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Effect of geometry & geosynthetics type on the effectiveness of reinforced soil (RS) walls as protection against blast loads

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ABSTRACT: Reinforced soil (RS) walls can be used to provide protection against blast effects. Compared to conventional protective structures such as concrete walls which are brittle, RS walls have many advantages, such as lower cost of construction and ductile. In addition, RS walls do not produce dangerous fragments and debris when damaged or destroyed by blast loading. Based on full-scale field tests conducted, it was observed that the wall dimension in the direction of the blast (i.e. width) have contributed significantly toward the resistance against the blast load. Thus the width to height ratio (B/H) of the wall directly controls how the wall behaves during a blast. In addition to geometry of the RS walls, the type of reinforcement material used also affects the behavior of the RS walls. These geosynthetics materials include the conventional geotextiles and 3-D confinement units such as Geocells. Some design charts have been derived which can be used to design RS wall for various sizes and types of blasts. These design charts use the deformation of the upper corner at the rear face of the RS wall and the volume of crater produced in the wall face from a blast as the key design parameters. Comparisons between the designs for close ranged medium scale blasts and for large scale blasts will be highlighted.

1 INTRODUCTION

A Geosynthetic Reinforced Soil (RS) wall mainly consists of geosynthetics such as geotextiles and geocells as reinforcement and facing materials wrapped around compacted backfill fill soil. The geosynthetics provide a confining effect in addition to the strength of the soil. In the face of prevalent terrorist attacks over the last few years, to protect buildings against small car bombs and suicide bombers, it has become extremely important to find means of providing protection for personnel and equipment. RS walls can be used to provide such protection. The advantages of using RS walls as protective blasts structures are elaborated in the next section. The effectiveness and response of RS walls when subjected to blast loadings is directly affected by many factors such as type of geosynthetics used, geometry of the RS wall and size of the charge weight and distance of blast to the RS wall.

To study these factors, a series of full-scale blast trials were conducted between 1998 and 2004 in Singapore and Australia. Based on the results from these tests, some design charts and procedures were derived for the design of RS walls subjected to close-ranged medium scale blasts (charge weights of 100 to 300 kg equivalent TNT and scaled distance, $Z < 1$) and large scale blasts (charge weights of 5 tons equivalent TNT and above and $Z > 1$). The scaled distance, Z is defined as:

$$Z = \frac{R}{\sqrt[3]{W}} \tag{1}$$

where R = Distance of Charge to Target (m) W = Charge Weight in Equivalent TNT (kg)

2 ADVANTAGES AND APPLICATIONS OF RS WALLS

RS walls have many advantages compared to conventional concrete walls. These include

(1) Lower cost of construction
(2) Can tolerate higher deformation before failure. RS walls are also more flexible and can accommodate more differential settlement
(3) Not subjected to brittle failure like concrete and can shield blast fragments and shell debris
(4) Do not produce dangerous fragments and debris when damaged or destroyed by blast loading

Due to these advantages, RS walls can be used at ammo points for protection against accidental explosions of ammo and they also can be built in between the main entrance of buildings and the car park areas for protection against small car bombs and suicide bombers (e.g. Figures 1 and 2).

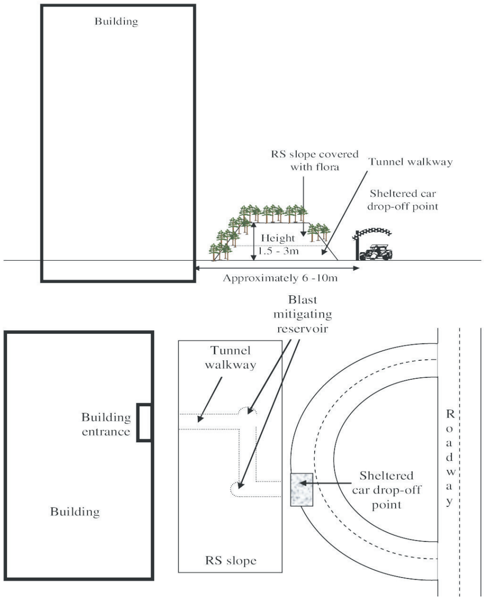

Figure 1. Cross sectional and top view of RS slope built between building and carpark (not to scale).

Figure 2. Geocell wall built at ammo point.

3 EFFECT OF GEOSYNTHETIC TYPE ON EFEFCTIVENESS OF RS WALLS

There are many types of geosynthetics that can be used for building RS walls. The most common is geotextiles and they have been used extensively around the world. Geocells (3-D confinement units) provides an alternative. In the blast trial ETSC2004 (Tan et al., 2005), two RS walls were built in Pulau Senang, Singapore and each subjected to charge weight of 110 kg equivalent TNT at scaled distances of less than 1. RSW1 was a conventional geotextile (PEC100) wall while RSW9 was a geocell wall (similar to Figure 2: Ammo point). Both walls were 3 m in height, 3 m in width and 6 m in length. PEC100 is a composite high strength geotextile with a non-woven polypropylene (PP) base with polyester (Pconsists of expendable, polyethylene, honeycomb-like cellular structures interlinked together. Table 1 states some characteristics.

