Design and construction of reinforced soil slope in the heavy rainfall tropical climate in Kapit, Sarawak, Malaysia

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ABSTRACT: This paper describes the successful use of soft engineering system using the geosynthetics for the design and construction of reinforced soil slope with maximum height of 12m and with slope inclination of 2(v):1 (h), typically in heavy rainfall zone in Sarawak, Malaysia. The reinforced soil slope system was adopted for this project site as part of the existing road widening. Residual earth fill material was chosen as the reinforced soil material due to the availability of the material on site and hence offered the most economical solution for the project site. However, under the continual influence of the wet tropical climate in Malaysia and acknowledging the fact that the earth fill, being the cohesive material has low permeability, the reinforcing geosynthetic material that was chosen for the reinforced soil slope must have good in-plane drainage property. The hydraulic properties of the reinforcing geosynthetic materials must be adequate to allow drainage to take place so that there will be no built-up of pore water pressure within the fill. Special reinforcing nonwoven geo-composite material with good in-plane drainage property was adopted for the wrap around reinforced soil slope system. This paper discusses the project background and its design criteria in particular the wet tropical climate. The methodology used in the wrap around reinforced soil slope system was also discussed in the paper. Steel fabric facing panels together with the stones were used for the front facing. The issues that arose during the construction of the reinforced soil slopes were also highlighted in this paper. Site investigations were carried out to ascertain the ground conditions of the proposed site whereby the reinforced soil slope would be constructed. On the basis of the laboratory tests, subsoil parameters of the underlying soil were obtained and were adopted in the design.

Keywords: geosynthetic reinforcement, reinforced soil slope, welded wire-mesh facing

1 INTRODUCTION

Soft engineering system using the geosynthetics for the design and construction of reinforced soil slope has been successfully used in tropical climate.

The proposed road widening project presented in this paper is located in the region of Kapit, Sarawak, East Malaysia. Due to the existing terrain with reduced level of 55mRL on sloping ground, a 12m high reinforced soil slope is adopted in achieving the proposed road level of 67mRL at CH9+484. Along this chainage, the road will be built on fill up embankment as well as side slopes fill according to the profile. The slope angle of 63° was proposed so that no land acquisition is required which in turn save time and cost.

The average annual rainfall is approximately 2500mm in Peninsular Malaysia and 5000mm in East Malaysia.The project site being located within the tropical climate and the heavy rainfall zone, the slopes in this region are very susceptible to failures after heavy downpour. The occurence of the slope failures increase dramatically during monsoon season.

Figure 1. Map of Malaysia

2 GROUND CONDITIONS

Geologically, the proposed project site lies in the Kapit Belaga Formation belonging to the Tertiary age. Lithologically, it consists of mainly shale, slate, phyllite, sandstone with marlstone.
Site investigations were carried out to ascertain the ground conditions of the proposed site whereby the reinforced soil slope would be constructed. Two (2) nos. of boreholes were conducted using rotary boring method. The typical soil profile is as shown in Figure 2 and generally it can be classified into three (3) layers.

The first layer of the subsoil consists of soft Clay of approximately 3m thick with SPT N-values within 1 to 2 blows/300mm. Thereafter, the subsoil is dominated by firm Clay with SPT N-values of 5 to 6 blows/300mm before encountering the hard layer. The hard layer with SPT N-values > 50 blows/300mm are found at depth of 7.5m below ground level. Ground water level was monitored in the boreholes and the water level is at 7.6m below ground level.

On the basis of the laboratory tests, subsoil parameters of the underlying soil were obtained and were adopted in the design.

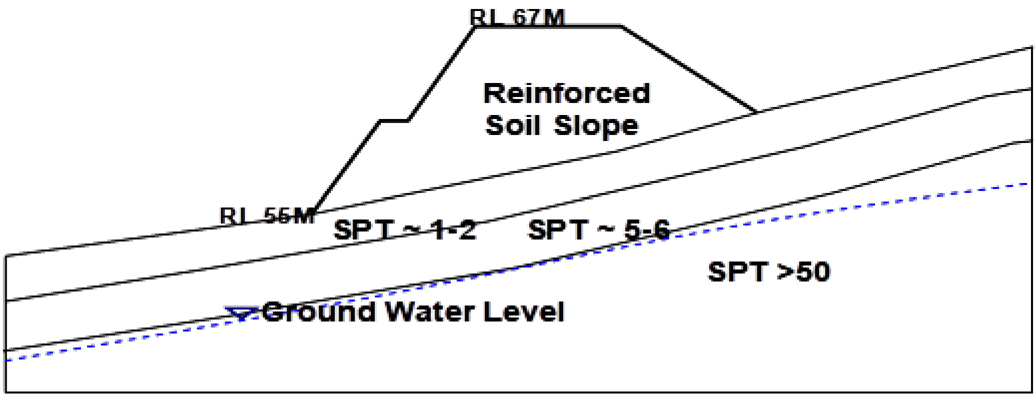

Figure 2. Typical subsoil profile

3 DESIGN AND STABILITY ANALYSIS

Residual earth fill material was chosen as the reinforced soil material due to the availability of the material on site and hence offered the most economical solution for the project site. However, the earth fill material has low permeability and to prevent built-up of pore water pressure within the fill, the reinforcing geosynthetic material that was chosen for the reinforced soil slope must have good drainage property.

