MITIGATION OF BLAST LOADS USING RAPIDLY CONSTRUCTED REINFORCED SOIL WALLS

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Abstract: Conventional geotextile Reinforced Soil (RS) walls have been shown to be highly effective in mitigation blast effects in previous blast trials conducted in Woomera, Australia and Singapore from 1998 to 2004. The construction time compared to that of conventional concrete protective walls is much faster. However, due to the prevalence of terrorist's attacks in recent times, it is important to further improve the speed of construction and reduce the dependency of the specialized skilled workers required for the construction. A 3-dimensional cellular type of geosynthetics product was used as the facing blocks without any external formwork for the construction of RS wall in Woomera 2004 and Singapore 2004 trials (called GeoCell wall). The construction process was found to be much faster (required only 1 day per wall) and required only menial labour. However, the new facing elements produced more debris and suffered more damaged when subject to an explosion then the previous RS walls using geotextiles wrapped around facing.

To further improve the speed of construction, a new RS wall with innovative and easy assemble modular facing blocks (called GeoBlock) was built and tested in Woomera, 2006. The wall was built within a few hours and did not require any specialized labour. The trial results showed that no significant debris was formed despite the wall suffering extensive damage due to the unexpected high intensity of the charge and a very closed scaled distance. Hence these new innovative GeoCell RS walls and GeoBlock RS walls can be considered as new generation of RS walls that can be built very rapidly and yet provide sufficient protection against blast pressure and debris.

Keywords: blast load, field performance, reinforced soil wall.

INTRODUCTION

A Geosynthetic Reinforced Soil (RS) wall mainly consists of geosynthetics used as reinforcement, a suitably facing materials, and compacted backfill soil. The geosynthetics reinforcement and facing unit provide a confining effect to the soil mass in addition to the original strength of the backfill soil. Conventional geotextile RS walls have been shown to be highly effective in mitigation blast effects (Bathurst *et al*., 1995) in previous blast trials conducted in Woomera, Australia in 2002, 2004 and Singapore in 1998 and 2004 (He *et al*., 2004 and Tan *et al*., 2005). These vertically faced RS walls are constructed with the help of wooden formwork and required around 2 to 3 days to complete a wall of dimension of 3 m height, 2-6 m width and 6-8 m length. This is much faster than the construction time required for conventional concrete retaining or protection walls, and is generally adequate for the normal applications. However, due to the prevalence of terrorist's attacks in recent times, it is important to further improve the speed of construction and reduce the dependency of the specialized skilled workers required for the construction. Further research was conducted on a number of innovative ways for the rapid construction of RS walls. Two new types of geosynthetic RS walls using GeoCell and GeoBlock as facing material were tested out in the blast trials in Woomera, Australia 2004 and 2006 and in Singapore 2004. The following sections discuss on the construction methodology of these walls and the results obtained from the blast trials conducted. These walls were subjected to various charge weights and placed at varying distances to the charge. To quantify these factors, a scaled factor called scaled distance, Z is used. The scaled distance, Z is defined as:

$$Z = \frac{R}{\sqrt[3]{W}}$$

where R = Distance of Charge to Target in m and W = Charge Weight in Equivalent TNT in kg.

GEOCELL WALLS IN SINGAPORE 2004 AND WOOMERA, AUSTRALIA 2004 BLAST TRIALS

Characteristics of GeoCell Walls Built

A 3-dimensional cellular type of geosynthetics product was used as the facing blocks without any external formwork for the construction of RS wall in Woomera 2004 (He *et al*., 2004) and Singapore 2004 (Tan *et al*., 2005) trials. This product is called GeoCell. For the Singapore 2004 blast trials, the GeoCell wall built (RSW9) was subjected to a bare charge of 110kg TNT at a distance of 2m away from the charge (Z = 0.4). For the Woomera 2004 blast trial, the GeoCell wall (RS4) was subjected to a bare charge of 5 tonnes at a distance of 36m (Z = 2). The characteristics of the GeoCell RS walls built are shown in Table 1. Table 2 shows the material properties of the GeoCell used. Residual soil at each site of construction was used as the backfill for the walls.

