GEOTEXTILE REINFORCED SOIL WALL USING LOESS BACKFILL AT HETAOYU COAL MINE COMPLEX, GANSU PROVINCE, CHINA

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ABSTRACT

China Huaneng Group, a Fortune Global 500 company, is China's largest power producer. The company is developing a coal processing plant at Hetaoyu coal mine complex in Zhengning County, Qingyang City of Gansu Province in China. This coal mine complex is located within the Loess Plateau. A platform of approximately 1 km long and 140 m wide was created to site the processing plant. To optimise the creation of useable land a retaining wall was constructed beside Jinghe River which flows by the southern boundary of the development site. The reinforced soil retaining wall is about 1 km long and averages 25 m in height but is 35 m at its highest section. The soil used for backfilling was obtained by cutting into selected borrow areas within the project site. This retaining wall was constructed using high tenacity polyester geotextiles as reinforcing elements laid horizontally between layers of compacted backfill soil. Soil bags were generally used to help form the wall facing profile. The reinforcing geotextiles were wrapped around the soil bags and returned at the next level of reinforcement. A total quantity of 510,000 m^2 of high tenacity woven polyester geotextiles of ultimate tensile strength up to 300 kN/m was used for the construction of the reinforced soil wall at Hetaoyu. The reinforced soil retaining wall is divided into a few bermed segments. The reinforced soil wall was built in vertically faced segments until elevation 896 m. For the portion of wall constructed with vertical facing, a 0.5 m thick reinforced concrete facial structure was provided. The portion of wall above elevation 896 m till final platform was constructed with vertical to horizontal inclination ratio of 4:1. Over this portion of the wall, a 150 mm thick steel wire mesh reinforced shotcrete cover was provided for long term protection. A cast-in-place reinforced concrete edge capping unit of 0.3 m deep and 1m wide was provided for at the final platform elevation. Construction of the reinforced soil structure began in July 2009 and was completed within a time frame of slightly over 1 year.

Keywords: Geotextile, reinforced soil wall, soil bags, loess soil

INTRODUCTION

China Huaneng Group, a Fortune Global 500 company, is China's largest power producer. The company oversees the national government's interests in 10 subsidiaries, including a 51% stake in Huaneng Power International, a company simultaneously listed on the Stock Exchanges of Hong Kong, Shanghai and New York. Through subsidiaries it develops and operates more than 85 thermal and hydro power plants. The client is also actively investing in coal sources to secure supply at stable prices.

The company is developing a coal processing plant at Hetaoyu (which literally means Walnut Valley in Chinese) coal mine complex in Zhengning County, Qingyang City of Gansu Province in China. A platform of approximately 1 km long and 140 m wide is created to site the coal processing plant.

Figure 1 shows the artist impression of the coal processing plant at Hetaoyu. To optimise the creation of useable land a retaining wall was constructed beside Jinghe River which flows by the southern boundary of the development site. The reinforced soil retaining wall is about 1 km long and averages 30 m in height but is 35 m at its highest section.

Fig. 1 Artist impression of coal processing plant at Hetaoyu

The soil used for backfilling was obtained by cutting into the hill slope as part of the overall earthworks within the project site. This retaining wall was constructed using high tenacity polyester geotextiles as reinforcing elements laid horizontally between layers of compacted backfill soil.

THE LOESS PLATEAU OF CHINA

The Hetaoyu coal mine complex in Gansu Province is located within the Loess Plateau of China. The Loess Plateau, where the sedimentary loess deposits may be hundreds of meters thick in places, stretches over 7 provinces in China, including Gansu Province (see Fig. 2). The Loess Plateau covers an area of 380,000 square kilometers in area. It is located in the middle reaches of the Huanghe River (Yellow River) and bordered by Taihang Mountain in the East, extending westward to Wuqiaoling Mountain and Riyue Mountain, and by Qinling Mountain in the South, stretching northward to the Great Wall (Zhang et al, 2002). The Loess Plateau with an altitude of 1,200 m to 2,000 m reduces in height from North to South and from West to East.

