Application of reinforced soil structure in Dulong mining expansion project

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ABSTRACT: With the development of geosynthetics application technology, more and more reinforced structures are used in civil engineering area. Especially in the mountainous area, where the topography is usually very complicated, it will be much better to build a reinforced structure rather than traditional structure. TensarTech™ reinforced structure include two different forms as reinforced slope and reinforced wall, with different feature and different scope of application. Based on Dulong mining expansion project, this paper introduced how to use the special feature of reinforced slope and reinforced wall to solve the engineering problem, with various kinds of difficulty, such as high structure, limited area, complicated topography, poor geological condition, water, etc. Except the technology problem, TensarTech™ reinforced structure also gains good economic and environmental benefits in this project. This paper is used to promote the application of reinforced structure and help the engineering technicists to solve similar problems much better.

Keywords: reinforced structure, retaining wall, reinforced slope, geogrid, tailings pond

1 INTRODUCTION

There is a long history of reinforced soil structures used in civil engineering projects. Natural materials such as branches, straw, etc. were used as soil reinforcing materials since ancient times. With the invention of polymeric geogrids in 1979, more and more reinforced soil structures were built providing great economic benefits while solving various kinds of problems in civil engineering.

In China, with its ever-growing economic development, a large number of construction projects were built and are carrying on being built in recent years. China is a mountainous country, especially the southwest part of it, which leads to a number of construction challenges. One such challenge is the construction of high earth retaining structures required to bridge grade separation of heights in excess of 20m.

Taking Dulong mining expansion project as an example, this paper describes the application of reinforced soil structures under complicated conditions including excessive heights, limited construction space, complicated topography, poor geological condition, water and so on.

2 DESIGN

2.1 *Background*

Dulong mining expansion project is located in Dulong town, southeast of Yunnan province, southwest of China. It is a single series metal dressing mill with the largest capacity in the world and the key construction project in Yunnan province.

Dulong project was constructed on mountainous area abutting upstream the Xintian mine tailings pond. The original terrain of this area consists of ridges and gullies (Figure 1), with typical grade separation levels ranging from 1348m AOD to 1524m AOD i.e. up to 176m height of natural mountainous terrain sloping at an existing face angle of up to 40° .

Figure 1. Typical existing topography

At the specific location where the main mine plant building was to be constructed, the natural mountain slope height is about 90m. The existing mountain slope side had to be cut and filled to create a platform upon which, the new mine building could be constructed at the required elevation level. The new platform was created and supported by a >30m high reinforced soil structure, which is the subject of this paper. On elevation, the new reinforced soil structure is about 300 meters in length and the maximum height is in excess of 30 meters on the northwest side of the elevation.

Traditional retaining structures such as concrete walls were difficult to be constructed because of the poor geological condition, complex geometry, excessive grade separation height and other adverse conditions in this project. Reinforced soil structure was therefore the best choice. Nearly 99% in volume of a reinforced soil structure is soil, which makes such structure flexible and therefore more suitable in complex mountainous terrain conditions.

2.2 *Design of reinforced structure*

Client of Dulong project required to construct a retaining structure with green, vegetated, naturally looking appearance, which would blend with the existing green, vegetated, natural environment. Technically, as the retaining structure abuts upstream of Xintian mine tailings pond, the lower part of the structure will be submerged under water during its service life.

The solution chosen for this project was a composite structure comprising a 3-tier, near vertical reinforced soil wall with up to 12m cumulative high at the lower part of the structure and designed for full submerged conditions (Figure 2). A 2-tier reinforced soil slope (H:V=0.75:1, i.e. about 53°) was utilized at the middle and upper part of the structure with cumulative height in the order of 20m. Overall the composite structure reached a cumulative height of 32m. In order to reduce the excavation while keeping the structure stable, a rubble concrete block was used to replace part of the poor foundation soil.

