Geotechnical Analysis: Soil Stability Under Coal Embankment

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Abstract

This document presents a geotechnical analysis report of the soil stability under coal embankment on a certain area in project Smelter Ferronckel Kolaka held by PT. PP (Persero) Tbk. This document is intended for a portfolio to demonstrate the competency and experience of the author. We do not intend to share sensitive information in the project, and hence, we do not disclose as much sensitive information as possible.

Contents

1 GENERAL

1.1 Introduction

This document covers a geotechnical analysis of the coal embankment in Coal Homogenization Storeroom. The analysis is intended for an assessment of the soil stability on the yard where a large embankment of coal material is located. As a reinforcement to the soil underneath the embankment, a geomembrane is applied. The detail designation of the configuration will be described on the next section.

1.2 Specifications, Codes and Standards

National codes:

SNI 8460:2017 Persyaratan Perancangan Geoteknik

As required in the project design basis, the maximum soil displacement is expected to be less than 25.00 mm.

1.3 Units of Measurements

The units of measurements used in this document are the International System of Units, known as SI (*Système International*).

1.4 Material Properties

The materials to be used in this design include the virgin soils on the field, backfilling soil and the geomembrane. For the coal embankment, the mechanical properties required in the analysis is extracted from common sources.

The detail soil properties will be presented on the next section, since additional calculations are required. The initial information of the soil properties are obtained from the soil report which is provided in the attachment of this document. The basic properties of the geomembrane in use is presented as in table 1. The source of the information in table 1 is provided in the attachment.

Table 1: Basic properties of geomembrane

Property	Notation	Value	Unit
Thickness	t	1.50	mm
Yield strength	F_y	23.00	kN/m
Yield strain	ε_y	13.00	%
Break strength	F_b	43.00	kN/m
Break strain	ε_b	700.00	%

1.5 Software and Platform

The following software and programs are used in the development of this document and its contents:

a. PLAXIS 2D
   The finite element (FE) based software PLAXIS 2D will be used as the main apparatus in the geotechnical analysis of the embankment.

b. Microsoft Excel
   Excel is used as a database platform for the soil parameters extracted from the soil report as well as from assumptions.

c. Jupyter Notebook-Python
   Jupyter Notebook is an open-source web application commonly used for data cleansing, data analysis and machine learning (ML) computation which supports programming languages such as Julia, R and

Python. We use Jupyter Notebook with Python to conduct external calculations such as geomembrane axial stiffness and the estimation of the coal embankment weight.

d. Overleaf LaTeX
This report is arranged in Overleaf, a collaborative cloud-based LaTeX editor used for writing, editing and publishing scientific documents.

2 LAYOUT AND GEOMETRIES

The initial information for developing the design is from an input provided by a partner company that work together with PT. PP (Persero) Tbk in the project. The developed drawings are presented in figure 1.

