforts and support including the supply of a crane truck for the assistance in the undertaking of the testing procedures.

Finally, my deepest appreciation goes to my wife and family for their understanding, support and patience throughout this undertaking.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Equations

List of Appendices

Chapter 1 - Introduction

1.1 Outline

This dissertation has been developed to outline the characteristics of the interaction of recycled crushed concrete and Tensar Geogrid reinforcement. The interaction characteristics relate to the construction of a 14.0 m high reinforced earth structure where recycled crushed concrete has been used as the embankment material in the structure.

This reinforced earth structure forms part of a major redevelopment of the Former Townsville General Hospital site which is located at the foothills of Castle Hill overlooking Cleveland Bay in Townsville. The former hospital is being redeveloped into a multi use site including a freehold residential land precinct, a commercial space and piazza precinct and a medium density multi unit precinct.

The residential land development will provide for twelve elevated level allotments with commanding views across Cleveland Bay towards Magnetic Island. To allow the above development objectives to be met, a fourteen meter high reinforced earth structure has been constructed to retain the embankment for the twelve residential allotments, refer Figure 1.

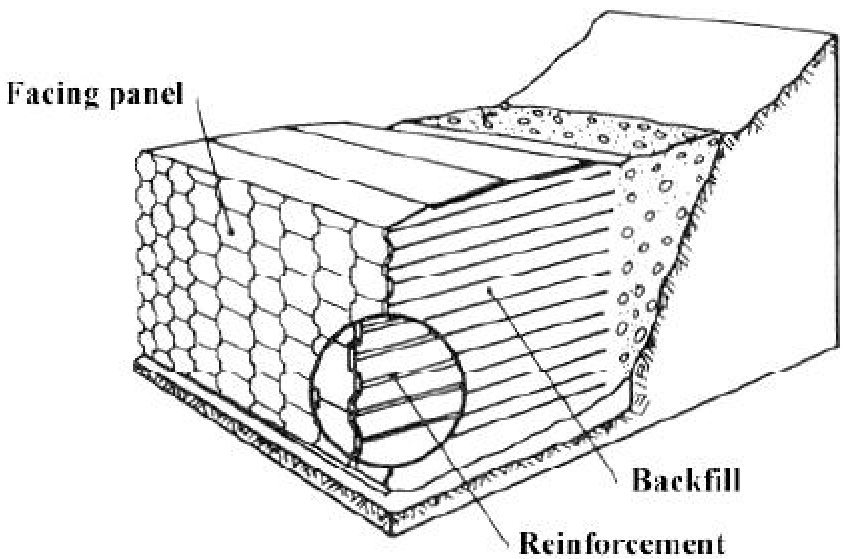

Figure 1 Schematic of Reinforced Earth Structure

The embankment material used in the reinforced earth structure is a crushed concrete material that has been recycled from the demolished buildings that once served as the hospital. The crushed concrete material has been reinforced with Tensar Geogrid to provide a suitable structure to build residential dwellings on.

This project will analyse the interlocking of the Tensar Geogrid with three different crushed concrete material samples using a simply constructed testing apparatus.

1.2 Project Objectives

This project consists of three objectives which include; physical model testing for the reinforced earth wall and possible environmental savings and financial cost savings associated with adopting the recycled embankment material on site.

The physical model testing includes the construction of testing apparatus to allow the testing of three individual cases of reinforced crushed concrete material. This testing will allow a physical analysis between three alternative gradings of recycled crushed concrete material with Tensar Geogrid reinforcement.

An environmental savings analysis will be undertaken to highlight the effectiveness of recycling demolished concrete structures as an alternative to disposing to waste.

A financial cost analysis will be undertaken to show the benefits that can be achieved in recycling demolition materials for reuse onsite as an alternative to disposing of waste and importing replacement materials.

1.3 Reinforced Earth Objectives

The constructed reinforced earth wall consists of Tensar Geogrid pillows at 500 mm vertical spacings and a horizontal depth of 10.2 m. (Refer Figure 2).

These Tensar Geogrid pillows are progressively filled with earth material, being crushed concrete in this case, as the height of the wall is developed. The Geogrid pillows are tied together using a bodkin tie to ensure that the constructed wall will act as one unit by transferring externally applied forces through the adjacent pillows. Hence the layers of Tensar grid are acting as reinforcement to the soil zone to prevent failures.

This method of retaining the embankment material does not require a solid facing such as a masonry wall or concrete panels to retain the earth. The facing of the reinforced earth structure can vary to suit the landscape requirements.

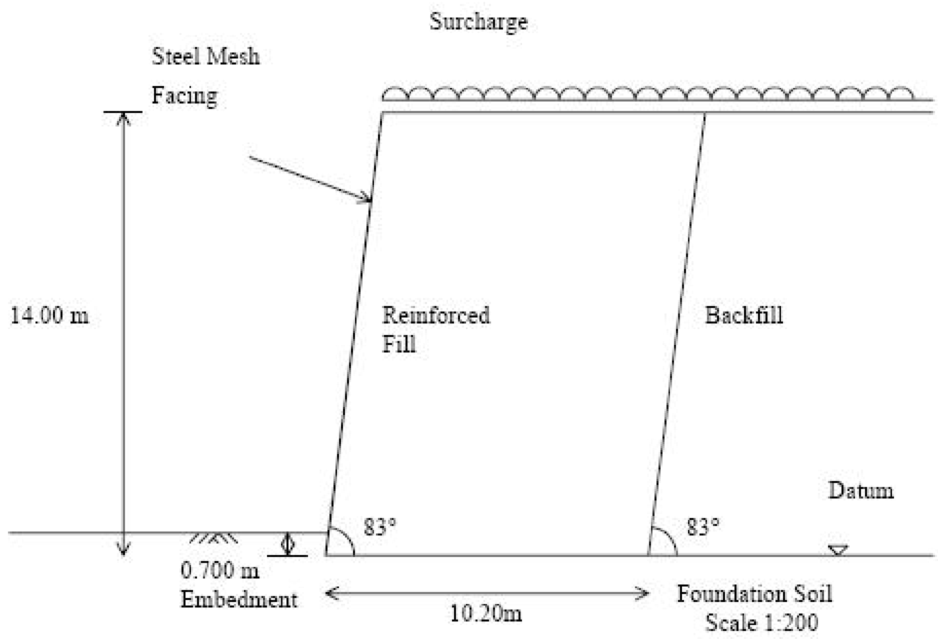

Figure 2 Design Section of Reinforced Earth Structure

1.4 Reinforced Earth Material

The initial design thoughts were to crush the concrete from the demolished buildings to a 100 mm minus material and adopt this material as the general embankment material. However as the reinforced earth design evolved, investigations and advice suggested that 100 mm minus material would not be suffice for binding/interlocking with the Tensar Geogrid. Therefore the concrete material was then specified to be crushed further to a 75 mm minus.

The design then evolved further when investigations required the material to be blended with 2% flyash before placement. This would allow the material to bind together and provide for a more solid reinforced soil zone. So the material in the reinforced zone of the embankment was specified to be crushed to a 75 mm minus concrete material with the inclusion of 2% flyash.

As an outcome of the above design developments this project will look to test the interlocking of the Tensar Geogrid with the three different material samples using a simply constructed testing apparatus.

These materials being:

1. 100 mm minus crushed concrete;

2. 75 mm minus crushed concrete; and

3. 75 mm minus crushed concrete with 2% flyash.

The main project objective is to test the binding/interlocking of the various crushed concrete materials as outlined above. The project will not analyse the performance of the Tensar Geogrid but only the performance of the varied embankment material type.

1.5 Environmental Objectives

Another objective of this project is to analyse the environmental benefits of recycling the demolished concrete buildings and using the crushed concrete as an embankment material onsite as an alternative to importing embankment material from a quarry.

The fill required to achieve the desired outcomes for the twelve residential lots amounted to approximately 40,000 cubic meters. The crushing and retaining of the concrete onsite provided approximately 30,000 cubic meters of embankment material. This will have significant environmental value as opposed to the dumping of the entire demolished material.

Another added environmental benefit of crushing the concrete is the opportunity to separate the steel reinforcing from the concrete structures. This allowed for the steel to be transferred to a steel recycling plant rather than disposing to waste.

1.6 Financial Objectives

The third objective of this project is to analyse the financial benefits of both constructing a reinforced earth wall as opposed to a general type of retaining wall and also adopting the recycled crushed concrete fill material as opposed to importing a general fill material.

The design of the twelve residential lots required an earth embankment of approximately 14.0 meters in height. In general the cost of a wall to retain a 14.0 m high embankment would encompass massive expense. Ensuring a feasible solution is a high priority in a development of this nature.

The importation of a large quantity of fill would be another concern for this development. Not only are just the costs of the fill a concern, but also the transportation to a redevelopment site which is located within the city business district.

Chapter 2 – Literature Review

2.1 Project Intention

The project intention is to test the binding/interlocking characteristics of the various crushed concrete materials as outlined in section 1.2 by undertaking a series of pullout tests.