Special reinforcing nonwoven geo-composite material with good in-plane drainage property was used for the wrap around reinforced soil slope system. The composite geotextile consists of a continuous fibre nonwoven polypropylene sheet reinforced with a grid network of polyester yarns. The high tenacity polyester yarns provide adequate tensile strength required while the continuous filament nonwoven polypropylene sheet provides in-plane drainage and optimum friction in between the geotextile and soil interface. The nonwoven polypropylene sheet also provides protection to the reinforcing yarns against UV degradation and installation damage during construction, which would affect the overall performance of the geotextile. Given the above features, the reinforcing nonwoven geo-composite material are suitable to use in condition where poor drainage soils are used as backfill material as well as granular fill.

Two (2) tiers of reinforced soil slopes were built with 11 layers of reinforcing nonwoven geo-composite material for each tier. The reinforcing nonwoven geo-composite material were spaced at 0.5m vertical spacing to control the localised failure with achorage length range from 5m at the top layer to 15m at the bottom layer.

The internal stability analysis of the 12m high reinforced soil slopes was carried out in accordance with British Standard BS 8006:1995. The internal stability is related to the effectiveness of the geosynthetic reinforcement in holding the reinforced soil mass together. The internal stability analyses determine the minimum tensile strength and the vertical spacing and hence the number of layers of the geosynthetic reinforcement.

The external stability analysis examines the stability of the reinforced soil zone with respect to active earth forces generated by the self-weight of the retained soil and distributed surcharge presures beyond the reinforced zone. This determines the minimum length of geosysthetic reinforcement.

Global stability analysis was carried out to ensure the global stability of the reinforced soil structure. Global stability analysis was performed by Slope-W computer program using Morgestern Price method. Due to the presence of the 3m thick soft Clay, total removal and replacement of the subsoil with well compacted suitable fill was proposed in order to increase the global stability of the reinforced soil slopes.

In the design of the reinforced composite geotextile, the long-term design strength is taken into consideration. The partial factors involved in determining the long-term design strength for reinforcement at different design life are as follows:

$$T_d = T_c / f_c \cdot f_d \cdot f_e \cdot f_m$$

where:

T_d = long-term design strength of the reinforcement at specific design life
T_c = characteristic short-term tensile strength of the reinforcement
f_c = partial factor of creep effects over the design life of the reinforcement
f_d = partial factor of installation damage
f_e = partial factor of environmental effects
f_m = partial factor of manufacturing consistency

4 CONSTRUCTION STAGE

The weather at the project site is warm and humid throughout the year with heavy rainfall as shown in Figures 3.

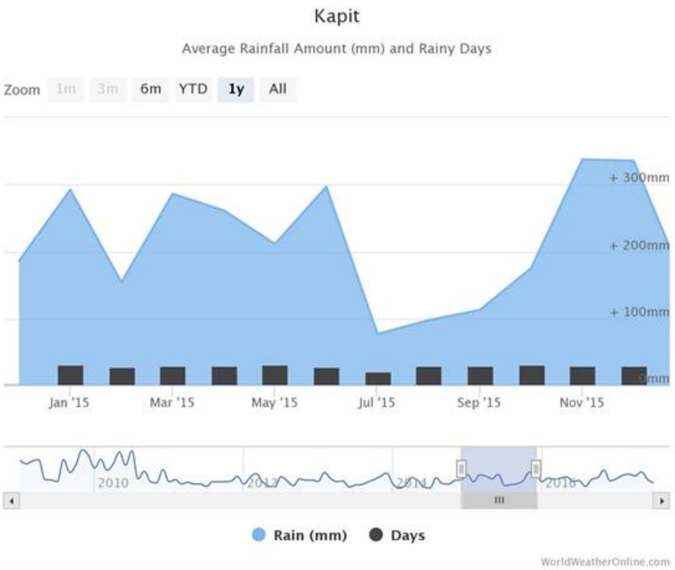

Figure 3. Average rainfall amount and rainy days

From the graph, the wettest period starts form October to December with almost 20 days of raining day per month, while the average is more than 10 raining days per months.

Fill materials available from nearby borrow pits are relatively fine-grained soil with high silt content of more than 65%. Imported fills are expensive and hence prohibited as the project site can only be accessed via river with no direct road access.