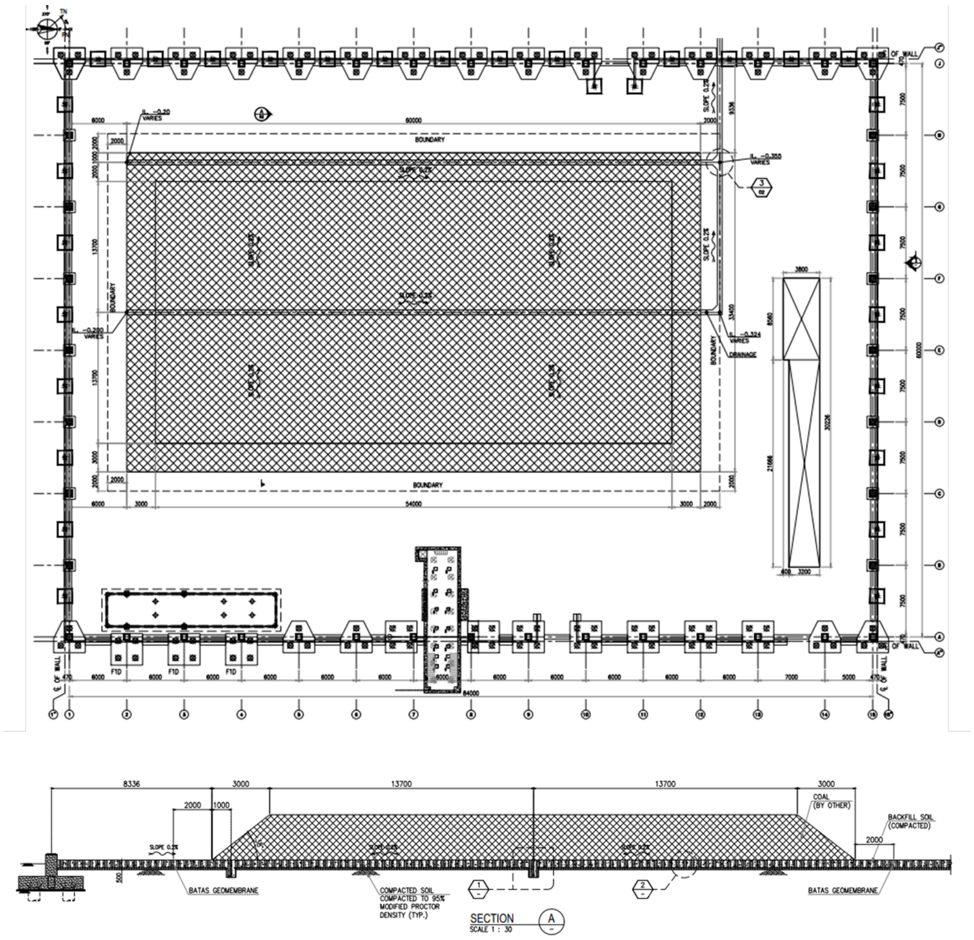

Figure 1: Configuration of the coal embankment

3 SOIL MECHANICAL PROPERTIES AND PARAMETERS

3.1 Existing Virgin Soil

The soil mechanical properties of the existing virgin soil are mainly obtained from the soil report. However, some essential parameters do not present due to the lack of laboratory tests. These missing properties include the soil unit weights, internal friction angle and cohesion of certain layers. To handle these missing values, we use assumptions based on correlations provided by verifiable sources.

The original data from the soil report to be used in the analysis is given in table 2. For instance, the value γ for the soil ML is missing as we can observe in table 2. Other parameters are also missing. For soil without γ, we will use the value from other literature based on the other properties possess by the soil such as its class, consistency and N-SPT.

Table 2: Original soil parameters of BH.1.9.03 from soil report

Level		ID	Class	Consistency	N-SPT	γ (kN/m^3)	γ_{sat} (kN/m^3)	ϕ' (Deg)	c' (kPa)	E_s (kPa)
0.00	1.50	ML	Silt	Medium	4					9600
1.50	6.00	CS	Sandy Clay	Soft	2	15.82				4800
6.00	8.30	CH	Clay	Medium	5	14.10		9.30	18.30	8000
8.30	11.35	SW	Well Graded Sand	Loose	5			25.00	0.00	6000
11.35	18.00	GW	Well Graded Gravel	Dense	50			45.00	0.00	60000

For the soil ML, we use references values from (Lindeburg, 2018) for γ and γ_{sat}, and we obtain

$$\gamma = 13.67 \text{ kN/m}^3\,, \quad \gamma_{sat} = 15.71 \text{ kN/m}^3\,. \qquad \text{(for ML)}$$

And we use the same reference (Lindeburg, 2018) for soils SW and GW, and we obtain as follows:

$$\gamma = 14.14 \text{ kN/m}^3\,, \quad \gamma_{sat} = 19.48 \text{ kN/m}^3 \qquad \text{(for SW)}$$
$$\gamma = 20.42 \text{ kN/m}^3\,, \quad \gamma_{sat} = 21.99 \text{ kN/m}^3 \qquad \text{(for GW)}$$

The value of ϕ' and c' for both ML and CS are assumed to be equal to those of CH, since their characteristic can be deemed almost similar. Besides, no references can be found for this case other than assumptions. Then for γ_{sat} of CS and CH, we use an equation from (Das and Sobhan, 362) with known values of specific gravity G_s and void ratio e. The equation is given by

$$\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1 + e}\,,$$

where $\gamma_w = 9.81$ kN/m^3 is the unit weight of water. With the equation above, we obtain the values in table 3.

Table 3: Calculation table of γ_{sat} for CS and CH

Soil ID	G_s	e	γ_{sat} (kN/m^3)
CS	3.37	2.30	16.86
CH	2.95	3.23	14.33

Note that the values in table 2 is essential for the modelling of the soil in PLAXIS. We have solved the missing values in that table, and as a revision, we present table 4.

