OPTIMIZATION OF COST-EFFECTIVENESS FOR SOIL-NAILED SYSTEM IN RETAINING WALL

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DEDICATION

This dissertation is dedicated to my supervisor, who taught and guides me with the best kind of knowledge along this journey. It is also dedicated to my mother, wife and children who always pray for me and told me that stay focus to finish the writing.

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ABSTRACT

Soil nailing is one of in situ soil reinforcement method to improve stabilization of slopes, retaining system, and excavation works. Soil nailing designs are optimized to be cost-effective in construction management. This dissertation aims to analyze the optimization of the soil nailing with three different parameters: inclination, spacing, and length of the nail. All optimizations must meet the factor of safety (FOS) permissible limit. The case data was collected from three selected sites in Selangor. The slope with soil nailing was reanalyzed using SLOPE/W software program based on the limit equilibrium method (LEM) and also Morgenstern and Price Method (M-P) to optimize the design and compute the FOS. During reanalysis, all three nail parameters were separately optimized based on the case conditions and FOS requirements. The results of the reanalysis showed that reducing nail length can reduce the FOS, meanwhile reducing the nail inclination and nail spacing can increase the FOS. The reanalysis results proved that increased nail inclination does not increase the cost, but the cost decreases by the reduced nail length. Cost reduction is mainly affected by reducing nail length, and the number of nails. In addition, the problems of soil nailing such as rebar encroaching on neighbouring land can be solved by using a crib wall because it can be constructed on a small space. The combination of soil nailing and crib wall systems complement the drawback with each other's advantages and made the retaining system ideal to strengthen the hillside. When a cutting slope occurs in a narrow area bordering neighbouring land, combining these two systems is necessary for reducing construction costs. The construction costs of soil nailing and crib wall were compared and merged to prove the effectiveness of the combination system. The cost-benefit analysis results of the combined system is a good option when the benefit-cost ratio is greater than one and the net present value is greater than zero. The results indicated that the cost savings of the combined system are acceptable. Therefore, the optimization of the soil nailing and the combined systems contribute to cost-effective construction management.

ABSTRAK

Memaku tanah adalah salah satu kaedah pengukuhan tanah di situ untuk meningkatkan penstabilan cerun, sistem penahan, dan kerja penggalian. Reka bentuk paku tanah dioptimumkan untuk menjimatkan kos dalam pengurusan pembinaan. Disertasi ini bertujuan untuk menganalisis pengoptimuman paku tanah dengan tiga parameter yang berbeza: kecondongan, jarak, dan panjang paku. Semua pengoptimuman mesti memenuhi had faktor keselamatan (FOS) yang dibenarkan. Beberapa data kes diambil dari tiga tapak bina yang terpilih di Selangor. Cerun yang telah dipaku tanah dianalisis semula menggunakan program perisian SLOPE/W berdasarkan kaedah batas keseimbangan (LEM) dan juga kaedah Morgenstern dan Price (M-P) untuk mengoptimumkan reka bentuk dan mengira FOS. Semasa analisis semula, ketiga-tiga parameter paku dioptimumkan secara berasingan berdasarkan keadaan kes dan keperluan FOS. Hasil analisis semula menunjukkan bahawa dengan mengurangkan panjang paku dapat mengurangkan FOS, sementara itu mengurangkan kecondongan dan jarak paku dapat meningkatkan FOS. Hasil analisis semula membuktikan bahawa peningkatan kecondongan paku tidak meningkatkan kos, tetapi kosnya menurun dengan panjang paku yang dikurangkan. Pengurangan kos terutamanya dipengaruhi oleh pengurangan panjang dan jumlah paku. Di samping itu, masalah paku tanah seperti pencerobohan rebar di tanah bersebelahan dapat diselesaikan dengan menggunakan tembok krib kerana ia dapat dibina di ruangan kecil. Kombinasi sistem paku tanah dan tembok krib melengkapkan kelemahan dengan kelebihan masing-masing dan menjadikan sistem penahan sesuai untuk mengukuhkan lereng bukit. Apabila cerun pemotongan berlaku di kawasan sempit yang bersempadan dengan tanah bersebelahan, penggabungan dua sistem ini diperlukan untuk mengurangkan kos pembinaan. Kos pembinaan paku tanah dan tembok krib dibandingkan dan digabungkan untuk membuktikan keberkesanan sistem gabungan berkenaan. Hasil analisis kos-faedah sistem gabungan adalah pilihan yang baik apabila nisbah kos-faedah lebih besar daripada satu dan nilai kini bersih lebih besar daripada sifar. Hasil kajian menunjukkan bahawa penjimatan kos sistem gabungan dapat diterima. Oleh itu, pengoptimuman paku tanah dan sistem gabungan menyumbang kepada pengurusan pembinaan yang menjimatkan.

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LIST OF ABBREVIATIONS

UTM	-	Universiti Teknologi Malaysia
DDH	-	Drill hole diameter
SPT	-	Standard Penetration Test
FOS	-	Factor of Safety
BQ	-	Bill of Quantities
CBA	-	Cost-Benefit Analysis
PV (B)	-	Present Value Benefits
PV (C)	-	Present Value Costs
NPV	-	Net Present Value
BCR	-	Benefits Cost Ratio
BEM	-	Board of Engineers Malaysia
Nos.	-	Numbers
i.e.	-	In other word

LIST OF SYMBOLS

ß	-	The inclination of Soil Nail
ßs	-	Slope Angle
δ	-	The angle of Wall Friction
r_u	-	Pore Water Pressure
D	-	Diameter of nail
Mpa	-	Mega Pascal
Kpa	-	Kilo Pascal
kN	-	Kilo Newton
kN/m^3	-	Kilo Newton per meter cube
c	-	Cohesion
B	-	Slice base length
N	-	Base normal (W cos α)
φ	-	Phi or Friction angle
W	-	Slice weight
A	-	Slice base inclination
λ	-	Lambda
ft	-	Foot
τ_f	-	Shear strength
R	-	Distribution in elevation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia faces two monsoon seasons: the Southwest Monsoon from May to September, and the Northeast Monsoon from October to March. Northeast Monsoon brings high rainfall compared to the Southwest Monsoon. Most of the landslides occur within a month, especially in December (Habibah and Jamilah, 2011). They mentioned that a landslide is a deadly hazard that occurs quite frequently during the rainy seasons. However, landslides can happen any day. Landslide emerges on man-made slopes and is related to human factors. These human factors are hard to consider during the design process but can cause pressure on structural integrity (Qasim et al., 2013).

The average rainfall is 250 centimeters in a year that can contribute to an unstable slope, especially when the earth cannot retain a lot of continuous runoff water (Alsubal et al., 2018). Slope failure usually occurs in mountainous landscapes and is also common along river valleys and coastlines. Therefore, heavy rainfall becomes the main factor of landslide and it is recognized as the physical response to external triggers (Hu, 2016).

1.2 Research Background

Currently, most of the construction of a retaining system in Malaysia proposed for strengthening the slope. The different level of the earth or steep slopes makes the earth unstable. Landslide potential occurs in the highlands and steep slopes. This mechanism occurs because of geological and physical disturbance of soil suction as well as external factors such as water, snow, wind, and temperature changes. The addition of water from rainwater adds a burden to the slope. Water seeps into the soil or rock and replaces the air in the pore space or fractures. Since water is heavier than air, this increases the weight of the soil. Weight is a force, and force is stress divided by area, so the stress increases, and this leads to slope uncertainty. Alsubal et al. (2018) stated that the rise of the groundwater table due to rainfall could trigger a landslide. In the covetousness of human beings to meet the demand for land, many forests have been exploited and destroyed. Forest areas are exploited for the construction of buildings or logging, these areas become exposed to the weather and this leads to the possibility of disasters such as the frequent occurrence of landslides (Manap, Jeyaramah, and Syahrom, 2018). Therefore, the occurrence of landslides results in loss of property and human life and the worst scenario is a loss for the economy and tourism (Amashi et al., 2019; Dewedree and Jusoh, 2019).

The retaining system could be designed and constructed to minimize this problem. Stabilization of landslide is carried out with the built retaining system and managing it properly. During and after a defect liability period (DLP) ends, monitoring is the best way to minimize the hazard. Many types of retaining system methods can tackle this problem such as a reinforced concrete wall, cantilevered wall, gravity walls, sheet piling wall, bored pile wall, and soil nailing wall. There are alternative wall systems in the market such as anchor wall system, crib wall, gabion meshes, mechanical stabilization earth (MSE), and soil nailing technique. This research, therefore, chooses soil nail walls and crib walls to evaluate the best option for strengthening the slope.

1.3 Statement of the Problem

Generally, high-risk slope area needs a structure designed as a retaining system. The major concern is the suitability of structure that serves as the best solution to prevent the occurrence of any landslides (Galve, 2016). According to Dewedree and Jusoh (2019), slope failure problems result in death, and disrupt human safety. Therefore, local authorities presently require developers to engage Accredited Checkers as independent checkers for slopes with high risk to ensure safety (Gue and Tan, 2014). Slope Engineering Branch (2010) also mentioned that all the geotechnical designs should be checked by Independent Geotechnical Checker (IGC) appointed by the contractor.

Soil nailing system is used for strengthening slope. The design of slope stability is dependable on the value of the Factor of Safety (FOS) and the types of slope stabilization methods used. The important issue is the condition of the slope design that is directly related to the cost. The analysis should consider diversification situation to make the effectiveness of soil nailing more valuable. Furthermore, the selection of a combined retaining system adds advantage and enhances efficiency (FHWA, 2015). Clients have faced problems relating to limited buffer zone to construct a building, boundary issues, cutting slope issues, slope height, surcharge load, and high active pressure. Reducing slope inclination also increases the costs, directly and indirectly, such as increasing the number of nails or the involvement of the construction cost of mobilizing machinery and increasing materials. These increase the duration of the construction time that narrows client's desire to get more profit (FHWA, 2015). Any slope, especially near the boundary side, needs to be retained or trimmed to the required level. It would be a problem in the future when making the wrong decision. Soil nailing technique is a method either implemented in steep slope or vertical slope. However, the aesthetics of soil nailing can be an important decision-making factor.

Controlling the design of soil nailing cost can be done at the design stage. The consultant practices design optimum to make the system more efficient and cost-saving (FHWA, 2015). The soil nailing system has its limitations, especially if this system is used in a very active earth pressure. The aesthetic façade is not on the soil nailing side, but the crib wall system can cover the disadvantages, besides using the soil-nailed system only in the cut section and a crib wall system for the filler section (Rabie, 2016; Acharya, 2018). The crib wall also has its disadvantages, earth pressure from the backfilling works can lower the stability of the wall (Seewook, 2006; Acharya, 2018). Therefore, this research suggested a combination of soil nailing and crib wall system as an innovative and economical design alternative for implementing on a construction site.

1.4 Aim and Objectives of the Research

This research aims to analyze the optimization of the soil nailing system that stabilizes slopes from various conditions such as inclination, spacing, and length of the nail. All optimizations must according to the FOS permissible limit. The target of this research is to achieve the optimal soil nail design that is done through reanalysis and to evaluate cost differences after optimization. The construction cost to the crib wall and soil nailing system to be calculated for comparison. The last objective is to evaluate cost benefits combined system to solve an expected problem such as when facing the less buffer zone, encroaching neighbouring land, and filling soil area. The construction of the soil nailing system is not suitable in backfilling conditions, but not in the crib wall system that can cover the soil nailing weakness. The combined retaining system is the solution idea that can be used to stabilize slopes in both situations. Besides, to evaluate the cost benefits of both systems can proceed or not. The findings of this research will guide the decisions of clients and consultants in soil nailing construction activity. The research objectives (RO) are detailed as follows:

1. To optimize soil nailing design through reanalysis of various parameters including different degrees of nails inclination, nails spacing and nails length.
2. To evaluate the cost differences before and after optimization of soil nailing through reanalysis.
3. To compare slope stabilization of soil nailing to the crib wall system in terms of cost.
4. To evaluate the cost benefits of the soil nailing and crib wall when they are combined as a retaining system.

1.5 Research Questions

The research questions are created to fulfil the objectives stated and classified in the analysis stage. These research questions are important in guiding the researcher to the solutions from the research objectives. These also help focus the attention on the relationship between theories and concepts. The questions are relevant, manageable, and realistic within the scope of the research. Following are the research questions that generate the discourse throughout this dissertation:

Objective 1: To optimize soil nailing design through reanalysis of various parameters including different degrees of nails inclination, nails spacing and nails length.

RQ1. What are the parameters of soil nailing to optimize during reanalysis? How can the reanalysis of soil nailing contribute to the optimization?

Objective 2: To evaluate the cost differences before and after optimization of soil nailing through reanalysis.

RQ2. How much difference cost is before and after reanalysis in soil nailing system? Do these costs give value to the developer?

Objective 3: To compare the slope stabilization of soil nailing to the crib wall in terms of cost.

RQ3. How can construction of soil nailing reduce the cost of slope stabilization? Why is soil nailing system cheaper than other types of retaining system? How can the combination benefit each other?

Objective 4: To evaluate the cost benefits of the soil nailing and crib wall when they are combined as a retaining system.

RQ4. What are the cost benefits of soil nailing and crib walls when combined as a retaining system?

1.6 Scope and Limitation of the Research

The focus of this research is on cost evaluation and optimization methods. The study is limited to the soil nailing technique used in cutting slope only. The crib wall system uses a precast concrete wall type with granular infill material. Therefore, an evaluation was done with a combination of these two systems and a cost comparison between soil nailing and the crib wall system. This research carries out cost analysis using cost-benefit analysis (CBA). CBA is for projects that involve small to mid-level capital expenditures having short to intermediate terms of completion because, for mega projects with a long-term time horizon, CBA typically fails to account for important financial concerns such as inflation, interest rates, varying cash flows, and the present value of money.

SLOPE/W program was used to reanalyse design soil nailing that only observes different situations such as degrees of inclination, length, and spacing of the nail. Limit Equilibrium Method (LEM) was applied by comparing the shear strength of the soil and the current shear stress in the soil; this is the only method present in the SLOPE/W program. The determination of global and local FOS using Morgenstern and Price methods deliver the required design. The comparison cost is based on cost-benefit analysis and is limited to the cost involved in construction; it does not elaborate on the design of crib walls.

Data were taken from previous soil nailing design, previous cost estimation from Bill of Quantity (BQ), and crib wall details on the project in Klang Valley; a location in Selangor and Kuala Lumpur, chosen to proceed and explore. List of rates from BQ was compared to the estimated cost of the Public Works Department (JKR) for confirmation of cost estimates. The wastage is also taken into consideration. The area is in the environment of the hilly slope and has a valley view, in a rapidly developing area on the road. The projects are a residential building and a Mass Rapid Transit (MRT) project.

1.7 Significance of the Research

Soil nailing has become a famous technique in the industry. Soil nailing has merit and limitation techniques compared to other types of slope stabilization. The significance of the study is important to help design engineers in the determination of the optimum method in improving slope stability and time-saving cost. Optimization should be done at the design stage to make this method more cost-effective. This research serves as reference for organizations such as consultants and clients. Consultants need to ensure the design is in the right dimensions to meet the optimum requirement. The client chooses this system because it saves cost and period of construction. The decision-making should be fast in addressing some of the landslide problems with immediate construction as landslide occurrences are unpredictable, and time is essential especially as it involves human lives. The effectiveness of the combined system and a comparison of the construction costs of soil nailing and crib wall proved the relevant optimization results.

