Geogrid-reinforced structures in China subjected to seismic events

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ABSTRACT: In recent years the use of HDPE geogrids for soil reinforcement has become widely accepted in China as high quality products made locally have become available. As a result, a number of significant geogrid-reinforced structures were built in the country in the period 2004-2008. Many of these are in mountainous regions in the South-West of China as part of the national infra-structure and hydro-power development programmes. Then, in 2008, between May and October, this region experienced a series of earthquakes ranging up to 8.0 on the Richter scale. This paper describes 5 geogrid-reinforced projects that were subject to seismic accelerations during these earthquakes: 2 projects with walls of heights 10.5 and 12 metres, and 3 projects with slopes of heights 26, 52 and 66 metres. All survived these seismic events undamaged.

1 INTRODUCTION

During the past 20 years, the good seismic performance of geosynthetic-reinforced walls and slopes (GRSs) has been well recognised and reported, e.g. as summarised in Koseki, 2006. Since then, the use of HDPE geogrids for soil reinforcement has become widely accepted in China as high quality products made locally have become available. As a result, a number of significant GRSs were built in the country in the period 2004-2008. Then, in 2008, a series of earthquakes occurred in the South-West of China and for the first time a number of those significant GRSs were affected by these events in that country. This paper describes briefly 5 of those structures.

2 STRUCTURES

2.1 *Qinghai-Tibet Railway, Lhasa*

Near to Lhasa City the Qinghai-Tibet railway passes over valuable farm land with a fragile ecological balance. For an elevated section of track a solution that minimised land take and impact on the environment was required. Over a total length of 4km. the design shown in Figures 1 and 2 was adopted with heights up to 10.5m.

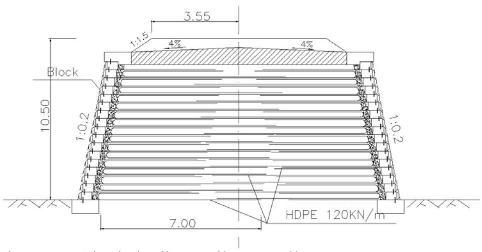

Figure 1: Qinghai-Tibet Railway walls

Figure 2: Qinghai Tibet Railway wall 10.5m high

The structural facing of these walls is full wrap-around of the geogrid reinforcement. Outside that there is an architectural face of concrete blocks 300mm high each. This is connected to the wrap-around structure by lengths of geogrid spanning through a drainage layer from alternate block joints into the soil structure between layers of structural geogrid. Reinforced fill was granular with $\phi_{cv}=30^0$. Design seismic acceleration at this location is 0.1g. Construction was from August 2003 to July 2004.

2.2 *Shuima Motorway, Yunnan Province*

This road is constructed through difficult mountain terrain. At the time of construction, 2005-2006, there was little experience in China of building geogrid-reinforced walls above 10m in height in such terrain. It was therefore decided that 2 experimental walls with total heights up to 19.7m would be built on this road at points where it was calculated that this technique could save approximately 50% of the cost of conventional solutions. Design seismic acceleration was 0.1g. The designs adopted are shown in Figures 3 and 4.

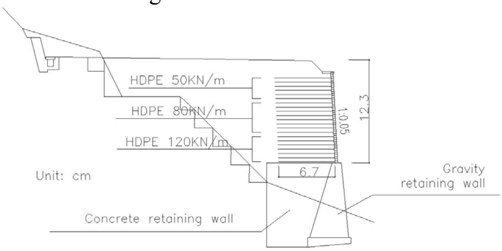

Figure 3: Shuima Motorway Wall 1.

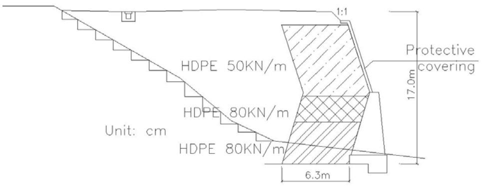

Figure 4: Shuima Motorway Wall 2

In both walls, the lower sections, where scour protection from the river was required, were constructed as conventional low-height gravity retaining walls with an embedment of 2m.