Table 4: Soil parameters of BH.1.9.03 for PLAXIS modelling

Level		ID	Class	Consistency	N-SPT	γ (kN/m^3)	γ_{sat} (kN/m^3)	ϕ' (Deg)	c' (kPa)	E_s (kPa)
0.00	1.50	ML	Silt	Medium	4	13.67	15.71	9.30	25.00	9600
1.50	6.00	CS	Sandy Clay	Soft	2	15.82	16.86	9.30	18.30	4800
6.00	8.30	CH	Clay	Medium	5	14.10	14.33	9.30	18.30	8000
8.30	11.35	SW	Well Graded Sand	Loose	5	14.14	19.48	25.00	0.00	6000
11.35	18.00	GW	Well Graded Gravel	Dense	50	20.42	21.99	45.00	0.00	60000

3.2 Parameters of Geomembrane

The required parameter of geomembrane to be included in the PLAXIS model is only its axial stiffness. This property can be obtained by dividing the strength with the strain. We will use a linear model for the geomembrane. Thus, we assume that the axial stiffness is the stiffness at the linear state, that is just before it undergoes yielding. With this designation, we obtain the axial stiffness as

$$J = \frac{F_y}{\varepsilon_y} .$$

Note that, J in the linear state can also be expressed by $J = EA$, where E is the Young's modulus of the geomembrane material and A is the cross section. However, the data that we have in table 1 are F_y and ε_y. Then the axial stiffnes is computed as follows:

$$J = \frac{23}{0.13} = 176.923 \text{ kN/m}.$$

The value of J above will be used in the PLAXIS model.

3.3 Weight of Coal Embankment

The coal embankment will be as illustrated in figure 1. The embankment will only be modelled as a line load on the soil since we do not need to control the stability of the coal embankment. The load of the coal embankment is formulated by

$$F_{coal} = \gamma_{coal} \cdot h_{coal} ,$$

where γ_{coal} is the unit weight of coal in kN/m^3 and h_{coal} is the height of the embankment in meters. We will use $\gamma_{coal} = 9.00$ kN/m^3. And the height of the embankment according to the design is $h_{coal} = 3.00$ m. Then we obtain

$$F_{coal} = 9.00 \cdot 3.00 = 27.00 \text{ kN/m/m}.$$

The value of F_{coal} above will be used in the PLAXIS model.

3.4 Wheel Loader Load

The heavy weight machinery to be operating around the area is a wheel loader for lifting coal materials. Therefore, its weight needs to be considered as well. We assume that the wheel loader in use has a total weight (including its loads) of $P = 100$ kN with a tire of diameter $D = 1.921$ m and a width of $b = 0.729$ m. We assume the distribution of the loads at the tires is 60% at the front and 40% at the rear side. Thus, the maximum ground pressure of the tire of the loader is estimated as follows:

$$F_{loader} = \frac{P}{n_{tire}} R \cdot b = \frac{100}{4} 0.5 \cdot 1.921 \cdot 0.729 = 42.845 \text{ kN/m/m}.$$

The value of F_{loader} above will used in the PLAXIS model.

4 EMBANKMENT MODELLING AND ANALYSIS

4.1 Modelling

First, we define soil materials in the PLAXIS database based on our designation in table 4. Then we model the virgin soil environment using the "Borehole" feature of PLAXIS and set the configuration as shown in figure 2.

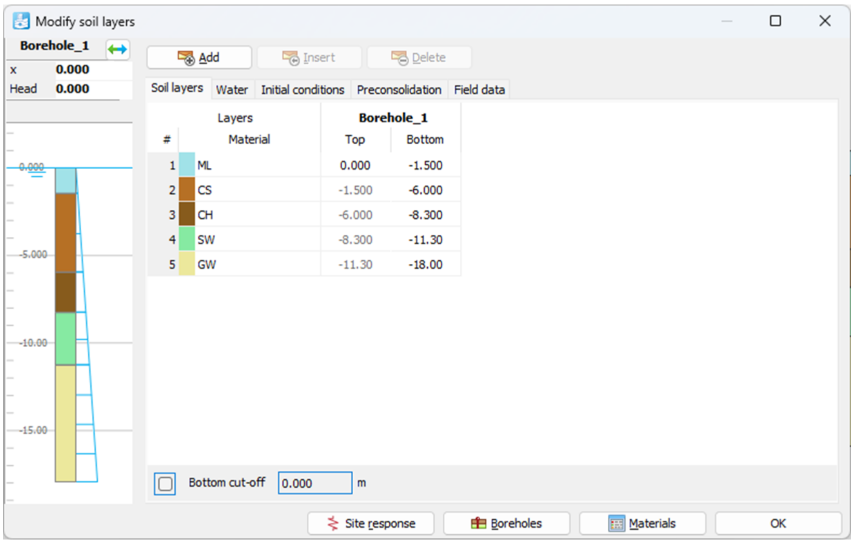

Figure 2: PLAXIS borehole configuration according to table 4

The generated virgin soil yield figure 3.