The Tensar Geogrid material used for the soil reinforcement has previously been through rigorous testing regimes and has been approved for use in engineering applications. Therefore it is not the intention of this project to reanalyse the sole performance of the Geogrid reinforcement material. Rather, this project will analyse the performance of the fill material and its associated characteristics with the Tensar Geogrid.

The Tensar Geogrid being used in this project is the 40RE which has a tensile strength of 52.5kN/m. The Geogrid is made from a High Density Polyethylene.

The following literature review critically analyses many previous studies that relate to this specific topic in some form. It will establish existing parameters adopted and how they relate to this project.

2.2 Literature Review

Reinforced soil structure behaviour is largely governed by interaction mechanisms that develop between the reinforcement inclusions and the fill material. The main function of the reinforcement is to redistribute stresses within the soil mass in order to enhance the internal stability of the soil structure (Sidnei et al. 2006).

The total pull-out resistance for geotextiles is contributed only by the frictional resistance. The frictional resistance for geotextiles is evaluated using Mohr-Coulomb yield criterion, which depends on the soil properties (i.e. soil friction angle and soil cohesion intercept), interface friction angle, interface adhesion, the embedded area and applied confining pressure (Koutsourais et al., 1998).

Ochiai et al. (1996) evaluated the pull-out resistance from pull-out tests of Geogrids in uniform fine sand. In their study, both field and laboratory pull-out tests were carried out in order to clarify the pull-out mechanism, and to determine the parameters needed for design and analysis of the reinforced soil structures. In order to evaluate the pull-out resistance, two evaluation methods were defined the Mobilising Process method and the Average Resistance method. Based on the pull-out mechanism, the Average Resistance method was further sub-divided in to three methods which are called the Total Area method, the Effective Area method and the Maximum Slope method.

Total Area Method

In this method the pulling force at the front and the whole area of the Geogrid in the pull-out box (in case of laboratory tests) are taken into consideration for the resistance evaluation. This method gives a reasonable average value of the pull-out resistance when the Geogrid is wholly pulled out with slight elongation (Ochiai et al., 1996). The advantage of this method is that only the pulling force at the front of the Geogrid needs to be measured.

Effective Area Method

This method is defined by the effective force with the related area for evaluating the pull-out resistance. The pull-out resistance is calculated by using the effective length of the Geogrid. In order to determine effective length, the displacements of each grid junction in the soil have to be measured in the test, as well as the pulling force at the Geogrid front. However, the effective area method agrees with the total area method when the whole Geogrid is totally pulled out (Ochiai et al., 1996).

Maximum Slope Method

In this method the slope of the tangent at a point of maximum tangent of the slope on distribution curve is used to evaluate the pull-out resistance. The pull-out resistance is calculated to express the maximum slope of the tangent to the tensile force distribution curves. However, this method gives an over estimation of the average pull-out resistance.

For practical use, the pull-out test with small vertical stress is recommended, together with the total area method, for evaluating the average resistance from the test results.

When analysing the binding/interlocking parameters of the crushed concrete fill material with the Tensar Geogrid, the main interaction mechanisms affecting the pullout resistance of the Geogrid are the skin friction, between soil and reinforcement solid surface and the bearing resistance that develops against transversal elements.

Pullout tests have often been used to determine the stress transfer mechanism taking place between the soil and the reinforcement. The redistribution of stresses within the reinforced soil mass depends on the shear strength properties of the soil.

The pullout resistance of a Geogrid can be evaluated using the following equation:

Equation 1 Pullout Resistance

$$P_R = P_{RS} + P_{RB}$$

Where P_R is the pullout resistance;
P_{RS} is the skin friction component; and

P_{RB} is the bearing component.

The above equation assumes that the different interaction mechanisms act at the same time independently of each other and at their maximum values.

A similar equation for the pullout resistance of a Geogrid can be expressed as:

Equation 2 Pullout Resistance Variation

$$P_{(R)} = 2\, k_{PULL}\, L_{a(R)}\, \Phi_{PULL}\, Gr(d_{(R)}\, \gamma^*_i + q_d + q_l) \tan(\varphi_i)\, \Phi_R$$

Where k_{PULL} is the coefficient of pullout resistance;
$L_{a(R)}$ is the Geogrid length beyond the failure plane;
Φ_{PULL} is the pullout factor;
Gr is the load factor;
$d_{(R)}$ is the average depth of overburden;
γ^*_i is the soil density;
q_d is the dead load surcharge;
q_l is the live load surcharge;
φ_i is the internal friction angle; and
Φ_R is the reduction factor.

The ultimate pull-out load (T_{ult}) of a Geogrid reinforcement can be computed using the following Equation:

Equation 3 Ultimate Pull-Out Load

$$T_{ult} = 2T_{ap} / A$$

Where T_{ap} is the pull-out resistance; and
A is the embedded area of the Geogrid specimen.

This empirical relation is defined as the average resistance method.

The coefficient of friction measured by a direct shear test is often very different from that measured by a pullout test, in some cases, the latter is 13 times greater than the former (Ingold 1982). It is believed that this phenomenon results from the dilatancy of soil under shear stress and also depends on the roughness of reinforcement (Ingold 1982; O'Rourke et al. 1990).

Theoretical studies undertaken by Moraci and Gioffre (2006) using different types of Geogrid and a single granular sand type of fill material have shown that the skin friction component only represents approximately 6% of the residual pullout resistance. Further practical studies undertaken by Moraci and Gioffre (2006) have shown that the differences in skin friction component ranged from 0% – 19% of the residual pullout resistance. These differences appear to be minimal and relative.

In the existing research there appears to be a lack of study into the friction coefficients for recycled crushed concrete material and how crushed concrete may affect the pullout friction compared to nominal granular materials. However, previous studies undertaken by Jie Han (2006) suggest that the required connection strengths can significantly change depending on the quality of fill. When a low quality fill is used the required connection strength is much higher as less pullout resistance is available for the reinforcement.

As shown in Figure 3, the low quality fill (Φ=20°) requires higher maximum tensile resistance than the baseline fill (Φ=30°).

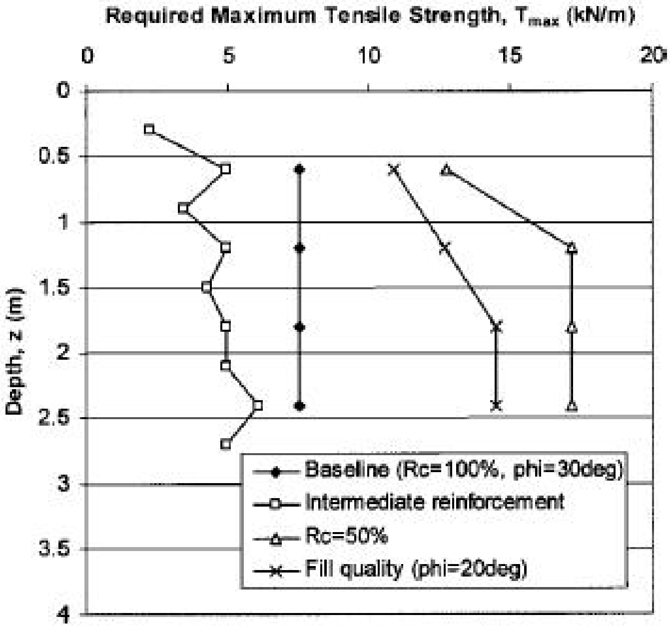

Figure 3 Required Maximum Tensile Strength

Given the characteristics of the crushed concrete material, the quality of the fill material should be considerably higher (approximately Φ=40°) requiring a lower maximum tensile resistance.

Rathje. et al., (2006) reported that results from consolidated shear tests indicated that crushed concrete has strength characteristics comparable to that of a high quality standard fill material and has a shear strength parameter of Φ=46°.

Pullout testing undertaken by Rathje. et al., (2006) on the crushed concrete with steel ribbed reinforcement provides observations that include the pullout friction factor being considerably higher than the values normally used in traditional predictive equations.

With the above in mind, a crushed concrete material to 100 mm minus should provide adequate strength characteristics to be able to meet the required pullout friction factors. Further crushing of the material to 75 mm minus and the addition of flyash should only enhance the pullout performance.

Testing to be undertaken in this project will provide measureable values for pullout friction factors of crushed concrete material which can be analysed against current values for conventional fill materials.

The drainage properties of a crushed concrete material should also be relatively high adding to increased pullout friction factors. However, Rathje. et al., (2006) has reported that hydraulic conductivity tests performed on crushed concrete material has indicated that the drainage properties of the material are lower than conventional fill materials. This concerning statement would appear to be inaccurate, with observations thus far showing that hydraulic conductivity is reasonably good. Further testing is required to provide a more detailed assessment of hydraulic conductivity.

Chapter 3 – Consequential Effects

3.1 Sustainability

Sustainability on projects today is clearly at the top of most design agendas. This project incorporates numerous sustainable outcomes.

