CASE STUDY OF SLOPE STABILIZATION EMBANKMENT SIAU AIRPORT RUNWAY SEGMENT 1 AND 1A, WITH TERRAMESH® REINFORCED SOIL WALL

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ABSTRACT: Pihise Airport is located in Siau Island, approximately 155km North of Manado, North Sulawesi. The proposed project consists of 1.4km runway construction and another 1.8km extension for further development. This project required significant slope stabilisation to support the new runway which is constructed at the top of the filled embankment due to the steep terrain. The reinforced soil structure adopts a Terramesh® reinforced soil structure (RSS) ranging between 31.5m to 35.5m in height. Paralink™ 300 grid was adopted in the design as soil reinforcement range from 12.5 to 25.0m in length with confined reinforced zone. An additional 10.0m of fill embankment was place above the structure at a slope angle of 1V:3H. The subsurface soil profile on site indicated fill underlain by medium dense silty sand followed by dense gravelly sand. To achieve sufficient bearing capacity, the structure had to be founded on dense to very stiff material. Due to the extensive foundation excavation for the structure, the total supported slope height extended to approximately 52.0m in height with a 60° batter. This paper describes the design methodology adopted to assess the stability and deformation of the structure. Finite element and limit equilibrium analyses were performed to verify critical design sections, including sensitivity check on key design parameters.

Keywords: Pihise Airport, Retaining wall, Slope stabilisation, Reinforced Soil Structure, Terramesh®, Paralink™

INTRODUCTION

Siau Airport is located approximately 155km north of Manado, North Sulawesi. This airport consist of 1.4km runway construction and another 1.8km extension for further development. A Terramesh® Reinforced Soil Structure (RSS) was constructed along the southern side of the runway to retain the filled embankment due to the steep terrain and constraint footprint. The Terramesh® RSS ranges between 31.5m to 35.5m in height with an additional 10.0m high embankment constructed above the structure with a 1V:3H batter. This paper outlines the design of the unconventional Terramesh® RSS system where the maximum slope height was ≈52.0m in height with a batter angle of approximately 60°.

TERRAMESH® RSS SYSTEM

The Terramesh® system adopted in the design comprises of a gabion front face with reinforcing elements extending back into the compacted reinforced backfill zone. The Terramesh® units are 2.0m (W) x 3.0m (L) x 1.0m (H) as indicated in Figure 1. The Terramesh® facing units were fabricated using heavily galvanized and polymer coated steel wire in order to meet the required design life of 75 years in accordance with SNI 8460:2017. The Terramesh® unit are then filled with rock varying in size between 100mm and 250mm in accordance with AS 2758.4-2000.

Due to the extreme height of the structure and constraint construction footprint, Paralink™ 300 high tenacity polyester geogrid was installed as tensile reinforcement at 1.0m vertical increments. With an ultimate tensile strength of 300kN/m and applying partial factors for creep (1.37), construction damage (1.10) and manufacturing (1.00), a design strength of 200kN/m at 75 years design life was adopted.

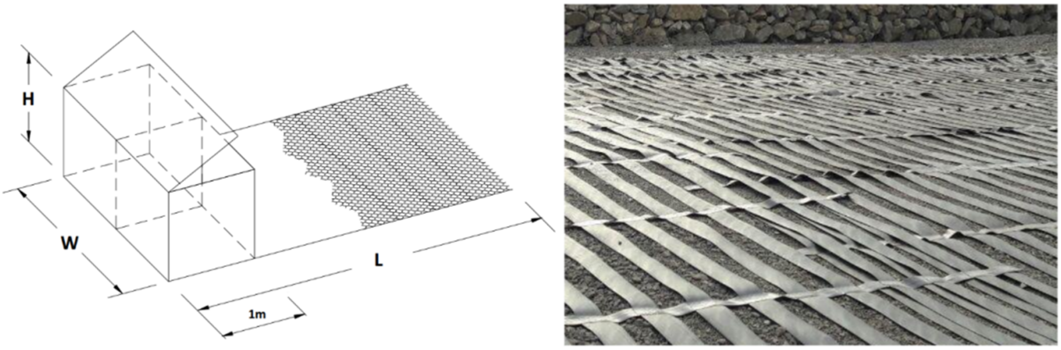

Figure 1. Typical Terramesh® Dimensions and Paralink™ Product

The reinforced backfill was sourced from locally won materials, mainly from the cut sections, which was installed and compacted in 300mm lifts following Paralink™ Installation (see Figure 2).