1.8 Contribution of the Research

The present study is a contribution to the existing literature for practical implications. In the early stage of innovation, the soil nailing system improves conceptual definitions of the original retaining system. The innovation in combining soil nail and crib wall system as a retaining system can reduce the potential problems such as nails protruding to the boundary line and hitting the building behind the wall since construction soil nailing system needs wider space compared to the crib wall system. The study contributed to the current understanding of achieving allowable FOS. Reengineered, the optimum results target to achieve a few guidelines. This also proved that the combined retaining system is the cost-effective engineered solution and a final decision to implementing the system. Clients have specific options to their requirements. They can select a range of mass-gravity retaining systems and reinforced soil structures to suit different site conditions, performance, and aesthetic requirements.

This research encourages clients to employ accredited checkers as independent checking works for slopes with high risk to ensure safety. Moreover, the study contributes to prior theory by applying and validating a soil nailing system analysis in the early stages of the innovation process in both retaining systems. This study plays a significant role in design innovation to improving the existing design as well as to get the optimum condition. Hence, contractors and developers benefit in terms of cost and time saving resulting in faster construction. Therefore, the research is adopted to present a choice and alternative to the clients.

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Appendix A Example Reanalysis Report Case 1

Reanalysis Report Case 1, Slope Stability_normal_1.5x1.5m_19m_t25_global

Project Settings

Unit System: International System of Units (SI)

Analysis Settings

Slope Stability_normal_1.5x1.5_15m_t25_global

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions from: Piezometric Line
    - Apply Phreatic Correction: No
    - Use Staged Rapid Drawdown: No
  - Unit Weight of Water: 9.807 kN/m³
- Slip Surface
  - Direction of movement: Left to Right
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Optimize Critical Slip Surface Location: No
  - Tension Crack Option: (none)
- Distribution
  - F of S Calculation Option: Constant
- Advanced
  - Geometry Settings
    - Minimum Slip Surface Depth: 0.1 m
    - Number of Slices: 30
  - Factor of Safety Convergence Settings
    - Maximum Number of Iterations: 100
    - Tolerable difference in F of S: 0.001
  - Solution Settings
    - Search Method: Root Finder
    - Tolerable difference between starting and converged F of S: 3
    - Maximum iterations to calculate converged lambda: 20
    - Max Absolute Lambda: 2

Materials

SPT<10

- Model: Mohr-Coulomb
- Unit Weight: 17 kN/m³
- Cohesion': 2 kPa
- Phi': 30 °
- Phi-B: 0 °
- Pore Water Pressure
  - Piezometric Line: 1

SPT 10-30

- Model: Mohr-Coulomb
- Unit Weight: 18.5 kN/m³
- Cohesion': 3 kPa
- Phi': 31 °
- Phi-B: 0 °
- Pore Water Pressure
  - Piezometric Line: 1

SPT>50

Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion': 10 kPa
Phi': 35 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Type: Range
Left-Zone Left Coordinate: (17.75, 27.8) m
Left-Zone Right Coordinate: (17.97, 27.8) m
Left-Zone Increment: 10
Right Type: Range
Right-Zone Left Coordinate: (35, 8.6) m
Right-Zone Right Coordinate: (35.860302, 8.6) m
Right-Zone Increment: 10
Radius Increments: 10

Slip Surface Limits

Left Coordinate: (0.2, 27.8) m
Right Coordinate: (52.35, 8.6) m

Piezometric Lines

Piezometric Line 1

Coordinates

	X	Y
Coordinate 1	0.2 m	24.8 m
Coordinate 2	0.7 m	24.8 m
Coordinate 3	4 m	24.8 m
Coordinate 4	5.4 m	24.8 m
Coordinate 5	6.9 m	24.8 m
Coordinate 6	7.9 m	24.6 m
Coordinate 7	9.2 m	24.2 m
Coordinate 8	10.9 m	23.5 m
Coordinate 9	12 m	22.9 m
Coordinate 10	13.1 m	22 m
Coordinate 11	14.1 m	20.7 m
Coordinate 12	15.3 m	18.75 m
Coordinate 13	16.85 m	16.1 m
Coordinate 14	18.15 m	14.15 m
Coordinate 15	19 m	13.15 m
Coordinate 16	20.4 m	11.7 m
Coordinate 17	21.5 m	10.4 m
Coordinate 18	23.3 m	8.4 m
Coordinate 19	25.45 m	7.25 m
Coordinate 20	27.7 m	6.7 m
Coordinate 21	29.8 m	6.25 m
Coordinate 22	31.95 m	5.9 m
Coordinate 23	35.35 m	5.45 m

Coordinate 24	39.05 m	5.25 m
Coordinate 25	52.3 m	5.3 m

Reinforcements

Reinforcement 1

Type: Nail
Outside Point: (34.55, 9.5) m
Inside Point: (23.273688, 5.39576) m
Slip Surface Intersection: (33.423865, 9.0901207) m
Length: 12 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 250 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 32.724923 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 21.156628 kN/m
Available Length: 10.801592 m
Required Length: 2.6619195 m
Governing Component: Tensile Capacity

Reinforcement 2

Type: Nail
Outside Point: (33.875, 10.85) m
Inside Point: (22.598689, 6.745758) m
Slip Surface Intersection: (31.341628, 9.9279277) m
Length: 12 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 250 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 32.724923 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 21.156628 kN/m
Available Length: 9.304041 m
Required Length: 2.6619195 m
Governing Component: Tensile Capacity

Reinforcement 3

Type: Nail
Outside Point: (33.205, 12.19) m
Inside Point: (21.928688, 8.085759) m

Slip Surface Intersection: (29.533828, 10.853803) m
Length: 12 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 250 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 32.724923 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 21.156628 kN/m
Available Length: 8.0932203 m
Required Length: 2.6619195 m
Governing Component: Tensile Capacity

Reinforcement 4

Type: Nail
Outside Point: (32.53, 13.54) m
Inside Point: (21.253688, 9.435759) m
Slip Surface Intersection: (27.913551, 11.859751) m
Length: 12 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 250 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 32.724923 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 21.156628 kN/m
Available Length: 7.0872785 m
Required Length: 2.6619195 m
Governing Component: Tensile Capacity

Reinforcement 5

Type: Nail
Outside Point: (29.548243, 15.51) m
Inside Point: (18.271931, 11.405759) m
Slip Surface Intersection: (25.259315, 13.948958) m
Length: 12 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 225 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN

Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 29.452431 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 19.040965 kN/m
Available Length: 7.4358184 m
Required Length: 2.9576883 m
Governing Component: Tensile Capacity

Reinforcement 6

Type: Nail
Outside Point: (28.869331, 16.84) m
Inside Point: (17.593019, 12.735759) m
Slip Surface Intersection: (24.081946, 15.097535) m
Length: 12 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 198 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 25.918139 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 16.756049 kN/m
Available Length: 6.9053719 m
Required Length: 3.3610094 m
Governing Component: Tensile Capacity

Reinforcement 7

Type: Nail
Outside Point: (28.185314, 18.18) m
Inside Point: (16.909002, 14.075759) m
Slip Surface Intersection: (23.008655, 16.295851) m
Length: 12 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 170 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 22.252948 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 14.386507 kN/m
Available Length: 6.4911149 m
Required Length: 3.9145875 m

Governing Component: Tensile Capacity

Reinforcement 8

Type: Nail
Outside Point: (27.501297, 19.52) m
Inside Point: (16.224985, 15.415759) m
Slip Surface Intersection: (22.044495, 17.533887) m
Length: 12 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 145 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 18.980456 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 12.270844 kN/m
Available Length: 6.1929932 m
Required Length: 4.5895163 m
Governing Component: Tensile Capacity

Reinforcement 9

Type: Nail
Outside Point: (24.5, 21.5) m
Inside Point: (16.042766, 18.421819) m
Slip Surface Intersection: (20.451525, 20.026476) m
Length: 9.0000003 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 145 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 18.980456 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 12.270844 kN/m
Available Length: 4.691703 m
Required Length: 4.5895163 m
Governing Component: Tensile Capacity

Reinforcement 10

Type: Nail
Outside Point: (23.83, 22.84) m
Inside Point: (15.372766, 19.761819) m
Slip Surface Intersection: (19.769402, 21.362063) m
Length: 9.0000003 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed

Face Anchorage: Yes
Pullout Resistance: 145 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 18.980456 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 12.270844 kN/m
Available Length: 4.6788023 m
Required Length: 4.5895163 m
Governing Component: Tensile Capacity

Reinforcement 11

Type: Nail
Outside Point: (23.16, 24.18) m
Inside Point: (14.702766, 21.101819) m
Slip Surface Intersection: (19.181715, 22.732023) m
Length: 9.0000003 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 145 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 18.980456 kN/m
Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 56.31724 kN
Pullout Force per Length: 12.270844 kN/m
Available Length: 4.7663983 m
Required Length: 4.5895163 m
Governing Component: Tensile Capacity

Reinforcement 12

Type: Nail
Outside Point: (22.485, 25.53) m
Inside Point: (14.027766, 22.451819) m
Slip Surface Intersection: (18.671937, 24.142159) m
Length: 9.0000003 m
Direction: 20 °
F of S Dependent: Yes
Force Distribution: Distributed
Face Anchorage: Yes
Pullout Resistance: 131 kPa
Resistance Reduction Factor: 2
Bond Diameter: 0.125 m
Nail Spacing: 1.5 m
Tensile Capacity: 196 kN
Reduction Factor: 1.5
Shear Force: 0 kN
Shear Reduction Factor: 1
Apply Shear: Parallel to Slip
Factored Pullout Resistance: 17.14786 kN/m

Max. Pullout Force: 87.111111 kN
Factored Tensile Capacity: 87.111111 kN
Pullout Force: 54.789854 kN
Pullout Force per Length: 11.086073 kN/m
Available Length: 4.9422238 m
Required Length: 4.9422238 m
Governing Component: Pullout Resistance

Surcharge Loads

Surcharge Load 1
Surcharge (Unit Weight): 10 kN/m³
Direction: Vertical

Coordinates

	X	Y
	0.2 m	28.8 m
	16.6 m	28.8 m

Points

	X	Y
Point 1	0.2 m	27.8 m
Point 2	21.35 m	27.8 m
Point 3	24.95 m	20.6 m
Point 4	26.95 m	20.6 m
Point 5	30 m	14.625 m
Point 6	32 m	14.626338 m
Point 7	35 m	8.6 m
Point 8	52.35 m	8.6 m
Point 9	52.3 m	-4.2 m
Point 10	0.25 m	-4.25 m
Point 11	22.85 m	24.8 m
Point 12	0.2 m	24.8 m
Point 13	32.2 m	14.2 m
Point 14	17.2 m	14.3 m
Point 15	0.2 m	14.3 m

Regions

	Material	Points	Area
Region 1	SPT<10	1,2,11,12	65.7 m²
Region 2	SPT 10-30	3,4,5,6,13,14,15,12,11	279.59 m²
Region 3	SPT>50	7,8,9,10,15,14,13	857.53 m²

Slip Results
Slip Surfaces Analysed: 121 of 1331 converged

Current Slip Surface
Slip Surface: 130
Factor of Safety: 1.547
Volume: 98.406281 m³

Weight: 1,841.0899 kN
Resisting Moment: 44,812.819 kN·m
Activating Moment: 28,969.043 kN·m
Resisting Force: 2,068.8436 kN
Activating Force: 1,337.6158 kN
Slip Rank: 1 of 1,331 slip surfaces
Exit: (35, 8.6) m
Entry: (17.772, 27.8) m
Radius: 23.776175 m
Center: (41.252278, 31.539387) m

Slip Slices

	X	Y	PWP	Base Normal Stress (kPa)	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Slice 1	17.961 m	26.85939 m	-121.8607 kPa	3.1877535	1.8404503 kPa	2 kPa	0 kPa	SPT<10
Slice 2	18.300622 m	25.35939 m	-111.66832 kPa	14.037494	8.1045509 kPa	2 kPa	0 kPa	SPT<10
Slice 3	18.725622 m	23.982135 m	-103.06507 kPa	26.754175	16.07553 kPa	3 kPa	0 kPa	SPT 10-30
Slice 4	19.35 m	22.331724 m	-93.600208 kPa	44.093639	26.494131 kPa	3 kPa	0 kPa	SPT 10-30
Slice 5	20.05 m	20.807695 m	-85.764124 kPa	62.487753	37.54643 kPa	3 kPa	0 kPa	SPT 10-30
Slice 6	20.6375 m	19.702584 m	-81.233991 kPa	83.731061	50.310697 kPa	3 kPa	0 kPa	SPT 10-30
Slice 7	21.1125 m	18.910216 m	-78.968531 kPa	94.083975	56.531356 kPa	3 kPa	0 kPa	SPT 10-30
Slice 8	21.425 m	18.418143 m	-77.764673 kPa	145.58651	87.477198 kPa	3 kPa	0 kPa	SPT 10-30
Slice 9	21.8375 m	17.826962 m	-76.513838 kPa	97.267192	58.444025 kPa	3 kPa	0 kPa	SPT 10-30
Slice 10	22.5125 m	16.91659 m	-74.94107 kPa	93.94724	56.449197 kPa	3 kPa	0 kPa	SPT 10-30
Slice 11	23.075 m	16.217143 m	-74.210975 kPa	100.81732	60.57716 kPa	3 kPa	0 kPa	SPT 10-30
Slice 12	23.57211 m	15.647489 m	-72.503503 kPa	89.48728	53.769382 kPa	3 kPa	0 kPa	SPT 10-30
Slice 13	24.11633 m	15.061777 m	-69.614193 kPa	93.012489	55.887542 kPa	3 kPa	0 kPa	SPT 10-30
Slice 14	24.66922 m	14.505448 m	-67.058511 kPa	84.609822	50.83871 kPa	3 kPa	0 kPa	SPT 10-30
Slice 15	25.2 m	14.003254 m	-64.917761 kPa	94.157614	65.929871 kPa	10 kPa	0 kPa	SPT>50
Slice 16	25.7 m	13.558179 m	-62.463625 kPa	104.26206	73.005081 kPa	10 kPa	0 kPa	SPT>50
Slice 17	26.2 m	13.137456 m	-59.53623 kPa	114.35164	80.069882 kPa	10 kPa	0 kPa	SPT>50
Slice 18	26.7 m	12.739448 m	-56.831598 kPa	124.39339	87.10119 kPa	10 kPa	0 kPa	SPT>50
Slice 19	27.325 m	12.274827 m	-53.773356 kPa	114.24588	79.995829 kPa	10 kPa	0 kPa	SPT>50
Slice 20	27.9625 m	11.826751 m	-50.829687 kPa	115.41625	80.815328 kPa	10 kPa	0 kPa	SPT>50
Slice 21	28.4875 m	11.482715 m	-48.559019 kPa	110.74064	77.541433 kPa	10 kPa	0 kPa	SPT>50
Slice 22	29.0125 m	11.15801 m	-46.477921 kPa	98.359342	68.871953 kPa	10 kPa	0 kPa	SPT>50
Slice 23	29.5375 m	10.851723 m	-44.577456 kPa	91.626839	64.157804 kPa	10 kPa	0 kPa	SPT>50
Slice 24	29.9 m	10.648736 m	-43.298055 kPa	107.93919	75.579836 kPa	10 kPa	0 kPa	SPT>50
Slice 25	30.325 m	10.426189 m	-41.794041 kPa	85.893152	60.143032 kPa	10 kPa	0 kPa	SPT>50
Slice 26	30.975 m	10.102174 m	-39.654142 kPa	93.3882	65.391122 kPa	10 kPa	0 kPa	SPT>50
Slice 27	31.625 m	9.8024224 m	-37.752198 kPa	108.4264	75.920986 kPa	10 kPa	0 kPa	SPT>50
Slice 28	31.975 m	9.6478856 m	-36.787964 kPa	327.66	229.43 kPa	10 kPa	0 kPa	SPT>50
Slice 29	32.1 m	9.5955832 m	-36.437282 kPa	146.81296	102.79954 kPa	10 kPa	0 kPa	SPT>50
Slice 30	32.48 m	9.4427167 m	-35.431355 kPa	93.092301	65.183931 kPa	10 kPa	0 kPa	SPT>50
Slice 31	33.04 m	9.2284945 m	-34.05735 kPa	70.648877	49.468876 kPa	10 kPa	0 kPa	SPT>50
Slice 32	33.6 m	9.0302414 m	-32.839953 kPa	64.688268	45.295213 kPa	10 kPa	0 kPa	SPT>50
Slice 33	34.16 m	8.8475385 m	-31.775057 kPa	43.921152	30.753922 kPa	10 kPa	0 kPa	SPT>50
Slice 34	34.72 m	8.6800126 m	-30.859003 kPa	7.2032664	5.0437814 kPa	10 kPa	0 kPa	SPT>50