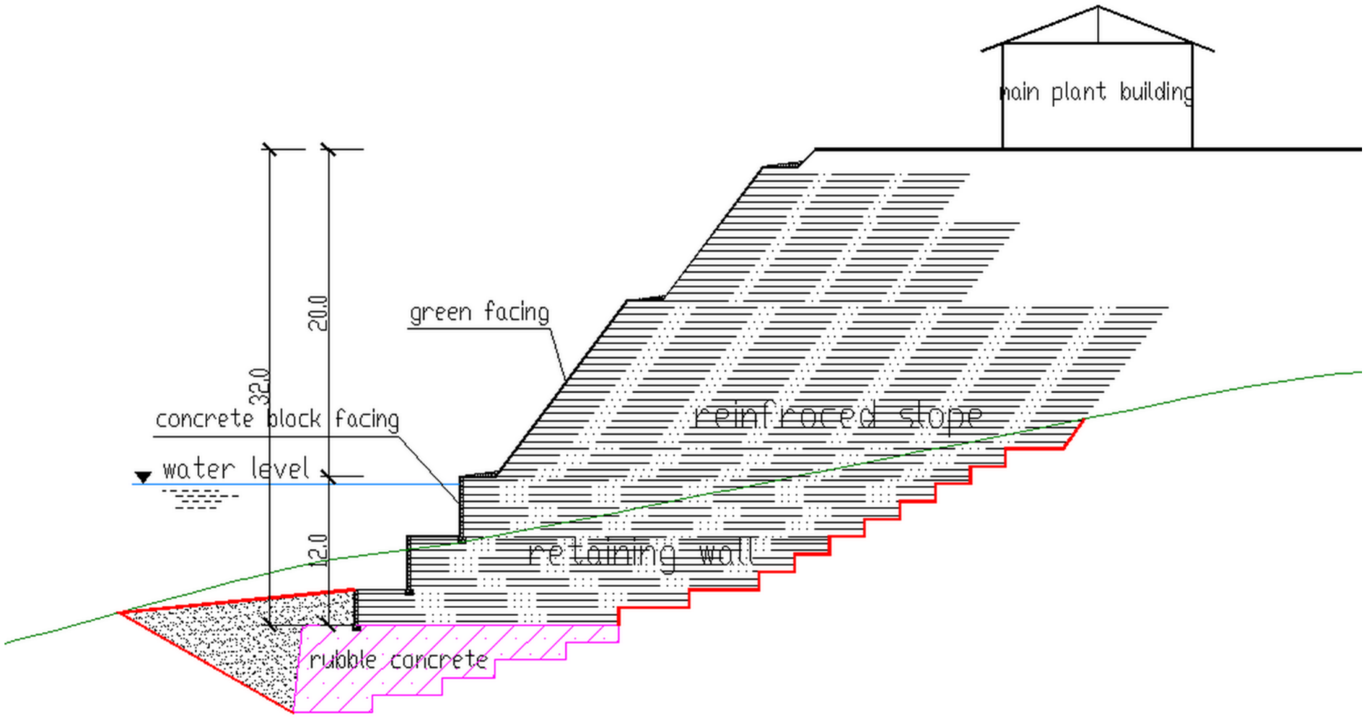

Figure 2. Typical section of the reinforced structure

2.3 *Foundation Soils*

The existing foundation soils at the base of the mountainous terrain where the reinforced soil structure was to be founded were weak and variable comprised a multi-layer of variable loose made ground and soft silty clays overlaying completely weathered schists. Competent weathered marble was encountered below the schist, which was deemed capable of supporting the proposed reinforced soil structures. All soil layers above the marble formation were therefore excavated and replaced with rubble concrete in order to create a stable foundation for the proposed reinforced soil structure.

2.4 *Reinforced structure components*

Reinforced structure in Dulong project consists of five major components: fill materials, facing, reinforced material, connector and drainage system.

2.4.1 *Fill materials*

Two types of fill material were used in the project. For the reinforced soil retaining wall, the reinforced fill is well graded granular fill with good permeability, which can perform well when submerged under water. For the reinforced soil slope, the fill material used is gravel soil that is a mixture of silty clay and weathered rock. All reinforced fill materials are site won and came from excavation area at the location of the project, so that a large quantity of outsourcing, spoil and relevant carbon emission can be avoided. This helped the project to gain good economic and environmental benefits.