Fig. 2 Map showing location of Hetaoyu coal mine and Loess Plateau in China

In simple terms loess is a light-coloured fine-grained accumulation of clay, silt and fine sand particles that have been deposited by wind. The loess deposits of the Loess Plateau in China have the characteristics of being dry, calcic and porous. Some 40 million people live in cave dwellings, a unique form of home constructed by digging into or built against the loess formation. These cave dwellings are visible at the project site, although currently abandoned (see Fig. 3). The climate here is semi-arid and the annual rainfall is in the region of 200 to 650 mm, mostly occurring during July to September.

However, rainfall can be of very high intensities over short duration; the maximum rainfall in 5 minutes can reach almost 60 mm. Although reasonably high in shear and compressive strengths the loess deposits are however susceptible to rapid erosion that can severely affect geotechnical stability. Occasionally landslides and dwelling collapses occur and are predominantly triggered by earthquakes or precipitation.

Fig. 3 Hill slope with cave dwellings at Hetaoyu project site

PROJECT SITE CONDITIONS

Site Accessibility

Zhengning County covers an area of 1329 km^2 with about a quarter million in population. The Hetaoyu coal mine complex is located about 35 km from the Zhengning County Administrative Center at the southeastern end of Gansu Province. The stretch of Jinghe River flowing in front of the project site practically forms part of the provincial boundary between Gansu Province and Shaanxi Province. The project site is about a three hours bus ride from the famed terracotta city of Xian in Shaanxi Province. The Xian-Lanzhou Expressway is about 93 km to the South. Accessibility is easy; the National Highway No. 212 passes through the central part of Hetaoyu coal mine complex and the project site is well connected by roads to villages and towns in the area.

Landforms

The landform of this area consists of plateaus, mesas, buttes and river terraces with altitudes ranging from about 900 m to 1300 m above sea level. The project site is located west of Ziwu Ridge, which is basically the North-South watershed ridge in the area.

The Shulohe River drainage basin and the Jinghe River drainage basin are to the east and west of the watershed ridge respectively. The Jinghe River drainage basin has Malianhe River, Wuritiangou Channel and Silanghe River as the key drainage sources discharging whole year round into Jinghe River. Jinghe River is the second largest tributary of Weihe River which itself is a tributary of Huanghe River. Jinghe River, flowing through in front of the project site, is generally a shallow meandering river within the river floodplain for most months of the year but water levels can rise quickly during flash floods of the rainy season.

Climate

According to records of Zhengning County Bureau of Meteorology from 1985 to 2004, winters and springs are generally cold and dry with prevailing winds coming from the Northwest while summers and autumns are generally warm and moist with mostly southerly winds. The average relative humidity is in the range of 53% to 60% in winter and spring. The average relative humidity is in the range of 56% to 75% in summer and autumn. The mean annual temperature is about 10^{o}C. The average summer temperature is about 25^{o}C while the winter lows can drop to below -10^{o}C. The ground may freeze in winter down to a maximum depth of about 0.9 m. The annual rainfall ranges from 410 mm to 868 mm with an annual mean of about 600 mm. Most of the rainfall occurs from July to September. The annual evaporation ranges from 1242 mm to 1776 mm with an annual mean of about 1500 mm, or 2.5 times the annual rainfall.

THE WALL SYSTEM

Earth retaining structures may be classified based on two principal categories of externally or internally stabilized systems (O'Rouke & Jones 1990). Gravity walls like masonry wall, concrete wall, cantilever wall, counterfort wall, gabion structure, crib wall, bin structure and cellular cofferdam are classified as externally stabilized systems. Internal stabilized systems are identified by reinforced soils with predominantly horizontally layered soil reinforcing elements. The wall system adopted for the Hetaoyu Project is an internal stabilized system known as geotextile reinforced soil wall. This wall system is well suited for this project because it allowed the use of native soil as backfill for the reinforced soil wall, resulting in a very economical solution.

Foundation Condition

The rock formation below the loess deposits consists of interbedded sandstones and siltstones. The reinforced soil wall is to be founded on the moderately weathered stratum of interbedded sandstones and siltstones, which is determined to have a safe bearing capacity of 700 kN/m^2. The top of this stratum is however not level. To locate the foundation level of the reinforced soil wall, excavation was carried out to expose the competent interbedded sandstones and siltstones. Lean concrete was then applied to raise and level the ground to the foundation level of the reinforced soil wall.