Appendix B   Example Free Body Diagram and Force Polygon Data

Case 1: Slice Information

Slice 19 - Morgenstern-Price Method
Factor of Safety 1.547
Phi Angle 35 °
C (Strength) 10 kPa
Pore Water Pressure -53.773 kPa
Pore Water Force -49.766 kN
Pore Air Pressure 0 kPa
Pore Air Force 0 kN
Phi B Angle 0 °
Slice Width 0.75 m
Mid-Height 7.5905 m
Base Length 0.92547 m
Base Angle -35.865 °
Anisotropic Strength Mod. 1
Applied Lambda 0.48875
Weight (incl. Vert. Seismic) 107.52 kN
Base Normal Force 105.73 kN
Base Normal Stress 114.25 kPa
Base Shear Res. Force 83.288 kN
Base Shear Res. Stress 89.996 kPa
Base Shear Mob. Force 53.846 kN
Base Shear Mob. Stress 58.182 kPa
Left Side Normal Force 262.68 kN
Left Side Shear Force 127.71 kN
Right Side Normal Force 262.63 kN
Right Side Shear Force 124.69 kN
Horizontal Seismic Force 0 kN
Point Load 0 kN
Reinforcement Load Used 19.549 kN
Reinf. Shear Load Used 0 kN
Surcharge Load 0 kN
Polygon Closure 0.53761 kN
Top Left Coordinate 26.95, 20.6 m
Top Right Coordinate 27.7, 19.130738 m
Bottom Left Coordinate 26.95, 12.545933 m
Bottom Right Coordinate 27.7, 12.003722 m

Appendix C Calculation, details parameters used and cost involved

(i) Nail inclination, spacing, length and cost per number of nails **before** reanalysis to the Case 1 and Case 6

*Note: All calculation in a computer-generated and all decimal places is taken into account for more precise value.

	Nail Row	Nail inclination (degrees)	Nail Spacing (m)	Tensile Capasity (KN)	Bond Diameter (m)	Nail Length (m)	Cost per Number (RM)
Before reanalysis Case 1, FOS = 1.984	1	20	1.5	196	0.125	15	2,856.50
	2	20	1.5	196	0.125	15	2,856.50
	3	20	1.5	196	0.125	15	2,856.50
	4	20	1.5	196	0.125	15	2,856.50
	5	20	1.5	196	0.125	15	2,856.50
	6	20	1.5	196	0.125	15	2,856.50
	7	20	1.5	196	0.125	15	2,856.50
	8	20	1.5	196	0.125	15	2,856.50
	9	20	1.5	196	0.125	12	2,570.00
	10	20	1.5	196	0.125	12	2,570.00
	11	20	1.5	196	0.125	12	2,570.00
	12	20	1.5	196	0.125	12	2,570.00
Before reanalysis Case 6, FOS = 1.735	1	20	1.5	322	0.125	9	2133.00
	2	20	1.5	322	0.125	9	2133.00
	3	20	1.5	322	0.125	9	2133.00
	4	20	1.5	322	0.125	9	2133.00
	5	20	1.5	322	0.125	6	1560.00
	6	20	1.5	322	0.125	6	1560.00
	7	20	1.5	322	0.125	6	1560.00
	8	20	1.5	322	0.125	6	1560.00

(ii) Calculation cost **before** reanalysis to Case 1 and Case 6

Case 1

Unit Price per number of nail (RM)	*18 m = 3060 15 m = 2856.5 12 m = 2570 9 m = 2133 6 m = 1560 3 m = 849*									
Wall Length	81	m								
Nail Spacing	1.5	m								
Berm	3	no./nos.								
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point									
	81	-	1	÷	1.5	+	1	=	54	points
Total points per berm	54	x	4	Rows				=	217	points
Grand Total Point	217	x	3	Berms				=	652	points
First Berm (RM)	4	rows	Rate =	2856.5	x	4	x	54	=	620,812.67
Second Berm (RM)	4	rows	Rate =	2856.5	x	4	x	54	=	620,812.67
Third Berm (RM)	4	rows	Rate =	2570	x	4	x	54	=	558,546.67
							Total cost RM			**1,800,172.00**

Case 6

Unit Price per number of nail (RM)	*18 m = 3060*		*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	125	m										
Nail Spacing	1.5	m										
Berm	2	no./nos.										
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point											
	125	-	1	÷	1.5	+	1		=	84	points	
Total points per berm	84	x	4	rows					=	335	points	
Grand Total Point	335	x	2	Berms					=	669	points	
First Berm (RM)	4	rows		Rate =	2133.0	x	4	x	84	=	713,844.00	
Second Berm (RM)	4	rows		Rate =	1560.0	x	4	x	84	=	522,080.00	
Third Berm (RM)		rows		Rate =		x	0	x	84	=	0.00	
								Total cost RM			**1,235,924.00**	

(iii) After nail length adjusted and cost per number of nails **after** reanalysis to Case 1 and Case 6

	Nail Row	Nail inclination (degrees)	Nail Spacing (m)	Tensile Capasity (KN)	Bond Diameter (m)	Nail Length (m)	Cost per Number (RM)
After reanalysis Case 1, FOS = 1.547	1	20	1.5	196	0.125	9	2133.00
	2	20	1.5	196	0.125	9	2133.00
	3	20	1.5	196	0.125	9	2133.00
	4	20	1.5	196	0.125	9	2133.00
	5	20	1.5	196	0.125	12	2570.00
	6	20	1.5	196	0.125	12	2570.00
	7	20	1.5	196	0.125	12	2570.00
	8	20	1.5	196	0.125	12	2570.00
	9	20	1.5	196	0.125	12	2570.00
	10	20	1.5	196	0.125	12	2570.00
	11	20	1.5	196	0.125	12	2570.00
	12	20	1.5	196	0.125	12	2570.00
After reanalysis Case 6, FOS = 1.660	1	20	1.5	322	0.125	6	1560.00
	2	20	1.5	322	0.125	6	1560.00
	3	20	1.5	322	0.125	6	1560.00
	4	20	1.5	322	0.125	6	1560.00
	5	20	1.5	322	0.125	6	1560.00
	6	20	1.5	322	0.125	6	1560.00
	7	20	1.5	322	0.125	6	1560.00
	8	20	1.5	322	0.125	6	1560.00

(iv) Calculation cost **after** reanalysis to Case 1 and Case 6

Case 1

Unit Price per number of nail (RM)	*18 m = 3060*		*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*
Wall Length	81	m									
Nail Spacing	1.5	m									
Berm	3	no./nos.									
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point										
	81	-	1	÷	1.5	+	1		=	54	points
Total points per berm	54	x	4	rows					=	217	points
Grand Total Point	217	x	3	Berms					=	652	points
First Berm (RM)	4	rows		Rate =	2133.0	x	4	x	54	=	463,572.00
Second Berm (RM)	4	rows		Rate =	2570.0	x	4	x	54	=	558,546.67
Third Berm (RM)	4	rows		Rate =	2570.0	x	4	x	54	=	558,546.67
								Total cost RM			**1,580,665.33**

Case 6

Unit Price per number of nail (RM)	*18 m = 3060*		*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*
Wall Length	125	m									
Nail Spacing	1.5	m									
Berm	2	no./nos.									
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point										
	125	-	1	÷	1.5	+	1		=	84	points
Total points per berm	84	x	4	rows					=	335	points
Grand Total Point	335	x	2	Berms					=	669	points
First Berm (RM)	4	rows		Rate =	1560.0	x	4	x	84	=	522,080.00
Second Berm (RM)	4	rows		Rate =	1560.0	x	4	x	84	=	522,080.00
Third Berm (RM)		rows		Rate =		x	0	x	84	=	0.00
								Total cost RM			**1,044,160.00**

(v) Nail inclination, spacing, length and cost per number of nails **before** reanalysis to the Case 3, Case 7 and Case 9

	Nail Row	Nail inclination (degrees)	Nail Spacing (m)	Tensile Capasity (KN)	Bond Diameter (m)	Nail Length (m)	Cost per Number (RM)
Before reanalysis Case 3, FOS = 2.115	1	20	1.5	322	0.125	9	2133.00
	2	20	1.5	322	0.125	9	2133.00
	3	20	1.5	322	0.125	9	2133.00
	4	20	1.5	322	0.125	9	2133.00
Before reanalysis Case 7, FOS = 2.306	1	25	1.5	322	0.125	12	2570.00
	2	25	1.5	322	0.125	12	2570.00
	3	25	1.5	322	0.125	12	2570.00
	4	25	1.5	322	0.125	12	2570.00

Before reanalysis Case 9, FOS = 1.589	1	10	1.5	196	0.125	15	2856.50
	2	10	1.5	196	0.125	15	2856.50
	3	10	1.5	196	0.125	15	2856.50
	4	10	1.5	196	0.125	15	2856.50
	5	10	1.5	196	0.125	12	2570.00
	6	10	1.5	196	0.125	12	2570.00
	7	10	1.5	196	0.125	12	2570.00
	8	10	1.5	196	0.125	12	2570.00
	9	10	1.5	196	0.125	12	2570.00
	10	10	1.5	196	0.125	12	2570.00
	11	10	1.5	196	0.125	12	2570.00
	12	10	1.5	196	0.125	12	2570.00

(vi) Calculation cost **before** reanalysis to the Case 3, Case 7 and Case 9

Case 3

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*		*12 m = 2570*	*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	80	m								
Nail Spacing	1.5	m								
Berm	1	no./nos.								
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point									
	80	-	1	÷	1.5	+	1	=	54	points
Total points per berm	54	x	4	rows				=	215	points
Grand Total Point	215	x	1	Berms				=	215	points
First Berm (RM)	4	rows	Rate =	2133.0	x	4	x	54	=	457,884.00
Second Berm (RM)		rows	Rate =		x	0	x	54	=	0.00
Third Berm (RM)		rows	Rate =		x	0	x	54	=	0.00
							Total cost RM			**457,884.00**

Case 7

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*		*12 m = 2570*	*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	70	m								
Nail Spacing	1.5	m								
Berm	1	no./nos.								
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point									
	70	-	1	÷	1.5	+	1	=	47	points
Total points per berm	47	x	4	rows				=	188	points
Grand Total Point	188	x	1	Berms				=	188	points
First Berm (RM)	4	rows	Rate =	2570.0	x	4	x	47	=	483,160.00
Second Berm (RM)		rows	Rate =		x	0	x	47	=	0.00
Third Berm (RM)		rows	Rate =		x	0	x	47	=	0.00
							Total cost RM			**483,160.00**

Case 9

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*	*12 m = 2570*	*9 m = 2133*	*6 m = 1560*	*3 m = 849*						
Wall Length	105	m										
Nail Spacing	1.5	m										
Berm	3	no./nos.										
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point											
	105	-	1	÷	1.5	+	1		=	70	points	
Total points per berm	70	x	4	rows					=	281	points	
Grand Total Point	281	x	3	Berms					=	844	points	
First Berm (RM)	4	rows	Rate =	2856.5	x	4	x	70	=	803,628.67		
Second Berm (RM)	4	rows	Rate =	2570.0	x	4	x	70	=	723,026.67		
Third Berm (RM)	4	rows	Rate =	2570.0	x	4	x	70	=	723,026.67		
								Total cost RM		**2,249,682.00**		

(vii) Nail inclination, spacing, length and cost per number of nails **after** reanalysis to the Case 3, Case 7 and Case 9

	Nail Row	Nail inclination (degrees)	Nail Spacing (m)	Tensile Capasity (KN)	Bond Diameter (m)	Nail Length (m)	Cost per Number (RM)
After reanalysis Case 3, FOS = 1.696	1	15	1.5	322	0.125	6	1560.00
	2	15	1.5	322	0.125	6	1560.00
	3	15	1.5	322	0.125	6	1560.00
	4	15	1.5	322	0.125	6	1560.00
After reanalysis Case 7, FOS = 1.534	1	20	1.5	322	0.125	6	1560.00
	2	20	1.5	322	0.125	6	1560.00
	3	20	1.5	322	0.125	6	1560.00
	4	20	1.5	322	0.125	3	849.00
After reanalysis Case 9, FOS = 1.528	1	20	1.5	196	0.125	12	2570.00
	2	20	1.5	196	0.125	12	2570.00
	3	20	1.5	196	0.125	12	2570.00
	4	20	1.5	196	0.125	12	2570.00
	5	20	1.5	196	0.125	9	2133.00
	6	20	1.5	196	0.125	9	2133.00
	7	20	1.5	196	0.125	9	2133.00
	8	20	1.5	196	0.125	9	2133.00
	9	20	1.5	196	0.125	9	2133.00
	10	20	1.5	196	0.125	9	2133.00
	11	20	1.5	196	0.125	9	2133.00
	12	20	1.5	196	0.125	9	2133.00

(viii) Calculation cost **after** reanalysis to the Case 3, Case 7 and Case 9

Case 3

Unit Price per number of nail (RM)	*18 m = 3060*		*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	80	m										
Nail Spacing	1.5	m										
Berm	1	no./nos.										
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point											
	80	-	1	÷	1.5	+	1		=	54	points	
Total points per berm	54	x	4	Rows					=	215	points	
Grand Total Point	215	x	1	Berms					=	215	points	
First Berm (RM)	4	rows		Rate =	1560.0	x	4	x	54	=	334,880.00	
Second Berm (RM)		rows		Rate =		x	0	x	54	=	0.00	
Third Berm (RM)		rows		Rate =		x	0	x	54	=	0.00	
								Total cost RM			**334,880.00**	