Table 1 shows the parameters of the reinforced fill materials.

Table 1. Parameters of reinforced fill.

Soil Type	c'(kPa)	ϕ_{pk}'/ϕ_{cv}'(°)	γ'(kN/m^3)
Slope fill	0	27/25	19.0
Wall fill	0	33/30	20.0

2.4.2 *Facing*

Due to the requirements of the project, two types of facing are used for the reinforced structure. The facing of the reinforced soil retaining wall was formed by modular blocks which were prefabricated by concrete on site and had good durability under water. The block dimensions were 200Wx200Dx400L. Vegetated facing, which was formed by uniaxial geogrid wrapped around ecological bags, was chosen for the reinforced soil slope thereby providing the required green finish and blending well with the natural environment.

2.4.3 *Reinforcing material*

The reinforcing material used in the structure is uniaxially orientated high-density polyethylene (HDPE) geogrid. For the design of reinforced structure, it is necessary to use the long-term properties of the geogrid including the effect of creep, installation damage and environmental degradation.

The design strength (T_{al}) of the geogrid is calculated from Equation (1) (see [1]):

$$T_{al} = \frac{T_{ULT}}{RF_{CR} \bullet RF_{D} \bullet RF_{ID}} \tag{1}$$

Where T_{al} = long-term tensile strength on a load per unit width of geogrid, T_{ULT} = ultimate tensile strength of geogrid, RF_{CR} = creep reduction factor, RF_D = durability reduction factor depending on the susceptibility of the geogrid to attack by microorganisms, chemicals, thermal oxidation, hydrolysis and stress cracking, RF_{ID} = installation damage reduction factor depending on backfill gradation and product mass per unit weight.

2.4.4 *Connector*

Connection of the facing with the geogrid is an important part of the of the structure performance, therefore, an effective connection between facing and geogrid is necessary. A mechanical polymeric connector which is made of HDPE is used to provide a high level of load transfer between the concrete block and uniaxial geogrid to form the facing of the reinforced soil retaining wall (Figure 3). Another kind of polymeric connector, known as 'bodkin', that is also made of HDPE can transfer the load from geogrid to geogrid effectively (Figure 4), which is used to form the facing of the reinforced soil slope.

Figure 3. Mechanical polymeric connector

Figure 4. Grid-to-grid 'bodkin' connector

2.4.5 *Drainage system*

The location of the project is subjected to subtropical plateau monsoon climate, where the average rainfall per year exceeds 2900mm, while more than 80% of rainfall concentrated in June to October. Additionally, a number of existing gullies needed to be cut off or buried by the new retaining structure, which had great influence to underground water and ground water. A robust drainage system was therefore designed and put in place to compensate and replace the nature drainage system disturbance.

At the bottom of the retaining structure, a concrete drainage pipe with 1.0 meter in diameter was set along the bottom of the biggest gully and a series of gravel drainage layer was set at the back of the reinforced structure and the bottom of each step to discharge the underground water off appropriately to the drainage system outside the reinforced structure.

3 DESIGN OF THE REINFORCED SOIL STRUCTURE

3.1 *Design method*

The design of the reinforced soil structure comprised design of the individual tiers for internal, compound and external stability as well as design of internal, compound and external stability of the overall structure.

Bishop's Simplified Method (see [2]) was used to check the internal, compound and external stability of the overall 5-tier cumulative slope and wall structure and find the minimum length of the reinforcing materials.

A 2-part wedge method (see [3]) was used to check the internal stability of the retaining wall.

3.2 *External stability*

External stability checking of the reinforced structure in Dulong project comprised two working conditions: normal (dry) loading condition and loading under submerged water level for when the tailings pond water level fluctuates up to the retaining wall heights.

For the external stability checking of water condition, the stability of the walls was checked for both the minimum and maximum tailing pond water level fluctuations. As the reinforced fill material for the walls was purposely chosen to be free draining, no rapid draw down water levels were considered in design.

