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Evaluation of Slope Stability at Interface using Thin Soil Material Model in Finite Element Software

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Abstract. Cases of landslides on clay shale slopes have been an intriguing study in Indonesia. Most of the slopes failed due to the weathering of the clay shale rock. As studies focused on the properties of clay shale, several FEM analyses indicated a unique translational type of failure between the interface of clay shale and its overburden. However, the modeling of the interface in a case study was still limited. This study aims to evaluate a landslide using a thin-soil interface model using FEM software. The model used two conditions, extreme groundwater level conditions. There were several iterations of the shear strength parameters of the interface layer conducted. Results indicated that the thin-soil interface could portray the interface condition at the landslide. Compared to laboratory interface results, the interface would fail at a high degree of saturation due to water infiltration at the surface. Also, granular overburden with high permeability had a higher chance of failure than cohesive overburden. From the results, this study opened the path to incorporating the interface layer in clay shale slope analysis. However, further studies are needed using the thin-soil interface model in other clay shale landslide cases to synthesize its repeatability.

1. Introduction

Landslides have been one of the most common causes of geotechnical engineering failures on natural and manufactured slopes. In Indonesia, landslides were affected by various factors such as soil type, rainfall intensity, and geological terrain. One of the problematic soil types which initiated landslides is the clay shale soil.

Many studies of clay shale in Indonesia focused on its properties, including its unique weathering property. Due to weathering, the initial properties of clay shale would change through the degradation of the structure [1]. The degradation of clay shale would further degrade its shear strength, which led to slope instability [2,3]. Various clay shale slope analyses indicated a typical translational failure plane. However, these analyses only incorporated the degraded shear strength parameters to the clay shale layers [4–6]. From these analyses, a landslide in Semarang during the toll road construction indicated a unique behavior. The study argued that the translational failure might be due to the interface failure between the clay shale rock and its overburden [6].

From the previous issue, it was clear that studies of soil-soil interfaces are needed. The recent trend of the interface shear strength also indicated that the research had shifted from the soil-solid interface to soil-soil and soil-rock interfaces [7]. Other than experimental studies, the studies of interface modeling were also developing. Most of the models used the Discrete Element Method (DEM) and Finite Element Method (FEM) to model the interface behavior in its element size [8–10]. However, recent back-analyses of clay shale slope demanded that the interface be included in a full-scale model analysis [4–6]. From the problems, the developing interface modeling could not answer the needs of landslide back-analyses. Thus, it is essential to explore the possibility of including the interface effect in landslide back-analyses.

One of the efforts is introducing the thin-soil material as the interface model. A previous study explored the thin-soil material using the FEM software using back-analysis of a clay shale slope [10]. However, the study was limited to the natural water table, which could not give a wide range of interface conditions at failure. Thus, this study would like to evaluate the thin-soil material model for different water table conditions. At the end of this study, interface shear strength laboratory results would be plotted simultaneously with the FEM results. Thus, an analysis of interface properties that led to slope instability can be deducted.

2. Methods

Previous research on the interface model focused on the element-size interface behavior [8–10]. Some of these models used ABAQUS and FLAC3D, FEM analysis software commonly used on the element-size model. On the contrary, the most common FEM software used for the back-analysis of a landslide is Plaxis. In Plaxis itself, the interface analysis could use the provided interface function taken from the properties of the surrounding soil. However, a previous Semarang-Bawen toll road slope analysis showed that the interface function had several limitations [2]. In this study, the thin-soil material model was used to replace the interface function of Plaxis.

For this study, Plaxis version 8.6 was used for the thin-soil interface model iteration since it is commercially available and still widely used in several practices. The back-analysis used the Semarang-Bawen toll road slope failure in 2015, which had already been used in previous interface slope stability research [2,10]. The slope was taken as the case study due to its known interface failure possibility from the landslide report [2].