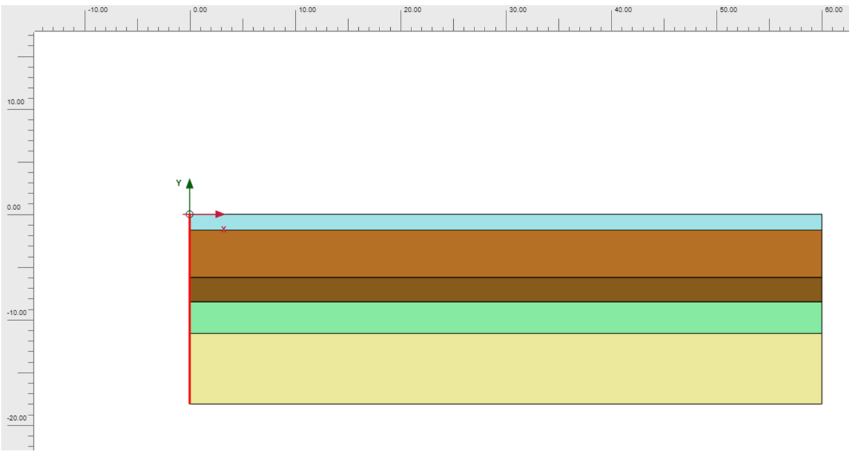

Figure 3: PLAXIS generated virgin soil

Now we model the geomembrane. We use the feature "Geogrid" in PLAXIS as a model for the geomembrane. We define the Geogrid material as illustrated in figure 4 where we use an isotropic material with the stiffness value as calculated in the earlier section.

Then we model the coal embankment as linear line load with the maximum load value as calculated in the earlier section. Then we also include the load due to the wheel loader located at the most possible critical location. The current PLAXIS model with the geomembrane, the coal embankment and the wheel loader is illustrated in figure 5.

With all the parameters set in the model, we now need to set a proper mesh to the model. The resulting

