Evaluation of Ground Anchor Design on Man-made Cut Slope of Cemented Sand: A Case Study

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Abstract. A system of ground anchor and horizontal drain on a steep cut-slope in Bogor, West Java was designed to stabilize the slope below a bridge structure spanning across a river. Due to the difficulties in the construction of the ground anchor, the design of the ground anchor was evaluated and analyzed for its effect on the stability of the slope. The slope is assumed to have three layers of soil consist of sandy clay (medium stiff), sandy silt (hard), sandy silt (medium stiff), and cemented sand gravel. Four scenarios were evaluated to examine the slope stability: initial stage, the addition of horizontal drain, construction of bored piles with horizontal drain, and addition of ground anchor after the construction of bored piles and horizontal drain. Analysis were done with evaluating the Factor of Safety (FS) of the slope. It was found that the addition of horizontal drain played a big part in stabilizing the slope from initial stage (FS = 0.933 to FS = 1.546), whereas the addition of ground anchor and bored piles were not apparent after the addition of horizontal drain (FS = 1.545 and FS = 1.555), indicating that the main problem of the slope was the high groundwater level. Other than the constructed solutions, shortcrete should also be given at the critical slip surface at the top and surface of the slope in order to reduce erosion by run-off water.

1. Introduction
A prestressed grouted ground anchor is known as a stabilization method for various structures in geotechnical engineering. It is a structural element installed to transmit an applied tensile load into the ground of soil or rock. The ground anchor is installed in grout filled drill holes with basic components such as anchorage, free stressing length, and bond length. The combined system is capable of transmitting the prestressing force from the prestressing steel to the ground surface of the supporting structure [1].

One of the uses of a ground anchor is for a vertical cut-slope stabilization. In this case study, a system of ground anchor and horizontal drain was designed to stabilize the cut-slope below a bridge structure located in Bogor, West Java. However, when the construction had taken place, the designed specification was not fitted to the situation on the field. It was found that the diameter of the ground anchor specified was too large and not suitable for boring as the slope material was very hard to be penetrated with the available equipment. The aim of this report is to evaluate the slope condition and analyze the effect of the ground anchor to the stability of the slope.
2. Site Condition

The slope in this case study is located at one of the abutments of a tollway bridge construction which spans across a river in Bogor, West Java, Indonesia (the exact location will not be mentioned here due to confidentiality). Literature study and field survey was conducted in order to understand the site condition for this report.

A literature study was conducted by first identifying the slope’s location to get its geological information. The geological information that was obtained from the Bogor Geological Map [2] inferred that the location is described as older sediments, lava, basalt and andesite with oligoclases-andesine, labradorite, olivine, pyroxene, and hornblende. From this information, it can be concluded that the location is dominated with vulcanic igneous rock due to its location near Gede-Pangrango mountain. It is also known that there wasn’t any fault found at the slope location. At the surface of the slope location, it was found that the weathered rocks are classified as red latosol, andosol, and weathered sandstone [3].

The field survey was done in March 2018 to understand the geometry and soil material visually. At that time, the geometry of the slope was already modified by the cutting works. The abutment of the bridge is located at the top of the slope whereas the pier of the bridge is located at the toe. A very steep slope from the cutting works with an angle of > 70° and a height of 26 m was located near the pier of the bridge. The surface material of the cut section from the slope could be seen to be quite hard with several holes from the attempted ground anchor construction and water flowed out of the horizontal drain holes (Figure 1). From the other side of the slope, there was flowing water from the upper part of the slope, but it wasn’t known whether it was from seepage of the slope or surface runoff (Figure 2).

2.1. Secondary Data Evaluation

There were no field and laboratory test done at this reviewed stage of construction due to the completion of the bridge structure at that time, and the situation in which the equipment was difficult to install. Analyses were made based on data from the previous tests done before the construction. The data included:
- Bridge Plan
- Longitudinal section of the bridge
- Boring log of ABT-1 (located at the abutment)
- Boring log of P-1 (located at the pier of the section)
- Boring log of NDB-17 (located near the river)
- Boring Record of Abutment-1 Bored Pile
- Boring log of Horizontal sub-drain
- Boring log of Ground Anchor

As mentioned before, the slope was located between the abutment and pier of the west side of the bridge. The boring logs of ABT-1, P-1, and NDB-17 were used to create the soil stratigraphy, whereas the longitudinal section was used to define the slope geometry. The initial section and the soil stratigraphy from the three boring logs can be seen in Figure 3. From this estimated section, a cut-slope construction was done between the P-1 boring point and P-1 location in order to construct the pier of the bridge at P-1 location. The initial section before the cutting works can be seen from the red full line of the geometry, whereas the dashed red line is the condition of the slope after the cutting works were done. The ground anchor and horizontal drain constructions at the point of the cut-slope near the P-1 location were known to be done after the bridge was completed. At the toe of Pier-1, a river flows through the bridge structure, which is around the NDB-17 point. The groundwater level was extracted from the boring log of P-1 and NDB-17 but was estimated at ABT-1 due to the unavailable data of the groundwater elevation from the boring log.

