New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-45775-0

Behaviour of reinforced earth structures founded on soft silt deposit in seismically active hilly terrains

P. Mahajan
J&K Cell, RITES Ltd. New Delhi, India

S. Biswas & A. Adhikari
Reinforced Earth India Pvt. Ltd., New Delhi, India

ABSTRACT: The reinforced soil walls for Quazigund to Baramulla project, while under various stages of construction, experienced earthquake of magnitude about 7.0 on Richter scale with epicenter about 150 km away from the site, in Pakistan. The equivalent magnitude of tremor on Richter scale at site was 5.4. The character of the titled paper is to bring forth a unique case for reinforced earth wall construction on soft clayey silt deposit with settlements of large magnitude and share the experience of performance under actual seismic activity vis-à-vis other structures in the vicinity of the project, as constructed in difficult terrains and climatic conditions.

1 INTRODUCTION

Reinforced earth solutions were adopted in the design and construction of approach embankments to rail over bridges, being a part of the railway expansion project from Quazigund to Baramulla in the north bound state of Jammu & Kashmir, India.

The project involves the construction of eight rail over bridge approaches using reinforced soil walls (total about 50,000 square meters of face area) with ground treatment using high tenacity polyester Geogrids as transition course and to improve the safety factors against slip circle failure. Reinforced soil walls using discrete cruciform panels and high adherence steel strip reinforcement were adopted for the construction of approaches to rail over bridges. The static design of reinforced earth wall was done as per BS 8006, 1995 and the seismic design as per AFNOR NF P 94-220, July 1992. The backfill used was selected well-graded riverbed material, mined and screened specifically to meet the technical requirement of mechanical, physical and hydraulic properties, meeting the electrochemical criteria.

This paper narrates the investigation, design and analysis aspects of retaining walls, ground treatment, and the behavior of the structures under seismic load and post construction settlements. Special detailing adaptable to typical high altitude terrains, flash flooding incidences, high water table considerations and cold weather freeze and thaw cycles are discussed in the paper.

2 FOUNDATION SOIL INVESTIGATION AND GENERAL DESCRIPTION

Initially extensive soil investigation has been conducted by the main client for this project to evaluate the foundation soil behavior. Dynamic cone penetration tests (DCPT) and standard penetration tests (SPT) upto 15 m depth have been carried out in each km at an interval of 250 meters for whole 118 km stretch. The typical N-values are shown in Figure 1.

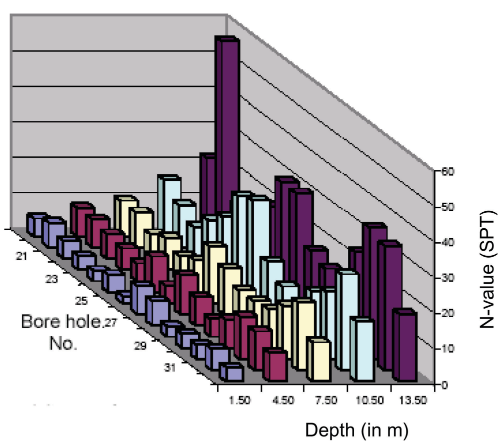

Figure 1. Typical SPT results from 22 km to 45 km.

The general description of foundation soil for most of the location is similar and consists of filled-up soil of 1–2 m and predominantly layers of fine grained clayey silt of low/medium plasticity upto 15–20 m depth. In some location sand has been encountered at 16 m depth. However, in general the top 15 m soil consists of clayey silt having 3–5% of sand, 80–95% of silt and 2–7% of clay. The top 6–10 m soil in all locations except for structure at 5B (for details refer the list of structure given in table no.1) consists of very loose soil having N-value (SPT) varying from 1 to 9.

3 FOUNDATION IMPROVEMENT

The maximum height of wall varied from 9.0 m to 12.0 m for the structures. The foundation soil did not have adequate bearing capacity to support high structures. The wall was therefore, proposed to be built in three stages. The gain in shear strength of subsoil due to consolidation under each stage of loading would allow construction of the next stage without any foundation failure. In order to accelerate the consolidation under each stage of loading the subsoil was initially proposed for treatment with prefabricated vertical drains (PVDs). However, after detailed soil investigation and recommendation from the design consultant the provision of PVD has been removed since the foundation soil is of low plasticity in nature and is self-draining. The reinforced soil structure walls are catered for total settlement of 400–650 mm for maximum wall height of 10 m depending on the location.

Layers of high strength polyester geogrids have been adopted to improve the stability of the structure against slip circle failure. Depending upon height, loading and foundation characteristics of sub-soil, and one or two layers of high tenacity polyester geogrids have been provided half meter below the reinforced earth wall panel. The analysis for slip circle failure is done using Talren 97 software for three stage of construction with FOS of 1.2 in seismic and typical out-put is shown in Figures 2, 3 and 4.