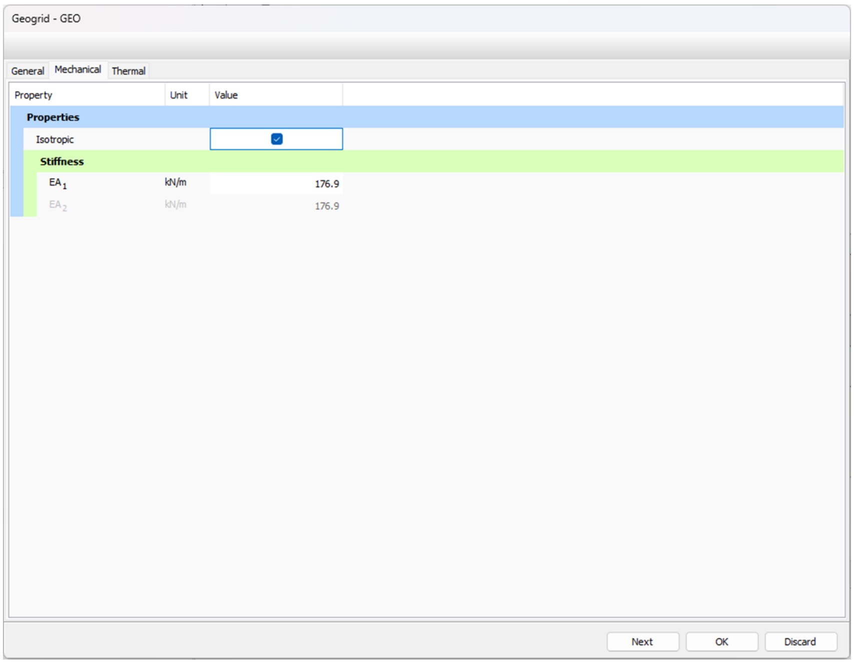

Figure 4: Geogrid material in PLAXIS

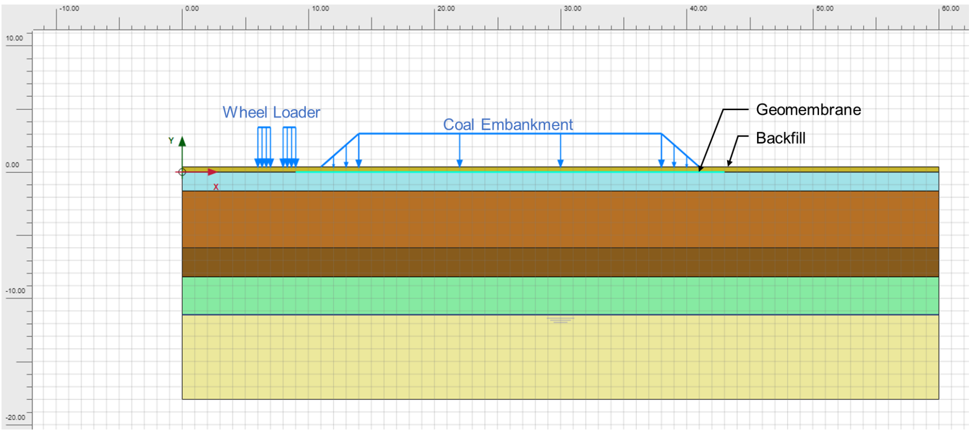

Figure 5: Current model with geomembrane, coal embankment and wheel loader

mesh is shown in figure 6. Once the meshing done, we set the construction stages to be simulated in the model. The detail description of the stages is presented as follows:

1. Initial Phase
   This stage consists of only virgin soil without alterations.

2. Phase 1
   The geomembrane and the backfilling is included in this stage. The plastic analysis will be executed.

3. Phase 2
   The total coal embankment is included in this stage. The plastic analysis will be executed.

4. Phase 3
   The model components are similar to that of phase 2. This stage will execute a safety analysis. It is preceded by phase 2.

5. Phase 4
   The circumstance is similar to that of the earlier phase only with the wheel loader be included in this stage. The plastic analysis will be executed. This stage is preceded by phase 2.

6. Phase 5
   The model components are similar to that of phase 4. This stage will execute a safety analysis. It is preceded by phase 4.

7. Phase 6
   This phase analyse the possible extreme variation with a half of embankment and the wheel loader. This stage will execute a plastic analysis and is preceded by phase 1.

8. Phase 7
   The circumstance is perfectly similar to that of phase 6. This stage will run the safety analysis and is preceded by phase 6.

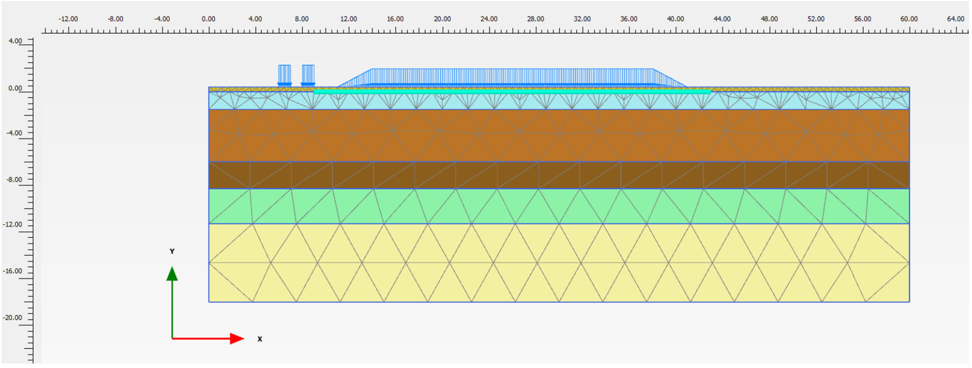

Figure 6: Model with medium mesh

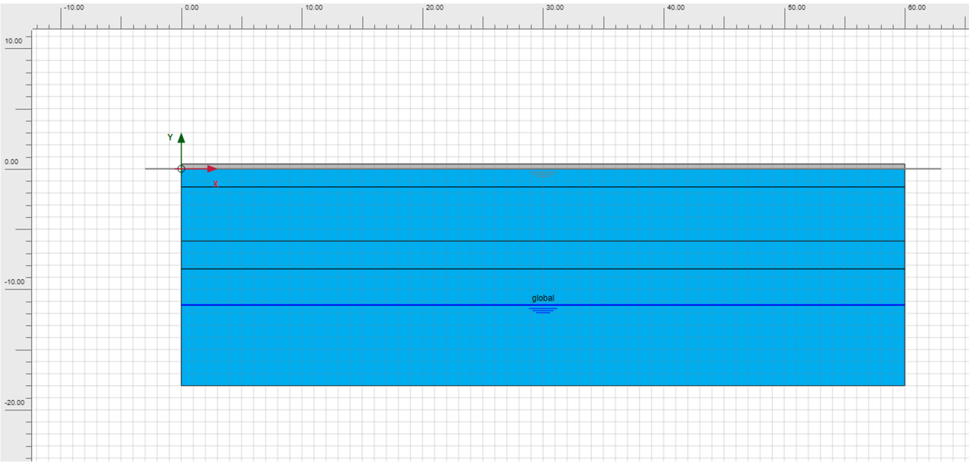

Figure 7: Setting the water level in the model based on the soil report

Then we run the computation with the result and analysis are provided in the next subsection.