Figure 3. Estimated longitudinal section of the bridge consisting of the three deep boring logs and the location of the bridge’s abutment (ABT-1) and pier-1 (P-1). The section shows the natural geometry before the construction of cutting and filling were executed.

In order to validate the interpretation for the stratigraphy in Figure 3, boring logs from the boring record of the bored pile in Abutment-1 was taken into account. It was known that the bored pile of 36.5 meters long was constructed from the elevation of +448.0 m from the top of the slope. At the boring log, elevation +448.0 m to +443.0 m was followed by red clay, which ended at boulders and hard soil at +443.0 m to +418.0 m, and boulders at elevation +418.0 m and 411.5 m. These data were then double-checked with the boring log for the horizontal drain construction at elevation +415.0 m at the face of the slope where breccia stone and andesite boulders with diameter > 35 cm and cemented clayey sand breccia was found. It can be inferred that the soil stratigraphy from the boring logs of ABT-1, P-1, and NDB-17 was correct according to the validation from the boring records.
2.2. Slope Stability Evaluation
Slope stability analysis was done by calculating the factor of safety (FS) of the slope which is basically the ratio of shear strength of the soil to the shear stress experienced by the soil (e.g. [4]). The shear strength is basically affected by cohesion (c) and internal friction angle (φ), whereas shear stress is affected by the weight of the soil itself or external loads at the surface. Some literature stated that a slope is safe when its FS is around 1.25 – 1.5 (e.g. [4] and [5]). Another source, which is the standard for geotechnical engineering construction in Indonesia (SNI 8460:2017) explained that the FS is based on the uncertainty of analysis, repairment cost if the structure failed, and the additional cost of designing the slope in a more conservative way [6]. From all the standards taken into account, this case study took the critical FS value of 1.5.

The slope analysis was done using the Finite Element Method (FEM) with Plaxis 8.2 2D software. The slope was assumed to be in plane strain condition (as seen in Figure 4) with the material model of Mohr-Coulomb.

![FEM model for the slope according to the identified soil stratigraphy.](image)

From the soil stratigraphy and N-SPT value from Figure 3, a correlation was done from the literature (e.g. [7]) in order to assume the needed parameters for the FEM model. The values used in the model can be seen in Table 1.
Table 1. Material parameters for each soil layer of the slope.

| Soil Properties | Layer 1: | Layer 2: | Layer 4: | Hard Soil |
|-----------------|---------|---------|---------|-----------|
| Layers          | Sandy Clay | Sandy Silt | Sandy Silt | (Sand Gravel) |
| N-SPT = 9.5     | N-SPT = 33 | N-SPT = 8.5 |
| Model Material  | Mohr-Coulomb | Mohr-Coulomb | Mohr-Coulomb |
| $\gamma_{\text{unsat}}$ (kN/m$^3$) | 17 | 13 | 17 | 18 |
| $\gamma_{\text{sat}}$ (kN/m$^3$) | 19 | 17 | 19 | 21 |
| E (kN/m$^2$) | 20000 | 30000 | 30000 | 80000 |
| v (poisson ratio) | 0.325 | 0.25 | 0.30 | 0.30 |
| Cohesion (kN/m$^2$) | 30 | 45 | 25 | 150 |
| Friction Angle (°) | 25 | 28 | 27 | 37 |

There are two stages of analysis in PLAXIS 8.2 for this case, the first is the initial stage of having the soil’s own weight taken into account and the latter is the strength reduction (phi-c reduction) analysis in order to find the FS and the critical slip surface of the slope. Strength reduction itself is a method in which the cohesion and friction angle of the material was reduced with the estimated FS calculated through Finite Element Method until the value is non-convergent [8]. The FS value from the analysis will be the ‘true’ FS value for the situation and can be considered as the FS for the slope.