Case 7

Unit Price per number of nail (RM)	*18 m = 3060*		*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	70	m										
Nail Spacing	1.5	m										
Berm	1	no./nos.										
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point											
	70	-	1	÷	1.5	+	1		=	47	points	
Total points per berm	47	x	4	Rows					=	188	points	
Grand Total Point	188	x	1	Berms					=	188	points	
First Berm (RM)	3	rows		Rate =	1560.0	x	3	x	47	=	219,960.00	
Second Berm (RM)	1	rows		Rate =	849.0	x	1	x	47	=	39,903.00	
Third Berm (RM)		rows		Rate =		x	0	x	47	=	0.00	
								Total cost RM			**259,863.00**	

Case 9

Unit Price per number of nail (RM)	*18 m = 3060*		*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	105	m										
Nail Spacing	1.5	m										
Berm	3	no./nos.										
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point											
	105	-	1	÷	1.5	+	1		=	70	points	
Total points per berm	70	x	4	rows					=	281	points	
Grand Total Point	281	x	3	Berms					=	844	points	
First Berm (RM)	4	rows		Rate =	2570.0	x	4	x	70	=	723,026.67	
Second Berm (RM)	4	rows		Rate =	2133.0	x	4	x	70	=	600,084.00	
Third Berm (RM)	4	rows		Rate =	2133.0	x	4	x	70	=	600,084.00	
								Total cost RM			**1,923,194.67**	

(ix) Nail inclination, spacing, length and cost per number of nails **before** reanalysis to the Case 2, Case 4, Case 5, Case 8 and Case 10

	Nail Row	Nail inclination (degrees)	Nail Spacing (m)	Tensile Capasity (KN)	Bond Diameter (m)	Nail Length (m)	Cost per Number (RM)
Before reanalysis Case 2, FOS = 1.997	1	15	1.5	322	0.125	9	2,133.00
	2	15	1.5	322	0.125	9	2,133.00
	3	15	1.5	322	0.125	9	2,133.00
	4	15	1.5	322	0.125	9	2,133.00
	5	15	1.5	322	0.125	9	2,133.00
	6	15	1.5	322	0.125	9	2,133.00
	7	15	1.5	322	0.125	9	2,133.00
	8	15	1.5	322	0.125	6	1,560.00
Before reanalysis Case 4, FOS = 1.747	1	25	1.0	322	0.125	12	2856.50
	2	25	1.0	322	0.125	12	2856.50
	3	25	1.0	322	0.125	12	2856.50
	4	25	1.0	322	0.125	12	2856.50
	5	25	1.0	322	0.125	12	2856.50
	6	25	1.0	322	0.125	12	2856.50
	7	25	1.0	322	0.125	12	2856.50
	8	25	1.0	322	0.125	12	2856.50
Before reanalysis Case 5, FOS = 1.813	1	15	1.0	196	0.125	12	2570.00
	2	15	1.0	196	0.125	12	2570.00
	3	15	1.0	196	0.125	12	2570.00
	4	15	1.0	196	0.125	12	2570.00
	5	15	1.0	196	0.125	12	2570.00
	6	15	1.0	196	0.125	12	2570.00
	7	15	1.0	196	0.125	12	2570.00
	8	15	1.0	196	0.125	12	2570.00
	9	15	1.0	196	0.125	12	2570.00
	10	15	1.0	196	0.125	12	2570.00
	11	15	1.0	196	0.125	12	2570.00
	12	15	1.0	196	0.125	12	2570.00
Before reanalysis Case 8, FOS = 1.628	1	10	1.2	322	0.125	15	2856.50
	2	10	1.2	322	0.125	15	2856.50
	3	10	1.2	322	0.125	15	2856.50
	4	10	1.2	322	0.125	15	2856.50
	5	10	1.2	322	0.125	15	2856.50
	6	10	1.2	322	0.125	15	2856.50
	7	10	1.2	322	0.125	15	2856.50
	8	10	1.2	322	0.125	15	2856.50
Before reanalysis Case 10, FOS = 1.597	1	10	1.5	322	0.125	12	2570.00
	2	10	1.5	322	0.125	12	2570.00
	3	10	1.5	322	0.125	12	2570.00
	4	10	1.5	322	0.125	12	2570.00
	5	10	1.0	322	0.125	9	2133.00
	6	10	1.0	322	0.125	9	2133.00
	7	10	1.0	322	0.125	9	2133.00
	8	10	1.0	322	0.125	9	2133.00

(x) Calculation cost **before** reanalysis to the Case 2, Case 4, Case 5, Case 8 and Case 10

Case 2

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	110	m									
Nail Spacing	1.5	m									
Berm	2	no./nos.									
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point										
	110	-	1	÷	1.5	+	1		=	74	points
Total points per berm	74	x	4	rows					=	295	points
Grand Total Point	295	x	2	Berms					=	589	points
First Berm (RM)	4	rows		Rate =	2133.0	x	4	x	74	=	628,524.00
Second Berm (RM)	3	rows		Rate =	2133.0	x	3	x	74	=	471,393.00
Third Berm (RM)	1	rows		Rate =	1560.0	x	1	x	74	=	114,920.00
									Total cost RM		**1,214,837.00**

Case 4

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	130	m									
Nail Spacing	1.0	m									
Berm	2	no./nos.									
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point										
	130	-	1	÷	1.0	+	1		=	130	points
Total points per berm	130	x	4	rows					=	520	points
Grand Total Point	520	x	2	Berms					=	1040	points
First Berm (RM)	4	rows		Rate =	2570.0	x	4	x	130	=	1,336,400.00
Second Berm (RM)	4	rows		Rate =	2570.0	x	4	x	130	=	1,336,400.00
Third Berm (RM)		rows		Rate =		x	0	x	130	=	0.00
									Total cost RM		**2,672,800.00**

Case 5

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*		*6 m = 1560*		*3 m = 849*	
Wall Length	160	m									
Nail Spacing	1.0	m									
Berm	3	no./nos.									
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point										
	160	-	1	÷	1.0	+	1		=	160	points
Total points per berm	160	x	4	rows					=	640	points
Grand Total Point	640	x	3	Berms					=	1920	points
First Berm (RM)	4	rows		Rate =	2570.0	x	4	x	160	=	1,644,800.00
Second Berm (RM)	4	rows		Rate =	2570.0	x	4	x	160	=	1,644,800.00
Third Berm (RM)	4	rows		Rate =	2570.0	x	4	x	160	=	1,644,800.00
									Total cost RM		**4,934,400.00**

Case 8

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*	*12 m = 2570*	*9 m = 2133*	*6 m = 1560*	*3 m = 849*						
Wall Length	165	m										
Nail Spacing	1.2	m										
Berm	2	no./nos.										
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point											
	165	-	1	÷	1.2	+	1		=	138	points	
Total points per berm	138	x	4	rows					=	551	points	
Grand Total Point	551	x	2	Berms					=	1101	points	
First Berm (RM)	4	rows	Rate =	2856.5	x	4	x	138	=	1,572,979.33		
Second Berm (RM)	4	rows	Rate =	2856.5	x	4	x	138	=	1,572,979.33		
Third Berm (RM)		rows	Rate =		x	0	x	138	=	0.00		
								Total cost RM		**3,145,958.67**		

Case 10

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*	*12 m = 2570*	*9 m = 2133*	*6 m = 1560*	*3 m = 849*						
Wall Length	155	m										
Nail Spacing	1.5	m	and	1	m							
Berm	2	no./nos.										
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point											
	155	-	1	÷	1.5	+	1		=	104	points	
Total points per berm	104	x	4	Rows					=	415	points	
Total of point in second row (point)	Length - Edged both side ÷ Nail Spacing + Starting point											
	155	-	1	÷	1	+	1		=	155	points	
Total Point per berm	155	x	4	Rows					=	620	points	
Grand Total Point										1035	points	
First Berm (RM)	4	rows	Rate =	2570	x	4	x	104	=	1,065,693.33		
Second Berm (RM)	4	rows	Rate =	2133	x	4	x	155	=	1,322,460.00		
								Total cost RM		**2,388,153.33**		

(xi) Nail inclination, spacing, length and cost per number of nails **after** reanalysis to the Case 2, Case 4, Case 5, Case 8 and Case 10

	Nail Row	Nail inclination (degrees)	Nail Spacing (m)	Tensile Capasity (KN)	Bond Diameter (m)	Nail Length (m)	Cost per Number (RM)
After reanalysis Case 2, FOS = 1.501	1	20	2.0	322	0.125	9	2,133.00
	2	20	2.0	322	0.125	9	2,133.00
	3	20	2.0	322	0.125	9	2,133.00
	4	20	2.0	322	0.125	9	2,133.00
	5	20	2.0	322	0.125	6	1,560.00
	6	20	2.0	322	0.125	6	1,560.00
	7	20	2.0	322	0.125	6	1,560.00
	8	20	2.0	322	0.125	6	1560.00
After reanalysis Case 4, FOS = 1.516	1	20	1.5	322	0.125	12	2856.50
	2	20	1.5	322	0.125	12	2856.50
	3	20	1.5	322	0.125	12	2856.50
	4	20	1.5	322	0.125	12	2856.50
	5	20	1.5	322	0.125	12	2856.50
	6	20	1.5	322	0.125	9	2133.00
	7	20	1.5	322	0.125	9	2133.00
	8	20	1.5	322	0.125	9	2133.00
After reanalysis Case 5, FOS = 1.523	1	20	1.5	196	0.125	9	2133.00
	2	20	1.5	196	0.125	9	2133.00
	3	20	1.5	196	0.125	9	2133.00
	4	20	1.5	196	0.125	9	2133.00
	5	20	1.5	196	0.125	9	2133.00
	6	20	1.5	196	0.125	9	2133.00
	7	20	1.5	196	0.125	9	2133.00
	8	20	1.5	196	0.125	9	2133.00
	9	20	1.5	196	0.125	9	2133.00
	10	20	1.5	196	0.125	9	2133.00
	11	20	1.5	196	0.125	9	2133.00
	12	20	1.5	196	0.125	9	2133.00
After reanalysis Case 8, FOS = 1.549	1	20	1.5	322	0.125	15	2856.50
	2	20	1.5	322	0.125	15	2856.50
	3	20	1.5	322	0.125	15	2856.50
	4	20	1.5	322	0.125	15	2856.50
	5	20	1.5	322	0.125	12	2570.00
	6	20	1.5	322	0.125	12	2570.00
	7	20	1.5	322	0.125	12	2570.00
	8	20	1.5	322	0.125	12	2570.00
After reanalysis Case 10, FOS = 1.591	1	15	1.8	322	0.125	12	2,570.00
	2	15	1.8	322	0.125	12	2,570.00
	3	15	1.8	322	0.125	12	2,570.00
	4	15	1.8	322	0.125	12	2,570.00
	5	15	1.8	322	0.125	12	2,570.00
	6	15	1.8	322	0.125	12	2,570.00
	7	15	1.8	322	0.125	12	2,570.00
	8	15	1.8	322	0.125	12	2,570.00

(xii) Calculation cost **after** reanalysis to the Case 2, Case 4, Case 5, Case 8 and Case 10

Case 2

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*			*6 m = 1560*		*3 m = 849*		
Wall Length	110	m											
Nail Spacing	2.0	m											
Berm	2	no./nos.											
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point												
	110	-	1	÷		2.0	+	1		=	56	points	
Total points per berm	56	x	4	rows						=	222	points	
Grand Total Point	222	x	2	Berms						=	444	points	
First Berm (RM)	4	rows		Rate =	2133.0	x	4	x	56	=		473,526.00	
Second Berm (RM)	4	rows		Rate =	1560.0	x	4	x	56	=		346,320.00	
Third Berm (RM)		rows		Rate =		x	0	x	56	=		0.00	
									Total cost RM			**819,846.00**	

Case 4

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*			*6 m = 1560*		*3 m = 849*		
Wall Length	130	m											
Nail Spacing	1.5	m											
Berm	2	no./nos.											
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point												
	130	-	1	÷		1.5	+	1		=	87	points	
Total points per berm	87	x	4	Rows						=	348	points	
Grand Total Point	348	x	2	Berms						=	696	points	
First Berm (RM)	5	rows		Rate =	2570.0	x	5	x	87	=		1,117,950.00	
Second Berm (RM)	3	rows		Rate =	2133.0	x	3	x	87	=		556,713.00	
Third Berm (RM)		rows		Rate =		x	0	x	87	=		0.00	
									Total cost RM			**1,674,663.00**	

Case 5

Unit Price per number of nail (RM)	*18 m = 3060*	*15 m = 2856.5*		*12 m = 2570*		*9 m = 2133*			*6 m = 1560*		*3 m = 849*		
Wall Length	160	m											
Nail Spacing	1.5	m											
Berm	3	no./nos.											
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point												
	160	-	1	÷		1.5	+	1		=	107	points	
Total points per berm	107	x	4	Rows						=	428	points	
Grand Total Point	428	x	3	Berms						=	1284	points	
First Berm (RM)	4	rows		Rate =	2133.0	x	4	x	107	=		912,924.00	
Second Berm (RM)	4	rows		Rate =	2133.0	x	4	x	107	=		912,924.00	
Third Berm (RM)	4	rows		Rate =	2133.0	x	4	x	107	=		912,924.00	
									Total cost RM			**2,738,772.00**	

Case 8

Unit Price per number of nail (RM)	*18 m = 3060 15 m = 2856.5 12 m = 2570 9 m = 2133 6 m = 1560 3 m = 849*										
Wall Length	165	m									
Nail Spacing	1.5	m									
Berm	2	no./nos.									
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point										
	165	-	1	÷	1.5	+	1		=	110	points
Total points per berm	110	x	4	Rows					=	441	points
Grand Total Point	441	x	2	Berms					=	883	points
First Berm (RM)	4	rows		Rate =	2856.5	x	4	x	110	=	1,260,668.67
Second Berm (RM)	4	rows		Rate =	2570.0	x	4	x	110	=	1,134,226.67
Third Berm (RM)		rows		Rate =		x	0	x	110	=	0.00
									Total cost RM		**2,394,895.33**

Case 10

Unit Price per number of nail (RM)	*18 m = 3060 15 m = 2856.5 12 m = 2570 9 m = 2133 6 m = 1560 3 m = 849*										
Wall Length	155	m									
Nail Spacing	1.8	m									
Berm	2	no./nos.									
Total of point in one row (point)	Length - Edged both side ÷ Nail Spacing + Starting point										
	155	-	1	÷	1.8	+	1		=	87	points
Total points per berm	87	x	4	Rows					=	346	points
Grand Total Point	346	x	2	Berms					=	692	points
First Berm (RM)	4	rows		Rate =	2570.0	x	4	x	87	=	889,791.11
Second Berm (RM)	4	rows		Rate =	2570.0	x	4	x	87	=	889,791.11
Third Berm (RM)		rows		Rate =		x	0	x	87	=	0.00
									Total cost RM		**1,779,582.22**

Appendix D Sensitivity Check on Soil Nail Spacing, Inclination and Length

Case 1

Given the wall height (H = 19 m) and face batter (α = 0), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails

- Adopt $S_H = S_V = 1.5$ m Check: $S_H \times S_V = 2.25\ m^2 \leq 3.24$ to $3.78\ m^2$
- This vertical spacing results in 12 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall

The spacing between the first row and the top of the wall (S_{V0}) is selected as:
- $S_{V0} = 1.0$ m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:
- $S_{VN} = 0.75$ m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:
- *i* = 20 degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length

The maximum soil nail length is selected for a simulation at:
- L = 0.6316 H = 12 m (L between 0.4 H and 1.2H) **ok**

Case 6

Given the wall height (H = 13 m) and face batter (α = 0), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails

- Adopt $S_H = S_V = 1.5$ m Check: $S_H \times S_V = 2.25\ m^2 \leq 3.24$ to $3.78\ m^2$
- This vertical spacing results in 8 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall

The spacing between the first row and the top of the wall (S_{V0}) is selected as:
- $S_{V0} = 1.0$ m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:
- $S_{VN} = 0.75$ m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:
- *i* = 20 degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length

The maximum soil nail length is selected for a simulation at:
- L = 0.4615 H = 6 m (L between 0.4 H and 1.2H) **ok**

Case 3

Given the wall height (H = 7 m) and face batter (α = 0), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails

• Adopt $S_H = S_V = 1.5$ m Check: $S_H \times S_V = 2.25$ m$^2 \leq 3.24$ to 3.78 m^2

• This vertical spacing results in 4 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall

The spacing between the first row and the top of the wall (S_{V0}) is selected as:

• $S_{V0} = 1.0$ m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:

• $S_{VN} = 0.75$ m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:

• $i = 15$ degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length

The maximum soil nail length is selected for a simulation at:

• L = 0.4615 H = 6 m (L between 0.4 H and 1.2H) **ok**

Case 7

Given the wall height (H = 7 m) and face batter ($\alpha = 0$), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails

• Adopt $S_H = S_V = 1.5$ m Check: $S_H \times S_V = 2.25$ m$^2 \leq 3.24$ to 3.78 m^2

• This vertical spacing results in 4 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall

The spacing between the first row and the top of the wall (S_{V0}) is selected as:

• $S_{V0} = 1.0$ m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:

• $S_{VN} = 0.75$ m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:

• $i = 20$ degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length

The maximum soil nail length is selected for a simulation at:

• L = 0.4615 H = 6 m (L between 0.4 H and 1.2H) **ok**

Case 9

Given the wall height (H = 19 m) and face batter ($\alpha = 0$), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails

• Adopt $S_H = S_V = 1.5$ m Check: $S_H \times S_V = 2.25$ m$^2 \leq 3.24$ to 3.78 m^2

• This vertical spacing results in 4 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall

The spacing between the first row and the top of the wall (S_{V0}) is selected as:
• $S_{V0} = 1.0$ m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:
• $S_{VN} = 0.75$ m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination
Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:
• i = 20 degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length
The maximum soil nail length is selected for a simulation at:
• L = 0.6315 H = 12 m (L between 0.4 H and 1.2H) **ok**

Case 2
Given the wall height (H = 13 m) and face batter (α = 0), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails
• Adopt $S_H = 1.5$ m; $S_V = 2.0$ m Check: $S_H \times S_V = 3.0\ m^2 \leq 3.24$ to $3.78\ m^2$
• This vertical spacing results in 8 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall
The spacing between the first row and the top of the wall (S_{V0}) is selected as:
• $S_{V0} = 1.0$ m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:
• $S_{VN} = 0.75$ m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination
Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:
• i = 20 degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length
The maximum soil nail length is selected for a simulation at:
• L = 0.6923 H = 9 m (L between 0.4 H and 1.2H) **ok**

Case 4
Given the wall height (H = 13 m) and face batter (α = 0), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails
• Adopt $S_H = S_V = 1.5$ m Check: $S_H \times S_V = 2.25\ m^2 \leq 3.24$ to $3.78\ m^2$
• This vertical spacing results in 8 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall
The spacing between the first row and the top of the wall (S_{V0}) is selected as:
• $S_{V0} = 1.0$ m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:

• S_{VN} = 0.75 m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:

• *i* = 20 degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length

The maximum soil nail length is selected for a simulation at:

• L = 0.9231H = 12 m (L between 0.4 H and 1.2H) **ok**

Case 5

Given the wall height (H = 19 m) and face batter (α = 0), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails

• Adopt $S_H = S_V$ = 1.5 m Check: $S_H \times S_V$ = 2.25 m^2 ≤ 3.24 to 3.78 m^2

• This vertical spacing results in 12 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall

The spacing between the first row and the top of the wall (S_{V0}) is selected as:

• S_{V0} = 1.0 m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:

• S_{VN} = 0.75 m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:

• *i* = 20 degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length

The maximum soil nail length is selected for a simulation at:

• L = 0.4737 H = 9 m (L between 0.4 H and 1.2H) **ok**

Case 8

Given the wall height (H = 13 m) and face batter (α = 0), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails

• Adopt $S_H = S_V$ = 1.5 m Check: $S_H \times S_V$ = 2.25 m^2 ≤ 3.24 to 3.78 m^2

• This vertical spacing results in 8 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall

The spacing between the first row and the top of the wall (S_{V0}) is selected as:

• S_{V0} = 1.0 m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:

• S_{VN} = 0.75 m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:

• i = 20 degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length

The maximum soil nail length is selected for a simulation at:

• L = 1.1538 H = 15 m (L between 0.4 H and 1.2H) **ok**

Case 10

Given the wall height (H = 13 m) and face batter ($\alpha = 0$), the following layout is selected for simulation in SLOPE/W.

Vertical (S_V) and Horizontal (S_H) Spacing of Soil Nails

• Adopt S_H = 1.5 m S_V = 1.8 m Check: $S_H \times S_V = 2.70\ m^2 \leq 3.24$ to $3.78\ m^2$

• This vertical spacing results in 8 rows of soil nails.

Vertical Spacing at the Top and Bottom of the Wall

The spacing between the first row and the top of the wall (S_{V0}) is selected as:

• S_{V0} = 1.0 m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (S_{VN}) is:

• S_{VN} = 0.75 m ≤ 0.5 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:

• i = 15 degrees for all nails (between 15 and 25 degrees) **ok**

Soil Nail Length

The maximum soil nail length is selected for a simulation at:

• L = 0.9231 H = 12 m (L between 0.4 H and 1.2H) **ok**

Appendix E Construction Cost of Soil Nailing and Crib Wall and Crib Wall/Soil Nailing System

i) Soil Nailing Construction Cost

Soil Nail Calculation

Length	100m
Height	9.7m
c/c	1.5m
Nos. of Soil Nails	
Vertical	6
Horizontal	68
Total Nos.	408

No.	Description	Unit	Qty	Rate	Amount (RM)
1.	Plant & Equipment				
	Prorate based on Vision Team	LS			14,500.00
2.	Soil Nailing				
	Minimum required length 9m	No.	408	2,133.00	870,264.00
3.	Soil Nail Head				
	450mm x 450mm x 100mm thick	No.	408	80.00	32,640.00
4.	Pull Out Test				
	Prorate based on Vision Team	LS			5,600.00
5.	Shortcrete				
	150mm thick	M2	970	165.00	160,050.00
6.	Horizontal Drains				
	9.01m - 9m long	No.	136	660.00	89,760.00
7.	Stormwater Drainage				
	75mm thick berm/toe drain	M	300	95.00	28,500.00
					1,201,314.00

ii) Crib Wall Construction Cost

Cribwall Calculation

Length 100m
Height 9.7m
Width 5.65m

No.	Description	Unit	Qty	Rate	Amount (RM)
1.	Mobilisation	LS			22,250.00
2.	Mackintosh Probe	LS			1,085.00
3.	RC Levelling Pad to receive cribwall	M	100	400	40,000.00
4.	Cribwall Supply and install of cribwall	M2	1940	716.00	1,389,040.00
5.	Granular backfilling	M3	3654	25.00	91,350.00
6.	Perimetre U-drain 300mm x 300mm	M	100	230.00	23,000.00
					1,566,725.00

iii) Combination Hybrid System Crib Wall/Soil Nail

Soil Nail & Cribwall Calculation

Length	100m
Height	9.7m
c/c	2.0m
Nos. of Soil Nails	
Vertical	5
Horizontal	50
Total Nos.	250

No.	Description	Unit	Qty	Rate	Amount (RM)
	Soil Nail				
1.	Plant & Equipment				
	Prorate based on contractor	LS			15,000.00
2.	Soil Nailing				
	Minimum required length 12m	No.	250	2,570.00	642,500.00
3.	Soil Nail Head				
	450mm x 450mm x 100mm thick	No.	250	80.00	20,000.00
4.	Pull Out Test				
	Prorate based on Vision Team	LS			4,200.00
5.	Shortcrete				
	150mm thick	M2	970	165.00	160,050.00
6.	Horizontal Drains				
	9.01m - 12m long	No.	100	660.00	66,000.00
7.	Stormwater Drainage				
	75mm thick berm/toe drain	M	300	95.00	28,500.00
	Cribwall				
8.	RC Levelling Pad				
	to receive cribwall	M	100	249	24,900.00
9.	Cribwall				
	Supply and install of cribwall	M2	1,940.00	423.00	820,620.00
10.	Granular backfilling	M3	2,160.00	25.00	54,000.00
11.	Perimetre U-drain 300mm x 300mm	M	100	230.00	23,000.00
					1,858,770.00

iv) **Costs** of building 100 m length of **soil nailing** system and maintenance in 2 years

Name of Cost	Monetary Value	RM
Soil Nailing Design (Consultant Fees)	6% x RM 1,201,314 =	72,078.84
Land Purchase	based on RM 1940.41/m2 x 100m x 6.1m	1,183,650.10
Construction (materials & machineries)	based on the calculation in Appendix D (i).	1,201,314.00
Maintenance after construction finish/rectification defects (DLP)	based on RM 400 x 12 months x 2 years	9,600.00
	Total PVC	**2,466,642.94**

v) **Benefits** of building 100 m length of **soil nailing** system in 2 years

Name of Benefits	Monetary Value	RM
Time Saving based on work programme (14 days)	If, 1 day = RM 1,201,314 x (15% ÷ 365 days) = RM 559.36 Therefore, in 14 days =	6,911.67
Reduce Injury/Life saving	5 workers x RM 75 x 110 days	41,250.00
	2 general workers x RM 65 x 365 days x 2 years	94,900.00
Pollution Reduction	RM 2,000 x 110 days	220,000.00
	RM 2,000 x 365 days x 2 years	1,460,000.00
Create Job in 110 days plus 12 months DLP	1 gang x 5 workers x RM 75 x 110 days (project start until finish)	41,250.00
	2 general workers x RM 65 x 12 months x 2 years	3,120.00
	Total PVB	**1,867,431.67**

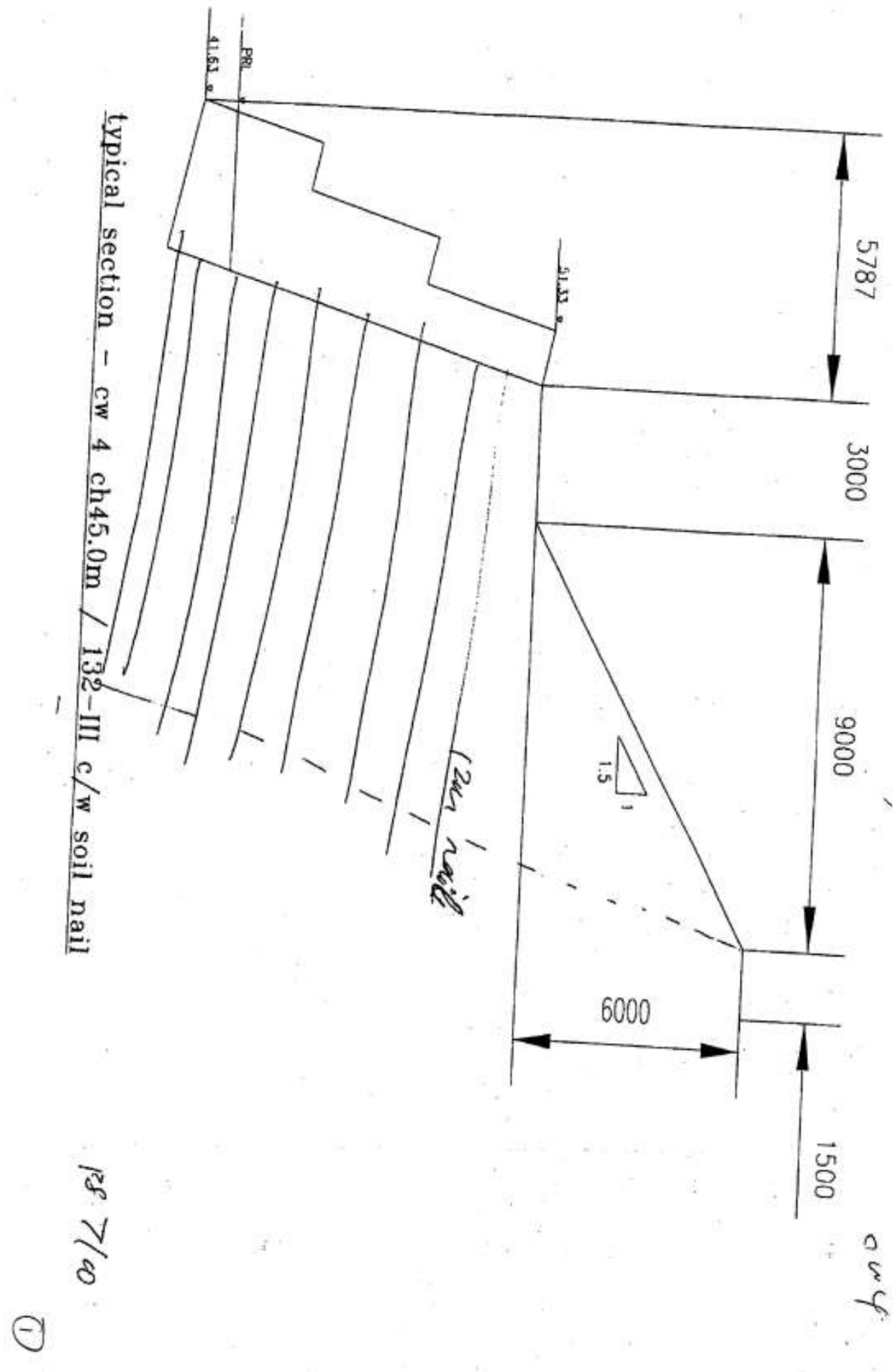
vi) **Costs** of building 100 m length of the **crib wall** system and maintenance in 2 years