The thin-soil layer was limited to one meter tall, which is very small compared to the overall slope geometry. The model used for the soils was the Mohr-Coulomb model. Mohr-Coulomb was selected due to the limited data available on the slope, which only provided the boring log, cone penetration test, index properties, and triaxial tests [2]. Thus, using other models in the Plaxis software would lead to inaccurate results.

Another variation to assure that the range of interface shear strength accommodated any critical condition is the groundwater level. Two groundwater level combinations were used in this study: low-groundwater-level and high-groundwater-level. In the model, the thin-soil interface layer was kept saturated. The condition was necessary to ensure that the model could depict the slope situation at failure and the interface laboratory testing assumption.

For the Plaxis 8.6 analysis steps, two analyses were used in this study. The analyses were the total multipliers step and the Phi-C reduction analysis. The total multipliers analysis was used to calculate the weight of the entire slope due to its gravity. Afterward, the Phi-C reduction analysis was used to calculate the safety factor. The limit of the factor of safety ranged from 1.00 to 1.10. The translational failure plane deducted from the landslide analysis was also used as a control for the model. If any results did not comply with the range of a safety and failure plane factor, the iteration of the shear strength parameters should be repeated for another variation. Overall, the flowchart of the thin-soil interface model iteration in this study can be seen in Figure 1. Around five iterations were used in this study to ensure a linear trend for each groundwater level variation.

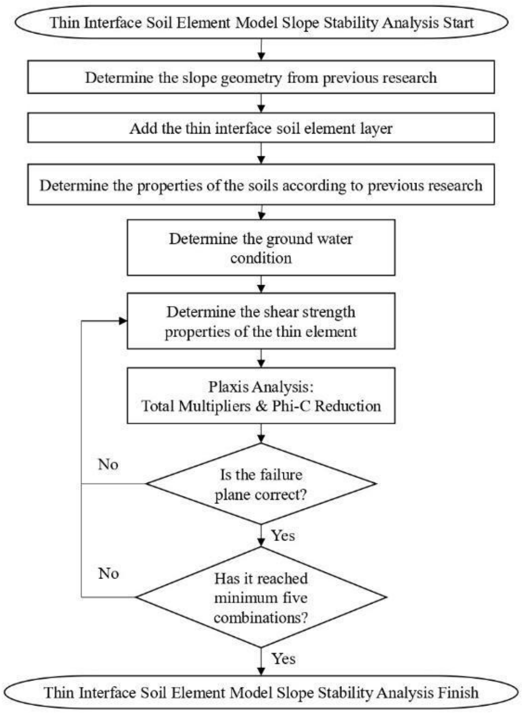

Figure 1. Thin-soil interface model analysis flowchart

Lastly, the laboratory test results using the Progressive Reversal Interface Direct Shear Test (PRIDST) were plotted into the interface model results. The interface shear strength experiment was conducted using undisturbed clay shale and laterite-sand overburden variations according to the tuff breccia on the Semarang-Bawen toll road slope failure [1]. The variations of laterite-sand overburden included: 100% sand: 75% sand: 25% laterite, 50% sand: 50% laterite, 25% sand: 75% laterite, and 100% laterite. A range of interface cohesion and friction angle from the laboratory results would be able to be analyzed from the plotting.

3. Results and Discussion

3.1. Interface Shear Strength Parameters Results at the Thin-Soil Interface Material

As stated in the previous section, the thin-interface model used previous research geometry of the Semarang-Bawen toll road landslide on KM 483+200 in Figure 1 [2]. The soil properties input used the Mohr-coulomb material type and the clay shale interface soil layer (as seen in Table 1). However, the interface shear strength properties were determined using the iteration in this study.