4.2 Result and Analysis

The result of the computation will be presented based for each of the phases as follows:

1. Phase 1
Plastic analysis is executed with the geomembrane together with the backfilling. No significant displacements occur.

2. Phase 2
Plastic analysis is executed with the circumstance as shown in figure 8. The distribution of vertical displacement u_y can be observed in figure 9. The result shows that the maximum verical displacement on this phase is is given by
$$|u_y| = 22.33 \text{ mm} < 25.00 \text{ mm},$$
which shows that the displacement is satisfiable on this phase.

3. Phase 3
Safety analysis is executed with the circumstance perfectly similar to that of phase 2. The resulting factor of safety with respect to the computational steps is presented in figure 14. It is obtained that the safety factor of phase 3 is $\mathrm{SF} \geq 5.5$, which concludes that the substructure is safe on this phase.

4. Phase 4
Plastic analysis is executed with the circumstance as shown in figure 10. The distribution of vertical displacement u_y can be observed in figure 11. The result shows that the maximum verical displacement on this phase is is given by
$$|u_y| = 22.30 \text{ mm} < 25.00 \text{ mm},$$
which shows that the displacement is satisfiable on this phase.

5. Phase 5
Safety analysis is executed with the circumstance perfectly similar to that of phase 4. The resulting factor of safety with respect to the computational steps is presented in figure 14. It is obtained that the safety factor of phase 5 is $\mathrm{SF} \geq 5.0$, which concludes that the substructure is safe on this phase.

6. Phase 6
Plastic analysis is executed with the circumstance as shown in figure 12. We set the coal embankment as a half of that of phase 4 to observe the possible significant differential displacement. The distribution of vertical displacement u_y can be observed in figure 13. The result shows that the maximum verical displacement on this phase is is given by
$$|u_y| = 23.34 \text{ mm} < 25.00 \text{ mm},$$
which shows that the displacement is satisfiable on this phase.

7. Phase 7
Safety analysis is executed with the circumstance perfectly similar to that of phase 6. The resulting factor of safety with respect to the computational steps is presented in figure 14. It is obtained that the safety factor of phase 7 is $\mathrm{SF} \geq 3.5$, which concludes that the substructure is safe on this phase.