Figure 2. Compaction of reinforced fill behind Terramesh® structure

PROJECT DESIGN METHODOLOGY

Geotechnical Investigation

The airport is located on a steep terrain that required extensive earthworks activities to balance the cut and fill volume for construction purpose. Any potential import fill is unfavourable due to the isolated location. It is vital to engineered the in-situ materials with appropriate construction methodology to meet any design intends. Extensive earthwork activities in the project are shown in Figure 3.

Figure 3. Large fill embankment and existing masonry wall

Geotechnical investigation was conducted using Cone Penetration Tests (CPTs), Standard Penetration Tests (SPTs) and Test Pits (TP) to visualise the existing geotechnical profile for design purpose. The subsurface profiles generally consisted of existing embankment fill material, underlain by medium dense silty sand, followed by dense gravelly tuff sand. A long section of subsurface profile is show in Figure 4.

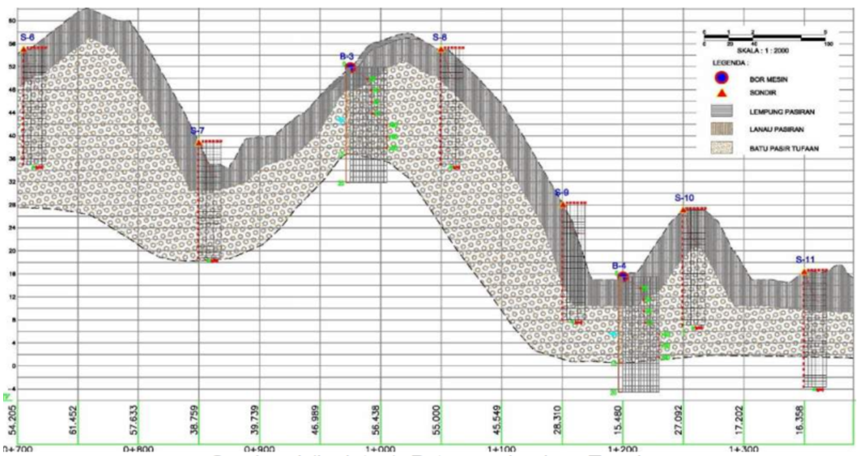

Figure 4. Long section subsurface profile

Design Parameters and Geometries

Prior to stability analysis, soil properties were interpreted based on the laboratory test results and field observations. The originally factual report indicated anomalies in the soil stiffness for soaked and unsoaked samples. These inconsistencies were unable to correlate with the literature values and sensitive to the design outcomes. Therefore, the author had relied on the past experience and due diligent to interpret the design parameters summarised in Table 1 below. A thorough verification and validation process was established in the safety in design to mitigate any potential risks.

Table 1. Unfactored material parameters adopted in geotechnical model

Material	γ - Unit Weight (kN/m^3)	c′ - Effective Cohesion (kPa)	φ′ - Effective Friction Angle (deg)
Existing Embankment Fill	18	15	20
MD Silty Sand	17	5	30
D Gravelly Sand	18	5	35
Reinforced Fill	20	5	30

The geometries of the RSS system was finalised based on the iterations of the design requirements, construction constraints and cost effectiveness. As described in previous paragraphs, the steep terrain and footprint constraint had massive influence of the final geometry of the structure. Due to these, the author had opted to design the structure departs from the conventional criteria recommended in BS8006:2010 or NCMA. The key criteria departed from the standard industry practice are the minimum reinforcement length of 0.7H and engineered fill. To avoid potential pore pressure accumulation behind the reinforced zone, adequate drainage system was designed to dissipate the pore pressure. The final geomtery of oen f the critical and highest section is indicated in Figure 5 below. The uniformly distributed load of 20kPa was assigned for multiple construction traffic above the Terramesh® RSS.