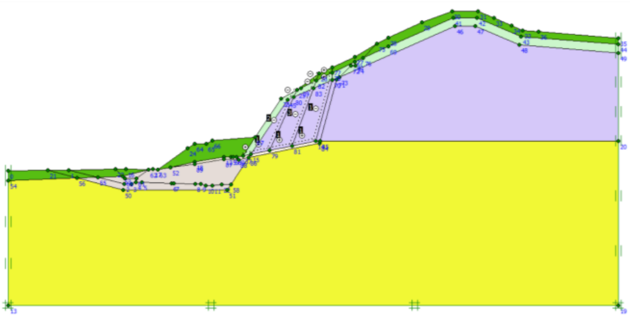

Figure 2. Geometry and Plaxis 8.6 model of the Semarang-Bawen toll road slope

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Table 1. Soil properties input for Plaxis 8.6

Soil Properties	Tuff Breccia	Weathered Tuff Breccia	Silty Clay	Fresh Clay Shale	Interface Clay Shale
Color	Purple	Slight Green	Dark Green	Slight Brown, Dark Yellow	Light Yellow
Unsaturated Unit Weight (kN/m^3)	17	17	15	18	18
Saturated Unit Weight (kN/m^3)	18	18	17	18	18
Elastic Modulus (kN/m^2)	150000	60000	10000	100000	100000
Poisson Ratio	0.25	0.25	0.30	0.30	0.30
Shear Modulus (kN/m^2)	60000	24000	3846	38460	38460
Cohesion (kN/m^2)	100	50	15	250	
Friction Angle (°)	38	30	30	41	

From the geometry of the slope, two groundwater level conditions were determined using the phreatic line determination. The results for the low-groundwater-level (LWL) and high-groundwater-level (HWL) input into the software can be seen in Figures 3 and Figure 4.

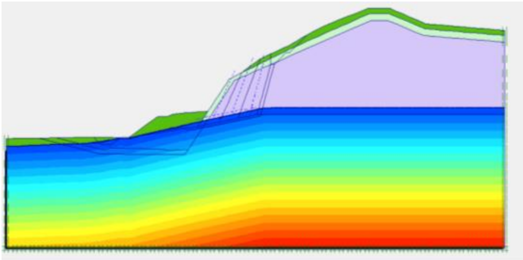

Figure 3. Low-Groundwater-Level (LWL) model for Plaxis 8.6 thin-soil interface model

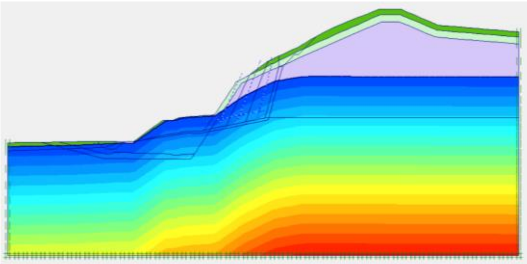

Figure 4. High-Groundwater-Level (HWL) model for Plaxis 8.6 thin-soil interface model

Lastly, the iteration was controlled using the factor of safety range and the failure plane during the landslide (as seen in Figure 5). As previously mentioned, the limitation was needed to ensure that the interface contributed to the landslide force. Thus, the range of the results in this study would be limited to only interface cohesion and interface friction angle that would initiate landslide in two extreme groundwater conditions. Thus, the limitation and the minimum number of iterations taken into this study would limit the bias of the results data.

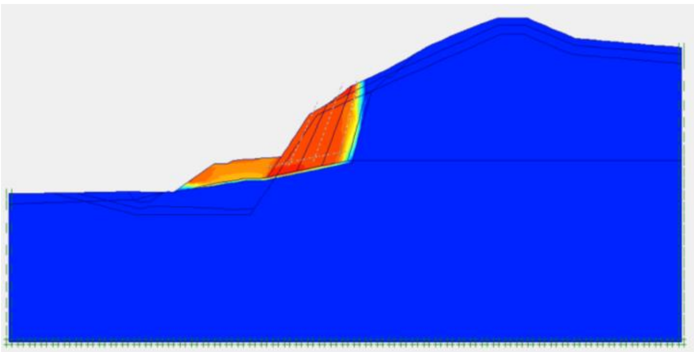

Figure 5. Failure plane reference for the Semarang-Bawen toll road slope failure

3.2. *Interface Shear Strength Parameters Results at the Thin-Soil Interface Material*
After several iterations of the slope stability analysis using Plaxis 8.6 for both groundwater level conditions, a series of interface cohesion and friction angle with its Factor of Safety (FS) can be deducted. The results can be seen in Table 2.

