Behaviour of Reinforced Mine Waste Model Walls under Uniformly Distributed Loading

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ABSTRACT

Mine waste is a by-product of mine processing units that produce ore. Approximately on an average 2.5 to 3 tons of mine waste is generated to produce a ton of iron ore in Goa state, India. Considering the growing mining activity in Goa region, mine waste from Advalpal village was used in the study as an alternative backfill material for reinforced soil walls. Model tests were performed on reinforced mine waste walls to examine the horizontal displacement of fascia and failure mechanism under uniformly distributed loading. Steel grid in the form of L-shaped discrete units was used to prepare wall fascia and bamboo strips were used as reinforcement material. The length of reinforcement (L_r) used in the study was 0.3H, 0.5H and 0.7H, where H is height of wall. The results show that bamboo strips are effective in reducing the horizontal displacement of the wall fascia. The displacements are reduced with increasing length of reinforcement and the uniformly distributed loading at failure increased with increasing length of reinforcement.

KEYWORDS: Mine waste, bamboo strip, steel grid, reinforced walls.

INTRODUCTION

In view of the rapidly increasing production of mine wastes in industrialized countries, potential application of this material needs to be considered. Mine wastes represent the highest proportion of waste produced by industrial activity, billions of tones being produced annually (Bell & Donnelly, 2006). Goa is amongst the major iron ore exporting state and over 60% of Country's iron ore export is from Goa. In terms of foreign exchange earnings for the state it amounts to nearly Rs.1000 core per annum. The average annual production of iron ore is about 15 to 16 million tones and resulting waste is 40 to 50 million tones. This huge quantity of mining waste
creates a problem for its storage thereby causing severe environmental problems like deforestation, groundwater pollution, and dust pollution. Mine waste from Advalpal region in Goa has silt and clay content (Kandolkar and Mandal, 2012) and hence it falls in the category of low draining soils. Silts or low plasticity clays were used as backfill material for many structures (Ingold, 1983a; Hannon and Forsyth, 1984; Sego et al., 1990; Burwash and Frost, 1991; Farrag and Morvant 2004). Plastic clays were used in some cases (Hashimoto, 1979, Yamanouchi et al. 1982, Tatsuoka and Yamauchi 1986). In a few cases, industrial or mine wastes were used as embankment fill (Jewell and Jones 1981). Low draining soils are recommended to be reinforced with permeable geosynthetics that function as reinforcement as well as lateral drains (Zornberg and Mitchell, 1994). Reinforcing locally available cohesive soils encourages economical and practical solution for the reinforced soil walls, when cohesionless backfill is not easily available. Murray & Boden (1979) used clayey sand as a fill material for reinforced wall and concluded that, despite construction difficulties, cost savings could be achieved in comparison with the utilization of granular material imported from far away locations. Over the years strengthening of soil is done with variety of reinforcements which include natural geosynthetics made from jute, coir, bamboo for various geotechnical applications like, consolidation of soil (Asha and Mandal, 2012; Bera and Roy, 2012), improving bearing capacity of soft soils by using non woven geotextile with bamboo fascine mattress (Toh et al. 1994), as a general soil reinforcing material (Datye, 1988). Natural geosynthetics are bio-degradable and cheaper if they are locally available. Bamboo a perennial grass is such a sustainable material harvested from renewable natural resources. It exists abundantly in tropical, subtropical and temperate zones of the world and is a potential material for reinforced earth (Punmia, et al., 2005). Studies are done with bamboo in reinforced slope (Lin et al., 2010), bearing capacity of soft subgrade (Kamali and Hashim, 2010; Anusha and Kindo, 2011). So far there is no attempt on study of mine waste walls reinforced with bamboo strips.

The present study uses the combination of locally available materials mine waste and bamboo strips to study the behaviour of laboratory model walls under uniformly distributed loading (udl). This study gives an insight about the usability of mine waste as a material for reinforced soil wall construction.