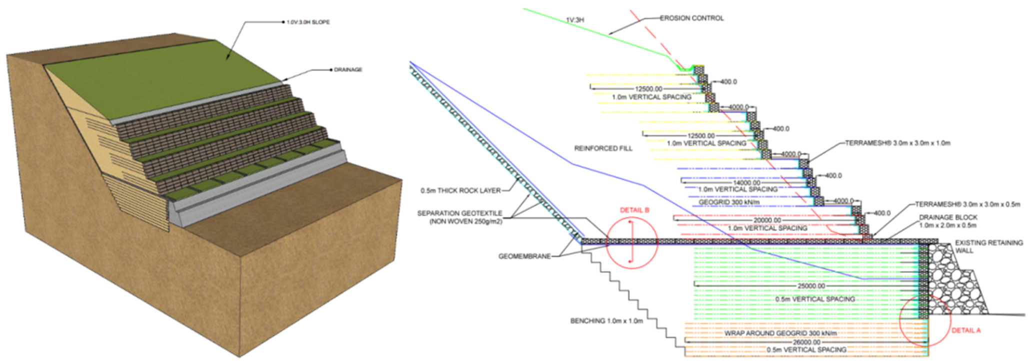

Figure 5. Typical isometric view and cross section Of Terramesh® RSS

The Terramesh® RSS system parameters were modelled using strengtht=F (overburden) material model with a constant unit weight of 16.8kN/m3 and tau/sigma ratio of 1. Terramesh® facing was modelled with a shearing resistance similar to an equivalent friction angle of 40° - 45° depending on void ratio and an apparent cohesion`of 40kPa as per the CIRIA C683 Rock Manual (1991).

According to the Indonesia seismic zone map (see Figure 6), Siau Airport is located at seismic zone with a peak ground acceleration between 0.25g to 0.35g. Therefore, seismic acceleration coefficient of 0.125g was adopted in the design. A minimum FOS of ≥1.10 shall be achieved for the Terramesh® RSS with earthquake load in accordance with SNI 8460:2017.

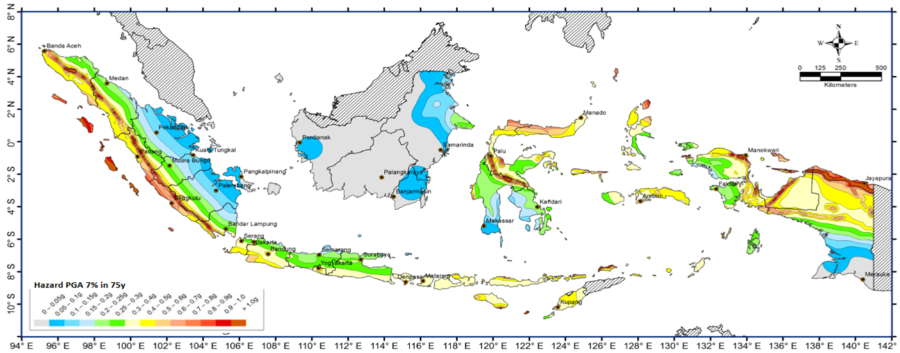

Figure 6. Seismic Map for Probability 7% exceed in 75 years

Limit Equilibrium Approach

Limit-equilibrium approaches are routinely adopted for the design and analysis of reinforced soil structures. Slope stability of the Terramesh® RSS system was conducted to ensure that the minimum design criteria were met for global stability. Ultimate Limit State (ULS) and Serviceability Limit State (SLS) approaches are adopted to verify the external and internal stability of the system. These includes the minimum shear strength required along a potential failure surface to maintain stability and then compared to the interpreted shear strength of the soil. The factor of safety is assumed to be constant along the entire failure surface. The factor of safety for global stability is FOS ≥ 1.50.