The previously described analysis was done to four stability scenarios according to the construction phases for the slope after the cutting works were finished. The first scenario represented the initial state after the cutting of the slope. The second scenario represented the condition after the horizontal drain was constructed. The third scenario represented the condition of the slope after the foundation for the pier and abutment were constructed, with the addition of horizontal drains. Lastly, the last scenario represented the condition the same as the third scenario with the addition of ground anchors.

2.3. Ground Anchor Modelling in PLAXIS 8.2

Ground Anchor in PLAXIS 8.2 was specifically modeled as a node-to-node element with the end of the structure as geogrid (tensile) elements. The node-to-node anchor modeled the free length of the ground anchors. As is implied in the name, the anchor was connected at both ends to nodes in the structural element, as if there was no contact of the anchor body to the surrounding soil. As for the geogrid (tensile) element, the model was designed to accommodate the bond length of ground anchors. In practice, the bond length was normally pressure grouted so that the soil can be completely in contact with the grouted body [9].

Although the precise stress state and interaction of the soil, in reality, is much more complex and cannot be modeled in 2D with precision, this estimation of stress distribution, deformations, and the stability of the structure on a global level is sufficient. It is also important to note that the grout body was assumed to not slip relative to the soil. Another consideration was that this type of model could not evaluate the pullout force of the ground anchor [10].

3. Results and Discussion

3.1. Finite Element Results

The results and analysis of the four scenarios are given below.

3.1.1. Initial Condition. The initial condition of the slope was reviewed with high Groundwater Elevation (GWL) starting from elevation +443.0 m at the top of the slope to around +420.0 m at the face of the slope, continued by the surface of the water from the river. These elevations
were taken from the boring log of the three boreholes and can be seen in the software in Figure 5. The result for this condition was a factor of safety (FS) of 0.933 and potential of steep slight movement at the bottom of the slope as seen in Figure 6. This value indicated that at the intial condition, the slope was not safe as the calculated FS value was lower than 1.5.

![Figure 5. Finite Element representation of the initial groundwater level condition of the slope.](image)

![Figure 6. Simulation result for the initial groundwater condition (FS = 0.933).](image)

**3.1.2. Groundwater Condition Altered due to Horizontal Drain.**

The second scenario was reviewed after the horizontal drain was constructed. The specification of the horizontal drain was 16 m long with the inclination degree of 5° towards the horizontal surface and was constructed at elevation +415.0 m as seen in Figure 7. This construction lowered the groundwater level at the surface slope which raised the FS value to 1.546. When compared to the initial condition, it can be seen that the slip surface of the slope shifted from the surface of the slope to the top of the slope which happened to be at the medium stiff to stiff sandy clay layer and very stiff to hard sandy silt layer. Since the value of FS for the slope at this condition is above 1.5, the slope is considered to be safe. The potential movement of the critical slip surface illustration of the slope can be seen in Figure 8.

![Figure 7. Finite Element representation of the altered groundwater condition due to horizontal drain construction.](image)

![Figure 8. Simulation result for the altered groundwater condition due to horizontal drain construction (FS = 1.546).](image)

**3.1.3. Condition after bored pile construction.**

In the construction process, the bored pile construction was done before the construction of horizontal sub-drain. However, this research wanted to emphasize the bored pile as a structure to stabilize the slope rather than only as a structure of the bridge itself. On the other hand, the horizontal sub-drain construction on this research was meant to emphasize the role of groundwater level for the stability of the slope.
The specifications for the bored pile were $f'_c = 29$ MPa and Diameter = 1.2 m, whereas the length of the bored pile was 35 m for abutment-1 and 24 m for pier-1. The situation of the bored pile can be seen in Figure 9. The result of this condition can be seen in Figure 10. The FS value for this condition is 1.545. This value is not far off from the FS value in the horizontal drain condition which indicates that the bored pile construction didn’t contribute much to the safety of the slope. Theoretically, the bored pile should contribute to the stability of slope when it is constructed at the failure area of the slope. From Figure 10, it can be seen that the critical slip surface of the slope was located at the tip of the steep cut slope, whereas the position of the bored piles was located at the top of the slope and at the toe of the steep cut slope. The critical slip surface location indicated that the bored pile's location was not in the critical slip surface of the slope, which is the reason why the FS value didn’t increase from the bored pile constructions.