### MATERIAL PROPERTIES

**Mine waste**

Mine waste soil obtained from the mining dumps at Advalpal village in Goa was used in reinforced mine waste wall model tests. The specific gravity of mine waste was 2.62. The mine waste from this region mostly contains sand (58%) and silt size (26%) particles. The coefficient of uniformity \((C_u)\) is 305.88 and the coefficient of curvature \((C_c)\) is 1.995. Mine waste obtained from this region was classified as silty sand as per IS1498, 1970. The maximum dry unit weight \((\gamma_{d\ max})\) is 20.1 kN/m³ and the optimum moisture content (OMC) is 11.17%. The electrochemical property pH of mining waste was 5.48. Representative sample of mine waste is shown in Figure 1(Kandolkar and Mandal, 2012).
Chemical composition of soil

The mine waste soil was tested for its chemical composition at the Sophisticated Analytical Instrument Facility (SAIF), I.I.T., Bombay. X-Ray fluorescence test was performed by using a spectrometer (Philips PW 2404). The chemical composition of mining waste soil is given in Table-1.

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>27.782</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>10.441</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>10.748</td>
</tr>
<tr>
<td>CaO</td>
<td>0.004</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.501</td>
</tr>
<tr>
<td>MnO</td>
<td>0.052</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.018</td>
</tr>
<tr>
<td>SrO (ppm)</td>
<td>15.384</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.449</td>
</tr>
</tbody>
</table>

Steel grid fascia

Fascia is made of steel grid with a L-shape as shown in Figure 2. The length of each arm is 75 mm, steel wire thickness is 1.2 mm. The apparent opening size is 12mm x 12 mm. The fascia is covered with jute cloth to prevent the soil from falling out.
Reinforcement

Bamboo strips were used as reinforcement. The strip dimension was 20 mm wide, 1.5 mm thickness. Length of strips considered in the model wall tests were, \( L_r = 0.3H, 0.5H \) and 0.7H. Where, \( H \) is the height of the model wall. Figure 3; show the connection between reinforcement and fascia unit.

Tensile strength of bamboo strip

The tensile strength of bamboo strip is evaluated by conducting the test, breaking force and elongation of textile fabrics (strip method), which is performed as per ASTM D5035. Sample strip of size 20 mm wide x 100 mm gauge length was subjected to tensile pull. Figure 4; show the bamboo strip in tension test after failure. Figure 5 show the load-strain curve of bamboo strip tension test and Table-2 gives the properties of bamboo used in the present study.
Figure 4: Bamboo strip failure in tension

Figure 5: Load versus strain curve for bamboo strip sample

Table 2: Properties of bamboo strip

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass per unit area (gm/m^2)</td>
<td>563.54</td>
</tr>
<tr>
<td>Tensile Strength (kN/m)</td>
<td>87.8</td>
</tr>
<tr>
<td>Maximum elongation</td>
<td>2.30 %</td>
</tr>
<tr>
<td>Initial tangent modulus (kN/m)</td>
<td>38.09</td>
</tr>
</tbody>
</table>
EXPERIMENTAL PROGRAM

Tests conducted on Reinforced Mine Waste walls

Experimental program details are given in table-3.

Table 3: Experimental Program

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Reinforcement Length</th>
<th>Coverage Ratio ($C_r$)</th>
<th>Type of loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model-1</td>
<td>Mine waste wall without fascia</td>
<td>Without reinforcement</td>
<td>NIL</td>
<td>udl</td>
</tr>
<tr>
<td>Model-2</td>
<td>Mine waste wall with steel grid fascia and bamboo strip reinforcement</td>
<td>0.3H</td>
<td>0.4</td>
<td>udl</td>
</tr>
<tr>
<td>Model-3</td>
<td>Mine waste wall with steel grid fascia and bamboo strip reinforcement</td>
<td>0.5H</td>
<td>0.4</td>
<td>udl</td>
</tr>
<tr>
<td>Model-4</td>
<td>Mine waste wall with steel grid fascia and bamboo strip reinforcement</td>
<td>0.7H</td>
<td>0.4</td>
<td>udl</td>
</tr>
</tbody>
</table>

Here, $C_r$ is the coverage ratio; it is defined as the ratio between gross width of the strip and center-to-center horizontal spacing between strips (Elias et al., 2001)

These tests were conducted to study the behaviour of mine waste walls with respect to failure surface, horizontal displacement of the fascia and vertical settlement of the backfill soil without and with reinforcement under uniformly distributed loading.