The most obvious sustainable achievement is the incorporation of the demolished concrete into the embankment material. This outcome eliminated the disposal to waste option for the concrete. This in turn has resulted in very minimal offsite cartage of the concrete material to landfill.

Another sustainable achievement is the recycling of the steel reinforcement from within the concrete. Due to the concrete being crushed to a fill material the steel was able to be separated from the concrete and therefore recycled rather than disposing to waste.

The recycling of concrete for a general bulk fill material should become a mandatory occurrence in the future. Rather than disposing of concrete materials to waste, a concrete recycling station could be introduced at local transfer stations where the materials can be recycled and the crushed concrete sold as a general fill material.

3.2 Safety

The Workplace Health and Safety Regulations are essential considerations when undertaking the testing required for this project. It is important to ensure the safety of those involved in the testing regime. All hazards which cannot be mitigated in the design will be reduced where possible.

The Australian Standards also provide particular design criteria for the design of reinforced earth structures. Partial performance or failure of the design could have catastrophic consequences.

3.3 Ethical Responsibility

This project not only carries safety and sustainability effects but also carries an ethical responsibility and a responsibility to ensure the welfare of the community and to act in their best interest.

The opinions and statements in this report shall be made with fairness and honesty and only on the basis of adequate knowledge. To ensure that this is possible, adequate research and information gathering is required to make informed decisions.

It is important to make note of the Code of Ethics that exists for Engineers and the ethical standards and requirements that are contained within.

Chapter 4 – Project Methodology

4.1 Testing Apparatus

The objective of this project is to test the binding/interlocking of the various gradings of crushed concrete materials with the Tensar Geogrid reinforcement.

To undertake this testing, an apparatus was required to be constructed to allow an adequate analysis to be undertaken. The apparatus developed is similar to that shown in Figure 4.

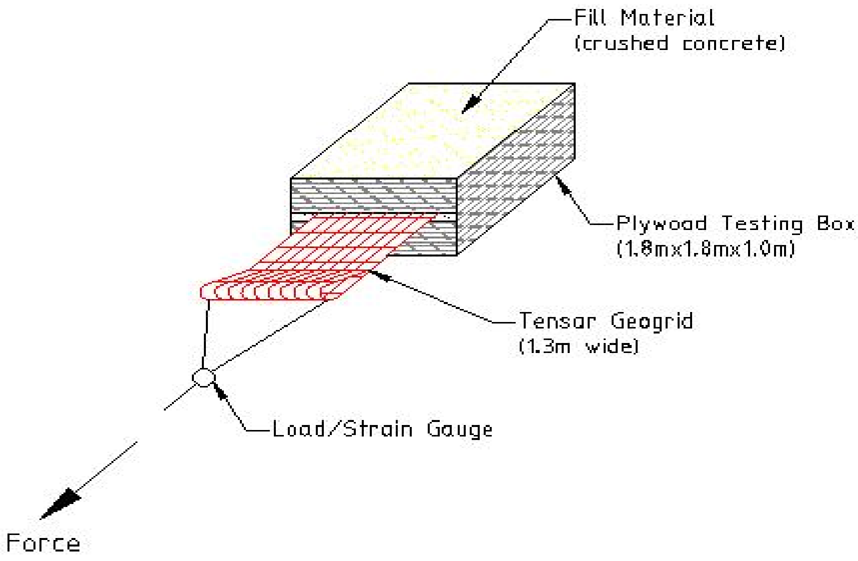

Figure 4 Testing Apparatus

The apparatus is a simple plywood box construction that allows for the compaction of various material types within. The constructed box is 1800 mm x 1800 mm in dimension with a window cut in the front panel to allow for the extrusion of the Tensar Geogrid.

A layer of Tensar Geogrid being 1.35 m wide is incorporated into the compacted fill representing the layered effect as constructed within the actual reinforced earth structure.

A load gauge is able to be attached to the Tensar Geogrid to record the pullout loads applied to the Tensar Geogrid. The load gauge used in the tests is displayed in Figure 4.1b. The test would cease once the Tensar Geogrid pulls from the compacted fill with minimal effort or once the Geogrid fails.

Figure 5 Load Gauge

To apply the load to the testing apparatus, the hydraulic arm on a crane truck was used. The arm was able to be manoeuvred into position to ensure that the force applied to the Geogrid was horizontal and was not impeded.

4.2 Testing Analysis

This project is being undertaken to analyse the binding/interlocking characteristics and pullout resistance between 3 different samples of crushed concrete material.

The three tests will include the following materials:

1. 100mm minus crushed concrete;

2. 75mm minus crushed concrete; and

3. 75mm minus crushed concrete + 2% Flyash.

The three materials were compacted into the apparatus using small scale compaction equipment ensuring that similar compactive efforts were achieved.

All three tests that were undertaken included the same strength Tensar Geogrid. The Tensar Geogrid being used in this analysis is the 40RE as shown in Figures 6 and 7.

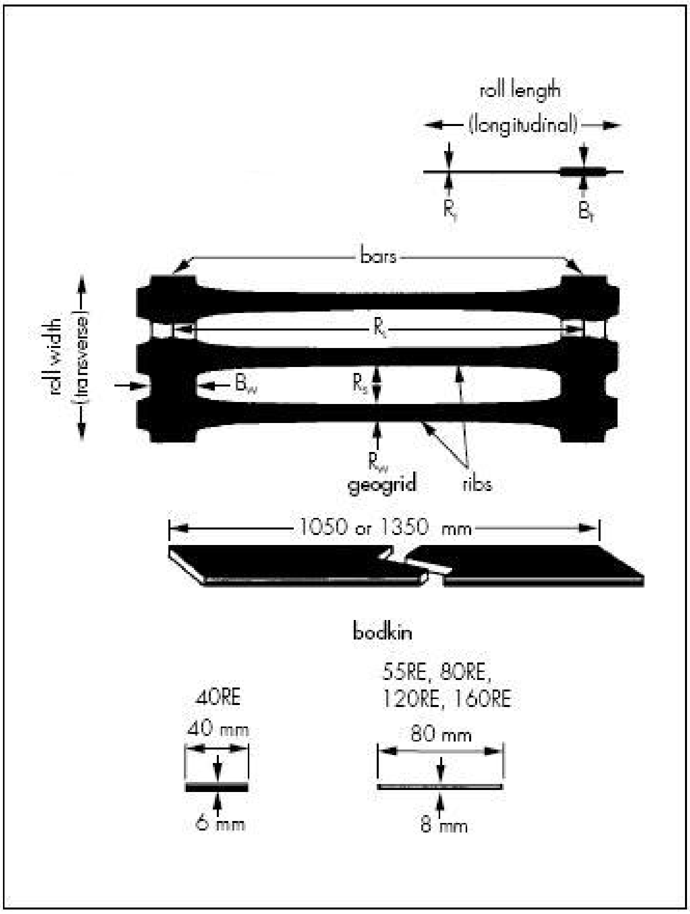

Figure 6 40RE Tensar Geogrid used in Tests

Geogrid grade	40RE	55RE	80RE	120RE	160RE
Rib dimensions (mm)					
length R_L	235	235	235	235	230
width R_W	6.0	6.0	6.0	6.0	6.0
thickness R_t	0.7	0.9	1.3	2.0	2.6
spacing R_s	16	16	16	16	16
Bar dimensions (mm)					
width B_W	16	16	16	16	16
thickness B_t	1.8 to 2.0	2.5 to 2.7	3.4 to 3.7	5.5 to 5.9	7.1 to 7.7
Roll					
length (m)	50	50	50	50	30
width (m)	1.0 or 1.3	1.0 or 1.3	1.0 or 1.3	1.0 or 1.3	1.0 or 1.3
weight of roll (kg)	14.5 or 18.8	20.0 or 26.0	30.0 or 39.0	47.0 or 61.1	37.2 or 48.4
Colour coding	Blue	Yellow	Orange	Dark Green	Red

Figure 7 40RE Tensar Geogrid Dimensions

Prior to undertaking the field tests a prediction of the field behaviour is to be calculated using numerical modelling techniques. A theoretical prediction of the expected field results is vitally important when analysing the outcomes of the testing. The numerical model will be analysed in Chapter 5.

The results received from the field testing will be compared to the numerical analysis of the reinforced structure. The relationship that can be discovered between the theoretical analysis and the field testing can then be applied to make more accurate assumptions of the 14.0 m high reinforced earth structure.

The important objective that this project discovers is the comparative difference in the interlocking ability and pullout resistance between the three different materials being tested.

4.3 Financial Analysis

This project has a significant financial benefit resulting from the use of recycled concrete for embankment material. The financial analysis to be undertaken in this project will include the following:

- An analysis of the costs applicable to crush the concrete on site and incorporate the flyash as opposed to disposing the concrete off site to landfill and importing an embankment material; and

- An analysis of the associated costs to further crush the material from a 100 mm minus to a 75 mm minus and incorporate the flyash in comparison to the extra interlocking strength achieved.

The analysis shall be presented in a table form that can provide simple comparisons.

4.4 Environmental Analysis

To undertake an environmental analysis of this project, it is important to understand the quantities of materials involved on the broader scale of the project.