In view of the high rainfalls and high silt content in the fill materials, the reinforced soil structure with relatively porous facing and good drainage capability is paramount for project site of this nature. Rock-faced steel fabric panel facing was chosen (Figure 4) to provide a porous facing. This, together with the geotextile composite with horizontal drainage capability and granular drainage layer will ensure good drainage and kept the reinforced zone dry.

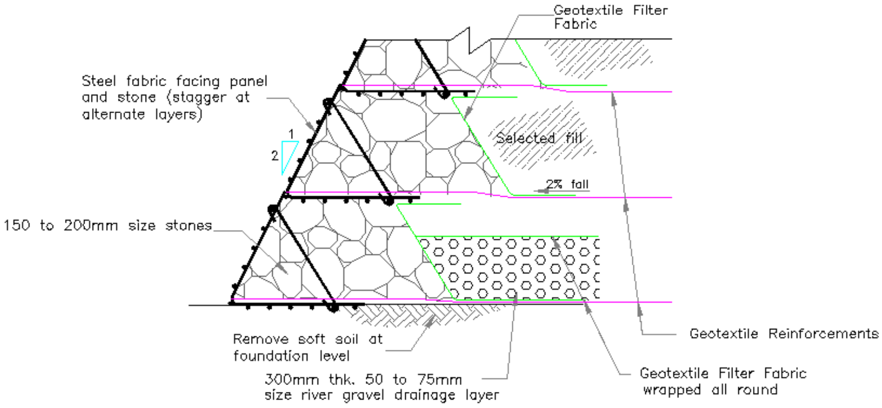

Figure 4. Rock-faced steel fabric panel facing

Hot-dipped galvanised steel fabric facing panels made from standard BRC, machine bended to inclination of 2(v) :1 were used as the facing unit to ensure the slope angle is achieved. Stones of 150 to 200mm size were placed behind the steel fabric facing panel and separated from the reinforced fill material with a layer of nonwoven geotextile to prevent erosion.

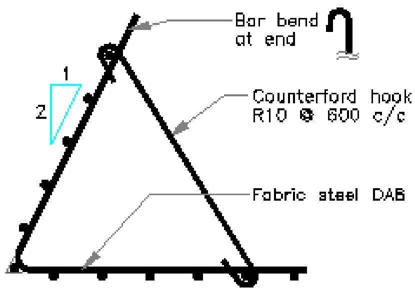

Figure 5. Steel fabric panel facing details

Figure 6. Installation of steel fabric panel facing

The construction of the reinforced soil structure is relatively simple. The unsuitable soil and soft Clay is excavated from the foundation and re-compacted with 0.5 to 1.0m thick of granular fills on top of a layer of geotextile separator to form a competent layer of levelling pad.

The steel fabric facing panels were then placed and strengthened with steel counter-ford hooks. A layer of geosynthetic reinforcement was then placed and fastened to the facing panels with zip-ties. Stones were hand-placed behind the facing panels and the geosynthetic reinforcement was pulled taut and pegged at the end. Small trench was excavated under the middle of the geosynthetic reinforcement panel to provide pre-tensioning. Please refer to Figure 7 and Figure 8.

Figure 7. Laying of geosynthetic reinforcement

Figure 8. Placing of stones behind the facing panels

The reinforced fills were placed in lifts of 150mm and compacted with plate compactors up to approximately 1.0m from the facing of the wall, after which a lift of 300mm was placed and compacted with regular roller. Reinforced fills were compacted to minimum proctor density of 90 percent. The process was repeated for the subsequent layers. It was very challenging during construction in achieving the required compaction during heavy rainfalls and with high silt content of fill material. The soil was covered with plastic sheets during rains to prevent seepage of water into the backfill and work had to stopped even during light rains due to large surface water run-off. Horizontal and vertical drainage layers consist of 300 mm thick aggregate were placed a the bottom and back of the reinforced fill at each berms to remove water seeping from the back and top of the reinforced soil structures.

Figure 9. Compaction in progress

As the rainfalls during monsoon seasons can be quite intense, velocity of surface runoffs from high altitute can be very high. For high slopes, the reinforced soil structures were divided into berms of 5m to 6m high each with concrete berm drains to collect the runoff water and together with the porous rock facing, to break the energy of the water runoff.

5 CONCLUSION

Similar slopes have been contructed in the area for the past 10 years and no distress has been observed for the slopes constructed despite the annual high rainfall.

Due to logistic difficulty, high rainfall and available local fill materials which are sensitive to moisture content, a reinforced soil slope system with the inclusion of composite geotextile that provide excellent in-plane drainage properties is suitable. Furthermore, the system does not required heavy machinery and hence it is practical if the site access is a constraint.

Sufficient internal and external drainage is needed to prevent build-up of pore water pressure and this together with good compaction of the backfill material is important to ensure the stability and safety of the reinforced soil structure is achieved.

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