Construction of reinforced mine waste wall

A mild steel tank of size 600 x 340 x 550 is used for the construction of mine waste model wall. Figure 6; show the schematic sketch of model wall test set up and Figure 7; show photographic view of experimental set up. The front side of the tank is fitted with acrylic sheet for the purpose of visibility of failure surface and deformation of the wall fascia. A wooden plank of width same as tank width is clamped to tank at a distance of length of fill. This serves as temporary support during wall construction and compaction. This support is also required to prevent horizontal deformation of fascia prior to load application. The height of wall is divided into seven layers based on the height of each unit of fascia. The quantity of dry soil ($W_s$) required for each layer is determined as $W_s = \gamma_d \times V$, where $\gamma_d$ is the dry unit weight of the mine waste and $V$ is the volume of each layer. The quantity of water to be added to this soil is determined as $W_w = W_s \times w$, where $w$ is moisture content of mine waste. The moisture content used is 5% dry of optimum. The mine waste required to fill each layer is mixed thoroughly by adding the calculated amount of water and converted into a homogeneous mix. Above the foundation the fascia unit is placed along with reinforcement attached to it. The homogeneous mix of mine waste is poured over the reinforcement, spread evenly and compacted with Proctor hammer to achieve a degree of compaction as much as 90% of the maximum dry unit weight of mine waste. Each layer was placed in similar manner up to the total height of the wall. Marking is done at each layer of mine waste on the side fitted with acrylic sheet. The top surface of fill is given a level finish to ascertain uniform load distribution on backfill. Moisture content was monitored by checking moisture content of samples before and after the test. A total of 8 trial tests were performed prior to the actual model tests. The wall is subjected to uniformly distributed load up to failure. Failure condition is attained when the load decreases with increase in horizontal deformation at the fascia. Loading is applied through load cell which is fitted to automatic loading jack system. Horizontal
deformation of fascia along the wall height is recorded by using Linear Variable Differential Transducers (LVDTs).

**BEHAVIOUR OF REINFORCED MINE WASTE WALL**

Horizontal displacement of facing units at various points along the height of wall is measured corresponding to each load in increments of 0.25 kN. The first LVDT is placed at 75mm from top of foundation level and next three are placed equidistant from each other at 125 mm vertical spacing. Relation between normalized facing displacement \( \delta/H \) (%) and normalized height of the wall \( y/H \) is plotted. Where, \( \delta = \) horizontal facing displacement, \( y = \) distance of LVDT from the base of the wall, \( H = \) height of the wall (height of fascia and wall are same) for all tests the vertical spacing between reinforcement, \( S_v = 0.142H \), and the coverage ratio \( C_r = 0.4 \) is maintained constant. Length of reinforcement is varied as 0.3H, 0.5H and 0.7H.

![Figure 6: Schematic sketch of model wall test set up](image)

**RESULTS AND DISCUSSION**

**Horizontal Displacement of Facing**

**Model 1: Mine Waste Wall without Reinforcement and Fascia under Uniform Surcharge Pressure.**

The mine waste wall test without reinforcement was considered as the reference test. Immediately after the application of uniformly distributed load on the unreinforced mine waste wall, it moved laterally and collapsed giving failure surface at \( 45 + \phi/2 \) and a failure stress of 14.65 kPa. For unreinforced case the relation between normalized fascia displacements, \( \delta/H \) (%) and normalized height of wall, \( y/H \) is shown in Figure 8. It was noticed that the maximum fascia displacement at failure load occurs at \( 2/3^{rd} \) of wall height.
Models 2, 3, 4: Mine Waste Wall with Fascia and Bamboo Strip Reinforcement of Length, $L_r = 0.3 \text{H}$, $0.7\text{H}$ and $0.5\text{H}$ Subjected to Uniformly Distributed Loading