The main items that require exploring are:

- Volumes of concrete that has been recycled rather than disposed to waste;

- Volumes of steel that has been recycled once separated from the concrete rather then being disposed to waste; and

- The negation of transport vehicles that would have been required to not only transport the material to waste but also to import the fill material that would have otherwise been required.

It is important to tabulate this information so that it can be easily understood and validated realistically.

Chapter 5 – Prediction of Field Behaviour

5.1 General

As a comparison to the results received from the field testing, a numerical analysis has been undertaken to predict the results that should be observed in the field.

Much theoretical and field testing has been undertaken previously on general fill materials and their interaction with Geogrid reinforcements, however the parameters of the crushed concrete material offer some differing results.

In pull-out tests, the Geogrid reinforcement extensibility results in a non-uniform distribution of shear stresses and shear displacement along the length of the reinforcement specimen. This makes the interpretation of the test results difficult. In interpreting the pull-out test results, it is common practice to assume that the apparent shear stress or pull-out resistance (τ_a) is developed on planar surfaces adjacent to each face of the reinforcement.

This apparent shear stress or pull-out resistance (τ_{ap}) of a Geogrid reinforcement can be computed using the following Equation:

Equation 4 Pull-Out Resistance

$$T_{ap} = T_{ult} / 2 * A$$

Where T_{ult} is the ultimate pull-out load; and
A is the embedded area of the Geogrid specimen.

This empirical relation is defined as the average resistance method, and the formulation of this relation will be discussed in the next section of this chapter.

5.2 Pullout Phenomenon

The pull-out mechanism can be classified depending on the structure and geometry of the reinforcement material. For reinforcements like Geogrids, the contribution to the pull-out resistance is provided by two main components, the frictional resistance offered mainly by the longitudinal members of the Geogrid, and the passive bearing resistance offered by the transverse members of the Geogrid.

The pullout resistance or pullout force of a Geogrid reinforcement can be evaluated using the following equation:

Equation 5 Pull-Out Force

$$P_{(R)} = 2\ k_{PULL}\ L_{a(R)}\ \Phi_{PULL}\ Gr(d_{(R)}\ \gamma^*_i + q_d + q_l)\tan(\varphi_i)\ \Phi_R$$

Where k_{PULL} is the coefficient of pullout resistance;
$L_{a(R)}$ is the Geogrid length beyond the failure plane;

Φ_{PULL} is the pullout factor;
Gr is the load factor;
$d_{(R)}$ is the average depth of overburden;
γ^*_i is the soil density;
q_d is the dead load surcharge;
q_l is the live load surcharge;
φ_i is the internal friction angle; and
Φ_R is the reduction factor;

The ultimate pull-out load (T_{ult}) of a Geogrid reinforcement can be computed using the following Equation:

Equation 6 Ultimate Pull-Out Load

$$T_{ult} = 2T_{ap} / A$$

Where T_{ap} is the pull-out resistance; and
A is the embedded area of the Geogrid specimen.

The frictional force discussed here has the same formulation as that of the apparent shear stress or pull-out resistance (τ_a) discussed in Section 5.1.

This represents the sum of all the areas close to the latitudinal member along the numerous apertures present in the Geogrid. Since the passive bearing force is offered by the thickness and the width of the aperture (i.e., the soil interlocks within the aperture width with the help of the thickness of the transverse member).

Therefore, it is the product of the number of apertures, width of the aperture and the thickness of the transverse member. In order to have a maximum benefit from the passive bearing resistance, it is better to have more apertures with enough thickness of the transverse members.

5.3 Numerical Analysis

The numerical analysis provides the following calculated average ultimate pullout load for the Geogrid in the crushed concrete material:

Values calculated and adopted:

Equation 7 Numerical Analysis

k_{PULL} = 0.85;
$L_{a(R)}$ = 1.356 m (based on 1.5 m length of Geogrid and a failure angle of 60 degrees);
Φ_{PULL} = 0.8;
Gr =1.0;
$d_{(R)}$ = 0.25 m;

γ^*_i = 20 kN/m^3;
q_d = 0 kPa;
q_l = 0 kPa;
φ_i = 40 degrees; and
Φ_R = 1.0.

These values provide the following ultimate pull-out load:

T_{ult} = 7.64 kN/m (test area of Geogrid is 1.35 m wide and 1.5 m long).

As per section 2.2, a suggested value of Φ=40° has been adopted as the internal friction angle of the crushed concrete material. This friction angle value provides a theoretical pullout load of 7.64 kN/m.

Furthermore section 2.2 reported a value of Φ=46° from the results represented by Rathje. et al., (2006) for a high quality standard fill material. This value provides a theoretical pullout load of 9.43 kN/m.

The calculated values above will be compared to the field pull-out test results in section 8.5.

Chapter 6 – Field Pullout Tests

6.1 General

The field pullout tests were undertaken over a duration of a few weeks. This allowed the apparatus to be constructed, the materials placed and compacted and a sufficient period of time for the material to settle prior to the testing taking place. The material that included the 2% flyash mix was able to be cured during this time.

The programming of the testing was an important aspect of the project to ensure that all the tests could be undertaken in a similar environment which would allow the results to be easily compared.

6.2 Field Setup

The three identical testing boxes were setup along side each other at the testing site. A small bucket loader was used to place the materials into the testing boxes. The material which incorporated the 2% flyash was mixed separately prior to placing.

A vibrating plate was then used to compact the material into place ensuring an even compaction rate between the three test specimens. The application of water during the compaction effort was necessary to achieve the correct compaction densities.

The design of the 14.0 m high reinforced structure incorporated layers of reinforcement at 500 mm vertical spacings. Likewise this test would consist of a 500 mm layer of compacted material with reinforcement placed centrally within the material.

A window provided in the testing boxes allowed the Tensar Geogrid to extrude from the box once placed into position. The Tensar was placed 1.5 m deep into the fill material and centrally positioned so that it was clear from the box surrounds.

Figures 8 - 11 below provide a visualisation of the above procedures.

Figure 8 Placing the 100mm minus Material

Figure 9 Compaction of the Crushed Concrete Material with a Vibrating Plate

Figure 10 Placing the Tensar Geogrid 40RE

Figure 11 Finalising Material Compaction with Tensar Geogrid in Place

6.3 Field Tests

6.3.1 Dynamic Cone Penetrometer Testing

Following the construction of the test specimens, it appeared that the crushed concrete material, once compacted in place, had bound together rather tightly giving the impression that the concrete had reacted following the inclusion of water and regained some of its strength properties.

To investigate if this was actually the case, some Dynamic Cone Penetrometer (DCP) testing was undertaken on the filling behind the 14.0 m retaining structure. Three tests were performed on separate materials which included the 100 mm minus crushed concrete, 75 mm minus crushed concrete and general fill material.

Figure 12 Dynamic Cone Penetrometer Testing

The DCP tests involve a steel rod with a 9 kg slide hammer that provides the force to penetrate the steel rod into the material. The number of blows to penetrate 100 mm is recorded. A maximum of 25 blows for 100 mm of penetration is classed as refusal.

Figure 13 Dynamic Cone Penetrometer Testing (Penetration of steel rod)

The results from these DCP tests are tabulated below.

Table 1 Dynamic Cone Penetrometer Tabulated Results

DCP Test 1 (75mm minus material)	
Depth (m)	**Drops**
0.0 - 0.1	20
0.1 - 0.2	15
0.2 - 0.3	12
0.3 - 0.4	10
0.4 - 0.5	25
0.5 - 0.6	0
0.6 - 0.7	0
0.7 - 0.8	0
0.8 - 0.9	0
0.9 - 1.0	0
1.0 - 1.1	0
1.1 - 1.2	0

Table 2 Dynamic Cone Penetrometer Tabulated Results

DCP Test 2 (100mm minus material)	
Depth (m)	Drops
0.0 - 0.1	14
0.1 - 0.2	18
0.2 - 0.3	25
0.3 - 0.4	0
0.4 - 0.5	0
0.5 - 0.6	0
0.6 - 0.7	0
0.7 - 0.8	0
0.8 - 0.9	0
0.9 - 1.0	0
1.0 - 1.1	0
1.1 - 1.2	0

Table 3 Dynamic Cone Penetrometer Tabulated Results

DCP Test 3 (General Fill material)	
Depth (m)	Drops
0.0 - 0.1	5
0.1 - 0.2	4
0.2 - 0.3	3
0.3 - 0.4	4
0.4 - 0.5	7
0.5 - 0.6	17
0.6 - 0.7	17
0.7 - 0.8	25
0.8 - 0.9	0
0.9 - 1.0	0
1.0 - 1.1	0
1.1 - 1.2	0

The tabulated results above indicate that the general fill material was easily penetrated however the crushed concrete material reached refusal very early following the initial penetration. The results have been graphed and are displayed in Figure 13 below.