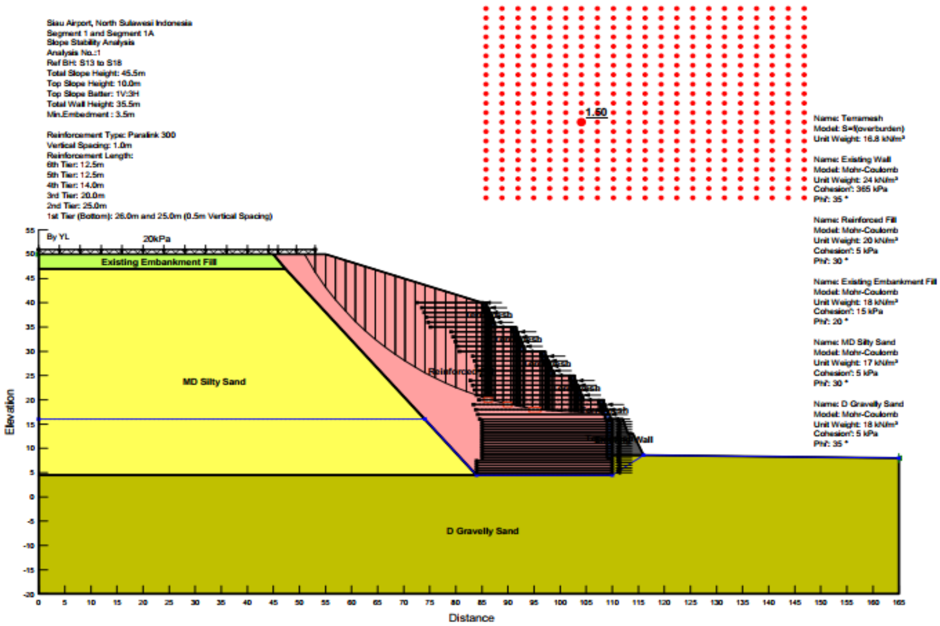

Figure 7. Result for static global stability assessment on segment A

For internal stability of the system, connection strength between the geogrid reinforcement and the Terramesh® RSS system to prevent rupture or slippage of the reinforcement due to the applied tensile force, calculation of interface shear capacity and connection capacity developed between the system and the geogrid reinforcement were taken into account within the design.

Instead of adopting the conventional monolithic model for the Terramesh® RSS system a new constitutive model is developed based on the large scale direct pull-out test results conducted at the University of New South Wales, ADFA, Australia (UNSW Canberra). The normal stress versus shear stress relationship is modelled to simulate the shear capacity of reinforcement at different wall heights.

Finite Element Analysis

Paralink™ 300 high tenacity polyester geogrid are visco-elastic-plastic materials and hence offer challenges in numerical modelling. In practical terms these materials have properties that are strain level and load rate dependent. In geosynthetic practice, stiffness in units of force over length (kN/m) are used since cross-section area and thickness of these materials varies and is hence problematic.

In most numerical codes, this value required be converted to a modulus (E) for an equivalent solid material with constant area and thickness. Commercial finite-element software PLAXIS was used for analysis. In the finite-element modelling, the system components were carefully modelled and with refined mesh adopted to fully account for the construction procedures. No interface was introduced between the soil and the reinforcements assuming no slip between the reinforced fill and the geogrid reinforcements. The objective of the analysis is to justify the recommended maximum allowable movement of the connections to minimize the post construction wall face deformation to 50mm as per AS4678-2002.

Design and Construction Challenges

As described in previous paragraphs, the geometry was constraint by the steep terrain and construction footprint. These factors resulted a departure from the standard industry practices and design codes. To mitigate the potential risks raised from the unconventional reinforcement length configurations, sensitivity analysis has been conducted to quantify the global stability of the critical sections with different length of geogrid reinforcement. A minimum FOS of ≥1.50 shall be achieved for long term stability. Several models have been established to conduct the global stability assessment with geogrid reinforcement length of 26.0m, 24.0m, 22.0m, 18.0m and 16.0m respectively from the bottom of the foundation level.

Figure 8 and Figure 9 demonstrated the results of the sensitivity analysis for the maximum geogrid reinforcement length and the corresponding cutting volume of the existing slope. The minimum geogrid reinforcement length required for the bottom layer is 26.0m without any additional ground improvement.