Table 1: Characteristics of RS Walls Built

Walls	H (m)	L (m)	W (m)	Type of Reinforcement	Soils	Other Features
RSW9	3	6	2.7	GeoCell (3-D Confinement Units)	Residual Soil	Embedded 0.1 m Below Ground
RS4	3	6	2.7	GeoCell	Residual Soil	Embedded 0.2 m Below Ground

Table 2: Technical Specifications of GeoCell

GeoCell (EC300A)	
Material	High UV Resistant Polyethylene
Sheet Thickness (mm)	1.25 ± 0.5
Density (g/cm^3)	0.939 – 0.960
Seam Strength (kN/m)	116
Panel Weight (kg) (per 100 mm Depth)	Max. 25

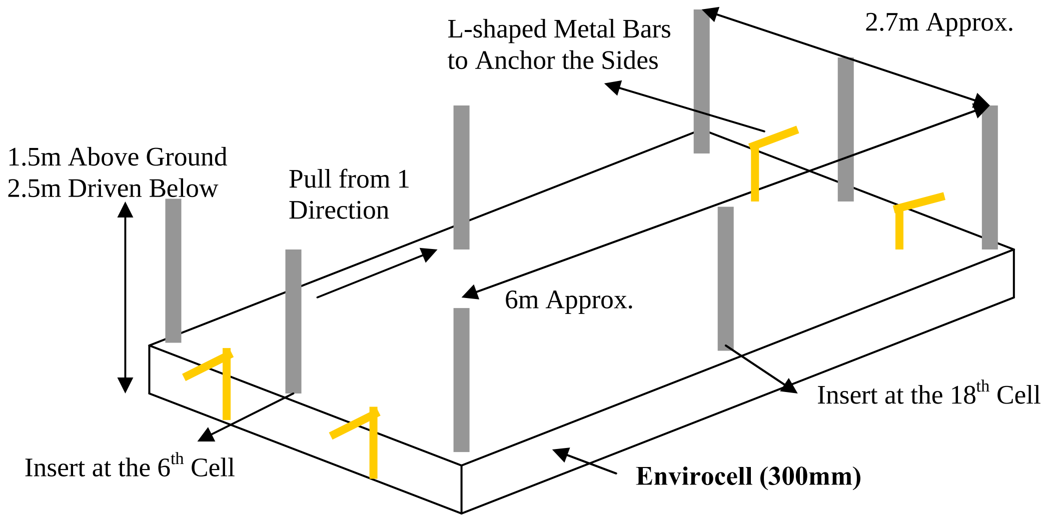

Figure 1. Schematic of Construction Method for R9

Construction Methodology for GeoCell Walls

The construction method for RSW9 and RS4 are as follows:

1) 8 pieces of metallic pins of around 4 m length are first driven into the ground to be used as anchors for the GeoCell. This is done with an excavator. Figure 1 shows a schematic diagram of the construction method.
2) Next, the GeoCell is slotted into these poles and pulled across so that the cells are fully expanded. This will ensure the full confining strength of the GeoCell is achieved. Metal L-shaped sections are used to provide additional anchoring at the sides. Figure 2 shows the actual construction process.
3) Soil is then poured in and compacted using a small 0.5ton compactor. Soil is filled to slightly above 300 mm in height to minimize damage to the cells as the soil compaction is carried out. A layer of geotextile (2.5 m length and 5.2 m width) is placed in between each layer of GeoCell (Figure 3).
4) This process is repeated until the wall is completed

The completed RSW9 is shown in Figure 4. The construction method was similar for RS4 and the completed wall is shown in Figure 5. It was observed that the construction process was found to be much faster and required only menial labor. Both walls were constructed within a day. Comparatively conventional geotextile walls require at least 2 days to be constructed for a wall of similar size and specialized workers have to be employed as wooden formwork is needed.