In wall 1, the space behind the gravity retaining wall was small and filled with mass concrete to provide the foundation for the geogrid-reinforced wall above. This upper wall had a segmental block face, with the reinforcement geogrids cast-in to the blocks to give full-strength face connections. This finished wall is shown in Figure 5.

In wall 2 a geogrid-reinforced thrust-relief structure was built behind the gravity retaining wall to provide the foundation for the wall above. This time the upper wall was built as a wrap-around structure with soil-filled sand bags lining the face. Also, each geogrid layer was bodkin-joined to the layer above. After settlement a 300mm-thick stone facing was mortared in place.

Figure 5: Segmental Block facing of Wall 1.

2.3 *Chuxiong 800kV Transformer Station, Yunnan Province*

This transformer station is a key project to provide additional secure electricity supplies from inland to the industrial growth area of Guangdong. To provide sufficient level ground for the transformer station, fill up to 29m in depth with a green face was required. Design seismic acceleration at this location is 0.15g.

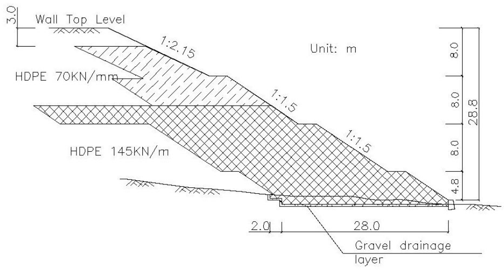

Figure 6: Chuxiong Transformer Station Slope

The design selected to balance cost and land-take is shown in Figure 6 with the finished structure shown in Figure 8.

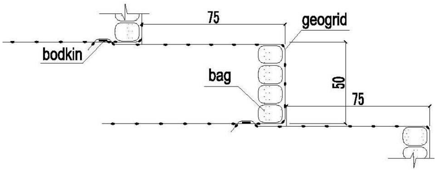

Figure 7: Chuxiong Slope face detail

Each lift of the geogrid-reinforced slopes was built as a small step with the geogrid wrapped up around soil-filled sand-bags and bodkin-jointed to the layer above to give continuity of face constraint as shown in Figures 7 & 9. Reinforced fill was primarily clay with $\phi_{cv}=25^0$.

Figure 8: Chuxiong 800kV Transformer Station

Figure 9: Chuxiong Transformer Station Slope: face detail

Construction of the slope started in September 2007 and was finished in the Spring of 2008.

2.4 *Jinping Mianshagou Slope.*

The Jinping Hydroelectric Power Station on the Yalong River in the Sichuan Province is a major new source of power for China. Building the required 10.5m-wide road though the mountainous terrain leading to it posed a range of interesting engineering challenges. These included a design seismic acceleration of 0.1g in design calculations. At Mianshagou the road was to cross a scree-filled gulley at an elevation of nearly 60m above the river. Also, this was one of the few places where it would be possible to generate sufficient space for a concrete preparation area for the onward construction. Because of the proximity to the river the only possible solutions were either high retaining walls or a steep, geogrid reinforced slope. As the foundation soil could not support the former without expensive treatment the slope was by far the cheaper option.
Also to be considered was the speed of construction required through the dry season of November to April. This, coupled with cost benefits led to the slope option being chosen, even though this would be the highest geogrid-reinforced slope in China when it was finished. Also it was believed that a flexible, geogrid-reinforced structure would be most secure long term in the local seismic conditions.