3.1 *Typical proposed foundation improvement programme*

For reinforced soil walls upto a height of 4m, no ground treatment was proposed. Walls exceeding 4m height, the ground was proposed to be treated with one or two layers of high strength PET geogrid, which, were extended 3 m on both sides beyond the structure width depending on detailed analysis.

Typical ground treatment proposed for 10 m high walls for various structures depending on type of foundation soil is as follows:

Two or three-stage construction was proposed for wall exceeding height of 4 m. The details of stage construction were as follows:

1. Stage I: Reinforced earth wall upto 4m high, were built first. Thereafter, 30–40 days pause period was provided for allowing consolidation of the subsoil.

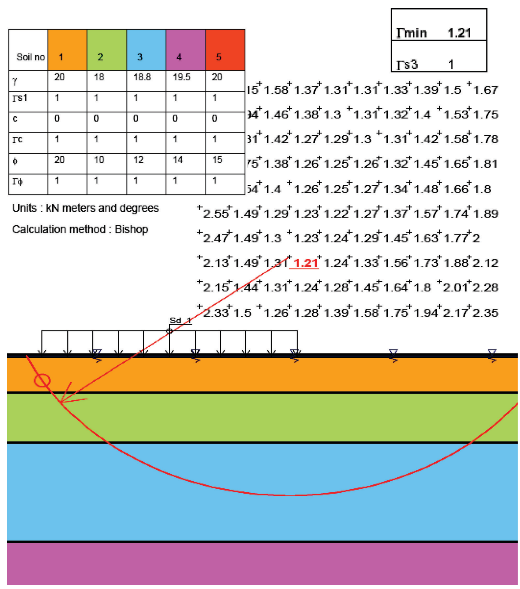

Figure 2. Slip circle analysis for Stage-I construction.

Table 1. Shear strength and consolidation parameters.

Site locations	Cohesion* 'c' (kg/cm^2)	Angle of internal fiction (ϕ^0)*	Coefficient of consolidation (c_c)	Initial void ration (e_0)
Bridge no.-127	0.03 to 0.20	10 to 20	0.18 to 0.27	0.70 to 0.90
Bridge no.-131	0.05 to 0.15	7 to 15	0.19 to 0.21	0.77 to 0.86
Bridge no.-139	0.10 to 0.20	10 to 25	0.18 to 0.22	0.64 to 0.82
Bridge no.-161	0.04 to 0.25	8 to 25	0.19 to 0.23	0.77 to 0.82
Bridge no.-165	0 to 0.15	7 to 20	0.18 to 0.21	0.79 to 0.87

* Test conducted both by direct shear and triaxial.

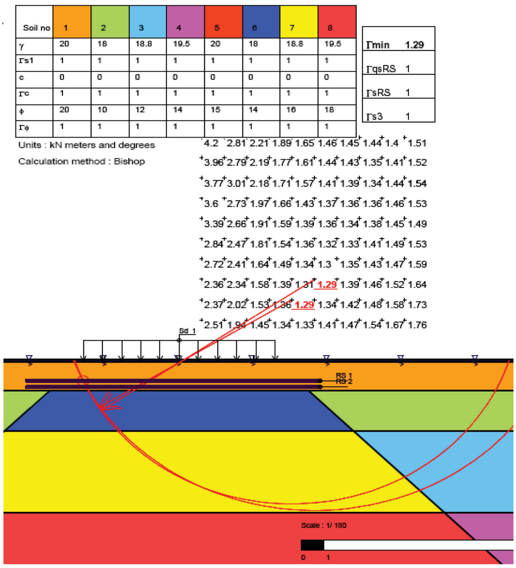

Figure 3. Slip circle analysis for Stage-II construction.

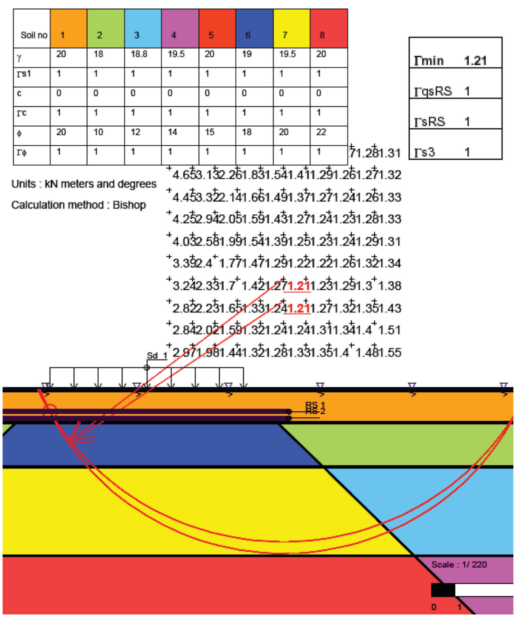

Figure 4. Slip circle analysis for Stage-III construction.