Backfill Choice

Except for the inclusion of components like reinforcement layers, facing and subsurface drainage, the construction of the reinforced soil wall is similar to that of an earthworks operation involving cut and fill. The backfill soil for the reinforced soil wall and retained fill behind is generally clayey silt, obtained at site from cutting into the loess hillside. Table 1 shows the physical properties of three different types of loess in Gansu Province. Wucheng is located within Qingyang City, Gansu Province and is relatively close proximity with the Hetaoyu Project site. The densities of the compacted backfill soils at site ranged from 15.4 kN/m^3 to 18.0 kN/m^3. This is in line with the properties of the Wucheng loess.

Figure 4 shows the relationship between residual gravimetric water content and the shear strength properties of remoulded loess referred to in Table 1. Residual gravimetric water content is the moisture content of the soil sample at the end of the shearing test. Generally, the friction angles of the remoulded loess tested are quite high.

The peak friction angle for the three loess samples range from 38^o at Malan to 40^o at Wucheng at corresponding residual gravimetric water contents from 5% to 7%. The residual friction angle for all three loess samples averages at 35^o attained when the residual gravimetric water content exceeds the threshold value of 18%.

Table 1 Properties of different types of Gansu loess (Hassel and van Asch, 2003 and Derbyshire et al, 2000)

Property	Unit	Wucheng/Lishi loess	Malan loess
Particle size, d_{50} (μm)	μm	10 - 18	30 - 40
Clay content (particles less than 2μm)	%	18 - 25	8 - 14
Silt content (particles from 2 μm to 64μm)	%	70 - 77	63 - 69
Sand (particles greater than 64μm)	%	5	23
Cohesion (undisturbed sample)	kN/m^2	75 - 100	50 - 75
Bulk density	kg/m^3	1,520 – 1,810	1,380 – 1,440

The lowest measured friction angle is 33°. The cohesion for the three loess samples show a linear increase from 0 kPa at 0% residual soil water content to about 20 kPa at the threshold residual gravimetric water content value of 18%. Beyond the threshold value of 18%, the average cohesion of the loess samples is about 5 kPa.

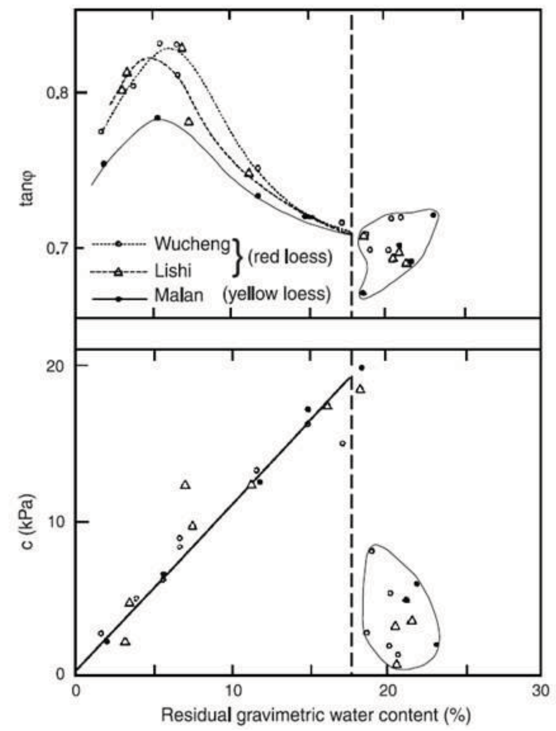

Fig. 4 Relationship between residual gravimetric soil water content and c and ϕ for remoulded loess (Hassel and van Asch, 2003 and Derbyshire et al, 2000)

Soil Reinforcement Type

High tenacity woven polyester geotextiles were chosen as soil reinforcement material based on technical and economic reasons. They have high resistance to creep, can be used for design lives of up to 120 years and have good interaction properties with backfill soils that have high content in fines.