Table 1. Specifications of PEC100 and GeoCell.

PEC100		Geocell	
Tensile Strength (kN/m)	(MD/CD) 80/14	Sheet Thickness (mm)	1.25 ± 0.5
Elongation at Break (%)	(MD/CD) 12.5/85	Density (g/cm^3)	Around 0.95
Long Term Design Strength -120 years (kN/m)	46.5	Seam Strength (kN/m)	116
Mass (g/m^2)	426	Panel Wt. kg/100 mm)	Max. 25

After being subjected to blasts, the physical behaviour of RSW1 and RSW9 were significantly different. Figure 3 shows the damage on the front faces of RSW1 and RSW9. The front facing of RSW1 was completely burnt off leaving only tatters of PET yarns and PP base. The front face was still vertical and no debris from the wall was found. However for RSW9, 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 harder 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. Although, the tensile strength of PEC100 (80 kN/m) is similar to the seam strength of geocell (116 kN/m), the responses of the walls were significantly different. The geocell walls suffered significantly more damage compared to geotextile walls because the geocells break up before reaching their seam strength. This is due to their brittleness and inability to deform more. Thus this shows the type of geosynthetics used affects the effectiveness of the RS walls.

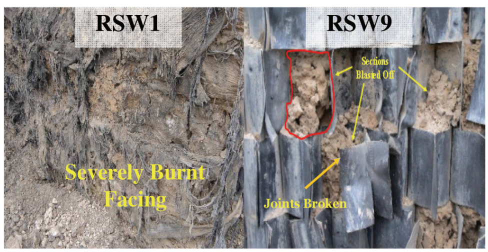

Figure 3. Damage on front face of RSW1 and RSW9.

4 EFFECT OF GEOMETERY ON THE EFFECTIVENESS OF RS WALLS

A very important factor in the effectiveness of RS walls is the width to height ratio (B/H) of the RS walls. Generally, the width cannot be too small compared to the height for the wall to be stable. For RS walls subjected to blast loading, based on the various field trials conducted, B/H should not be less than 0.7 for the RS wall to be effective in shielding the blast pressure.

Geometry plays a very important role in determining the response of the RS wall when subjected to blast loading. Again from blast trial ETSC2004, it was observed that after the blasts, all the walls (geotextile and geocell) showed a slight indentation at the front face of the wall (as shown in Figure 4) while the walls remain generally vertical. This shows a localized effect on the RS walls. This was very different from the response of the RS walls that were subjected to large scale blasts in Australia Blast Trial 2002. In the Australia 2002 tests (He et al., 2004), the geotextile RS walls (3.5 m in height, 6 m in width and 7.8 m in length) were subjected to charge weights of 27 tons equivalent TNT at Z > 1. The RS walls experienced global effect with the RS walls deforming as a whole (as shown in Figure 5).

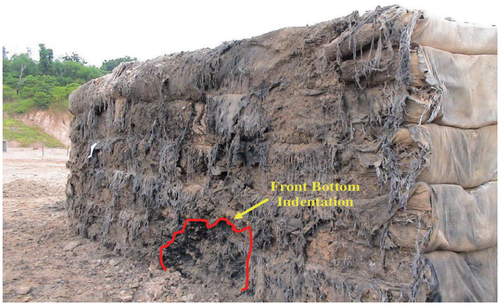

Figure 4. Localized blast effect in ETSC2004, Singapore.

Figure 5. Global blast effect in Australia blast trial 2002.

These results show that if the actual distance between the charge and the wall is small with respect to the dimensions of the wall, localized blast effect will occur instead of globalized effect. For ETSC2004, the distance was between 1 to 4 m while for Australia 2002, the distance was 60 to 90 m.

5 DESIGN CHARTS

Based on the numerous blast trials conducted, design procedures were derived for RS walls subjected to blast loading. As seen from the previous sections, there is a distinct difference in the response of the RS walls when subjected to close-ranged medium scale blasts and large scale blasts. Thus there is a need to consider the design separately.

5.1 *Design for close ranged medium scale blast (localized effect)*

For the close range medium scale blasts, the RS Walls experienced localized effect. The most significant observation was the slight indentation in the front faces of the walls in both Singapore tests conducted in 1998 and 2004 (ETSC98 and ETSC2004). This volume of crater that was formed by the blast is an indication of the degree of damage the RS wall has sustained.

The volume of the crater, V can be idealized as either a partial/full cylinder or sphere. Using results from ETSC98 and 2004, the following design chart was obtained (Figure 6). Thus for a specific B/H ratio and scaled distance, the expected V/W ratio will be obtained. If a desired V/W ratio is decided for a specific Z, the required B/H ratio can also be obtained from this design chart. As seen, for a specific Z value, the lower the B/H ratio, a higher crater volume will be obtained. A serviceability limit of the volume to charge weight ratio (V/W) of 10 m^3/ton is set as the failure criteria.