2. Stage II: In next stage another 2 m-compacted soil was filled up, increasing the wall height to 7 m. Thereafter, another 30–40 days pause period was provided for allowing for consolidation of the subsoil.
3. Stage III: Wall upto 10 m high was built after the pause period, including granular sub-base (GSB), wherever applicable. Thereafter, another pause period of 40 days was provided.
4. Then the pavement structure was built.

Table 2. Settlement recorded in trial embankment.

Site 1 (near bridge no. 127)		Site 2 (near bridge no. 139)	
Height of filling (in m)	Settlement (in mm)	Height of filling (in m)	Settlement (in mm)
1	13	2	16
5	28	5	32
9	155	8	160
Site 3 (near bridge no. 165)		**Site 4 (near bridge no. 161)**	
Height of filling (in m)	Settlement (in mm)	Height of filling (in m)	Settlement (in mm)
2	19	1	14
5	38	3	37
7	239	8	305

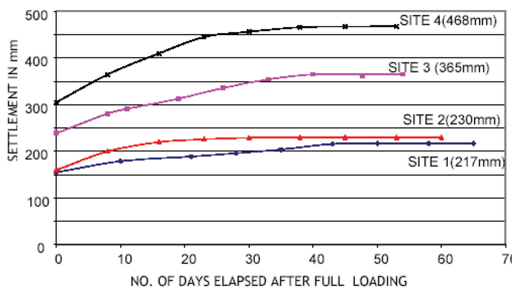

Figure 5. Recorded settlement at trial embankment constructed using sand bag.

4 FIELD TRIALS FOR SETTLEMENT

Test embankments were constructed at four places to determine the magnitude and rate of settlement in the embankment. The observed settlements are shown in Table 2 and in Figure 5. It is very clear from Figure 5 that the settlement is not increasing with time and the curve has become asymptotic after about 45 days after full loading. Some features observed during actual testing are:-

a) 65 to 70 % of total settlement took place during construction stage of embankment.
b) Post construction settlement became stable beyond 40–45 days.
c) No heaving was observed on either side of the test embankment.

Table 3. Actual panel settlement recorded till Jan, 2007.

Structure	Max. panel height of wall (in m)	Maximum recorded panel settlement (in mm)
Bridge no.-127	9.920	181
Bridge no.-131	10.670	555
Bridge no.-139	10.105	Not Available
Bridge no.-5B	9.170	10
Bridge no.-25	10.855	200
Bridge no.-161	11.605	400
Bridge no.-165	10.855	350
Bridge no.-178	8.980	75

d) Wet patches are observed near embankment at two sites where soil below is more slushy which may be due to dissipation/consolidation of base soil.

5 RECORDED PANEL SETTLEMENT

The panel settlement was recorded by measuring the panel top levels at each stage of construction. The total panel settlement recorded till date is as follows:

The settlement in test bank (Figure 5) is higher than the measured settlement in actual construction inspite of the fact that the earth is well compacted in actual banks whereas the test bank has been constructed by heaping sand bags without any compaction. This is due to the fact that the panel with steel strip reinforcement settles less than the fill and also use of basal geogrid reinforcement in the foundation has distributed the load over larger area and hence less settlement.

6 EARTHQUAKE EXPERIENCED DURING CONSTRUCTION

The Kashmir earthquake (also known as the South Asia earthquake or the Great Pakistan earthquake) of 2005, was a major earhquake whose epicenter was the Pakistan administered Kashmir. The earthquake occurred at 08:50:38 hr. Pakistan standard time (03:50:38 UTC) on 8*th* Oct. 2005. It registered 7.6 on the richer scale making it a major earthquake similar in intensity to the 1935 Quetta earthquake, the 2001 Gujarat earthquake, and the 1906 San Francisco earthquake. As of 8 November, the Pakistani government's official death toll was 73,276, while officials say nearly 1,400 people died in the Indian-administered Kashmir which is very close to construction site (Figure 6) and fourteen people in Afghanistan. The equivalent magnitude of tremor on Richter scale at site was 5.4.

All the reinforced earth structures on Baramula – Quazigund section has experienced the impact of this earthquake without any damage in the wall. The vertical alignment, individual panel joints, vertical and horizontal gap between the panels were found to be intact. No bulging, differential movement between the panels, sapling or any damage in the panels was observed after the earthquake (Photo 1). The constructed height of the wall was 6 m during this period. However, many residential structures in the vicinity were collapsed or damaged due to earthquake (see photos 2 & 3).