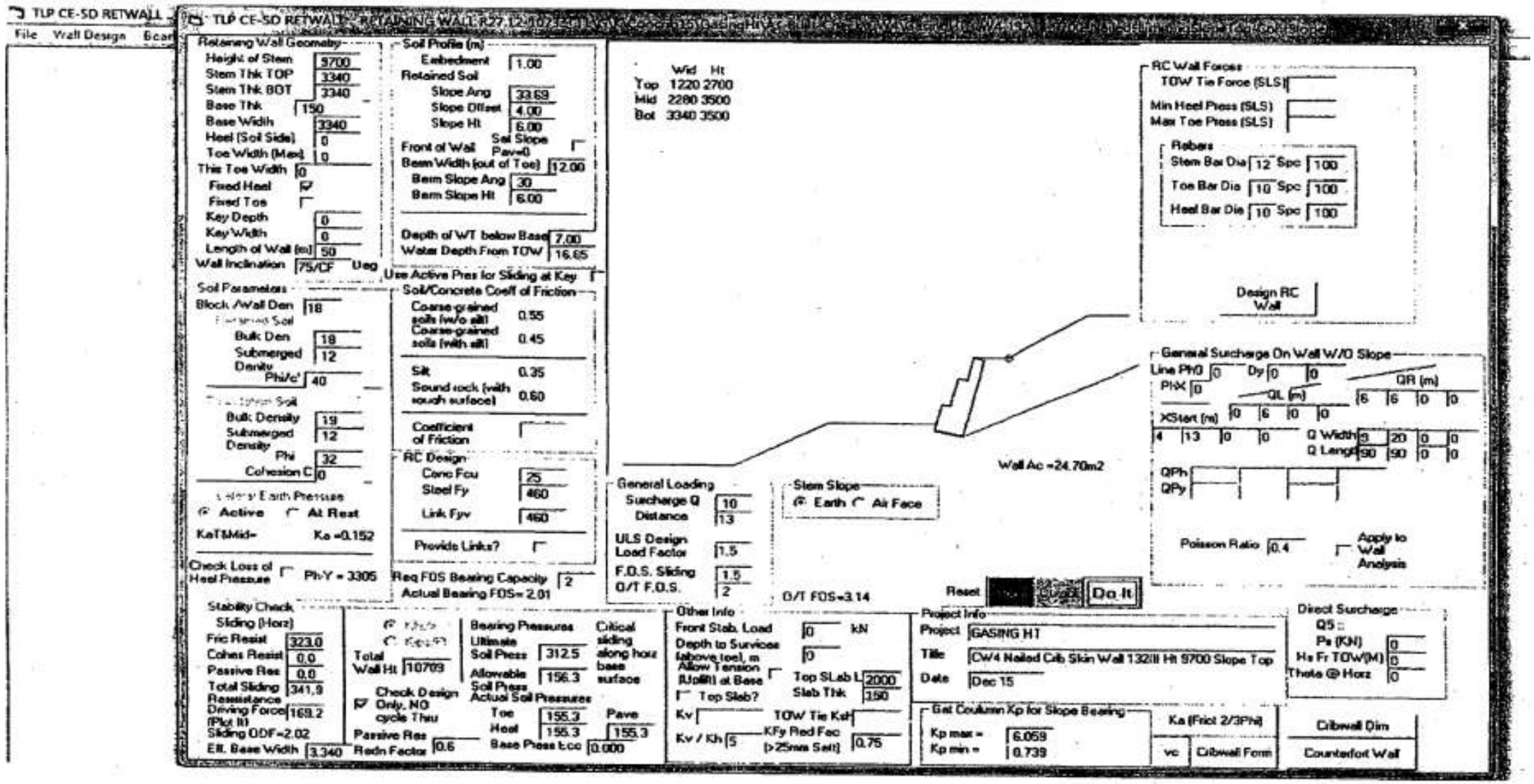
Name of Costs	Monetary Value	RM
Crib Wall Design (Consultant fees)	6% x RM 1,566,725 =	94,003.50
Construction (materials and machineries)	Based on the calculation in Appendix D (ii)	1,566,725
Maintenance after construction finish/rectification defects (DLP)	based on RM 400 x 12 months x 2 years	9,600
	Total PVC	**1,670,328.50**

vii) **Benefits** of building 100 m length of the **crib wall** system and maintenance in 2 years

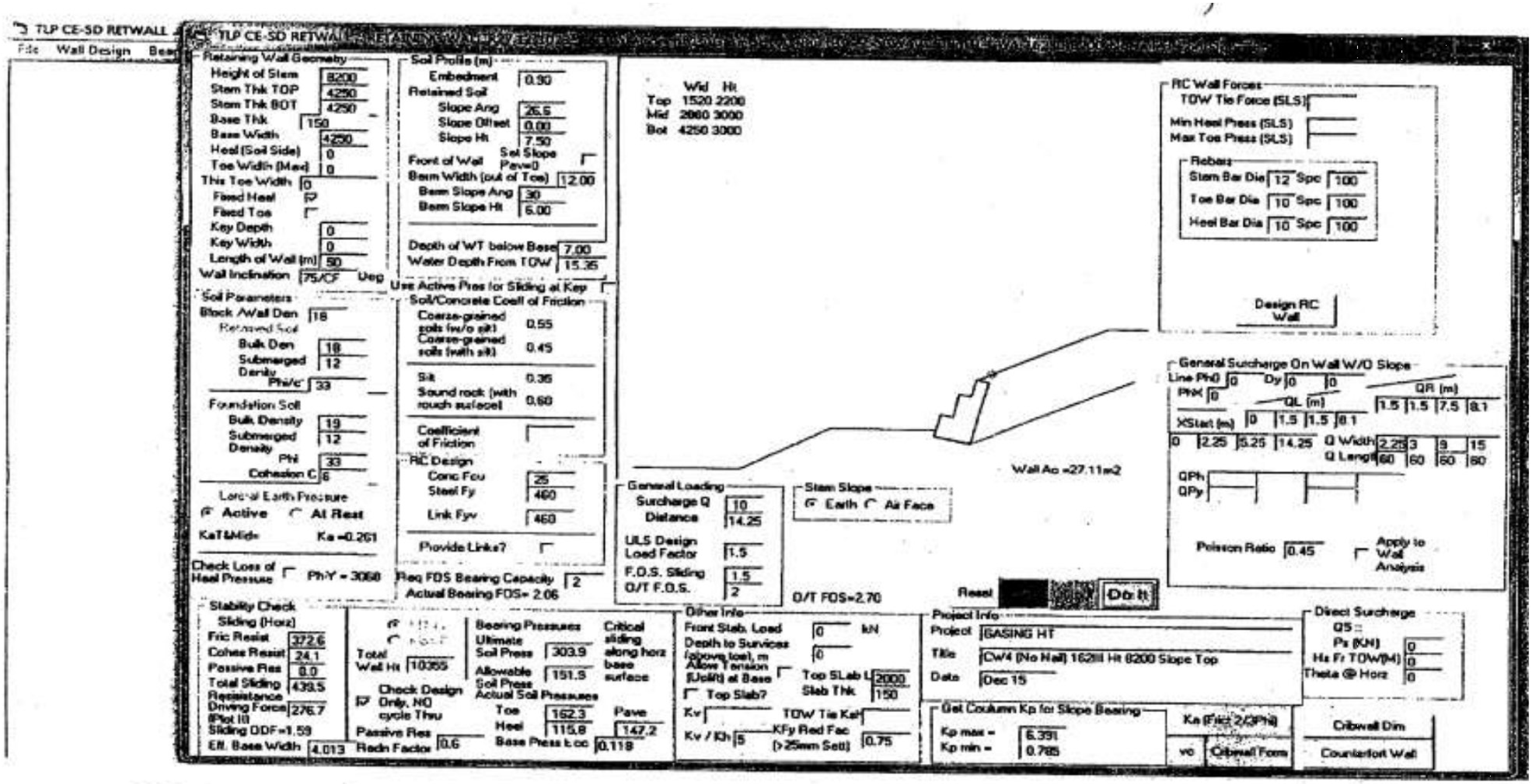
Name of Benefits	Monetary Value	RM
Time Saving (7 days from work programme)	If, 1 day = RM 1,566,725 x (15% ÷ 365 days) = RM 643.86 Therefore, in 7 days =	4,507.02
Reduce Injury/Lifesaving	1 gang x 4 workers x RM 75 x 120 days	72,000.00
	2 general workers x RM 65 x 12 months x 2 years	3,120.00
Pollution Reduction	RM 2,000 x 365 days x 2 years	1,460,000.00
	RM 2,000 x 120 days	240,000.00
Create Job in 120 days and plus 12 months DLP	1 gang x 4 workers x RM 75 x 120 days (project start-finish)	36,000.00
	2 general workers x RM 65 x 365 x 2 years	3,120.00
	Total PVB	**1,818,747.02**

Appendix F   Sample of Crib Wall/Soil Nails Design Analysis

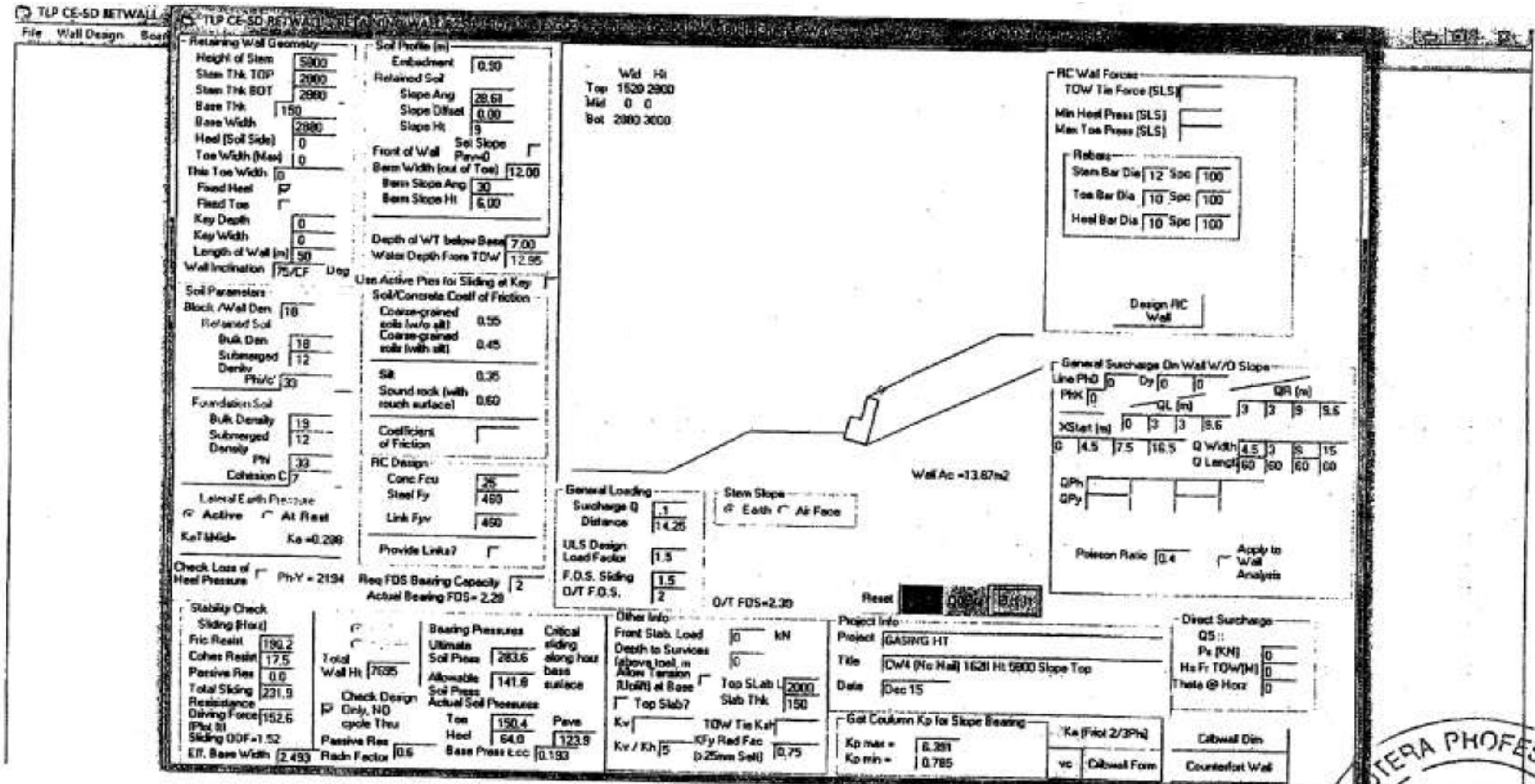




CW4 CRIB SKIN WALL (Nailed) Type 132-III (9700 high) with Offset Top Slope.



CW4 CRIB WALL (No Nailed) Type 162-III (8200 high) with Top Slope.



CW4 CRIB WALL (No Nailed) Type 162-II (5800 high) with Top Slope.

TLP1298 CRIBWALL DESIGN AT GASING HEIGHT PROJECT

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GEOCO SDN BHD | Sheet No.
Program: SLOPE Version 12R.03 Revision A15.B12.R41 |
Licensed from GEOSOLVE | Job No.
Run ID. GASING-CW4B | Made by :
GASING | Date: 7-09-2015
CW 4 B | Checked :

Units: kN,m

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	-25.00	-3.30	0.00	0.92	2.20	3.03	3.34	4.05
Stratum	Y-Coordinates							
1(GL)	-0.00	-0.00	-0.00	3.70	3.38	6.68	6.60	6.43
2	-0.00	-0.00	-0.00	-0.23	-0.55	-0.75	-0.83	2.04

Grid line	9	10	11	12	13	14	15	16
X-Coord	4.93	5.95	8.96	17.95	19.45	28.45	29.95	38.95
Stratum	Y-Coordinates							
1(GL)	9.99	9.66	9.66	15.67	15.67	21.67	21.67	27.67
2	5.55	9.66	9.66	15.67	15.67	21.67	21.67	27.67

Grid line	17	18	19	20
X-Coord	40.45	49.45	50.95	59.95
Stratum	Y-Coordinates			
1(GL)	27.67	33.67	33.67	39.67
2	27.67	33.67	33.67	39.67

SOIL PROPERTIES

----- Stratum ----- No.	Description	Bulk unit wt. below GWL kN/m3	above GWL kN/m3	-------Strength parameters------- C kN/m2	Phi (deg)	dC/dY kN/m2/m	Datum for C
1	Crib Wall	20.00	20.00	0.00	35.00		
2	Very Stiff Clayey Silt	18.00	18.00	8.00	37.00		

GROUND WATER CONDITIONS
Unit wt. of water = 10.00 kN/m3

Grid line	1	2	3	4	5	6	7	8
X-Coord	-25.00	-3.30	0.00	0.92	2.20	3.03	3.34	4.05
Ground water level	-6.00	-2.02	-1.42	-1.25	-1.01	-0.86	-0.81	-0.70

Grid line	9	10	11	12	13	14	15	16
X-Coord	4.93	5.95	8.96	17.95	19.45	28.45	29.95	38.95
Ground water level	-0.56	-0.40	0.07	1.47	1.70	3.10	3.33	4.73

Grid line	17	18	19	20
X-Coord	40.45	49.45	50.95	59.95
Ground water level	4.97	6.37	6.60	8.00

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(5)

SOIL REINFORCEMENT

Reinforcement geometry

Layer No.	Elev.	Inclin. (degs)	Elev. defined	Extent from X1	Extent to X2	Anchorage condition at X1	Anchorage condition at X2	Reinf type
1	9.050	-15.00	X1	5.73	17.73	Anchored	None	5
2	7.300	-15.00	X1	5.31	17.31	Anchored	None	5
3	5.550	-15.00	X1	4.88	16.88	Anchored	None	5
4	3.800	-15.00	X1	4.46	16.45	Anchored	None	5
5	2.050	-15.00	X1	4.04	16.04	Anchored	None	5
6	0.300	-15.00	X1	3.61	15.61	Anchored	None	5