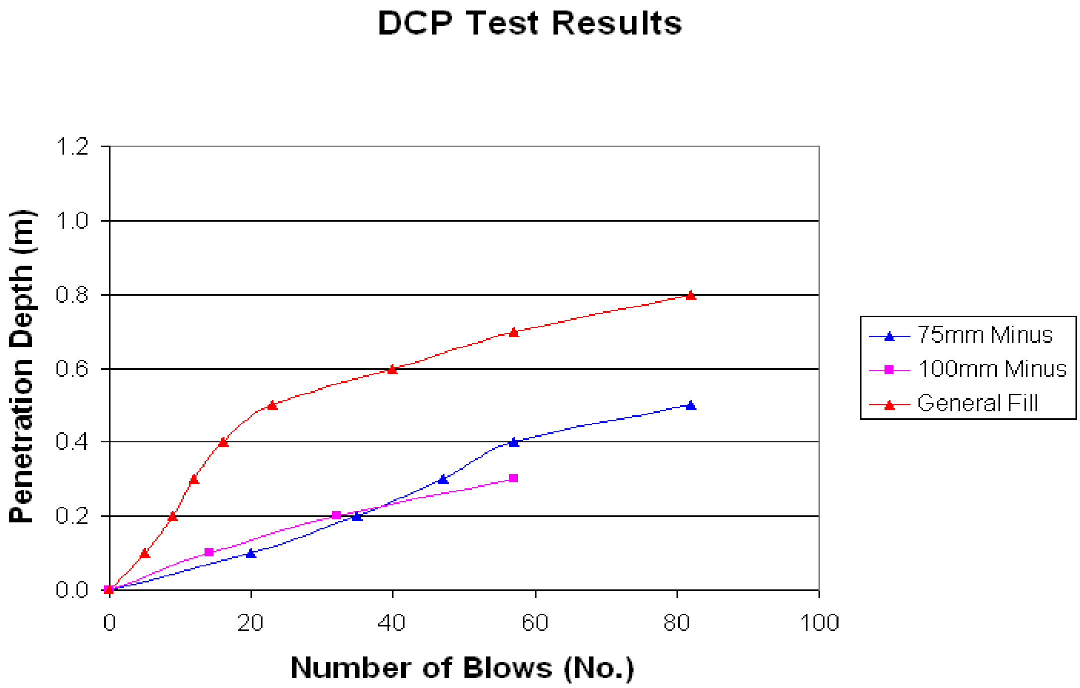

Figure 14 Dynamic Cone Penetrometer Test Results

It is clear from Figure 13 that the crushed concrete material was not easily penetrated and reached refusal prior to a depth of 0.5 m. This may be related to the grading of the material and the steel rod not being able to penetrate past a larger diameter concrete particle. However the number of blows required to penetrate the steel rod into the crushed concrete material indicated that the material has bound together very tightly and perhaps the concrete is reacting to reform some of its former strength properties.

6.3.2 Pullout Testing

Pullout tests were carried out with the use of a hydraulic arm on a crane truck. This method allowed a steady increase of pullout load to be applied to the testing specimen. The Tensar material was attached to a steel bar using a bodkin tie. This steel bar allowed the pullout load to be applied evenly to the Tensar Geogrid material. The steel bar was attached to the load cell which was inturn attached to the hydraulic arm with chains and shackles. Refer Figure 14.

Figure 15 Tensar Geogrid attached to hydraulic arm with chains and shackles

The pullout load was then progressively applied with readings recorded by the electronic display attached to the load cell. The data being collected included the applied load, displacement of the Tensar Geogrid material and maximum load required for failure. Failure was recognised when the interaction between the Geogrid and material was lost and little force was required to pullout the Geogrid.

The figures below indicate the testing undertaken.

Figure 16 Pullout Load applied to Tensar Geogrid

Figure 17 Tensar Geogrid interaction begins to fail under load

Figure 18 Tensar Geogrid interaction fails under pullout load

Chapter 7 – Pullout Test Results

7.1 General

The three tests were performed under similar conditions using identical equipment and machinery. Each test was successfully undertaken and provided numerous results that could be critically analysed and compared against the theoretical analysis previously undertaken.

Observing the test specimens prior to testing gave a visual indication that perhaps the crushed concrete material had bound together so tightly that the Tensar was not going to be able to be pulled from the testing box prior to breaking. It appeared that the material had regained some of its original strength characteristics.

7.2 Field Test Results

The test results are indicated in the Figures below showing profiles of the applied pullout forces as a function of displacement of the Tensar material.

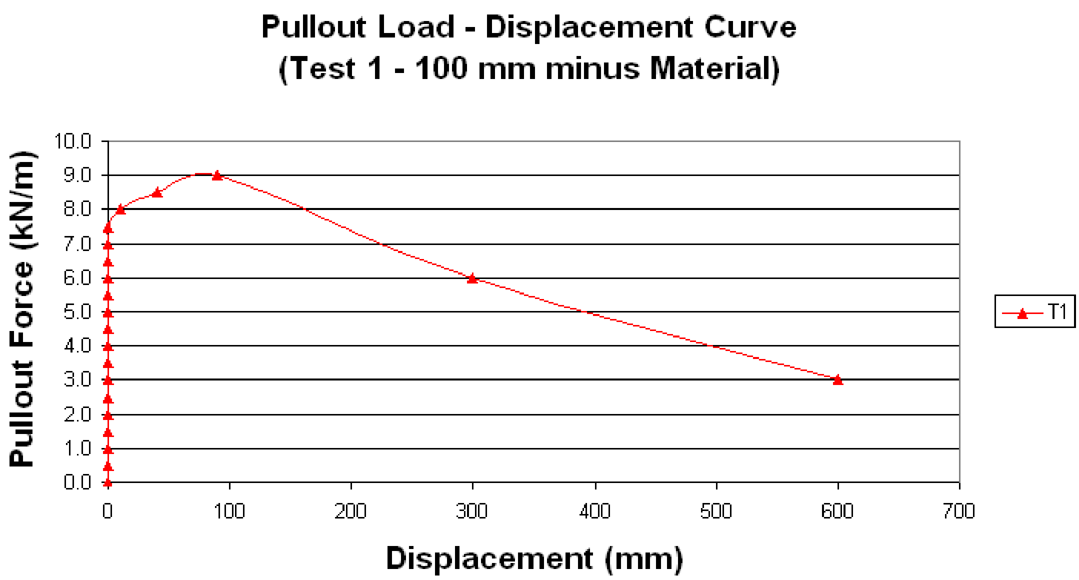

Figure 19 Pullout Test Results - 100mm minus Material

The 100 mm minus crushed concrete material appeared to perform rather well while the Tensar Geogrid was under load. The interaction between the fill material and the Geogrid was reasonably good. However upon failure of the interaction between the two materials, the Tensar was pulled from the test box with relative ease.

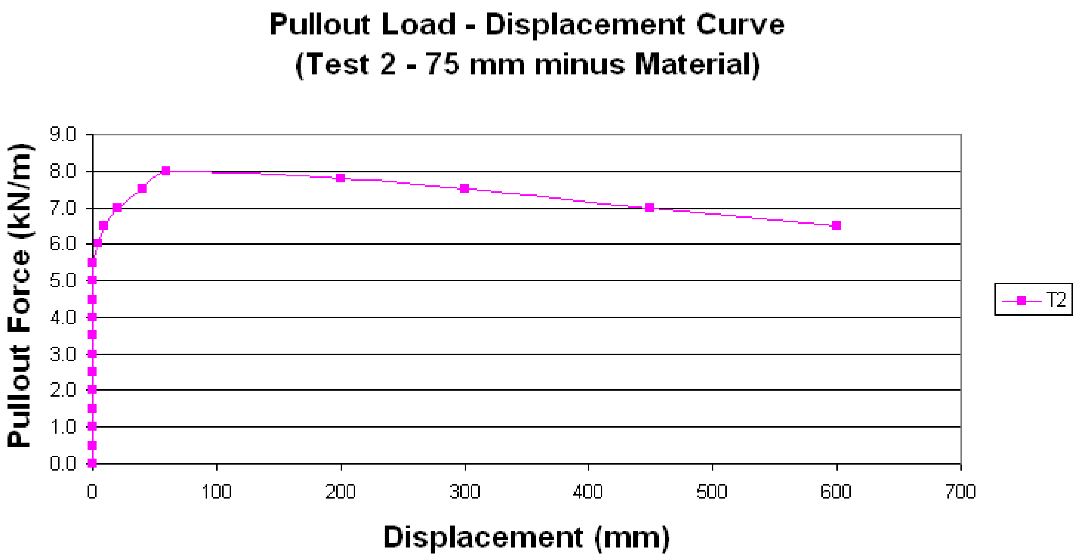

Figure 20 Pullout Test Results - 75mm minus Material

The 75 mm minus crushed concrete material also performed rather well while the Tensar Geogrid was under load, however the pullout load of the 100 mm minus material was not achieved. The interaction between the fill material and the Geogrid was reasonably good and this continued after the failure of the interaction between the two materials. A considerable force was still required to pull the Tensar from the testing box.