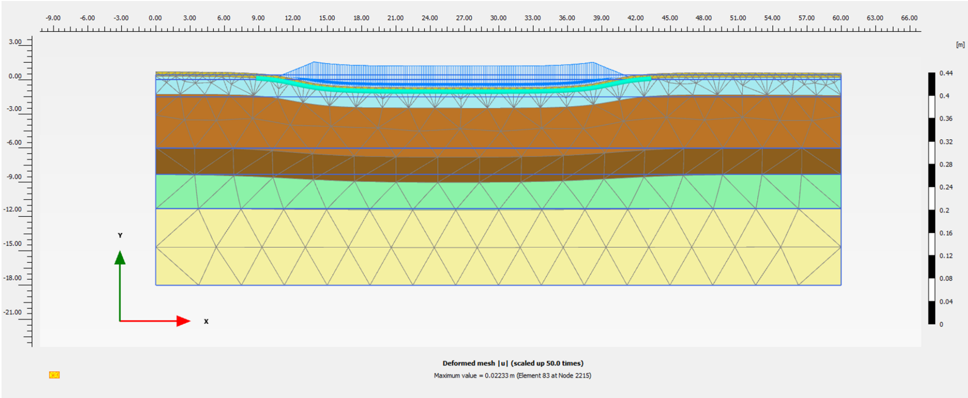

Figure 8: Displacement norm of phase 2

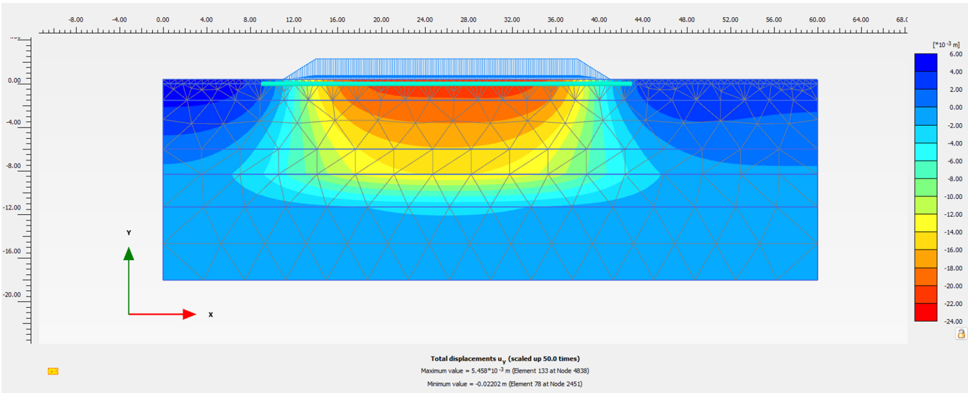

Figure 9: Distribution of vertical displacement u_y of phase 2

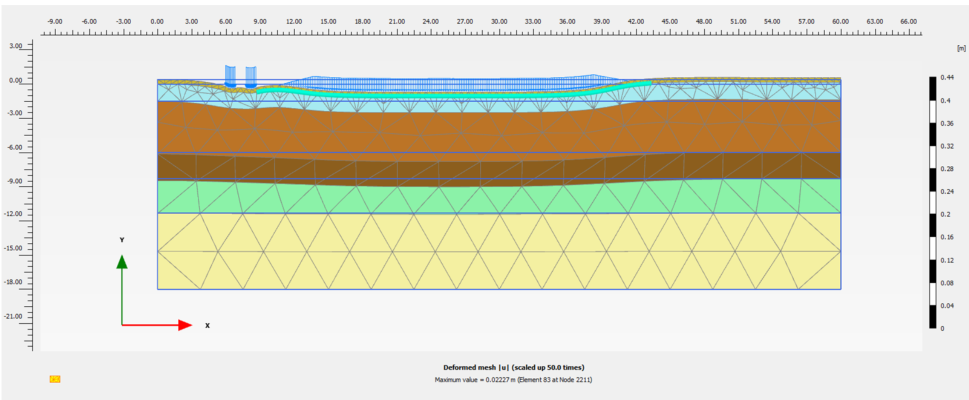

Figure 10: Displacement norm of phase 4

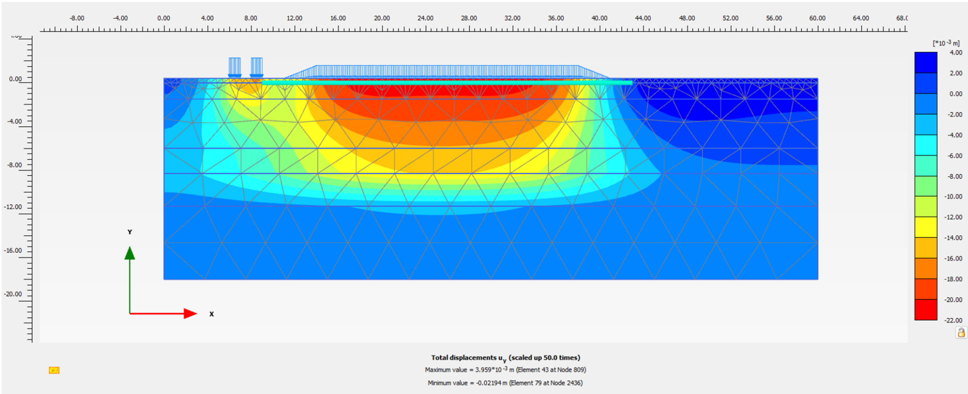

Figure 11: Distribution of vertical displacement u_y of phase 4

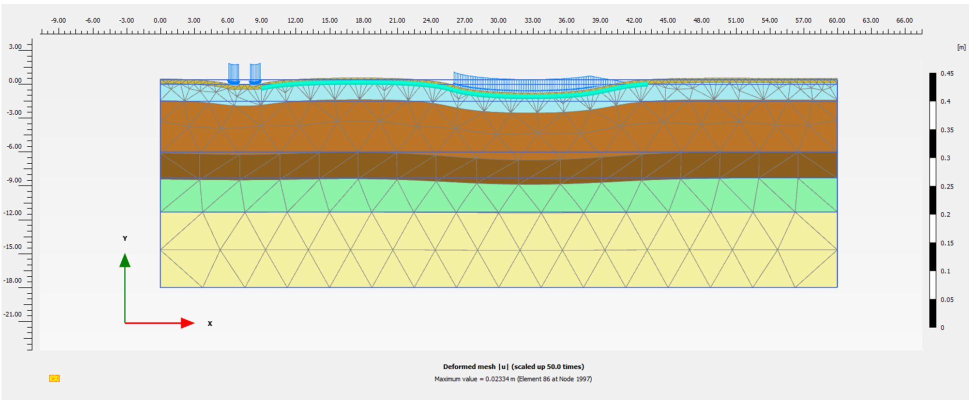

Figure 12: Displacement norm of phase 6

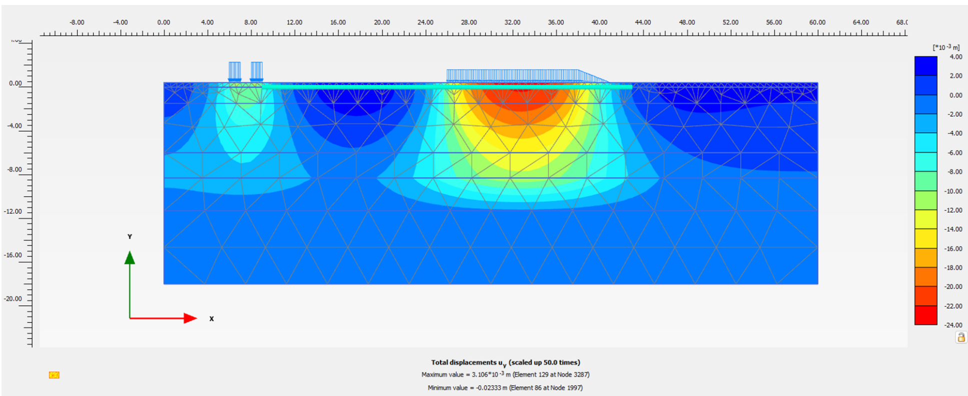

Figure 13: Distribution of vertical displacement u_y of phase 6

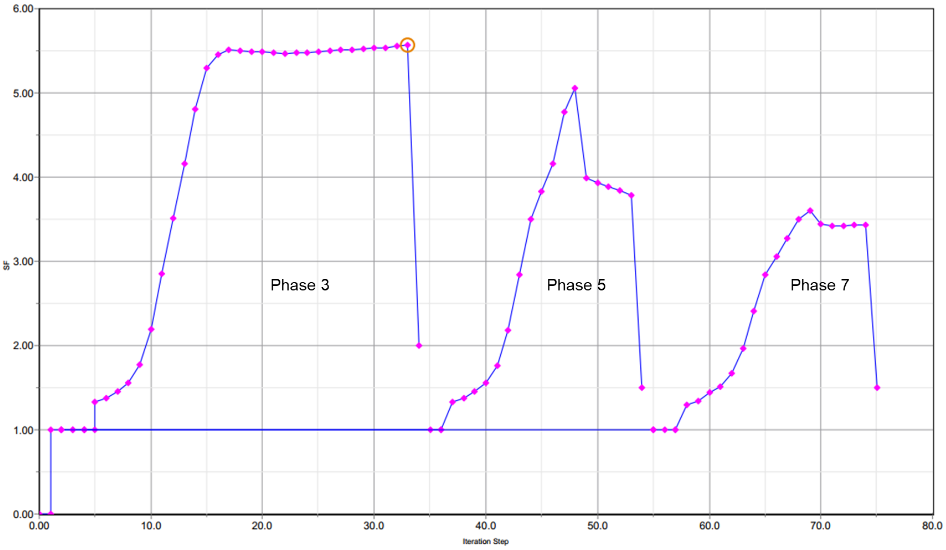

Figure 14: Factor of safety with respect to computational steps on phase 3, phase 5 and phase 7

5 CONCLUSION

We have conducted a thorough computation and analysis on the coal embankment with the ground soil reinforced with a geomembrane of thickness 1.50 mm. The condition of the system is analysed against the full coal embankment, the full coal embankment combined with a wheel loader during operation, and against a half of coal embankment combined with a wheel loader during operation. The result shows that the maximum vertical displacement of all phases is given by

$$|u_y| = 23.34 \text{ mm} < 25.00 \text{ mm},$$

and the most critical factor of safety of all phases is given by

$$\mathrm{SF} \geq 3.5\,.$$

This result show that all the conditions under the analysis are satisfiable.

References

Das, B. M. and Sobhan, K. (362). *Principles of Geotechnical Engineering*. Cengage Learning.

Lindeburg, M. R. (2018). *PPI PE Civil Reference Manual 16th Edition: A Comprehensive Civil Engineering Review Book*. Kaplan Company.