A 20kPa temporary surcharge was modelled at the crest of the reinforced structure in order to model the traffic of the road.

Peak values of soil shear strength were utilized in Bishop's Simplified method and the geometry of the geogrid reinforced zone was confirmed according to the check of external and compound stability.

3.3 *Internal stability*

Two fundamental checks were carried out for internal stability: failure against rupture and pull-out. According to the checking of internal stability, strength and spacing of geogrid could be confirmed.

3.3.1 *Internal stability of individual retaining wall*

According to the 2-part wedge design method used, a series of wedges at each level of geogrid per 3° were checked for the internal stability of retaining wall. Besides that, sliding on geogrid and between two layers of geogrids were also checked to make sure the length and spacing of geogrids is appropriate.

The reinforced slope was modelled as permanent surcharge above the retaining wall and constant volume (cv) soil shear strength was utilized while checking the internal stability of the individual retaining walls.

3.3.2 *Internal stability of individual reinforced slope*

For the reinforced slope, the geogrid is assumed to be placed in horizontal layers and its effect is to apply a series of restoring forces to the slip surface being considered in the analysis in Bishop's Simplified method.

4 CONSTRUCTION OF THE REINFORCED SOIL STRUCTURE

The construction of the reinforced soil structure comprised three major stages as following:

(1) Placing and compacting of fill materials. The reinforced fill material was transferred from the excavation area. Before placing and compacting, the excavated boulders had to be broken into smaller pieces to meet the requirement of gradation and particle size. Fill was then compacted in layers with 200mm in thickness and to a minimum 94% MDD (maximum dry density) compaction. Drainage layers were also installed at this stage as per the project requirements (Figure 5).

(2) Installation of facing. For the retaining wall, the facing was formed by modular blocks that were laid dry without using mortar. The modular blocks were made of concrete withwide/deep/long=200/200/400mm before the construction of reinforced structure. For the reinforced

slope, the facing was formed by ecological bags filled with planting soil which was suitable for grass growing. The geogrid was wrapped around the bags to the required face angle of 53° (H:V=0.75:1).

(3) Placing of geogrid. Appropriate type of geogrid according to detailed design and drawings was laid in-between the compacted fill layers at a vertical spacing typically varying from 200mm to 400mm.

Figure 5. Reinforced soil structure under construction

The reinforced soil structure in Dulong project was constructed in about nine months. Near the end of the construction, the rainy season arrived and lasted longer than three months. According to visual inspections and monitoring carried out during the rainy season, the drainage system of the reinforced structure performed well, as expected.

Frequent site visits and visual inspections of the project were carried out for more than three years after construction completion. The reinforced soil structure developed the vegetated green face as expected and performed very well without any signs of differential settlement or any other apparent deformations (Figure 6).

Figure 6. Completion of the reinforced structure

5 CONCLUSIONS

In Dulong mining expansion project the utilization of a Tensar geogrid reinforced soil retaining structure fully embodied the advantages in solving retaining problems in mountainous area with complex geometry and challenging conditions and offered great economic and environmental benefits.

Due to their flexible nature, reinforced soil structures can fit to a wide range of slope angles and working conditions. A variety of facing types can be chosen for different site conditions to satisfy the requirements. Furthermore, it is very convenient to combine two or more different types of facing types together to meet special conditions such as Dulong project.

One key point is the stability of the reinforced structure. It is important to adopt appropriate method to check the stability of the complicate reinforced structure. Besides that, designers shouldn't neglect the local climate, such as seasonal heavy rainfall, which may severely damage the reinforced structure, if not adequately addressed. Appropriate drainage system is as important as the rest of the structural and geotechnical components of the calculation of the stability.

In recent years, reinforced soil structures have been widely used in various types of civil engineering projects including metallurgy, electric power and mining industry in Yunnan province, providing a lot of extraordinary retaining structures high filling problems under complicated conditions while securing great economy and long term sustainable solutions.

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