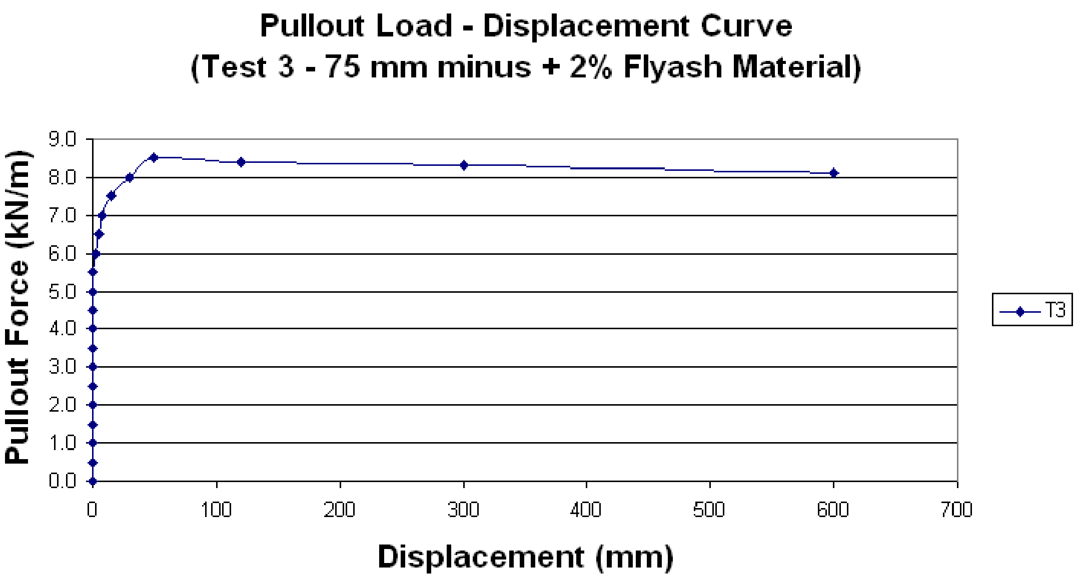

Figure 21 Pullout Test Results - 75mm minus + Flyash Material

The 75 mm minus crushed concrete material that included the 2% flyash additive had a similar performance to the previous two tests while the Tensar Geogrid was under load, however the pullout load of the 100 mm minus material was not achieved. The interaction between the fill material and the

Geogrid was very good and this continued well after the failure of the interaction between the two materials. The applied pullout force was still required to pull the Geogrid from the testing box after initial failure.

Figure 21 below shows a comparison of the profiles for all three tests.

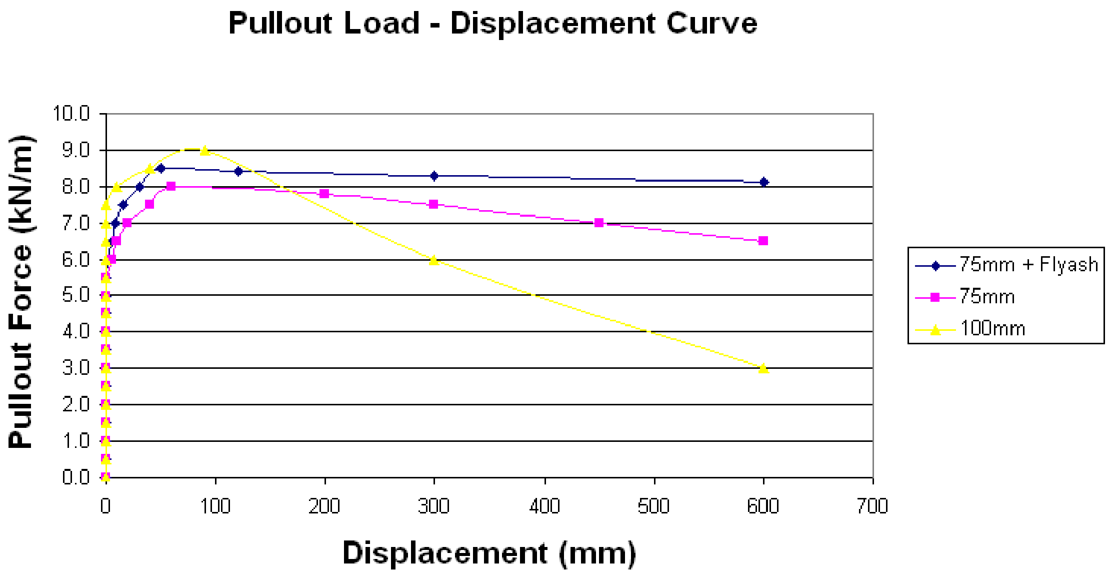

Figure 22 Pullout Test Results - Comparison of all 3 tests

The results from the three tests indicate that all three material samples have a similar failure pullout load, however upon failure the interaction between the materials and the Tensar Geogrid is considerably different.

Chapter 8 – Analysis of Pullout Test Results

8.1 General

The above test results indicate that all three materials have relatively similar maximum pullout forces to reach the point of failure. However the results beyond the point of failure do provide some differences.

8.2 Pullout Resistance

As mentioned in section 1.4, previous investigations and advice suggested that the 100 mm minus embankment material would not provide sufficient interlocking ability and pullout resistance with the Tensar Geogrid material. However, the testing results indicate that the 100 mm minus crushed concrete material has in fact provided the highest maximum pullout resistance of the three materials tested.

The maximum pullout failure load for the 100 mm minus crushed concrete material was approximately 9.0 kN/m. Beyond the failure load very little force was required to provide further displacement to the Tensar Geogrid.

The maximum pullout failure load for the 75 mm minus crushed concrete material was approximately 8.0 kN/m. Beyond the failure load a reduced load was required to provide further displacement to the Tensar Geogrid.

The maximum pullout failure load for the 75 mm minus crushed concrete plus 2% flyash material was approximately 8.5 kN/m. Beyond the failure load, a continued load of relatively the same magnitude was required to provide further displacement to the Tensar Geogrid. This result suggests that a continuous force would need to be applied over a period of time for the interaction failure to be evident.

8.3 Small Failure Prior to Maximum Pullout Load

The test results indicate that a small failure occurred in all three tests just prior to achieving the maximum pullout load.

Following an analysis of the results and the testing procedure, it is assumed that the small failure is a result of the initial extrusion of some concrete particles along with the Tensar Geogrid through the small envelope window in the front panel of the testing box.

Figure 22 below indicates the location of the small failure.

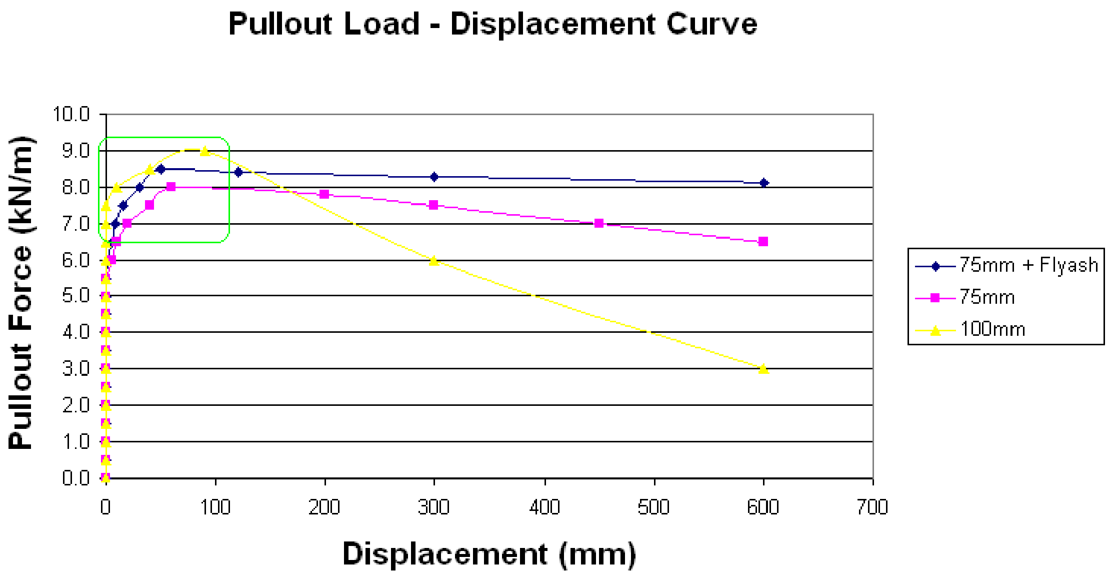

Figure 23 Pullout Test Results – Small Initial Failure

There is a possible argument that suggests that the front panel of the testing boxes should have been removed prior to the testing taking place. The front panel may have been providing a reactive force against the material in the box which would have contributed to the maximum pullout load being applied to the Tensar Geogrid.

The removal of the front panel may have also prevented the opportunity of any particles having to pass through the small window.

It is considered that because all three tests were undertaken in similar circumstances, the results achieved would be comparable.

