Construction and monitoring of a 22.5 m high geosynthetic reinforced segmental retaining wall in India

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ABSTRACT: Widening of a hill road leading to a hill top temple in the town of Vijayawada, India required the construction of a 22 m high retaining wall. The option of segmental retaining wall using geosynthetics was chosen among the other options such as a bridge, widening by blasting of the hill based on technical feasibility and cost economics. The reinforced soil wall was constructed using high strength polyester reinforcing geocomposite with a locally available murum soil as reinforced fill. The retaining walls constructed using soils having low permeability experience distress in the long run. Hence, special care was taken during the construction to keep the backfill soil as dry as possible. This paper reviews some aspects of the design and construction of this wall, highest of this kind in India at the present time.

1. INTRODUCTION

The soil is weak in tension but is strong under compression. The introduction of reinforcement elements (metallic or synthetic) in the soil imparts tensile strength to it thereby improving the overall mechanical performance. The resulting composite, termed as reinforced soil, has emerged in the last few decades as a technically attractive and cost-effective solution to many geotechnical problems. Especially in the context of stability under seismic conditions, the reinforced soil walls are quite superior due to their flexible nature.

The first geosynthetic reinforced soil retaining wall in India was constructed on National Highway No. 1, near Ludhiana, Punjab in the mid-eighties for a road over rail bridge approach. Geosynthetic strips were used as reinforcing elements and pre-cast concrete panels were used as fascia elements. The maximum height of this wall was 8 m and the cost savings was more than 15% compared to the conventional reinforced concrete retaining wall. Since then, a very large number of bridge approach roads, RoBs etc on National Highway Development Projects have employed reinforced soil wall concepts. The facing treatments in these walls include full-height panel walls, incremental facing panels, modular blocks, gabion boxes etc. The typical heights of these walls range from 3 m to almost 16 m.

2. NEED FOR THE RETAINING WALL

The approach road to a very popular hill top temple in the town of Vijayawada, India was built about 40 years ago by blasting and clearing the rocks. The road is open to motor traffic round the year. The road is a typical hill road with several sharp bends. Due to the difficulties encountered in blasting the rocks and the nature of the terrain, the road could not be laid with uniform width over the full length. At some stretches, the road is quite narrow as shown in Figure 1.

Figure 1. Photograph showing the level difference and typical narrow section of road

These narrow sections of the road lead to frequent traffic congestions during the festival seasons when large number of pilgrims visit the temple. Hence, it was decided to widen the road to accommodate increased traffic. The height of the narrow road section of the road from the ground level varies from 19 m to 22 m over a length of 65 m.

The different options considered for widening the road section were (i) excavation of hill slopes (ii) construction of a bridge and (iii) construction of reinforced soil wall. The geosynthetic reinforced soil wall provided the most cost effective and relatively simpler option due to the following advantages;

- Reinforced soil wall construction does not disturb the existing hillock which is already fairly steep,
- Reinforced soil wall provides an additional 20 m wide space over existing 3 m wide road,
- Geosynthetic reinforced segmental retaining wall is economical and fast, and
- Geosynthetic reinforced segmental retaining wall does not require heavy machinery for construction.

3. SITE CONDITIONS ANS MATERIALS

The foundation soil at the site consists of approximately 1.5 m thick loose soil deposit at the top followed by hard rock. The top loose soil was completely excavated and the leveling pad was directly placed on the hard rock. The in situ rock is competent to safely carry the imposed stresses of more than 400 kPa without any bearing capacity failure or excessive settlements.

The soil from a local quarry was used as backfill material. The soil has good gradation meeting the specifications for construction of reinforced soil retaining walls. The percentage of different sized particles in the soil are: gravel 39%, coarse sand 5%, medium sand 12%, fine sand 8% and silt and clay 36%. The fine soil fraction is non-plastic with plasticity index less than 6%. Hence, this soil could be used as backfill material in reinforced soil walls. The shear strength properties of the soil determined from large-scale direct shear box tests are cohesion of 35 kPa and friction angle of 34° to 36°. For design purposes, the cohesion was neglected and the friction angle was considered as 32°.