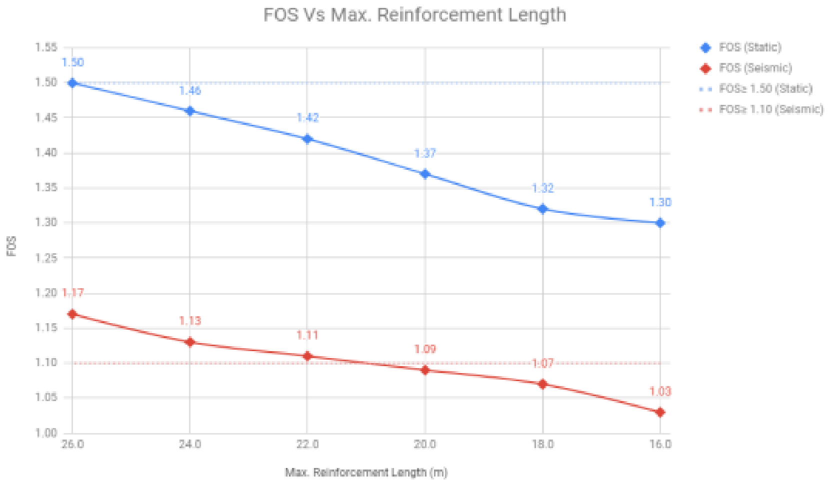

Figure 8. FOS compared with maximum reinforcement length

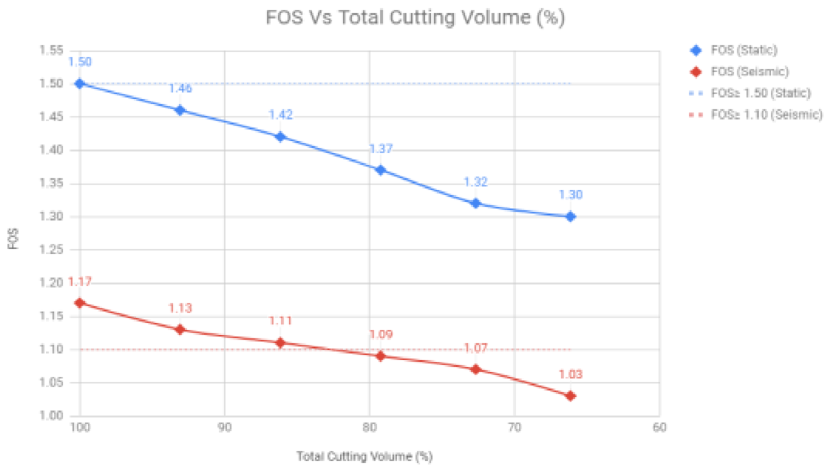

Figure 9. FOS compared with total cutting volume

In addition, the inconsistencies of the site investigation works and laboratory test results poses another great challenge to the design. The originally factual report indicated anomalies in the soil stiffness for soaked and unsoaked samples. These inconsistencies were unable to correlate with the literature values and sensitive to the design outcomes. A safety in design and risk assessment approach were adopted to establish a thorough verification and validation process during construction to mitigate the potential risks. Field observation approach such as materials selection and foundation verification were implemented by the author to eliminate those inconsistencies.

RECOMMENDATION AND CONCLUSION

An overview of the project at completion provides the following recommendations and conclusions with particular emphasis on achieving goals set at the beginning of design:

- Terramesh® system can be adopted for extremely high reinforced soil structures provided design adopts applicable standards and construction quality is taken seriously.

- Terramesh® system provides a cost effective solution as on-site material can be utilized in construction.
- Terramesh® system can be a cost effective solution due to use of on-site material as reinforced fill. Correct partial factors should be adopted for long-term design and adopted design values reflect the actual material tested on site.

The long term performance of the structure under displacement is one of the key issues for the design of a Terramesh® RSS system due to the significant height. In order to fully address the design risks, the strain-based finite element approach for displacement analysis should be adopted in addition to the traditional stress-based limit equilibrium approach for stability assessment.

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