8.4 Additional Testing Feedback

During and following the undertaking of the pullout testing, feedback was received from the crane truck operator in regard to the loads applied by the hydraulic boom on the crane truck.

The operator's advice suggested that following the interlocking failure of the 100 mm minus crushed concrete material, very little load was applied by the boom to pull the Geogrid from the material.

In comparison though, once the interlocking failure had occurred in the 75 mm minus crushed concrete material with the 2% flyash, the hydraulic boom continued to apply a considerable load to the Geogrid to ensure the material was displaced from the testing box.

The operator added that he could feel the hydraulics really working to continue to apply the load. This achievement was very unlike the tests on the material that did not include the flyash addition.

8.5 Theoretical Pullout Comparison

The field pull-out tests provided in section 7.2 show comparative values of pull-out loads between the various crushed concrete materials tested.

The table below indicates the measured field test values against the predicted values of pull-out loads.

Table 4 Pull-out Load Comparison

TEST MATERIAL (Type)	ANGLE OF FRICTION (Φ°)	CALCULATED PULL-OUT LOAD (kN/m)	FIELD TEST PULL-OUT LOAD (kN/m)
100 mm Minus	40.0	7.6	9.0
75 mm Minus	40.0	7.6	8.0
75 mm Minus + 2% flyash	40.0	7.6	8.5

Table 4 above indicates that the measured field pullout loads were infact higher than the calculated pullout loads. This would give an indication that the friction angle of the crushed concrete material is higher than predicted and the design has allowed a conservative estimation of Φ = 40°.

Using the above measured pullout loads from the field tests it is possible to calculate the angle of friction of the crushed concrete materials and the friction angles are indicated in the table below.

Table 5 Angle of Friction Calculation

TEST MATERIAL (Type)	CALCULATED ANGLE OF FRICTION (Φ°)	FIELD TEST PULL-OUT LOAD (kN/m)
100 mm Minus	44.7	9.0
75 mm Minus	41.3	8.0
75 mm Minus + 2% flyash	43.0	8.5

The calculated friction angles of the crushed concrete material range between 41.3 and 44.7 degrees. These friction angle values lie between the suggested value of Φ = 40° and the reported value of Φ=46° (Rathje. et al., 2006) in section 2.2.

Chapter 9 – Financial Analysis

9.1 General

The recycling of the demolished concrete for embankment material has provided this project with some great financial benefits. A financial analysis has been undertaken to compare the use of recycled concrete material from demolished buildings on site with the alternative of importing embankment material and carting the demolished buildings to land fill.

9.2 Analysis

The opportunity of recycling the concrete material on site and not importing embankment material for the construction of the reinforced soil structure has provided both the project and the surrounding environment with substantial positive economical outcomes.

The recycling of the steel reinforcement following the separation from the concrete has also provided additional cost benefits. Some of the reinforcement included steel 'I' beams which were located within the columns of the buildings.

In addition to the steel reinforcement being recycled, the electrical copper cabling and copper pipes throughout the former hospital site were also able to be recycled at a cost benefit to the project. The former hospital had its own power generation by the way of an energy plant and the as a result there was a large amount of copper cabling located throughout the site.

Another economic benefit to the project which relates to the surrounding environment, and is a cost saving that was not fully realised by the project, is the opportunity of not having to rehabilitate or re-construct any external roads to the site. If the concrete material was discarded to landfill and the embankment material had been imported to the site then the traffic loads on the external roads would have resulted in pavement damage requiring rectification works.

Table 6 below represents the costs associated with recycling the concrete material and stockpiling onsite as embankment material ready for use. The costs include crushing the material to 100 mm minus and 75 mm minus and also the financial gains from being able to recycle the steel reinforcing once separated from the concrete.

Table 6 Recycling Concrete Costs

Costs Associated with Recycling Concrete for Embankment Material

Item	Cost	Total
Crushing concrete to 100mm minus (60,000t)	15.00 / t	$900,000.00
Crushed 100mm minus to 75mm minus (40,000t)	6.00 / t	$240,000.00
Recycling of steel (12,000t)	7.00 / t	-$84,000.00
Total		**$1,056,000.00**

The costs in the above table indicate broad costs associated with the recycling of the crushed material and total approximately one million dollars.

Table 7 below represents the costs associated with having to import the material to site as embankment material if the buildings were unable to be recycled into embankment material. The table also includes the associated costs of having to cart the demolished concrete buildings to landfill.

Table 7 Importing Embankment Material Costs

Costs Associated with Importing Embankment Material

Item	Cost	Total
Cartage of waste to dump (60,000t)	4.00 / t	$240,000.00
Dump waste to landfill (60,000t)	32.00 / t	$1,920,000.00
Import Fill material to site (60,000 t)	15.00 / t	$900,000.00
Total		**$3,060,000.00**

The costs in the above table indicate broad costs associated with importing the embankment material and total approximately three million dollars.

A comparison of the two tables above, indicate a potential cost saving to the development of approximately two million dollars.

Table 8 below provides further costs associated with crushing the recycled concrete from 100 mm minus to 75 mm minus and including the 2% flyash to the material.

Table 8 Flyash Costs

Costs Associated with Further Crushing and Flyash Inclusion

Item	Cost	Total
Crushed 100mm minus to 75mm minus (40,000t)	6.00 / t	$240,000.00
Inclusion of Flyash (2%)	5.50 / t	$220,000.00
Total		**$460,000.00**

The costs in table 8 above are representative of the further analysis of the original design. The original design consisted of 100 mm minus crushed concrete material. However following the advice on the mechanical interaction of the 100 mm minus material with the reinforcement, the design was altered to incorporate the 75 mm minus material. The flyash was then incorporated into the design to tighten up the reinforced soil zone and provide some ability to prevent the ingress of water.

In summary, it is evident from the testing results that the incorporation of the 2% flyash with the 75 mm minus crushed concrete material provided an improved performance of the interlocking characteristics of the material. The inclusion of the flyash represents approximately 20% of the cost to provide the crushed concrete embankment material. The performance of the flyash within the crushed concrete material, in relation to the extra costs incurred, ensure that the design is a very feasible and effective solution.

The economic feasibility of recycling depends largely on the application. In general, virgin materials have a quality control advantage over recycled materials. But the economic feasibility of recycling is increasing with time, as virgin materials become increasingly scarce and the disposal costs of construction waste and other associated waste materials keep increasing. More importantly, we will see a proliferation of Green Building and sustainability development principles, which will modify the economic picture in favor of the environment. We all agree that we cannot keep wasting our natural resources. Eventually they all will run out.

Chapter 10 – Environmental Analysis

10.1 General

A sustainable development promotes the use of energy and natural resources in a way that assures long-term viability of human life. This viability is threatened by depleting energy and raw material resources and unacceptable levels of environmental pollution from solid, liquid, and gaseous waste products.

The recycling of the concrete material, resulting from the demolished buildings from within the site, for embankment material has provided substantial environmental benefits to this project. An environmental analysis has been undertaken to compare the use of recycled concrete material from demolished buildings on site with the alternative of importing embankment material and transporting the demolished buildings to land fill.

10.2 Analysis

The opportunity of being able to reuse the demolished concrete from onsite for this project is a very favorable outcome for the environment.

Traditionally, fill material for an embankment project would have been sourced from a quarry or borrow pit, however the relative cost to do this is reasonably high depending on locality, availability and transportation routes. This project is heavily reliant on the availability of cost-effective sources of fill material due to the large volumes required.

The positive environmental outcomes for the project include but are not limited to the following:

1. Minimal disposal to waste at landfill sites by recycling concrete, steel reinforcement, copper pipes, cabling and fixtures; and

2. A limited number of vehicular trips on the adjacent roads for transportation of waste material and imported embankment material which in turn decreases the number of Carbon emissions.

Among the key environmental concerns for construction today is the depletion of natural sources of good quality aggregate materials, limited available landfill sites for dumping of demolished construction waste and possible contamination of groundwater that results from washing out fresh concrete returned from construction sites.

Concrete waste to landfill sites account for approximately 50% of the total waste generation. According to the growing trend of concrete waste, an annual increase of 24% between 1991 & 2006 has highlighted the need to reduce the amount of landfill being generated. (Environmental Protection Department 2006).

The reuse of concrete demolition debris reduces unsightly stockpiles of concrete rubble, animal infestation of stockpiles and creates an overall environmental improvement when re-used.

When concrete waste is disposed to landfill sites, the possibility exists for contamination of groundwater or natural rivers and creeks resulting from the washing out of the concrete components. The reuse of the crushed concrete onsite in this project has provided a suitable embankment for development purposes while also being contained within a concrete facing as part of the reinforced structure. This has in return provided a secure, retained deposit of recycled concrete that has limited potential of contaminating our water sources.

Where recycled concrete material can be used within the same metropolitan area, this can lead to a decrease in energy consumption from hauling and the production of material and can help improve air quality through reduced transportation source emissions. This project used mobile crushers to crush the concrete material onsite for reuse. This procedure offered significant environmental benefits because no external transportation of the site was required. The following table provides an indication of the reduced Carbon emissions.