Wall Facing

The wall was constructed as a reinforced soil wall with soil bags wrapped around with the reinforcement at the front of the wall. The reinforced soil wall was built in vertically faced segments until elevation 896 m. For the vertical portions of the wall, a 0.5 m thick superficial reinforced concrete wall was provided for permanent protection. A reinforced concrete base was constructed at foundation level which was sequentially extended as the reinforced soil wall was built.

The facing wall that was cast in place over the geotextile wraparound. The portion of wall above elevation 896 m till final platform ranging from elevations 914 m to 921 m was constructed with vertical to horizontal inclination ratio of 4:1. For the sloping portions of the wall, a 150 mm thick steel wire mesh reinforced shotcrete cover was provided for long term protection. The steel wire mesh reinforced shotcrete cover was structurally attached to the reinforced soil wall with the aid of steel dowel pins.

THE WALL DESIGN

Shear Strength of Soil

For the initial reinforcement layout, the design values used for the backfill soil are as follows; friction angle, ϕ, of 28°; cohesion, c, of 25 kN/m^2 and compacted density, γ, of 18 kN/m^3. This combination was selected on the basis of local practice and to be representative of both insitu and compacted backfill soils. The design of the reinforced soil walls for the Hetaoyu Project was also subject to a sensitivity analysis under different c, ϕ combinations.

Seismic Condition

For the initial reinforcement layout, a design value of horizontal seismic acceleration of 0.1g was adopted, also based on local practice. The design of the reinforced soil walls for the Hetaoyu Project was also subject to a sensitivity analysis under horizontal seismic acceleration of up to 0.2g.

Surcharge Loading

The foundations for the structures of the coal processing plant were designed with piled foundations. As such there will not be any load impact on the reinforced soil retaining wall from the structures of the coal processing plant. A uniformly distributed surcharge load of 20 kN/m^2 was used for design of the retaining wall to cater for machinery and equipment during as well as post construction.

Subsoil Drainage

The site is located in an arid climatic area. The design of the reinforced soil walls for the Hetaoyu Project assumed the groundwater table exists below the reinforced soil wall structure. Subsoil chimney drains were provided for between the reinforced backfill and the retained soil to prevent infiltration of rainwater to the wall structure. The subsoil chimney drains consisted of aggregates, sandwiched between layers of nonwoven geotextiles.

Reinforcement Long Term Allowable Strength

Table 2 shows the derived allowable long term design strength of the high tenacity woven polyester geotextiles used for the design of the reinforced soil walls for the Hetaoyu Project. The FHWA and GRI procedure was used to derive the allowable long term design strength of the geotextiles. The design life was 120 years at average ambient soil temperatures of 20^{O}C.

Soil/Geotextile Interaction Properties

The value of 0.8 was used in design for the coefficient of woven polyester geotextile pullout from soil, α_{po}, and 0.7 for the coefficient of woven polyester geotextile direct shear against soil, α_{ds}. These values were in line with the test results reported by Koutsourais et al. (1998).

Stability Analyses

The design of the geotextile reinforced soil wall involves ensuring adequate safety against various modes of failure summarized as follows (see also Fig. 5):

- External stability
  - Sliding failure
  - Overturning failure
  - Bearing capacity failure
  - Global slip failure
- Internal stability
  - Internal slip failure combined with reinforcement rupture
  - Internal slip failure combined with reinforcement pullout
- Composite stability
  - Composite slip failure with partial reinforcement rupture

For external stability, sliding failure, overturning failure and bearing capacity failure were calculated using manual calculations. The rest of the failure modes were covered when GeoSlope software was used to analyze the various slip failures.

