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Design And Construction Of A 20.5 M High Innovative Nehemiah Wall Near Cameron Highland, Pahang

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ABSTRACT: An exceptionally high wall of height 20.5 m was constructed to span a deep valley in the Cameron Highland using the Nehemiah Anchored Earth technology. It was proposed as an alternative to the original design of a via duct. The alternative was eventually constructed and found to be practical, cost effective and time saving. In addition, excessive deep fills and cuts are minimized.

1.0 INTRODUCTION

After the successful completion of the first East-West Highway, the construction of the second East-West Highway was started in 1997. The second East-West Highway links Simpang Pulai in Perak to Kuala Berang in Terengganu while passing through Ladang Blue Valley in Pahang. This highway is divided into eight packages. Package 1 which stretches from Simpang Pulai to Pos Selim and Package 7B which stretches from Kg. Teris to Kuala Berang have both been completed. At the time of writing, Packages 2,3,4, and 7 have been awarded to some contractors and are now under construction. Package 2 links Pos Selim to Ladang Blue Valley in Cameron Highland. It cuts across the Main Range of Peninsular Malaysia. The steepness of the mountain terrain poses tremendous engineering challenge. Innovative design and construction method are needed to overcome the challenge and construct the highway within the budgetary constraint of time and cost. This paper describes the use of innovative Nehemiah walls as one of the methods used to avoid excessive deep fills. It is also found to be cost effective and practical when compared to the original design of using long viaducts to span the deep valleys.

2.0 GEOTECHNICAL INVESTIGATION

According to the site investigation that included subsurface exploration by boreholes and seismic refraction surveys and surface geological mapping, the area is underlain by moderately to slightly weathered schist. A typical geological ground profile of the hill slope where the wall is located is shown in Fig. 1. The base of the wall is founded on a sloping ground with steepness of about 40°, and hence the preparation of foundation of the wall required some excavation into the slope in order to prepare the base platform. Due to the nature of slope forming material the global stability of the slope is not governed by slip circle type failures. The intact strength properties of the bedrock are very high when compared to the foundation pressure of the wall, and such occasions the global stability is controlled by the presence and orientation of discontinuities in the bedrock with respect to the ground slope. Therefore, the discontinuity patterns in the bedrock were mapped in detail. Generally the bedrock, schist, is closely foliated and dips into the hillside hindering any possible sliding along it. Besides foliation two major joint systems were identified as, joint set 1: 210°/85 and joint set 2: 260°/46° in order of dip direction/dip. These joints are generally tight with some discolored surfaces and dry in nature.

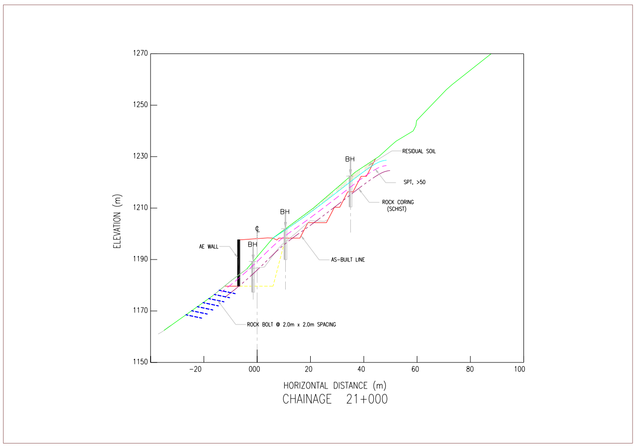

Figure 1: Geological Ground Profile

3.0 GLOBAL STABILITY ANALYSIS

The orientation of two joint systems was analyzed for potential sliding with respect to the downslope below the foundation level of the wall. According to the analysis the formation of narrow wedges bounded by the two joint sets is possible. The sliding can occur along the joint set 2. The factor of safety became 0.28 under the loading condition induced by the wall. The wedges with average surface area of 20 m^2 on the ground slope can be stabilized by 50 tons external load applied on 15° inclination to the horizontal direction. Therefore 10-ton capacity rock bolts with 6 m anchorage length were used at 2m x 2m spacing to stabilize the failures with factor of safety of 1.6.

4.0 DESIGN

The Nehemiah wall is a type of reinforced soil system. It employs the combination of soil reinforcement and deadman anchorage technology. The advantage of such a system is cost effectiveness through design and use of locally available material like steel bars and concrete. The design is based on the BS 8006:1995 code of practice for Strengthened/reinforced soils and other fills. The typical design cross section is shown in Fig. 2.