Reinforcement type 5 Total reinforcement length = 41.14 m per m run

Reinforcement properties

Reinfor-cement type (Description)	Reinfor-cement material	Tensile strength (Anchorage) (strength)	Width or diam. (Lateral) (spacing)	Friction coeff. Pull-out (Direct) (sliding)	Adhesion (kN/m2) (A factor)
1	Sheet	52.00kN/m	1.000	0.560	0.00
(-)		(52.00)	(1.000)	(0.560)	
2	Sheet	39.00kN/m	1.000	0.560	0.00
(-)		(39.00)	(1.000)	(0.560)	
3	Sheet	26.00kN/m	1.000	0.560	0.00
(-)		(26.00)	(1.000)	(0.560)	
4	Sheet	13.00kN/m	1.000	0.560	0.00
(-)		(13.00)	(1.000)	(0.560)	
5	Nail	90.00kN	0.100	Interaction coeff. = 0.900	
(Y25)		(90.00)	(1.750)		
6	Nail	150.00kN	0.100	Interaction coeff. = 0.900	
(Soil Nail 2)		(150.00)	(1.500)		

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	-10.00	11.00
Grid increment	2.00	2.00
No. of grid lines	15	15

The grid of centres will be extended automatically until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	3.34	-0.83

Number of points = 1

ANALYSIS OPTIONS

Method of analysis: JANBU - for reinforced soil

Factors of safety calculated on Soil + Reinforcement Strength

Interslice friction/adhesion factor = 0.000

Partial factor of safety on tan(phi) = 1.000

Partial factor of safety on drained cohesion = 1.000

Partial factor of safety on undrained cohesion = 1.000

Partial factor of safety on soil weight = 1.000

Partial factor of safety on surcharge loads = 1.000

Partial factor of safety on reinforcement strength = 1.000

Partial factor of safety on pull-out resistance = 1.000

Partial factor of safety on direct sliding = 1.000

Minimum number of slices = 10

Units: kN,m

Brief results for selected circles through common point no.1

---Centre--- X	Y	Radius R	Factor of safety	Slipped mass (Reinf.) (force) kN/m	Restoring moment (Disturbing) (moment) kN.m/m	Out of balance moment (Iter) kN.m/m
2.00	59.00	59.85	1.566	12590	568909	-29860
				(110)	(333463)	(6)
0.00	61.00	61.92	1.568	11924	561821	-27479
				(136)	(330801)	(6)
4.00	57.00	57.84	1.571	13337	579779	-32834
				(103)	(336270)	(6)
2.00	57.00	57.85	1.571	11988	525263	-27724
				(115)	(306640)	(6)
0.00	59.00	59.93	1.573	11373	520584	-25585
				(140)	(305274)	(6)
2.00	55.00	55.85	1.575	11442	485825	-25779
				(120)	(282594)	(6)
0.00	57.00	57.93	1.575	10831	480684	-23760
				(145)	(281347)	(6)
4.00	55.00	55.84	1.576	12714	534746	-30433
				(103)	(308961)	(6)
-2.00	61.00	62.06	1.576	10816	516136	-23705
				(154)	(303813)	(6)
0.00	55.00	55.93	1.577	10290	442449	-22252
				(150)	(258320)	(6)
-2.00	59.00	60.07	1.577	10292	476619	-22079
				(154)	(280147)	(6)
2.00	53.00	53.85	1.577	10882	446916	-24046
				(125)	(259299)	(6)
-2.00	57.00	58.08	1.577	9774	438884	-20746
				(154)	(257500)	(6)
2.00	51.00	51.85	1.579	10323	409687	-22652
				(130)	(236855)	(6)
4.00	53.00	53.84	1.579	12157	494402	-28204
				(103)	(284933)	(6)
0.00	53.00	53.94	1.579	9754	406140	-20889
				(154)	(236249)	(6)
6.00	55.00	55.90	1.581	14174	593752	-36386
				(103)	(339189)	(6)
4.00	51.00	51.84	1.583	11556	453613	-26283
				(103)	(260355)	(6)
4.00	49.00	49.84	1.583	10977	415244	-24659
				(103)	(237590)	(6)
-2.00	55.00	56.09	1.585	9277	404142	-19389
				(154)	(235620)	(6)

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Run ID. GASING-CW4B | Made by :
GASING | Date: 7-09-2015
CW 4 B | Checked :

Units: kN,m

Analysis options

Method of analysis: JANBU - for reinforced soil
Interslice friction/adhesion factor = 0.000
Factors of safety calculated on Soil + Reinforcement Strength

Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on reinforcement strength = 1.000
Partial factor of safety on pull-out resistance = 1.000
Partial factor of safety on direct sliding = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000

Exclusion options

The summary results and selected results for each exit point exclude:
All slip surfaces where the interlock value in any slice is less than 0.1000
All slip surfaces where the slipped mass is less than 1.0 kN/m run

Critical Factor of Safety for each Common Point

---- Common point -----			---------- Critical circle ---------				Total
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safety	Reinf. force
1	3.34	-0.83	2.00	59.00	59.85	1.566	110 <---

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GASING |
CW 4 B | Date: 7-09-2015

FACTORS OF SAFETY AT CENTRES OF CIRCLES

X-coordinates: -10.00, -6.00, -2.00, 2.00, 6.00, 10.00, 14.00

Y-coord														
61.00	.		1.663	1.614	1.589	1.576								
1.568	. . . .													
59.00	.		1.679	1.626	1.590	1.577	1.573							
1.566	. . . .													
57.00	.		1.696	1.636	1.599	1.577	1.575	1.571						
1.571	. . . . . .													
55.00	.		1.704	1.649	1.608	1.585	1.577	1.575	1.576					
1.581	. . . . .													
53.00	.		1.712	1.654	1.617	1.592	1.579	1.577	1.579					
1.587	. . . . .													
51.00	.		1.723	1.658	1.622	1.598	1.588	1.579	1.583	1.592				
1.591	. . . .													
49.00	.		1.747	1.666	1.626	1.603	1.591	1.588	1.583	1.596	1.598			
1.610	. . .													
47.00	.		1.768	1.682	1.630	1.606	1.595	1.593	1.586	1.600	1.604			
1.619	. . .													
45.00	.		1.793	1.699	1.643	1.609	1.599	1.599	1.597	1.601	1.608	1.627		
1.643	. .													
43.00	.		1.812	1.716	1.657	1.616	1.599	1.607	1.605	1.610	1.611	1.635	1.655	
1.656	.													
41.00	.		1.834	1.739	1.669	1.630	1.602	1.609	1.612	1.622	1.621	1.640	1.666	1.670
1.689														
39.00	.		1.857	1.752	1.684	1.641	1.616	1.609	1.619	1.630	1.634	1.648	1.664	1.689
1.709														
37.00	.		1.897	1.767	1.693	1.651	1.627	1.618	1.622	1.637	1.648	1.668	1.671	1.700
1.732														
35.00	.		1.936	1.802	1.700	1.660	1.637	1.631	1.632	1.643	1.659	1.685	1.690	
1.726	.													
33.00	.		1.976	1.833	1.719	1.665	1.644	1.640	1.648	1.650	1.686	1.705		
1.713	. .													
31.00	.		2.017	1.865	1.751	1.675	1.649	1.650	1.667	1.672	1.695	1.720		
1.738	. .													
29.00	.		2.061	1.897	1.782	1.700	1.656	1.658	1.678	1.693	1.723			
1.731	. . .													
27.00	2.329	2.093	1.928	1.807	1.729	1.681	1.662	1.686	1.718					
1.752	. . . .													
25.00	2.410	2.131	1.947	1.830	1.756	1.703	1.690	1.695	1.738					
1.783	. . . .													
23.00	2.513	2.205	1.973	1.844	1.774	1.736	1.720	1.727						
1.757	. . . . .													
21.00	2.618	2.279	2.031	1.860	1.783	1.758	1.748							
1.765	. . . . . .													
19.00	2.722	2.367	2.088	1.907	1.792	1.767	1.785							
1.812	. . . . . .													
17.00	2.830	2.449	2.154	1.951	1.828	1.787								
1.813	. . . .													

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GASING                                                     | Date: 7-09-2015
CW 4 B                                                     | Checked :
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Units: kN,m

Analysis options

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Partial factor of safety on pull-out resistance = 1.000
Partial factor of safety on direct sliding = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000

DETAILED RESULTS FOR CRITICAL CIRCLE

Factor of safety = 1.566

Slipped mass = 12590 kN/m Out of balance vertical force = 0 kN/m
Out of balance horizontal force = -2 kN/m
Out of balance moment = -29860 kN.m/m
Total reinforcement force = 110 kN/m
Centre of circle: X = 2.00 Y = 59.00 Radius = 59.85
Overturning moment = 333463 kN.m/m Restoring moment= 568909 kN.m/m

Slip surface coordinates			Piezometric elevation	------- Interslice forces -------- horizontal		vertical
No.	X	Y	Y(w)	E(total) kN/m	E'(effective) kN/m	Q kN/m
1	-8.02	-0.00	-2.89	0	0	0
2	-3.30	-0.61	-2.02	43	43	0
3	0.00	-0.81	-1.42	84	84	0
4	0.92	-0.84	-1.25	114	114	0
5	2.20	-0.85	-1.01	175	175	0
6	3.03	-0.84	-0.86	224	224	0
7	3.34	-0.83	-0.81	247	247	0
8	4.05	-0.81	-0.70	372	372	0
9	4.93	-0.78	-0.56	445	445	0
10	5.95	-0.72	-0.40	531	531	0
11	8.96	-0.44	0.07	747	746	0
12	17.95	1.32	1.47	1294	1294	0
13	19.45	1.76	1.70	1365	1365	0
14	28.45	5.32	3.10	1586	1586	0
15	29.95	6.08	3.33	1584	1584	0
16	38.95	11.92	4.73	1309	1309	0
17	40.45	13.14	4.97	1222	1222	0
18	49.45	22.53	6.37	508	508	0
19	50.95	24.57	6.60	376	376	0
20	55.05	31.31	7.24	79	79	0
21	58.24	38.53	7.73	2	2	0

Slice No.	Cohesion (avge) kN/m2	Tan(phi) (avge)	Pore pressure (avge) kN/m2	Weight of slice W kN/m	Forces on base of slice --- normal --- P kN/m	P' kN/m	shear S kN/m
1	8.00	0.7536	0.00	26	31	31	39
2	8.00	0.7536	0.00	42	45	45	38
3	8.00	0.7536	0.00	48	49	49	28
4	8.00	0.7536	0.00	111	111	111	60
5	8.00	0.7536	0.00	96	96	96	50
6	8.00	0.7536	0.06	47	46	46	24
7	8.00	0.7536	0.70	103	128	127	65
8	8.00	0.7536	1.65	150	148	147	75
9	8.00	0.7536	2.65	200	194	192	97
10	8.00	0.7536	4.12	553	531	519	265
11	8.00	0.7536	3.28	1981	1839	1809	917
12	8.00	0.7536	0.54	382	347	346	174
13	8.00	0.7536	0.00	2452	2198	2198	1107
14	8.00	0.7536	0.00	431	385	385	194
15	8.00	0.7536	0.00	2537	2277	2277	1151
16	8.00	0.7536	0.00	409	373	373	189
17	8.00	0.7536	0.00	2079	1954	1954	1007
18	8.00	0.7536	0.00	273	268	268	142
19	8.00	0.7536	0.00	525	526	526	294
20	8.00	0.7536	0.00	146	129	129	103

Reinforcement forces

Layer No.	Elev.	Inside slip surface Length m	Inside slip surface Pull-out kN/m run	Outside slip surface Length m	Outside slip surface Pull-out kN/m run	Available Reinforcement force kN/m run
1	9.05	No intersection				
2	7.30	No intersection				
3	5.55	No intersection				
4	3.80	11.75	51.43a	0.24	7.56	7.56
5	2.05	7.81	51.43a	4.20	51.43	51.43
6	0.30	3.42	51.43a	8.57	51.43	51.43

Note: 'a' indicates end of reinforcement is anchored
'w' indicates end of reinforcement is wrapped around

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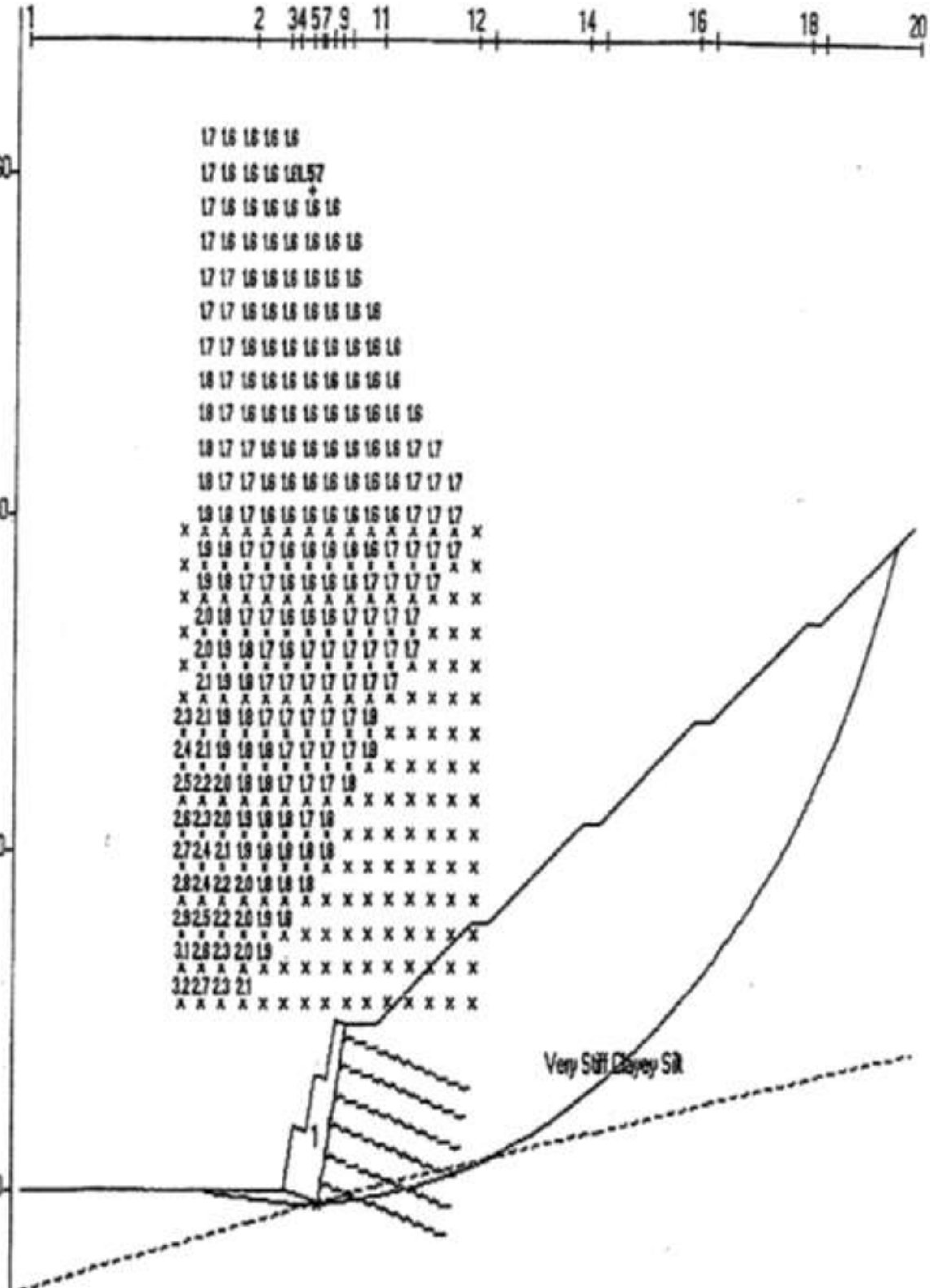

Appendix G Sample of Soil Nails Design

Step 1: Project Requirements

A 9.7 m high soil nail wall, 100 m in length, surcharge load is 10 kN/m^3 is planned for construction of a retaining slope project.