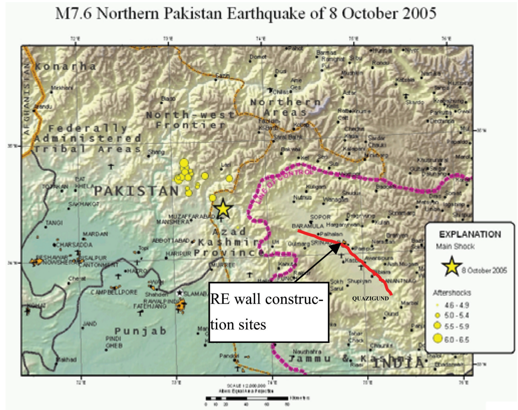

Figure 6. Map showing the epicenter of earthquake and construction site.

Photo 1. Reinforced earth wall for bridge no. 127.

7 SPECIAL DETAILING

The special detailing adopted for flooding incidences, high water table considerations and cold weather freeze and thaw cycles are discussed below.

7.1 *Typical detailing adopted for flooding*

One structures was adjacent to the existing canal running parallel to the approach retaining wall. The toe of the structure was 2 m away from the canal (see Figure

Photo 2. Damaged building at Uri about 30 km from the construction site.

Photo 3. Damaged building near the construction site.

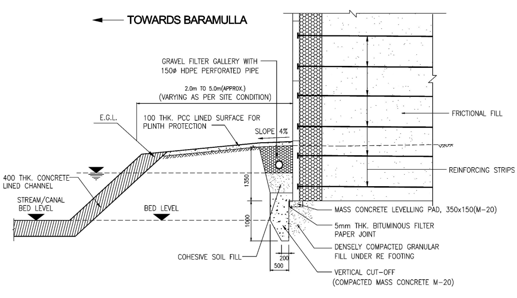

Figure 7. Typical toe detailing adopted for reinforced earth wall near canal.

7 and photo 4) and the top of the pad was above the base level of canal. To avoid seepage and any chance of toe erosion for long-term performance, a concrete cut-off wall was provided.

7.2 *Typical detailing adopted for snow fall area*

This part of India is subjected to extreme cold weather conditions and hence significant use of deicing salts

Photo 4. Reinforced soil wall running parallel to the canal.

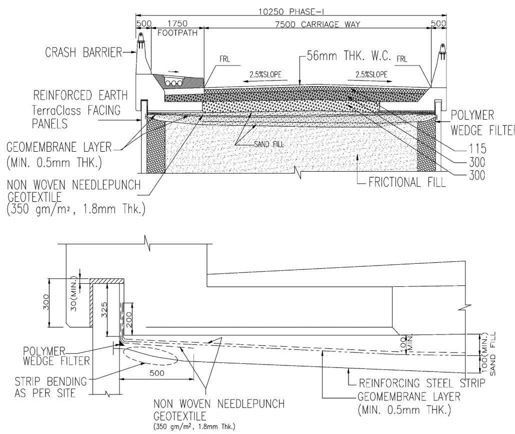

Figure 8. Geomembrane detailing at top to prevent salt percolation and corrosion steel strip.

is anticipated. To prevent the steel reinforcement from corrosion, an impervious barrier (one layer of geomembrane) beneath the pavement structure and just above the reinforced fill zone was provided. Sand drainage layer was adopted above the membrane layer to drain-out the seepage water from sub-surface layers (see Figure 8).

8 CONCLUSIONS

This paper presents a unique case of construction of reinforced soil structures on a foundation susceptible to high settlement and has experienced earthquake without causing any damage to the structures. Although the structure was not complete and not at its most critical state to make any conclusion on seismic behavior, but it was noted that there was no serviceability damage observed in any structures. Performance of reinforced soil retaining structures

Photo 5. Photograph showing installation of geomembrane.

Photo 6. Photograph of completed structure of Bridge No. 165.

constructed over soft foundation soil is also found to be satisfactory under seismic loading.

Reinforced soil wall being a flexible structure can be constructed over very soft soil where the expected settlement is very large and in high seismic prone area. However, special arrangement shall be provided to cater large differential settlement like provision of slip joints.

Reinforced soil structures can be built over loose soil having N-value (SPT) less than 10 without any major deep foundation treatment, subjected the soil is less plastic (Plasticity index less than 15) and clay content less than 10%. However, in such cases special attention shall be given against possibility of any slip circle failure from construction factors. High strength geogrid/geotextile shall be used in foundation as a stress transition layer to prevent any slip circle failure.

REFERENCES

AFNOR NF P 94–220, July 1992. " Soil Reinforcement, Backfilling structures with inextensible and flexible reinforcing strips or sheets." French Standard.

BS 8006: 1995. "Code of Practice for Strengthened/reinforced soils and other fills." British Standard.

Singh Kanwarjit, Bhanu Prakash & Chopra Rakesh. 2003. Construction of Railway abutment and bridges in the Kashmir valley for Qazigund – Srinagar – Baramulla project, IABSE symposium.