In model-2 mine waste is reinforced with bamboo strips of length, $L_r = 0.3\text{H}$, vertical spacing is kept constant at $S_v = 0.14\text{H}$, where $\text{H}$ is the height of wall. Figures 9(a) (b) and (c) show the relation between normalized fascia displacement $\delta/H \ (%)$ and normalized height of wall, $y/H$ for
length of reinforcement 0.3H, 0.5H and 0.7H. The results show that for an udl of 25.64 kPa, the normalized fascia displacement increase with the normalized height of wall. Maximum fascia displacement at failure occurs approximately at a point $y = \frac{2}{3}H$ of wall height. Also the udl supported by the wall at failure was increasing as the length of reinforcement was increased in the order of 0.3H, 0.5H and 0.7H.

Figure 9: Continues on the next page.
Figure 9: Variation of normalized fascia displacement with normalized wall height for length of reinforcement (a) 0.3H (b) 0.5H and (c) 0.7H

Figure 10 show the variation of normalized fascia displacements with normalized wall height for length of reinforcement; $L_r = 0.3H, 0.5H, 0.7H$ and for a uniformly distributed load of 25.64 kPa. It was noticed that for a constant coverage ratio and vertical spacing the normalized fascia displacements were more for wall reinforced with length of reinforcement 0.3H. The normalized fascia displacements reduced as the length of reinforcement was increased to 0.5H and 0.7H. The failure load observed was highest and fascia displacements were least for wall with $L_r = 0.7H$. The results indicated that as the reinforcement length increases the normalized fascia displacement reduces as compared to the unreinforced case.

Table 4 summarizes the maximum lateral displacement of facing for a uniformly distributed load ($q$) of 25.64 kPa at $L_r = 0.3H, 0.5H$ and 0.7H. It was observed that the reinforced wall behaves stiffer compared to the unreinforced wall. The normalized fascia displacements of reinforced walls were much lesser than the corresponding values for walls without reinforcement.

**Table 4:** Normalized maximum lateral fascia displacement with $L_r = 0.3H, 0.5H$ and 0.7H at uniformly distributed load of 25.64 kPa

<table>
<thead>
<tr>
<th>Length of bamboo strip reinforcement ($L_r$)</th>
<th>q kPa</th>
<th>$(\delta_{max}/H)$%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3H</td>
<td>25.64</td>
<td>1.85</td>
</tr>
<tr>
<td>0.5H</td>
<td>25.64</td>
<td>1.64</td>
</tr>
<tr>
<td>0.7H</td>
<td>25.64</td>
<td>1.33</td>
</tr>
</tbody>
</table>
Table 5 summarizes the effect of length of reinforcement on uniformly distributed load at failure. It was observed that model wall constructed without reinforcement, collapsed suddenly at a load of 14.65 kPa, displaying horizontal deformation which increases from bottom to top. When the model walls are reinforced with bamboo strips, the fascia displacements are reduced, being minimum at the base of the wall and maximum at 2/3rd of the height of wall. Also, as the reinforcement length is increased the mine waste behaves stiffer. Maximum fascia displacement was seen to be reducing as the length of reinforcement was increased.

<table>
<thead>
<tr>
<th>Length of bamboo strip reinforcement (Lr)</th>
<th>Uniformly distributed load at failure (qf) kPa</th>
<th>% increase in uniformly distributed load w.r.t. unreinforced case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreinforced</td>
<td>14.65</td>
<td></td>
</tr>
<tr>
<td>0.3H</td>
<td>38.55</td>
<td>61.99</td>
</tr>
<tr>
<td>0.5H</td>
<td>47.24</td>
<td>68.98</td>
</tr>
<tr>
<td>0.7H</td>
<td>53.12</td>
<td>72.42</td>
</tr>
</tbody>
</table>