The reinforcement used in the walls was a geocomposite consisting of high tenacity polyester yarns stitched to a polypropylene nonwoven needle punched geotextile. This particular product was chosen because it has the advantage of good drainage properties and reinforcement properties. Heavy rainfall occurs at this location and hence good drainage is required to dissipate any pore pressures generated within the backfill soil. The strength of the interface between the soil and the geocomposite was found to be excellent with interface friction factor of nearly unity. The index tensile strength was determined based on ASTM D-4595-94 procedures using roller grips. The index tensile strengths ranged from 50 kN/m to 200 kN/m and the corresponding long term allowable design strengths ranged from 29 kN/m to 117 kN/m. The index tensile strength was developed at strains in the range of 9% to 10%.

The facing elements used at the site were modular blocks similar to rockwood blocks having mass of approximately 35 kg. These blocks are of length 450 mm on the front side and 350 mm on the backside. The height of each block was 200 mm. These blocks were manufactured by cold pressing process with cement concrete having minimum compressive strength of 35 MPa after 28 day curing.

The connection strength between the facing blocks and the geosynthetic was purely mobilized by friction alone. The connection strength was determined by performing large-scale laboratory tests as per ASTM D6638-07. Typical data obtained from such connection strength tests for a geocomposite having index tensile strength of 75 kN/m is given in the following table.

Table 1. Typical data from connection tests

Normal load (kN/m)	Approx. wall height (m)	Load at 20 mm displacement (kN/m)	Peak load (kN/m)
10	1.90	12.6	15.5
15	2.80	14	17.2
20	3.75	15.5	19.4
25	4.70	17.1	22.3
30	5.60	18.5	23.8
35	6.6	19.4	25.3
40	7.5	20.7	26.9
50	9.35	23.4	28.8

4. DESIGN OF THE WALL

The design of the wall was performed based on the recommendations of the BS 8006-1995 and NCMA guidelines authored by Simac et al. (1993). The seismic analysis was performed as per the recommendations of the design manual of Federal Highway Administration, Elias et al. (2001). Some early guidelines for the design of these walls were also given by Mitchell and Villet (1987).

The 22.5 m high wall was split into two tiers, 12 m of bottom wall and 10.5 m high upper wall with an offset of 5 m as shown in Figure 2. The top tier was designed as an individual wall with due consideration of traffic load whereas the bottom tier wall was designed considering the full surcharge of 10 m and traffic load from the upper tier wall. The guidelines given in FHWA manual for the design of the tiered walls were followed for determining the maximum tension forces and the stresses within the soil block.

The provision of the berm at mid-height of the wall resulted in economy, good aesthetics and ease of maintenance. The overall stability also improves due to the provision of the berm. The maintenance is easier in tiered walls since the top of each tier provides access to the next higher portion of the wall.

The wall has been checked for both external and internal stability. The lengths of the reinforcement layers for both upper and lower tiers were determined through external stability calculations, viz. sliding, over-turning and bearing failures. The vertical spacings of the reinforcement layers were determined through internal stability calculations, viz. pullout and rupture considerations. Further, the force in each reinforcement layer was also verified against the connection strength at that depth of wall.

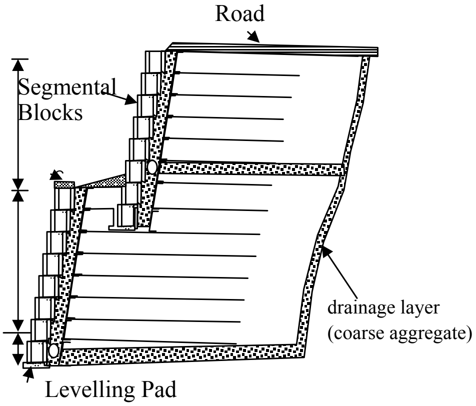

Figure 2. Cross-section of the 22 m high wall

The upper wall was treated as superimposed surcharge load on the bottom wall as per the FHWA guidelines.

The length of the reinforcement was 10.5 m for the bottom tier and 7.4 m for the upper tier. Apart from the dead and live loads, a seismic acceleration factor of 0.04 was considered in the design as per the local geological conditions. The computed reinforcement elevations are shown in Table 2. All spacings were in multiples of 200 mm which is the height of the facing block.