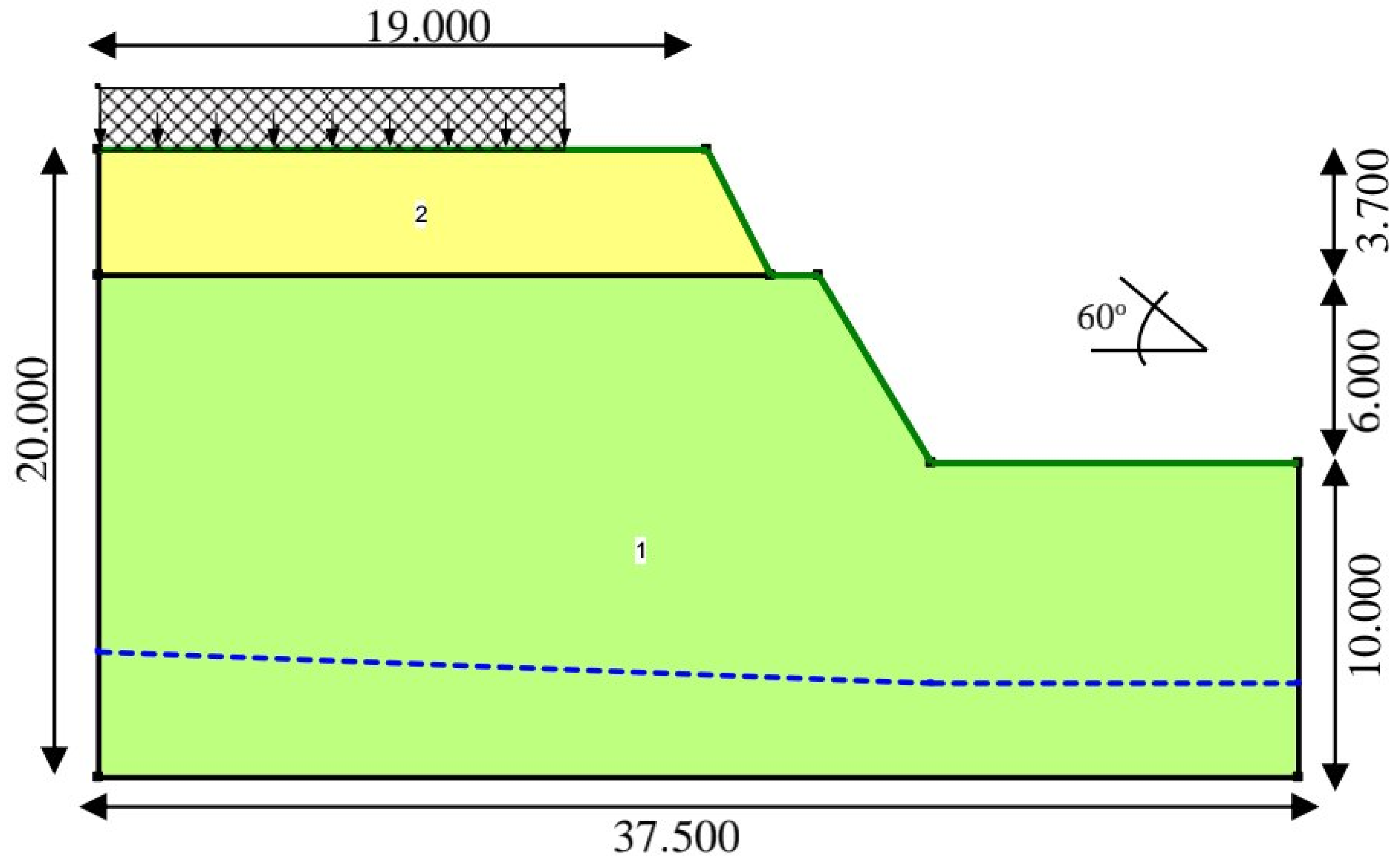

Figure 1.1 Illustration geometry model

Step 2: Subsurface Exploration and Development of Parameters for Design

It is assumed that a geotechnical exploration and a geotechnical laboratory testing program have been completed. Based on results from the geotechnical exploration and laboratory testing, the following geotechnical parameters have been selected for design:

<u>Upper layer</u>

- Materials SPT 10-30
- Mohr Column model
- soil unit weight, $\gamma s = 18\ kN/m^3$
- effective friction angle, $\varphi s' = 40^o$
- cohesion, c = 0 kPa

<u>Lower layer</u>

- Materials SPT 30-50
- Mohr Column model
- soil unit weight, $\gamma s = 19\ kN/m^3$
- effective friction angle, $\varphi s' = 32^o$
- cohesion, c = 0 kPa

There is no need to develop seismic parameters for design because it is assumed that the wall is in a zone with very low seismic hazard.

Step 3: Load Definition

3(a) Define Unfactored, Service Loads

It is assumed that the live load consists of a uniform load, QLS equal to 13.94 m^2, extending from the wall to 7.5 m behind the wall.

3(b) Select Load Combinations and Load Factors

The load combinations for this example only include Strength I and Service limit states. Load factors for overall stability are 1.0 for use with SLOPE/W.

Step 4: Soil-Nail Configuration and Material Selection

4(a) Develop Wall Layout, Cross-Sections, Nail Pattern, and Splaying

Given the wall height (H = 9.7 m) and face batter ($\alpha = 0$), the following layout is selected for simulation in SLOPE/W.

__Vertical and Horizontal Spacing of Soil Nails__

• Adopt;(1) $S_{H1} = 1.5$ m; $S_{V1} = 2.0$ m (upper soil level) and (2) $S_{H2} = S_{V2} = 1.5$ m (lower soil level)

Check (1): $S_{H1} \times S_{V1} = 3.00\ m^2 \leq 3.24$ to $3.61 m^2$ **ok**

Check (2): $S_{H2} \times S_{V2} = 2.25\ m^2 \leq 3.24$ to 3.61m2 **ok**

• This vertical spacing results in 2 rows (upper soil level) and 4 rows (lower soil level) of soil nails.

__Vertical Spacing at the Top and Bottom of the Wall__

The spacing between the first row and the top of the wall is selected as:

$S_{V0} = 0.85$ m ≤ 1.050 m **ok**

The spacing between the deepest row and the bottom of the wall (SV_N) is:

• $S_{VN} = 0.75$ m ≤ 0.6 to 0.9 m **ok**

Soil Nail Inclination

Because no utilities or obstructions exist behind the wall, the soil nail inclination is selected as:

• *i* = 20 degrees for all nails **ok** (between 15 and 25 degrees)

Soil Nail Length

The maximum soil nail length is selected for a simulation at:

• L = (L between 0.6 H and 1.2H) = 9 m **ok**

Distribution of Soil Nail Length in Elevation

A uniform pattern of soil nail lengths is first selected for simplification. Therefore, all six soil nails have L = 9 m. No sensitive structures exist immediately behind the wall; hence no special considerations for controlling wall deflections are needed

Soil Nail Pattern on Wall Face

Both "square" and "staggered" soil nail patterns are considered feasible. A staggered pattern would tend to result in smaller effective nail spacings, and therefore fewer nails than the square pattern. This design using square soil nail patterns.

Detail Corrosion Protection

It was assumed that the Owner specified a Class B level of corrosion protection for soil nails to accommodate their tolerance for risk and because the cost differential for providing a higher corrosion protection was estimated to be low.

Step 5: Selection of Resistance Factors

Safety factors selected for this example are presented in Table 1.0 for ASD calculations with SLOPE/W.

Table 1.1 Summary of Factors of Safety for Use with the ASD Method

Limit State	**Condition**	**Symbol per this manual**	**Minimum Recommended FOS**
Overall Stability	Internal	FOSos	1.5
Strength- Geotechnical	Pull-out Resistance	FOSpr	2
Strength - Structural	Tendon Tensile Strength	FOSt	1.8
Strength - Facing	Flexural	FOSf	1.5
Strength - Facing	Punching Shear	FOSps	1.5
Strength - Facing	A307 steel bolt (assumed)	FOSfh	1.5

Step 6: Overall Stability

6(a) Verify Internal Stability

Data Entry – Material Properties

The properties for soil layers, as well as dimensions and material properties of the soil nails, facing components, shotcrete/concrete, welded-wire mesh, rebar, bearing plate, and headed studs. Mean values of the soil resistance should be considered. The wall-soil interface friction is estimated to be 2/3 φs′ in SLOPE/W. This parameter, among others, is considered in SLOPE/W to perform checks for eccentricity (overturning), lateral sliding and bearing capacity.

Table 1.2 Summary of Properties of Soil Nail Components

Parameter	**Main Features**	**Additional Descriptions**
Nail Features	6 solid bars # Grade 75	bore hole diameter, DDH = 0.125 m
Facing thickness/type	initial: hi = 0.1 m Final: hf = 0.2 m	initial: shotcrete f'c = 4,000 psi final: CIP concrete f'c = 4,000 psi
Primary reinforcement grade/type	initial: Grade 60 WWM 6×6 - W2.9×W2.9	final: Grade 60 rebar; No. 4 @ 300 mm. (ea. way)
Added reinforcement in facing	initial: rebar 2 × #5 (ea. way)	final: none
Bearing plate	Square dimension: LP = 225 mm. thickness: tP = 25 mm.	Grade 50, fy = 50 ksi
Headed stud type	4 × (1/2 × 4 and 1/8)	Grade A307 steel
Headed stud dimensions	stud length: LS = 4.125 in. head diameter: DH = 1 in. head thickness: tSH = 0.31 in.	shaft diameter: D_{SC} = 12 mm. stud spacing: S_{SH} = 150 mm.

6(b) Verify Global Stability

The calculated factors of safety for global stability were larger than the minimum recommended values because SLOPE/W allows extending the slip surfaces to extend below the toe of the wall.

6(c) Results

After a few simulations, the length of the nails was modified to L = 9 m, spacing 1.5 m upper layer and lower layer and inclination 20°. The calculated factor of safety for overall stability was at or slightly above the minimum value (1.570). The output was also inspected until all the internal checks conducted by SLOPE/W indicated that the minimum requirements were exceeded.

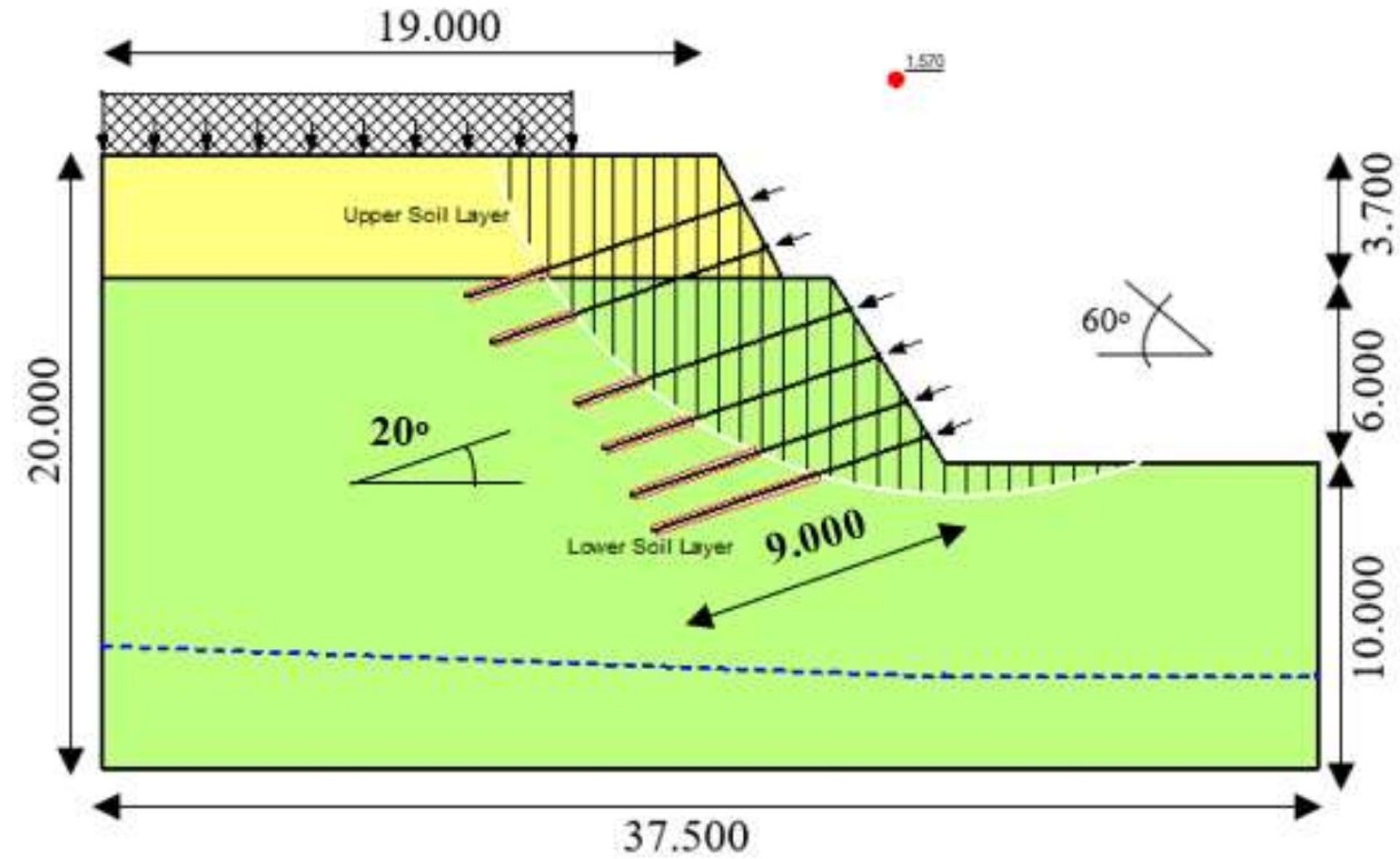

Figure 1.2 Soil nails results model

LIST OF PUBLICATIONS

1. **Mohd Sukry Mohamed**, and Samira Albati Kamaruddin (2017). Soil Nailing Design and Technique for Cut Slope Stabilization: A Review. In *2017 International Conference on Sustainable Infrastructure and Engineering (SustaIN).*

2. **Mohd Sukry Mohamed**, and Samira Albati Kamaruddin (2018). Optimization of Soil Nailing Designs for Cost-Effectiveness Analysis. *Journal of Advanced Research (ICEBM).*

3. **Mohd Sukry Mohamed**, Fathiyah Hakim Sagitaningrum, and Samira Albati Kamaruddin (2019). Optimization of Soil-Nailed Wall Design using SLOPE/W Software. *International Professional Doctorate Symposium* (IPDOCS 2019). Open International Journal of Informatics (OIJI). Vol 7 No 1 (2019): OIJI Special Session on Informatics in Industry. Published: 26-12-2019.

4. **Mohd Sukry Mohamed**, and Samira Albati Kamaruddin (2019). Cost-Benefit Analysis of Combined Retaining Walls Construction. *Proceedings of the International Conference on Sustainable Design, Engineering, Management and Sciences* (ICSDEMS 2019). Lecture Note in Civil Engineering (Springer). Published: 19-08-2020.