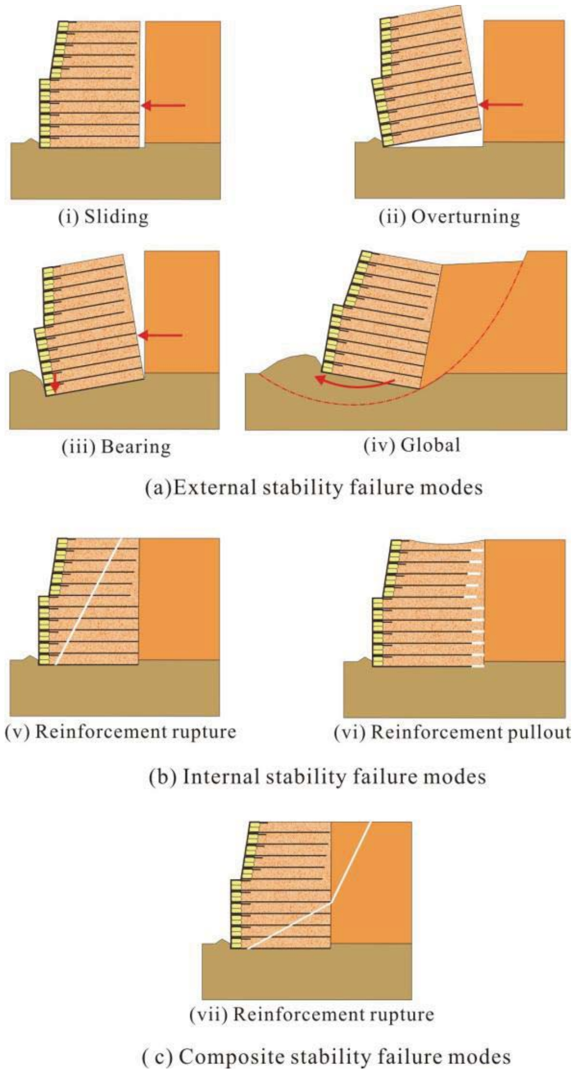

Fig. 5 Possible modes of failure for reinforced soil retaining wall

Table 3 shows the minimum factors of safety against various possible failure modes adopted in design of reinforced soil wall for Hetaoyu Project.

Table 2 Allowable long term design strength of reinforcement geotextiles used for the Hetaoyu Project

Property of geotextile	Strength of geotextile	Partial factor	Geotextile Type 1	Geotextile Type 2	Geotextile Type 3
Ultimate tensile strength	T_u (kN/m)		100	200	300
Long term creep		f_{mc}	1.45	1.45	1.45
Construction damage		f_{md}	1.1	1.1	1.1
Environment degradation		f_{me}	1.1	1.1	1.1
Allowable long term design strength, $T_a = T_u / (f_{mc} \text{ x } f_{md} \text{ x } f_{me})$	T_a (kN/m)		57	114	171

Table 3 Minimum factors of safety against various possible failure modes adopted in design of reinforced soil wall for Hetaoyu Project

Failure Mode	Minimum factor of safety
External stability	
Sliding failure	1.5
Overturning failure	2.0
Bearing capacity failure	2.0
Global slip failure	1.5
Internal stability	
Internal slip failure	1.5
Reinforcement pullout	1.5
Composite stability	
Composite slip failure	1.5

Sensitivity Analysis

A sensitivity analysis was carried out to test the reinforcement layout chosen for the retaining wall design under different c, ϕ combinations and seismic conditions. Figure 6 plots the factor of safety of the highest section of the reinforced soil wall for the Hetaoyu Project under different c, ϕ combinations and seismic conditions. The sensitivity analysis is useful in exploring the "what if" scenario concerning variations in shear strength parameters of soil and seismic condition.

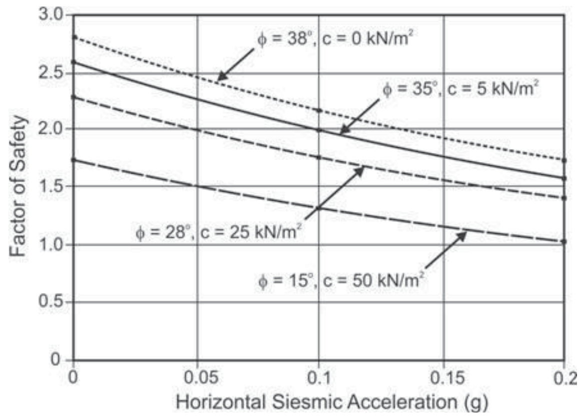

Fig. 6 Stability sensitivity analysis for the highest wall section by varying the soil shear and seismic conditions

Wall and Reinforcement Detailing

Figure 7 shows the layout plan of Hetaoyu coal processing plant and location of the reinforced soil wall. Figure 8 shows the front elevation of the reinforced soil wall with the type of facing indicated. Figure 9 shows the cross-section highest section of the reinforced soil wall.