Table 2. Reinforcement Layout

Type of reinforcement	Vertical spacing (mm)	Elevation (m)
Lower-tier		
PEC200	200 mm	0 to 1.6m
PEC200	400 mm	1.6 m to 6.8m
PEC200	600 mm	6.8 m to 12.0 m
Upper-tier		
PEC200	600 mm	12.2 m to 12.8 m
PEC 150	600 mm	12.8 m to 15.8 m
PEC 100	600 mm	15.8 m to 17.6 m
PEC 075	600 mm	17.6 m to 20.0 m
PEC 050	600 mm	20.0 m to 22.4 m

The total number of reinforcement layers in the bottom and upper tiers were 29 and 18 respectively.

5. CONSTRUCTION ASPECTS

The construction proceeded by first placing the levelling pad at the foundation level. Later, the modular facing units were placed manually one layer at a time. A picture showing the placement of facing blocks is shown in Figure 3. Simac (2006) has described several case studies of the failure of modular block walls and gave some recommendations for the successful construction and performance of modular block walls. The construction procedure has adopted many of these such as placing only one layer of blocks and compacting the soil in thickness equal to the height of the blocks, i.e. 200 mm.

Figure 3. Placement of facing blocks in rows

The construction of the wall had posed unique problems in that the construction area is quite narrow and there was no way out for the construction equipment. Once the equipment moved into the site at ground level, they do not have access to come out of the construction area. The equipments moved up along with the soil fill and came out of the construction area after the full height of the wall was reached. The overall view of the construction area and the drainage layers provided around the soil are shown in Figure 4.

Figure 4. Overall view of the construction area

The reinforcement layers of sufficient length were placed at appropriate elevations. The spacing of the reinforcement layers was 200 mm at the bottom part of the wall increasing to 400 mm and then to 600 mm towards the top of the wall. The reinforcement layers were provided with a 5° downward inclination in order to achieve good pullout capacity. The reinforcement layers were anchored in a trench at the back end in order to help mobilize higher tensile capacities in reinforcement layers.

The soil was placed in 200 mm thick layers and compacted to 95% dry density. In situ soil samples were collected during the construction from each layer of soil for monitoring the compaction quality. The soil was covered with polythene sheets at the end of each day or during rains to prevent entry of rainwater into the backfill soil. The construction work had to be stopped even during light rainfall due to large run-off water from higher elevations.

It was anticipated at the design stage itself that the drainage of rainwater would pose severe problems for the longevity of this retaining wall. As the monsoon rains are quite intense and surface runoff is very high from higher altitudes, effective drainage is to be provided. Hence, the reinforcement layers chosen were of geocomposite type which would function both as reinforcement layer and also as drainage layer.

Aggregate drainage layer of 300 mm thick was placed just behind the modular blocks and also behind the backfill for the entire height of the wall. The stone aggregate placed in this layer had uniform particle size in the range of 10 to 20 mm size as per the relevant highway standards. The vertical drainage layer behind the backfill soil is referred to as chimney drain.

6. MONITORING OF PERFORMANCE

The 22.5 m high reinforced soil wall was completed in October 2008 and the roadway on it was opened for traffic immediately. Figure 5 clearly shows the additional space created for widening of the hill road after the completion of the wall. This wall was completed well within the budgeted amount saving considerable money to the owners. The performance of the wall is being continuously monitored through external observations. No deformations in the wall or subsidence at the road level were observed over the past one year. The horizontal alignment of facing blocks is maintained well indicating that there are no undue settlements at the site.

The area has gone through one monsoon season when heavy rain fall occurs. The chimney drains and the horizontal drain at the base of the soil were observed to function well with all the rainwater draining away from and through the bottom of the wall.

Figure 5. View of the road after completion of wall

7. CONCLUSIONS

A 22.5 m high reinforced soil retaining wall was constructed using modular block wall facing and a geocomposite to serve as both a drainage layer and reinforcement layer. This wall was constructed within the time and budget limits. The observed performance over the past one year has not shown any distress in the constructed wall.

Another wall of height 44 m just next to this wall is under progress currently. This wall is constructed using four tiers. Fibre optic sensors (geodetect) were installed at mid-height to electronically monitor the performance of this wall. These two walls are the highest of their kind in India till date.

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