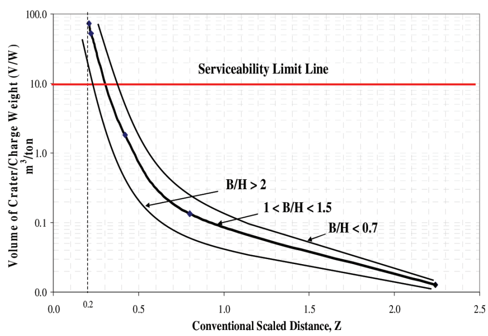

Figure 6. Design chart for RS wall subjected to close ranged medium scaled blasts.

5.2 *Design for large scale blast (globalized effect)*

The design procedure for large scale blast is significantly different from that for close ranged medium scale blasts. This is because in large scale blasts, RS walls experienced global effect. Thus the volume of crater formed can no longer be used as a gauge of failure since it does not occur in this case. Since the RS walls deform as a whole, the deformation of the RS walls is the most critical response of the wall. Thus the overall performance of the RS wall when subjected to large scale blast loading can be represented by the deformation at the upper corner of the back facing of the RS wall, DX.

Using this deformation to height of wall ratio (DX/H), a design chart is developed from the results from the large scale blast tests in Australia 2002 and 2004 (Figure 7). For a specific scaled distance and the B/H ratio of the wall, the expected deformation can be obtained. The serviceability limits for permanent and temporary structures were set at DX/H ratios of 15% and 20% respectively. For a specific Z value, the lower the B/H ratio, a higher deformation, DX will be obtained.

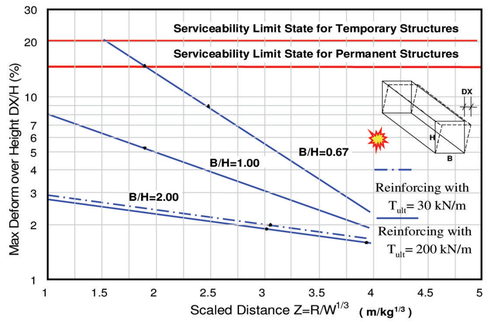

Figure 7. Design chart for RS walls subjected to large scale blasts.

Thus it can be seen that there are major differences in the design approach for these two types of blasts. However, a common feature is that the lower the B/H ratio, the weaker the RS wall will be as evidenced by the higher crater volume or deformation. From both graphs, it can be see the B/H ratio should not be smaller than 0.7 for sufficient resistance against blast loading.

6 CONCLUSIONS

Reinforced Soil (RS) walls can be used as protection for personnel and equipment from blasts. The type of geosynthetics used affects how the RS walls response during the blasts. Geocell walls were found to produce more debris compared to conventional geotextile walls due to their brittleness and inability to deform more. Geometry also plays an important part in the response of the RS walls. Various full scale blast trials were conducted between 1998 and 2004. The results show that if the actual distance between the charge and the wall is small with respect to the dimensions of the wall, localized blast effects (close range medium scale blasts) will occur instead of globalized effects (large scale blasts). Design charts were derived for both localized and globalized blast effects. These design procedures were significantly different. Close range medium scale blasts uses the crater volume in the front face as a gauge of the serviceability of the RS wall while large scale blasts uses the deformation of the wall.

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REFERENCES

Bathurst, R.J. and Hatami, K. (1998). "Seismic response analysis of a geosynthetic-reinforced soil retaining wall", *Geosynthetics International*, Vol. 5, Nos. 1-2, pp. 127-166.

Chew, S.H., Wong, W.K., Ng, C.C., Tan, S.A. and Karunaratne, G.P. (1998). "Strain gauging geotextiles using external gauge attachment method', Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM Special Technical Publication (STP 1379), Han 2000, pp. 97-110.

He, Z.W., Chew, S.H., Tan, H.W., G.P. Karunaratne, Seah, Y.T. and Chew, A. (2004). "Blast Tests of Full Scale Reinforced Soil Walls", GeoAsia 2004, Proceeding of therd Asia Regional Conference on Geosynthetics (Jun 2004), pp 725-732.

Mays, G.C. and Smith, P.D. (1995). *Blast Effects on Buildings*, Thomas Telford Ng, C.C. (2000). "Response of geosynthetics reinforced soil structures subject to blast", Master's Thesis, National University of Singapore.

Smith, P.D. and Hetherington, J.G. (1994). *Blast and Ballistic Loading of Structures*, 1st Edition, Butterworth-Heinemann Ltd.

Tan, H.W., Andy, Chew, S.H., He, Z.W., G.P. Karunaratne and Seah, Y.T. (2005). "Field tests of Reinforced Soil (RS) Walls subjected to Close Range Blasts", PARARI 2005, 7th Australian Explosives Ordnance Symposium.