Results and Discussion

Figures 6 and 7 show the GeoCell walls after the blast events. As can be seen, in both walls, the front face was severely damaged by the blast. The walls were obviously tilted at an angle. For RSW9 (Tan *et al.*, 2005), the first 2 rows of cells in the front face were completely blown off with the soil failing out. The GeoCell was also found to be stiffer than before. Moreover, pieces of GeoCell were found scattered throughout the whole site. This shows that GeoCell walls produce debris from the broken pieces of GeoCell material. The GeoCell walls suffered significantly more damage compared to geotextile walls because the adjacent units of broken out even before reaching their seam strength. This is due to their brittleness and inability to deform (Tan *et al.*, 2006).

For RS4, the 1st row of GeoCells was blown off and debris was also found throughout the side. In addition, the side faces were also damaged with some GeoCell strips falling out as seen in Figure 7. However, overall both GeoCell walls were still stable after the blast.-The instrumentation results of the blast trials also show that these GeoCell walls were equally efficient in mitigating blast pressures as conventional RS walls. However, GeoCell walls produce more debris and suffered more damaged compared to the conventional RS walls. Moreover, physical strength is needed due to the nature of the construction process where the layer has to be lifted over the poles. Thus although GeoCell walls offer rapid construction, it has a few shortcomings which need to be rectified.

Figure 2: Laying of Envirocell for RSW9

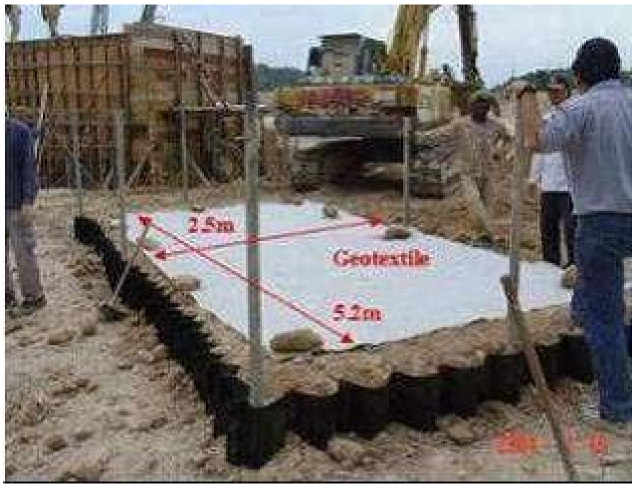

Figure 3: Geotextile Layer for RSW9

Figure 4: Completed RSW9 in Singapore 2004

Figure 5: Completed RS4 in Woomera, Australia 2004

Figure 6: RSW9 After Blast 2

Figure 7: RS4 after Blast in Woomera 2004

GEOBLOCK WALLS CONSTRUCTED IN WOOMERA 2006

To further improve the speed of RS walls' construction with sufficient protection ability and to remove the problems that GeoCell walls encounter under blast loading, a new RS wall with innovative and easy assemble modular facing blocks (called GeoBlock RS wall) was built and tested in Woomera, 2006.

Characteristics of GeoBlock Wall Built

The characteristics of the GeoBlock RS wall built are shown in Table 3. Table 4 shows the material properties of the GeoBlock and PEC100 used. Residual soil at each site of construction was used as the backfill for the walls. This wall was subjected to a charge of 6 tonnes at a distance of 20m (Z = 1.25).