Table 2. Interface residual shear strength parameters at failure condition

Trial	LWL			HWL		
	Cohesion (kN/m^2)	Friction Angle (°)	FS	Cohesion (kN/m^2)	Friction Angle (°)	FS
1	1	12	1.023	1	31	1.004
2	5	11	1.066	4	29.75	1.006
3	9	9.5	1.036	7	28.75	1.018
4	13	8.5	1.059	10	27.75	1.021
5	15	7.5	1.041	12	26.5	1.003
6	17	6.5	1.008	14	25	1.009
7	19	6	1.018	17	23.5	1.011
8	21	5.5	1.03	21	23	1.003

The cohesion for both the LWL and HWL was capped at 1 kPa and 21 kPa. The lowest 1 kPa was used due to the limitation of the Plaxis 8.6 software, which needed a positive cohesion value higher than zero. At the same time, the highest 21 kPa was selected according to the highest cohesion values from the laboratory results. Lastly, the FS ranged between 1.000 and 1.060. The ones nearing 1.10 were seen at low cohesion due to the difficulty of having the exact failure plane which controlled the back-analyses.

3.3. *Thin-Soil Interface Soil Model Results Plotted Against Laboratory Results*
The results from both groundwater level conditions were plotted in one graph. The graph consisted of the interface cohesion as the y-axis and the interface friction angle as the x-axis. Afterward, previous laboratory results were added to the graph. Thus, a range of cohesion and friction angle which would initiate failure could be acquired. The properties of the laboratory results which would be considered in the analysis are its degree of saturation and its laterite-sand ratio. The results can be seen in Figure 6.

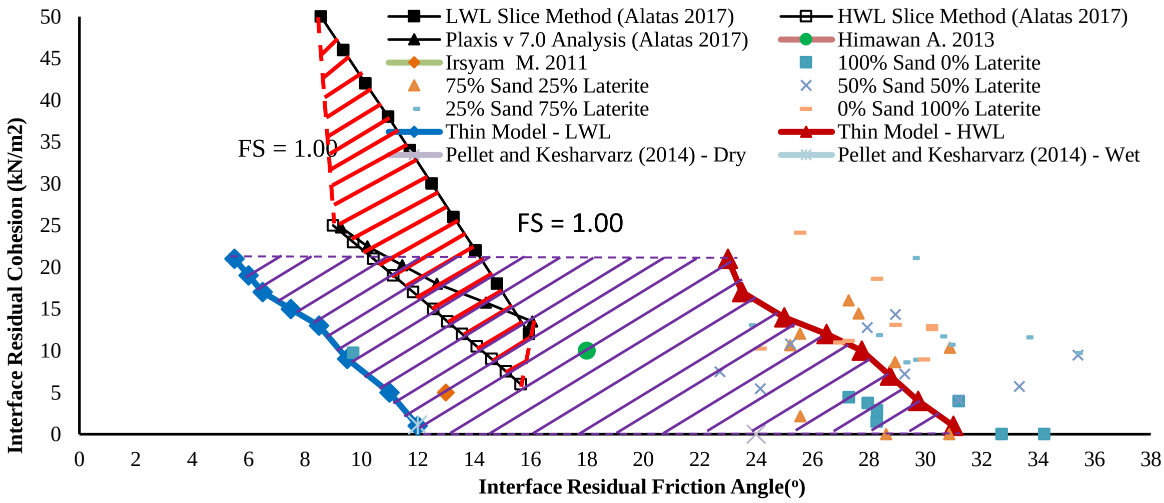

Figure 6. Comparison of interface shear strength thin-soil interface model with laterite-sand overburden variations

For comparison, the results of interface shear strength between clay shale with other soils were also included in the graph [11,12]. Furthermore, previous back-analyses were conducted on the same slope using the limit equilibrium slice method and finite element Plaxis ver. Seven were also added [13].