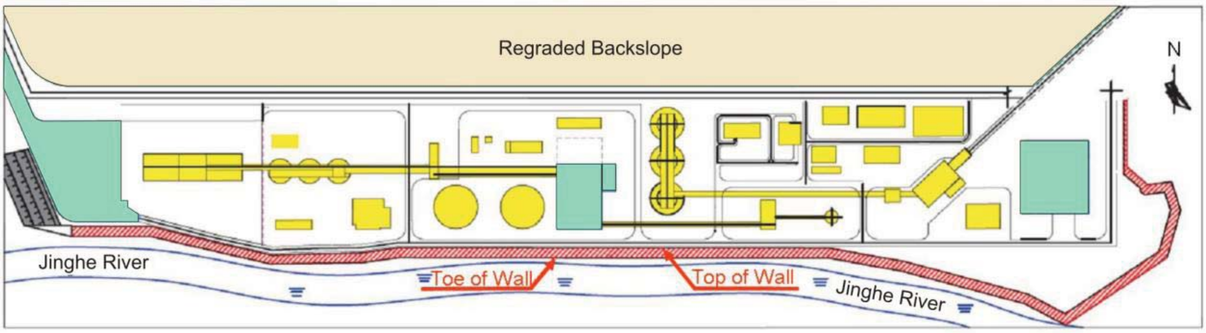

Fig. 7 Layout plan of Hetaoyu coal processing plant and location of reinforced soil wall