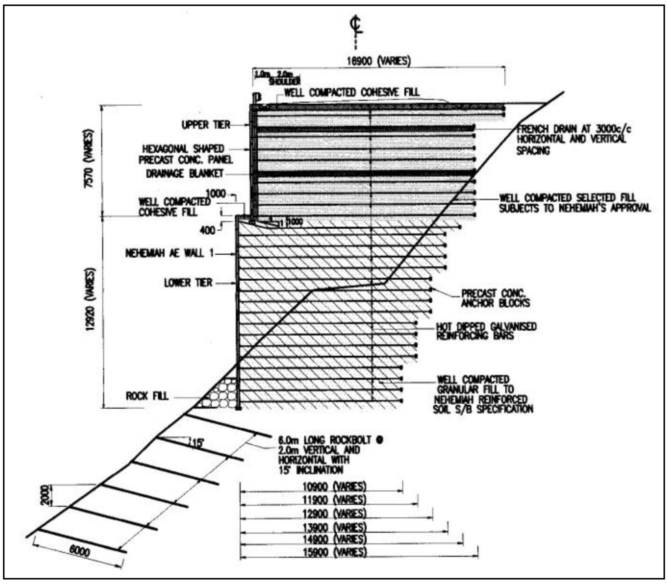

Figure 2: Typical Design Cross Section of Nehemiah Wall

The design of the Nehemiah wall involves the external stability analysis and the internal stability analysis. For the external stability analysis, the Nehemiah wall is analyzed as a gravity block. The various factors of safety against sliding, bearing, overturning and global stability analysis are checked. (see Fig. 3). The global analysis is discussed in the earlier section. The other externally stability analyses are quite standard geotechnical analyses. As such, they shall not be described in detail. The internal stability shall however be described in more detail below:

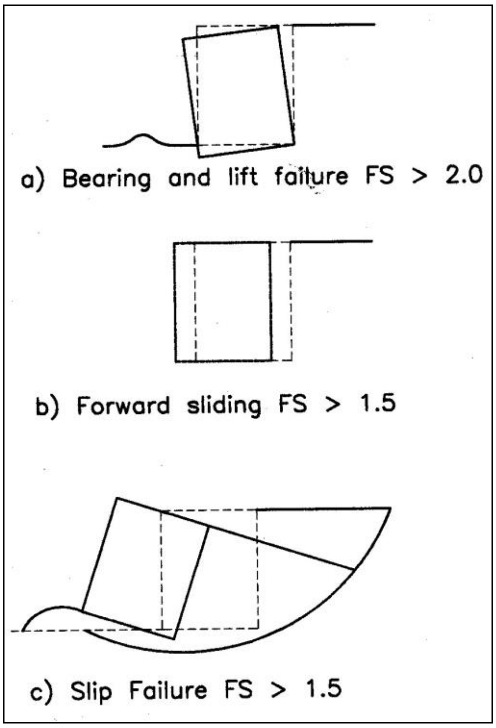

Figure 3: External Stability Checklist

4.1 Internal Stability

The internal stability analysis involved checks to ensure that the factors of safety against
tensile and pull-out failure of the reinforcing tendons are adequate.

4.1.1 Tensile Failure

$T_i = K\, S_v\, \sigma_v$

where

- T_i is tension developed in the reinforcing tendon at i th level
- K is the coefficient of earth pressure within the reinforced block
- S_v is the vertical spacing of the tendons
- σ_v is the vertical stress acting on the i th level of the tendons according to the Meyerhof pressure distribution

In the design, it is important that the number and size of reinforcing tendons are adequately provided so that the tension developed in the tendons is always less than the allowable tensile strength of the tendons.

4.1.2. Pull Out Failure

The ultimate pull out resistance of the reinforcing tendons is the sum of the shaft frictional resistance and the anchor capacity of the anchor block. The shaft resistance is determined by the friction developed between the backfill and the effective length of the tendon which is shown in Fig. 4.

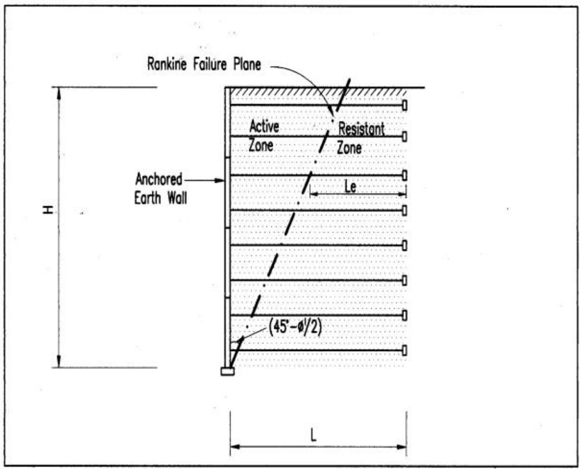

Figure 4: Effective Length of Reinforcing Tendons - L_e

The shaft resistance is computed as follows:

$F_s = \mu \tan Ø \, ¶ \, d \, L_e \, \sigma_v$

where

F_s	is the shaft resistance
μ	is the coefficient of friction
Ø	is the internal angle of friction of backfill
d	is the diameter of the tendon
L_e	is the effective shaft length (Fig. 4)

The anchor capacity is computed as follows:

$P_a = 4 \, K_p \, h \, w \, \sigma_v$

where

P_a	is the passive resistance of the backfill in front of the anchor block
σ_v	is the vertical stress at the i th level of tendon
K_p	is the coefficient of passive earth pressure
h	is the height of the anchor block
w	is the width of the anchor block

Hence, the total pull out resistance

$P = P_a + F_s$

5.0 CONSTRUCTION

The construction of the second East West Highway is a challenging task because of the steep terrain of the Main Range. Normal design would results in excessive cut and fill. Excessive earthwork can results in slope instability, cost escalation and adverse environmental impact. Nehemiah wall is used as one of the innovative methods to overcome excessive deep fills. This method is cost effective, saves time and provides a long term stability in support of the road embankment. The first step in the construction of the wall is site preparation.