Table 3: General Dimensions and Characteristics of RS Walls using GeoBlock

Walls	H (m)	L (m)	W (m)	Type of Reinforcement	Facing	Soils	Special Features
RSE	3	6	Varying (1.35m to 2.4m)	PEC100 & Edge Blocks	PEC100 & Edge Blocks	Residual Soil	Back Face Sloping, Embedded 0.2m below Ground

Table 4: Technical Specifications of PEC100 and GeoBlock

PEC100			GeoBlock	
Material	Polypropylene Continuous-Filament Needle Punched Non-Woven & High Strength PET Yarns		Size	400mm x 300mm x 30mm thick
			Material	Polypropylene Homopolymer
			Melting Point (°C)	164
Tensile Strength (kN/m)	(MD/CD) 80/14		Tensile Strength at Break (MPa	44.1
Elongation at Break (%)	(MD/CD) 12.5/85		Density (g/cm^3)	Around 0.90
Long Term Design Strength - 120 years (kN/m)		46.5	Elongation (%)	850
Mass (g/m^2)	426		Stiffness (MPa)	1,370

Construction Methodology for GeoBlock Wall

The edge blocks were shipped over from Singapore to Australia prior to the construction dates. The following construction steps were executed:

1) First the edge blocks were slotted together and secured in place using normal cable ties at each connection. Approximately 150 pieces of edge blocks were needed for each layer. Each layer is completed separately.
2) A small depth of soil (200mm deep) was cleared and the PEC100 geotextile pieces were then laid into position for both directions.
3) Once this is done the edge block layer is placed on top of the geotextile (Figure 8). The PEC100 pieces on the 2 shorter sides are then folded in.
4) Residual soil is filled up till 200mm (half a layer). The soil is then compacted for one round with a small compactor.
5) Next, the PEC100 pieces on the long side is folded back and slots are cut to take into account the support pieces (Figure 9). The PEC100 are pulled taut so that the facing of the wall will be vertical.
6) Soil is then filled again and compaction done (Figure 10). Thus a layer is completed

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The above process is repeated until the GeoBlock wall is completed. The wall consists of 8 layers. The wall was completed in 8 hours of a working day inclusive of lunch and tea breaks in between. Thus this was even faster than the construction for GeoCell walls. The wall was completed without any specialized equipment and workmanship which enable anyone with minimal technical background to construct this wall in times of emergency. Figure 11 shows the completed GeoBlock wall.

Results and discussion

As seen from Figure 12, GeoBlock wall suffering extensive damage due to the unexpected high intensity of the charge and a very closed scaled distance. The charge used was cylindrical in shape and stood at around 1m in height. This was a different charge compared to the previous blast trials in Woomera 2002 and 2004. The GeoBlock wall was designed with factor of safety of 1.0, i.e. just reach the failure state, based on the design charts developed from the previous trials. Due to the high center of gravity of the charge, the main blast pressure wave could have been concentrated at the middle part of GeoBlock wall. This resulted in the top 4 layers collapsing completely. The bottom 3 layers (approximately 40% of original volume) were still intact after the blast. The front face with the geotextile wrapped around the Geoblocks had been completed blown off.

Despite the severe damage, no significant debris was found around the site. This was due to the PEC100 wrapped around the GeoBlocks which prevented the GeoBlocks from being scattered throughout the site. In addition, the pieces of GeoBlocks that were found were much smaller than the GeoCell pieces in the previous trials, thus the danger of these fragments causing injuries to humans is significantly reduced. Thus GeoBlock walls can be used in emergency cases for rapid construction of RS walls against blast loadings with minimal debris produced.

Figure 8: Placing of GeoBlocks on top of Geotextile Layer

Figure 9: Geotextile Layer Folded Back after Compaction of ½ Layer of Soil

Figure 10: Completed GeoBlock Wall Layer

Figure 11: Completed GeoBlock Wall (Front View)