**SETTLEMENT OF REINFORCED BACKFILL**

The settlement of the mine waste backfill ($\rho$) under the influence of uniformly distributed load was measured by placing LVDTs at two points on the loading plate. LVDT 1 was fitted at a distance of 125 mm from the facing of the wall and LVDT 2 was fitted at a distance of 405 mm from the facing. The uniformly distributed load at failure was normalized with unit weight of the backfill and height of the wall ($q/\gamma H$). The settlement of the backfill was normalized with height.
of the wall ($\rho/H$). Figure 11: show the relation between the normalized settlements of backfill with the normalized uniformly distributed loading. For each length of reinforcement ($L_r = 0.3H, 0.5H$ and $0.7H$) two curves were plotted one representing readings at LVDT1 closer to fascia and other at LVDT 2 away from fascia. For all the cases of reinforcement the backfill settlement was slightly more near the facing than the settlement at far end of the facing, this was due to the lateral movement of the fascia under the influence of udl. The settlement values are least for the mine waste wall reinforced with $L_r = 0.7H$ as compared to the cases with $L_r = 0.3H$ and $0.5H$. Table-6; give the comparison of vertical settlement of reinforced wall with length of reinforcement as $0.3H$, $0.5H$ and $0.7H$. It was noted that wall with reinforcement length $0.7H$ resisted maximum udl ($q_f$) as much as 53.12 kPa and displayed very small values of normalized backfill settlements. Hence, for construction of reinforced mine waste wall the length of reinforcement can be restricted up to $0.5H$ to give reasonably good results w.r.t. an unreinforced mine waste wall.

![Figure 11: Relation between normalized settlement of backfill and normalized uniformly distributed load](image)

**Table 6:** Comparison of vertical settlement under uniform distributed loading of 25.64 kPa, at length of reinforcement, $L_r = 0.3H, 0.5H$ and $0.7H$.

<table>
<thead>
<tr>
<th>Length of bamboo strip reinforcement ($L_r$)</th>
<th>$\rho/H$ (%)</th>
<th>LVDT1 (near fascia)</th>
<th>LVDT2 (away from fascia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3H</td>
<td>0.91</td>
<td>0.84</td>
<td></td>
</tr>
<tr>
<td>0.5H</td>
<td>0.53</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>0.7H</td>
<td>0.0495</td>
<td>0.038</td>
<td></td>
</tr>
</tbody>
</table>
CONCLUSIONS

Retaining walls were constructed in a model tank using mine waste as alternative backfill material, reinforced with bamboo strip and with steel grid as fascia. Walls without reinforcement were also tested. The study was carried out to understand the behaviour of reinforced mine waste walls subjected to uniformly distributed loading. Fascia displacements, load resistance up to failure and the failure surface patterns were studied. The results obtained from the tests showed that reinforced walls behave stiffer in comparison with walls without reinforcement. Based on the experimental findings, following conclusions are drawn.

1. The mine waste model walls without reinforcement fail at a uniformly distributed load (qf) of 14.65 kPa. Whereas, walls when reinforced with bamboo strips of length 0.3H corresponded to uniformly distributed load at failure 38.55 kPa. Uniformly distributed load at failure for reinforced mine waste walls increased by 61.99% with a reinforcement length of 0.3H. For length of reinforcement 0.5H and 0.7H the uniformly distributed load at failure increased by 68.98% and 72.42 % respectively. Thus, load carrying capacity of reinforced mine waste model walls increased with increasing length of reinforcement.

2. For a particular value of uniformly distributed load 25.65 kPa, normalized fascia displacements decreased with increasing length of reinforcement. Length of reinforcement 0.3H corresponded to highest normalized fascia displacement, whereas 0.7H corresponded to lowest.

3. For all cases of reinforcement the mine waste walls settles slightly more near the fascia than at the far end. For walls reinforced with Lr = 0.7H, the overall normalized backfill settlement values are very small as compared to the settlement measured at Lr = 0.3H and 0.5H.

4. The backfill settlement of reinforced mine waste wall decreased with increasing length of reinforcement.

Thus the results from laboratory tests on reinforced mine waste walls, subjected to uniformly distributed loading indicate that mine waste from this particular region of Goa with its favourable properties can serve as good alternative material for backfill in the construction of reinforced soil walls.

REFERENCES


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