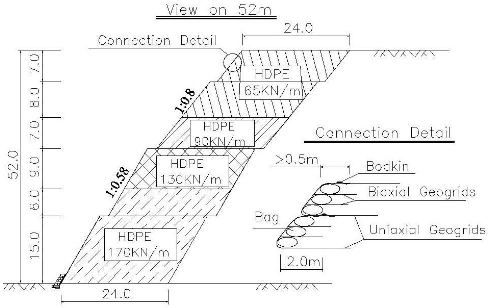

Figure 10: Jinping Mianshagou Slope

The design adopted consists of 4 tiers as shown in Figure 10 to give a total height of 52m. HDPE uniaxial geogrids provide the primary reinforcement with 2m pieces of biaxial polypropylene geogrid at intermediate positions to improve face stability. Reinforced fill was rock from tunnelling and cutting operations and primary reinforcement spacing was 600mm up to 21m, 1.0m above that.

Figure 11: The start of construction of Mianshagou slope.

Figure 12: Mianshagou slope after completion.

The start of construction of the slope in April 2005 is shown in Figure 11. The finished slope, completed in October 2005, is shown in Figure 12.

All fill required for this slope was generated in the construction of the road to Jinping power station.

2.5 *Jinping Yinbazigou Slope:*

Further along the road to the Jinping power station, significant quantities of surplus fill were to be generated. Much was from the number if tunnels on the road. Because this project was so far into the mountains it would have been extremely expensive and disruptive to carry this fill by truck back down the road.

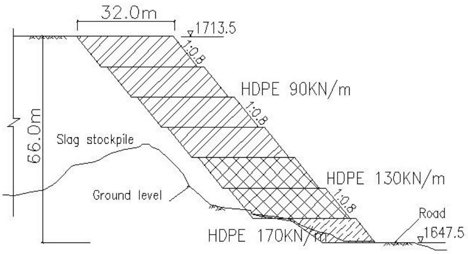

Figure 13: Jinping Yinbazigou Slope design.

However, there were no obvious land-fill sites available in this steep terrain. A steep-sided gulley available about 1km from the power station, but without sufficient volume capacity for normal filling However, following the success of the Mianshagou slope it was realised that another steep slope could generate the volume required at an economic cost. It was estimated that the height required to absorb the expected surplus fill would be up to 72.5m as foundation conditions would not allow the construction of a very steep face.

Figure 14: Jinping Yinbazigou Slope completed.

In the event, as the height reached 66m sufficient fill had been placed and so construction stopped at this point. The design built is shown in Figure 13. Vertical primary geogrid spacing is 800mm throughout. Construction started in January 2007 and was completed later that year as shown in Figure 14.

Once again, the valuable land space generated at the top of this slope is now in use for concrete preparation for the ongoing construction.

3 SEISMIC EVENTS.

During 2008 3 earthquakes in China each affected one or more of these structures as follows:

3.1 *12th May 2008: Wenchuan Earthquake*

Although distant from any one of the projects described here, this earthquake, at a level of 8.0 on the Richter scale, was sufficiently strong to cause accelerations of around 0.05g at both of the Jinping slopes.

3.2 *30th August 2008: Panzhihua Earthquake*

Although measuring less, at 6.1 on the Richter scale, this earthquake was sufficiently close to the Jinping slopes and the Shuima and Chuxiong projects to cause accelerations of around 0.1g at all 4 locations.

3.3 *6th October 2008: DangXiong Earthquake:*

This earthquake measured 6.6 on the Richter scale with an epicentre around 100km from the geogrid-reinforced walls on the Qinghai-Tibet Railway, where it caused accelerations of around 0.1g.

3.4 *Effects of Seismic events:*

From external observation of these structures and measurement of soil pressure, pore water pressure and displacement of the Chuxiong slope no deterioration of any of these structures has been found after these seismic events.

4 CONCLUSIONS

All the structures described have performed well in earthquake conditions close to their design limits. This confirms the resistance to seismic events that the use of HDPE geogrid reinforcement can give to soil structures.

REFERENCES

Koseki., J, et al, 2006: Seismic stability of reinforced soil walls. *Proceedings 8ICG, Geosynthetics*. Millpress, Rotterdam, pp 51-77