The previous slope stability analysis of the Semarang-Bawen landslide was seen to have higher cohesion and a narrower range of a factor of safety. Several reasons were known for the different results between this study and the previous study [13]. First, the previous study did not include any interface function in the analysis. Second, the cohesion values were capped according to the residual shear strength of the fresh clay shale. Third, the estimation of the groundwater level was different from this study. Lastly, the Plaxis analysis only included the existing groundwater level condition at failure.

This study argued that the thin-soil interface method would give a much similar situation to the landslide with a broader range than the previous analysis [13]. From Figure 6, it was clear that the laterite-sand variations, the residual clay shale properties [11], and the interface shear strength of steel-clay shale rock [12] mostly fell into the range of FS = 1.00. Thus, the thin-soil interface method could sufficiently depict the interface shear strength behavior in the FEM software. However, the thin-soil interface had several limitations, such as low repeatability and a highly user-dependent tendency. The reason was that this method was developed according to the landslide of the Semarang-Bawen toll road, but it might not be repeatable in other landslides. Several considerations, such as the depth of the interface and the landslide cases, should also be considered when using the model.

Table 3. Overburden variations of laterite-sand combinations at FS = 1.00 zone

Number	Laterite-Sand Overburden Variations	Degree of Saturation (%)
1	100% Sand	18.89%, 25.30%, 32.67%, 40.42%, 59.04%, 103.06%
2	75% Sand: 25% Laterite	38.66%, 45.91%, 53.07%, 60.97%, 101.68%
3	50% Sand: 50% Laterite	47.23%, 53.27%, 98.85%
4	25% Sand: 75% Laterite	48.85%, 100.59%
5	100% Laterite	36.29%, 50.32%, 100.52%

Lastly, a trend for the degree of saturation between various overburden conditions can be deducted from Table 3. The higher the degree of saturation, the more it is susceptible to failure. However, the 100% sand variation indicated a different trend where some lower degrees of saturation also initiated failure according to the thin-soil interface model. The reason might be due to the high permeability of sand and its granular texture. Both reasons lead to the low adhesion of the sand overburden to the wet undisturbed clay shale at the interface. Previous research indicated that higher clay content would give higher interface shear strength until a maximum value [14]. Other research also stated that clay had higher interface shear strength than sandy clay [15]. Thus, the results of this study are comparable with previous studies of the interface shear strength, where a higher clay ratio of the overburden would give higher interface shear strength.

From Table 3, the results also indicated that water had a significant role in determining the interface failure, where a higher degree of saturation would lower the interface shear strength. Although [16] argued that a higher degree of saturation would give higher interface shear strength of clay interface with concrete, other studies agreed with the current study's results [1–3]. Thus, water could be concluded to reduce the interface shear strength dominantly.

4. Conclusion

The study evaluated the thin-soil interface model using FEM software for interface slope stability back-analyses. In addition, laboratory results of interface shear strength tests were included in the analysis. Several conclusions can be deducted from the results and analysis of the thin-soil interface model.

First, the thin-soil interface model could be used to conduct a back-analyses slope stability case. The conclusion was made from the comparison to previous studies, which fell inside the FS = 1.00 zone, indicating failures of the slopes. Second, a comparison with laboratory results showed that the thin-soil interface model indicated that a higher degree of saturation at the interface would lead to failure regardless of the overburden variation. Attention should be given to 100% sand, which is purely granular, and failed at a low degree of saturation.

Lastly, further studies are needed to explore the possibility of the thin-soil interface model at other slopes. Clearly, the method was developed limitedly for the Semarang-Bawen toll road landslide. Thus, it needed several iterations on other cases to understand its repeatability and errors.

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