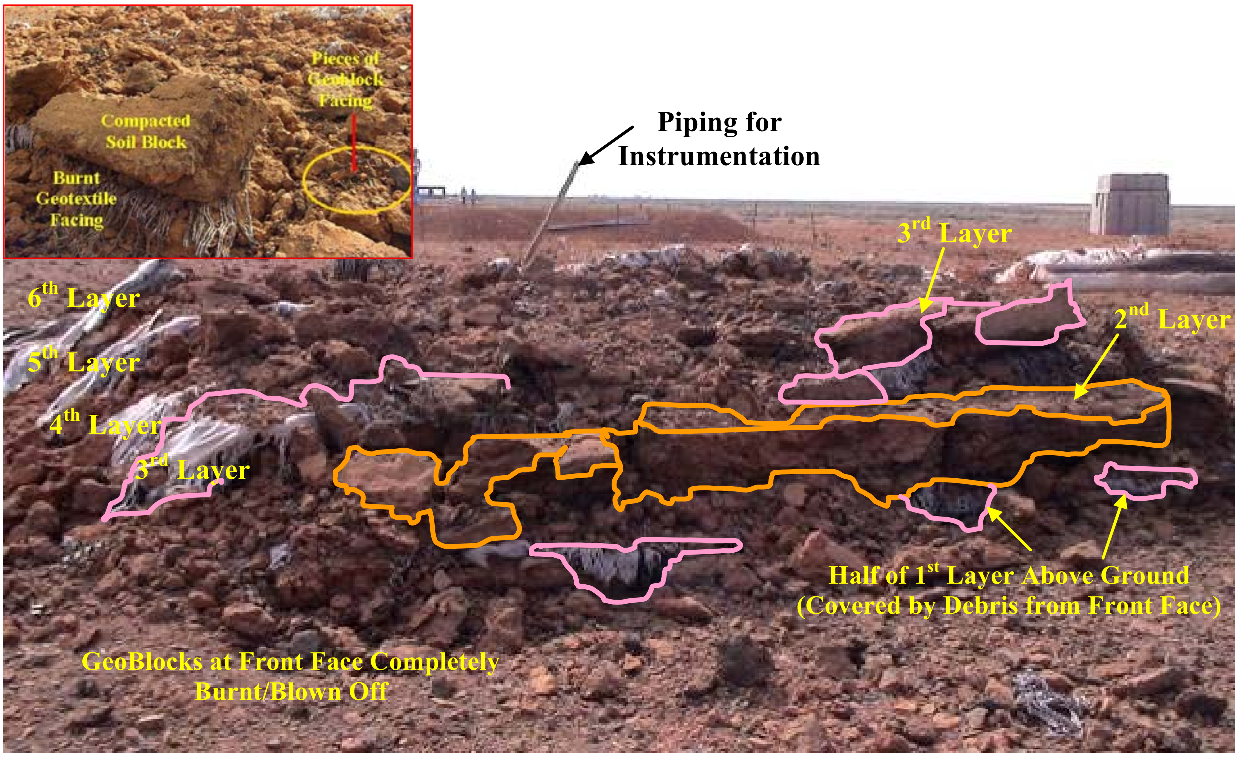

Figure 12: GeoBlock Wall after Blast

CONCLUSIONS

Due to the prevalent of terrorists' attacks recently, it has become extremely important to be able to provide rapidly constructed RS walls as protection against blasts. Conventional geotextile RS walls need specialized formwork and manpower. Hence, new facing materials were searched so as to improve the construction speed of RS wall. In Singapore Trial 2004 and Woomera Trail 2004, 2 GeoCell walls were built and subjected to blasts. The construction was rapid and each wall was completed without the need for specialized formwork or labor. However, they produce significant debris which can cause causality to human beings. Hence, in Woomera 2006, a new innovative GeoBlock RS wall was built to provide sufficient protection against blast pressure and yet produce very minimum debris. The GeoBlock wall was completed within 8 hours and no significant debris was found after the blast. Thus with their excellently rapid construction speed and requirement of only very minimum labor with no special equipment, these innovative GeoBlock walls can be deployed for the effective protection for buildings, equipment and personnel against impending terrorist's attacks.

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