Table 9 Reduced Carbon Emissions

Item	No. of Trips	Distance per trip (km)	Fuel Consumption (29.4L/100km) (L)	Carbon Emissions (2.9kg/L) (t)
Transportation to Landfill ($30{,}000\ m^3$)	1500	30.0	13,500	39
Import Fill from Quarry ($30{,}000\ m^3$)	1500	40.0	18,000	52
Total Carbon Emissions				**91**

Using the following assumptions:

- Average truck fuel consumption = 29.4 Litres per 100 km; and
- Carbon emissions = 2.9 kg per 1.0 Litre of fuel.

The Carbon dioxide emissions that have been reduced by recycling the concrete on site for embankment material are approximately 91 tonnes.

To help put this into perception, a single three bedroom home can hold on average 556 cubic meters. Therefore the amount of reduced emissions equates to approximately 164 three bedroom homes.

The principles of sustainable development are self-evident. It is difficult to disagree with the goal of passing on to future generations a world no worse than the one we were given. The political differences appear when it becomes necessary to balance the needs of environmental preservation against those of development to raise the living standard.

Chapter 11 - Conclusion

Many previous reports have provided substantial analysis of reinforced soil structures with general fill embankment materials. This report provides an analysis of the interaction of recycled crushed concrete and Tensar Geogrid reinforcement. The interaction characteristics relate to the construction of a 14.0 m high reinforced earth structure where recycled crushed concrete has been used as the embankment material in the structure.

The reinforced earth structure forms part of a major redevelopment of the Former Townsville General Hospital site which is located at the foothills of Castle Hill overlooking Cleveland Bay in Townsville. The 14.0 m high reinforced earth structure has been constructed to retain the embankment for the twelve residential allotments.

The embankment material used in the reinforced earth structure is a crushed concrete material that has been recycled from the demolished buildings that once served as the hospital. The crushed concrete material has been reinforced with Tensar Geogrid to provide a suitable structure to build residential dwellings on.

The concrete was originally crushed to 100 mm minus however the reinforced soil zone was designed for 75 mm minus with the addition of 2% flyash. As a result of this, pullout resistance testing was undertaken to test the interlocking of the Tensar Geogrid with the three different material samples using a simply constructed testing apparatus.

These materials being:

1. 100 mm minus crushed concrete;
2. 75 mm minus crushed concrete; and
3. 75 mm minus crushed concrete with 2% flyash.

Testing of this crushed concrete material with the Tensar Geogrid has provided some very positive results. Results indicate that the initial failure loads were very comparative between the three materials.

The maximum pullout failure load for the 100 mm minus crushed concrete material was approximately 9.0 kN/m. Beyond the failure load very little force was required to provide further displacement to the Tensar Geogrid.

The maximum pullout failure load for the 75 mm minus crushed concrete material was approximately 8.0 kN/m. Beyond the failure load, a reduced load was required to provide further displacement to the Tensar Geogrid.

The maximum pullout failure load for the 75 mm minus crushed concrete plus 2% flyash material was approximately 8.5 kN/m. Beyond the failure load, a continued load of relatively the same magnitude was required to provide further displacement to the Tensar Geogrid.

This result suggests that the addition of flyash provides great benefits to the interlocking characteristics of the crushed concrete material with the Tensar Geogrid. This result also suggests that a continuous force would need to be applied over a period of time for the interaction failure to be evident within the material.

In comparison to the theoretical pullout loads calculated for the crushed concrete materials, the field tests have indicated that higher than expected values of friction angle have been achieved. The theoretical calculated pull-out load was 7.6 kN/m based on a friction angle of 40 degrees which is clearly an under estimate when compared to the field test results. The field test results yielded pull-out loads on the Geogrid of between 8.0 and 9.0 kN/m, which relates to an internal friction angle of 41.3 to 44.7 degrees.

The results achieved by this testing indicate that the recycled crushed concrete material provides a very good source of embankment material for reinforced earth structures.

The use of recycled crushed concrete onsite as an embankment material has also provided some great financial and environmental benefits to the project.

Financial Savings

The economic feasibility of recycling depends largely on the application. The use of recycled concrete is increasing with time, as virgin materials become increasingly scarce and the disposal costs of construction waste and other associated waste materials keep increasing.

The use of recycled crushed concrete as an embankment material rather than importing a general fill material has provided cost savings in the order of two million dollars for the project. Adding to the cost savings was the ability to recycle the steel reinforcement from the demolished concrete.

The opportunity of not having to transport imported embankment material to the site has also provided cost benefits to the project including reduced wear and tear to roads and the direct transportation costs.

Environmental Values

Ageing infrastructure, decreasing availability of landfill space, and environmental concerns work together to increase the benefits of concrete recycling.

There are two possible approaches to recycling concrete. One alternative is to haul the concrete debris to a permanent recycling facility, usually close by to minimise transportation costs, for crushing and screening. The other approach is to undertake the crushing and screening at the demolition site where the recycled material is reused as soon as it is processed.

This second option has been used very successfully for this project and the extra benefits include reducing heavy materials hauling, thereby reducing transportation costs, energy use, and wear and tear on roads and equipment. The carbon dioxide emissions saved on the environment by undertaking this option have proved to be very significant.

The future for recycled concrete materials will be driven by reduced landfill availability, greater product acceptance, continuing government recycling mandates, and the continuing decay of a large stock of existing infrastructure, as well as by the demands of a healthy economy.

APPENDIX A
PROJECT SPECIFICATION

Appendix A

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION
Revision C – 21 October 2008

FOR: *Duane Nikalia Gibson*

TOPIC: Interaction of Recycled Concrete and Geogrid Reinforcement Material
- *14m High reinforced earth structure*

SUPERVISOR: Internal – *Jim Shiau* : *External – Henry Fracchia*

SPONSORHSIP: *UDP Consulting Engineers / Base iGi Consulting & Geofabrics.*

PROJECT AIM:

The aim of the project is to examine the interaction of recycled concrete and Geogrid reinforcement relating to a 14 m high reinforced earth structure.

Some of the aspects to be investigated are:

- Development of a testing apparatus to investigate the interlocking of the Tensar Geogrid with recycled concrete;
- Interlocking performance testing analysis of a reinforced earth structure consisting of Tensar Geogrid and recycled crushed concrete material – 100 mm, 75 mm & 75 mm with 2% flyash;
- A financial analysis on using recycled concrete from existing building demolition onsite for embankment material;
- An Environmental analysis on recycling materials during the building demolition as opposed to disposing to waste.

AGREED ______________________ (student) ______________________ (supervisor)

Date: / / 2008 Date: / / 2008

Co-examiner: ______________________

List of References

Moraci, N., Gioffre, D., 2006. A Simple Method to Evaluate the Pullout Resistance of Extruded Geogrids Embedded in a Compacted Granular Soil. Geotextiles and Geomembranes 24, 116 - 128.

Sidnei, H.C., et al., 2007. Pullout Resistance of Individual Longitudinal and Transverse Geogrid Ribs. Journal of Geotechnical and Geoenvironmental Engineering, 37 - 50.

Wang, Z., Richwien, W. 2002. A Study of Soil-Reinforcement Interface Friction. Journal of Geotechnical and Geoenvironmental Engineering, 92 - 94.

Ingold, T. S. 1982. Reinforced Earth. Thomas Telford Ltd, London.

O'Rourke, T. D., Druschell, S. J., and Netravali, A. N. 1990. Shear Strength Characteristics of Sand Polymer Interfaces. Journal of Geotechnical Engineering 116(3), 451 - 469.

Jie Han, P.E., Leshchinsky, D., 2006. General Analytical Framework for Design of Flexible Reinforced Earth Structures. Journal of Geotechnical and Geoenvironmental Engineering, 1427 - 1435.

Rathje, E., Trejo, D., Folliard, K. 2006. Use of Recycled Asphalt Pavement and Crushed Concrete as Backfill for Mechanically Stabilised Earth Retaining Walls. Project Summary Report 0-4177-S.

Peterson, L.M. and Anderson, L.R. (1980). "Pull-out Resistance of Welded Wire Mats Embedded in Soil," *Master of Science thesis*, Utah State University, Logan, UT.

Ochiai, H., Otani, J., Hayashic, S. and Hirai T. (1996). "The Pull-out Resistance of Geogrids in Reinforced Soil." *Geotextiles and Geomembranes,* Vol. 14.

Mallick, S.B., Elton, D.J. and Adanur, S. (1998). "A New Approach in Modeling of Soil-Geotextile Interface Behavior in Pull-out Tests." *Geosynthetics* '98.

Koutsourais, M., Sandri, D. and Swan, R. (1998). "Soil Interaction Characteristics of Geotextiles and Geogrids." *Geosynthetics* '98.

Ochiai, H., Otani, J., Hayashic, S. and Hirai T. (1996). "The Pull-out Resistance of Geogrids in Reinforced Soil." *Geotextiles and Geomembranes,* Vol. 14.

Greenfleet Technical Information – Carbon Emissions
http://www.greenfleet.com.au