5.1 Site Preparation

5.1.1 Excavation

Excavation for the base of the wall is carried out in accordance with the site setting out in accordance with the drawing.

5.1.2 Base Preparation

The foundation base is graded level and well compacted for a width equal to the length of the reinforcing elements. Any weak material or debri shall be removed and replaced with compacted granular material .

5.1.3 Concrete Levelling Pad

The plain concrete levelling pad is cast accurately to line and level as detailed on the drawing 24 hours before the actual wall erection works commence. Grade 20 concrete is used and no reinforcement is required.

Once the site preparation is completed, the wall erection can be commenced.

5.2 Wall Erection

5.2.1 Installation

The process of wall erection is summarized in the sketch shown in Fig. 5. The facing panels are hoisted with the aid of a lifting device. They are placed in successive courses. The spacing, level and alignment of each panel are checked immediately after its placement and again at the completion of each course.

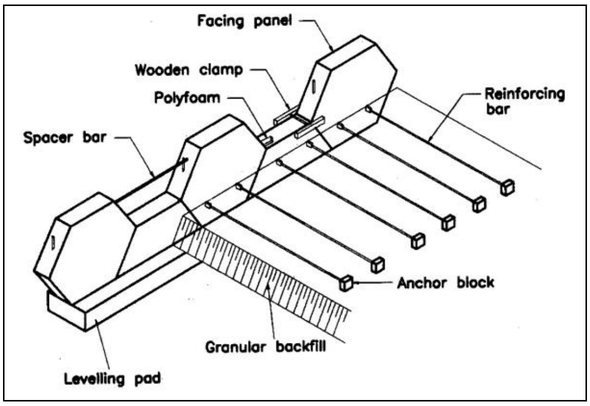

Figure 5: Construction of AE Wall

The initial row of panels are braced externally. Each row of the panels are followed immediately by the placement of fill and the connection of the reinforcing bars before the next successive horizontal row of panels is being erected. The subsequent rows of panels shall be held in place by temporary clamps securing the present rows of panels to the previously erected rows which is already held firmly in place by the reinforcing bars buried in the backfill.

Except for the bottom course of panels, all others panels shall be tilted towards the fill material during placement to compensate for the outward movement expected during or subsequent to compaction of the fill material. The degree of inclination shall be adjusted where necessary as placement and compaction of fill material proceeds to ensure that the verticality of the wall complies with the requirements.

5.2.2 Joint Materials and Cushion Pads

Joint materials are placed in all the joints between the panels. They shall be placed on the cleaned top edges of each facing panels just prior to the placing of the mating facing panel. No joint material is required between the leveling pad and the bottom course of the facing panels.

Cushion pads shall be placed at the slots on the top edge of each panel before the installation of the subsequent row of panels.

5.2.3 Alignment and Verticality

The alignment and verticality is constantly checked with a plumb bob and adjusted with the aid of temporary timber wedges inserted into the joints between the panels. The timber wedges shall be removed as soon as their functions are fulfilled.

5.3 Backfilling

5.3.1 Placement of Fill

Backfilling operation is carried out immediately following the completion of the installation of each row of panels. The fill material shall be deposited, spread, leveled and compacted in layers of thickness of not exceeding 375 mm so that each reinforcing bar can be fixed at the required level on top of the compacted fill material without any voids forming directly underneath the reinforcing bar.

The direction of travel of the construction vehicle for the placement, spreading and compaction of the fill is parallel to the alignment of the wall at all time. Sharp turn of vehicle causing centrifugal forces exerting toward the rear face of the panels is avoided.

No heavy vehicle weighing more than 1000 kg shall be allowed within the 1.5 m zone from the rear face of the panel.

The traveling of construction vehicles especially those with crawler track wheels directly onto the reinforcing element is prohibited.

5.3.2 Compaction

The fill material is compacted to 95% of the maximum dry density as determined in accordance with BS 1377:1975.

During the backfilling operation and compaction, trucks and heavy construction vehicles shall be kept back at least 1.5 m away from the back face of the facing panel. The 1.5 m zone shall be compacted with a 1.0 ton vibratory plate compactor.

6.0 CONCLUSION

The Nehemiah wall was successfully completed in February 2001 despite the challenge of very steep mountainous terrain. Excessive deep fills are avoided through the use of Nehemiah wall. It was found to be cost effective and practical in comparison with the original design of via duct. Further, the time saved is significant. However, for such a height of wall, it is imperative that the global stability is adequately checked with input from engineering geologist.

7.0 REFERENCE

BS8006:1995 Code of Practice for Strengthened/Reinforced Soils and Other Fills.

MTD (2001) "Slope Stabilization in Pos Selim – Ladang Blue Valley Highway Project", Proceedings for National Slope Seminar 2001, Cameron Highlands, Pahang.