![Figure 9. Finite Element representation of the slope condition after the construction of bored pile and horizontal drain.](image1)

![Figure 10. Simulation result for the slope condition after the construction of bored piles and horizontal drains (FS = 1.545).](image2)

### 3.1.4. Slope condition after ground anchor construction.

The construction of the ground anchor was done after the bored piles and horizontal drains were installed. The ground anchor specification in this research was the result of recalculating same bond strength of the ground anchor into a different diameter and spacing specification. The specification was altered due to the failure of penetrating the soil with even the highest grade of the drill bit. The aim of this analysis phase was to decide whether the new specification will still stabilize the slope in its constructed condition. The specification for the ground anchor in this condition was 25 m long with the diameter of 100 mm, the bond length of 6 m, and spacing of 2 m. The ground anchor was constructed at elevation +417.5 m and +421.5 m with 25° inclination from the horizontal axis (as seen in Figure 11). The pull out strength of the ground anchor was 600 kN. The simulation resulted with a critical slip surface around the top of the steep cut-slope surface, where the sandy clay and sand silt layers were located, with the FS value of 1.555 (as seen in Figure 12). This value of FS is not far off from the FS from the previous conditions. The FS value above 1.5 indicated that the design was safe enough for stabilizing the slope.
3.2. Discussion

According to the soil classification, it can be seen that the material at the steep cut slope itself was already quite hard. The data from the boring logs and field survey had shown that the material at the face of the slope was mostly cemented which indicated that the cohesion value of the soil is indeed quite high. But, this data should be reviewed with the Factor of Safety (FS) from the Finite Element Method where the summarized results can be seen in Table 2 below.

**Table 2. Finite Element Method Results.**

| Conditions                                      | Factor of Safety |
|------------------------------------------------|------------------|
| Initial Condition                               | 0.933            |
| Addition of Horizontal Drain                    | 1.546            |
| Construction of Piles with the addition of Horizontal Drain | 1.545            |
| Construction of Ground Anchor with Piles and Horizontal Drain | 1.555            |

From the Finite Element Method results, it can be seen that the natural condition’s FS was under 1.5, which can be considered as unsafe. In most cases, cemented condition for the hard soil of a slope would be enough to maintain its stability without any stabilization method. Yet, the unsafe value of FS indicates that the high groundwater level of the slope needs a stabilizing measure in order to make the slope safe. From the horizontal drains construction condition, it can be seen that installing the horizontal drain has a big effect in which it lowered the groundwater level within the slope. The installation of horizontal drains successfully raised the FS value into a safer condition (FS > 1.5). In contrast, the construction of bored piles and ground anchors did not result in a significant increment of FS value, which validates that the main problem of the slope was not the shear strength of the material, but instead was the groundwater level of the slope.

It should be taken into account that near the constructed slope with the horizontal drain, there were running water on the surface of the slope which is shown in Figure 2. This condition indicates that surface water should also be taken into account in stabilizing the slope. Due to that reason, other than applying ground anchor and horizontal sub drains at the surface of the steep cut slope, shotcrete should also be added as a covering for the surface in order to prevent erosion of the slope from surface runoff. Not only that, since the critical slip surface was located at the top of the cut-slope, shotcrete should also be applied there in order to prevent erosion which could lead to landslide at the top of the slope.
4. Conclusion
In this study, the stability of a very steep cut-slope of cemented sand was evaluated. The slope is located at a tollway bridge spanning through a river in Bogor, West Java and had gone through cutting works. Several conditions for stabilization of the slope were evaluated using the Finite Element Method in order to understand the effects of the stabilization to the safety of the steep cut-slope.

It can be concluded that the initial state of the slope after the cutting works was not safe with the FS value of 0.933 and an additional possibility of a shallow failure on the slope surface from the displacement shading of the FEM model. After the installation of horizontal drains, the slope became quite stable due to the altered elevation of the groundwater level at the surface of the slope with the FS value of 1.546 and an additional slope failure area which moved to the top of the surface instead. Afterward, construction of ground anchor was evaluated in order to know the effect of the ground anchor to the stability of the slope. It was known that the ground anchor doesn’t significantly add the stability of the slope with the FS value of 1.555 and the slope failure area still at the top of the slope. A similar condition of stability was seen when bored piles from the abutment and pier of the bridge were constructed, whereas the existence of the bored piles didn’t affect the stability of the slope in general with the FS value of 1.545 and the slope failure surface was still at the top of the slope, which is the same condition with the addition of horizontal drain.

From the conditions, it can be inferred that the main problem of the stability of the slope was the high groundwater level at the slope due to the rise of FS value from 0.933 to 1.545. For further protection, shortcrete should be applied to the surface of the slope and at the critical slip surface, in addition, the existing construction to reduce the possibility of erosion of the surface of the slope.

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