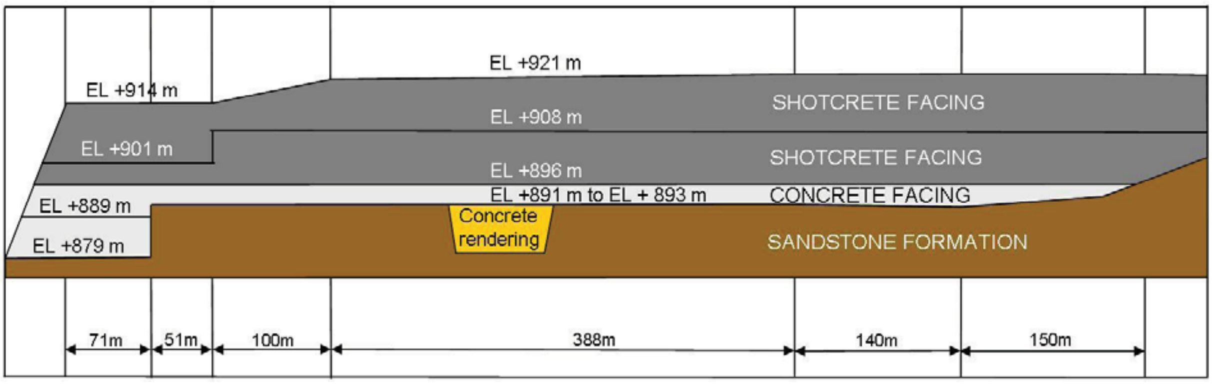

Fig. 8 Front elevation of the reinforced soil wall at Hetaoyu Project

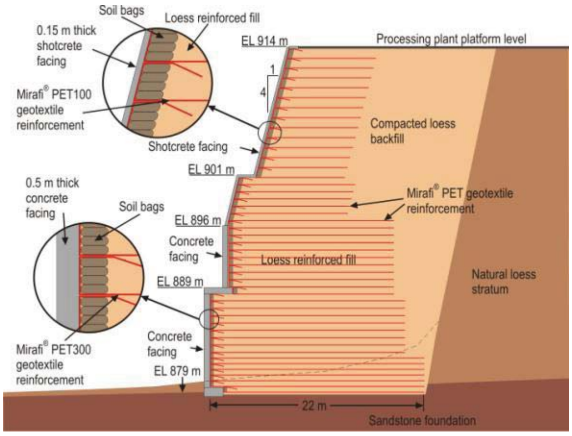

Fig. 9 Cross-section of reinforced soil wall at the highest section of the wall

CONSTRUCTION

Construction works began with the excavation to foundation level, followed by use of lean concrete to level the platform. Laying of reinforcement geotextile started over the prepared foundation (see Fig. 10). Backfilling was carried out in lifts of 200 mm. The backfill soil was compacted to a minimum of 95% of the maximum dry density at plus or minus 2% of the optimum moisture content, according to Standard Proctor.

Fig. 10 Laying of initial reinforcement layer over prepared surface

At the designed level the designated reinforcement geotextile was laid over the compacted backfill. The reinforcement geotextile was laid with the machine direction perpendicular to the wall face alignment, from the front of the wall face extending to the back of the reinforced soil zone. At the rear end of the geotextile reinforced fill zone, a subsoil chimney drain was constructed. This subsoil drain consisted of a 500 mm thick layer of single sized aggregate sandwiched between two layers of nonwoven filter geotextile.

Figure 11 shows the general view of the works involved with the construction of the geotextile reinforced soil retaining wall, which included the subsoil chimney drain. At the wall face the reinforcement geotextile was wrapped over stacks of soil bags included to help shape the angle of the facing (see Fig. 12). This method of construction with the reinforcement geotextile wrapping around soil bags also served the purpose of preventing erosion of the highly erodible soil at the facing area when rain falls during the construction period, prior to construction of the permanent facing cover.

Fig. 11 General view of construction

Fig. 12 View showing wraparound of reinforcement geotextile over soil bags

For the vertical portions of the wall, a 0.5 m thick superficial reinforced concrete wall was provided for permanent protection. For the sloping portions of the wall, a 150 mm thick steel wire mesh reinforced shotcrete cover was provided for long term protection. The steel wire mesh reinforced shotcrete cover was structurally attached to the reinforced soil wall with the aid of steel dowel pins.

Figure 13 shows the oblique frontal view of the substantially completed geotextile reinforced soil wall at Hetaoyu. A total quantity of 60,000 m^2 of Type 1 reinforcement geotextile, 200,000 m^2 of Type 2 reinforcement geotextile and 250,000 m^2 Type 3 reinforcement geotextile was used for the construction of the reinforced soil wall at the Hetaoyu Project site. Construction of the reinforced soil structure began in July 2009 and was completed by March 2011. There were no signs of distress during or after construction of the wall.

Fig. 13 Oblique frontal view of the substantially completed geotextile reinforced soil wall at Hetaoyu

CONCLUSIONS

A geotextile reinforced soil retaining wall of about 1 km long with an average height of 30 m and a maximum height of 35 m, using compacted loess soil as backfill was successfully completed within a construction time frame of about one and a half years. This project has demonstrated that reinforced soil wall can be constructed satisfactorily using fine grained soils as backfill, given the right soil conditions with appropriate design approaches and construction care.

REFERENCES

Derbyshire, E., Meng, X.M. and Dijkstra, T.A. (2000). Landslides in the Thick Loess Terrain of North-West China, Wiley, Chichester, 288 pp.

Hessel, R. and van Asch, T. (2003). Modelling gulley erosion for a small catchment on the Chinese Loess Plateau, Online Journal, Catena, 54(1-2):131-146.

Koutsourais, M., Sandri, D. and Swan, R. (1998). soil interaction characteristics of geotextiles and geogrids, Proc. of the 6th Intl. Conf. on Geosynthetics, Atlanta, U.S.A. 2:739-744.

O'Rourke, T.D. and Jones, C.J.F.P. (1990). An overview of earth retention systems: 1970-1990, Proc. of the ASCE Speciality Conf. on Earth Retaining Structures, Cornell: 22-51.

Zhang, K.L., Li, S.C. and Peng, W.Y. (2002). Erodibility of agricultural soils in the loess plateau of China, Proc. 12th Intl Soil Conservation Organisation (ISCO) Conf., Beijing, China, 551-558.