The importance of designer-contractor communication in geotechnical design as exemplified by a cut slope failure

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Abstract. A shallow slope failure has occurred on the cut slopes of the Bigadic-Simav-Abide highway at the section located between Km:125+530-125+870, during construction. A detailed investigation of the landslide mechanism, which includes site specific surveys, laboratory studies, and stability analyses indicates that the main reason of the failure lies within the construction procedure details. This study focuses on the forensic geotechnical engineering procedures applied for determining the cause of the slope failure. An emphasis was placed on the importance of strictly following the construction sequence as illustrated in the design documents in detail, as well as on the indispensable role of continuous communication between the designer and the contractor for successful performance of geotechnical works.

1. Introduction
Observation of deformations and local slumps at the slopes located between Km:125+530-125+870 along the Bigadic-Simav-Abide highway, which is under construction, has necessitated a geotechnical investigation to be undertaken to explore the possible causes of the failure and the remedial measures that can be taken to ensure the stability. This investigation included an assessment of the engineering geology of the site and the slopes, as well as geotechnical modeling studies, which led to an improved design of the roadway cut.

However, during the construction of the roadway cut slopes according to design, shallow slope failures have occurred unexpectedly. Thus, a study was planned to understand the main reason of this failure, which is necessary to ensure the future roadway safety. This study presents the geotechnical methodology applied to understand the root cause of the failures, inevitably focusing on the effects of construction sequence and procedures on the design assumptions.

2. The original design
The site under investigation where signs of slope instability were observed in terms of localized slumps and deformations at various portions of the cut slopes, is located between Km: 125+530-125+870 along the Bigadic-Simav-Abide highway, which is still under construction (Figures 1 and 2).

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Figure 1. Site location [1].

Figure 2. A view of the cut slope deformations between Km: 125+530-125+870 [1].
In order to determine the reasons of the signs of slope instability and to estimate the geotechnical properties for remediation studies, a site investigation program that included drilling of exploration boreholes at two locations with a total depth of 50 m was planned. According to the results of this study, the site is underlain by lower- middle Miocene aged sediments that consists of claystone-siltstone and mudstone units of varying degree of weathering. A close look at the boring logs indicate that highly weathered claystone and mudstone is overlain by from 2.0 m to as much as 18.0 m of clay and clayey sand/gravel especially on the upper portions along the cut slope. Ground water was observed mainly at the interface between the soil and rock layers. A cross-section of the slope under investigation is shown in Figure 3.

![Figure 3. A cross-section of the slope under investigation [1].](image)

The geotechnical parameters required for slope stability analyses were estimated based on in-situ and laboratory test results, which were quite limited both in terms of quality and quantity, especially for the soil layers mainly due to the urgent nature of the project. Note that Mohr-Coulomb failure model has been used for the rock unit modeling also, but the parameters were derived as a fit to Hoek-Brown criterion. The employed parameters for idealized strata are summarized in Table 1.

| Table 1. Geotechnical parameters employed in the slope stability analyses [1] |
|---------------------------------|-------------|-------|----------------|-------------|
| Clayey sand                      | Silty-clayey gravel | Clay  | Weathered claystone/mudstone |
| Unit weight, $\gamma$ (kN/m$^3$) | 18          | 19    | 18              | 21          |
| Effective stress friction angle, $\phi'$ (°) | 30          | 32    | 30              | 17          |
| Effective cohesion, $c'$ (kPa)   | 3           | 5     | 5               | 68          |
| Undrained shear strength, $s_u$ (kPa) | -           | -     | 110             |             |
For all slope stability analyses, a limit equilibrium-based computer program named Slide 2018 [2] was employed. For seismic conditions, the horizontal earthquake acceleration applicable to earth structures was determined to be 0.23g for the site, using the interactive web application available at AFAD website.

As an initial step, the stability of the slope was assessed for the existing conditions using the long-term, i.e., effective parameters given in Table 1. As shown in Figure 4, the results indicate a factor of safety (FS) of about 1.2 under static conditions, which is lower than the required value of 1.5 as specified by the General Directorate of Highways. Note that the corresponding FS is less than 1.0 under seismic loads, and it is expected that even lower FS values may be attainable locally at different locations within the investigated section of the highway.

![Figure 4](image-url)  
**Figure 4.** The results of stability analyses for the slope in its existing geometry under static loading conditions [1]

Considering the low FS values obtained from the limit equilibrium analyses along with the signs of instability observed at the site, remedial measures was decided to be undertaken, which include construction of an eight-meter high masonry wall at the toe of the slope and backfilling it using crushed rock, effectively forming a 5 m wide berm behind it (Figures 5 and 6).

As can be seen from Figure 5, a temporary small-scale excavation with a 45° slope has to be made in order to construct the foundation of the masonry wall. Therefore, care was taken to investigate the stability of the slope during the excavation stage as this might be a relatively critical condition due to the removal of material from the toe of the slope. Assuming that the excavation will not stay open for a long time until the masonry wall will be completed, short-term strength parameters were used for the analyses at this stage. Based on this assumption, and considering the observed facts that slopes with 45° angle remain only temporarily stable at the site, the design documents clearly stated to perform the excavation and wall construction at maximum ten-meter long sections, preferably during the dry season to minimize the time during which the excavation stays open.
Figure 5. The results of stability analyses during remediation works [1]

Figure 6. The results of stability analyses for the remediated slope after construction [1]
3. The second failure
During remediation works of the slope, before the masonry wall was constructed, shallow slope failures were observed at the site at several locations (Figure 7).

As soon as the designer became aware of the problem, a forensic geotechnical engineering study was initiated for determining the cause of the slope failures. Unfortunately, time and budget constraints prevented performing additional site or laboratory investigations. However, a detailed look at the slope stability problem based on the field records was enough to indicate at least two procedures that are not in compliance with those stated in the design documents.

First of all, as can clearly be seen from the field records and also from some of the photographs, the very important instruction in the design documents that stated to perform the excavation and wall construction at maximum ten-meter long sections to minimize open excavation time was not followed. Instead, first the whole excavation was made along the length of the cut slope, later to be followed by the wall construction. This clearly nullified the undrained behavior assumption made during the slope stability analyses for the temporary excavation case. In addition, it is understood that, probably after the first signs of slope instability, which might be cracks or some deformations, the contractor laid down a layer of crushed rock on the slope face to prevent further damage without the consent of the designer. The crushed rock particles can indeed be observed on the failed slope in Figure 7. This had a further adverse effect on the slope by increasing the destabilizing weight.

Limit equilibrium analyses simulating the above-mentioned conditions have been performed to investigate the slope stability (Figure 8). Note that, due to the long elapsed time of open excavation conditions, drained strength parameters were employed this time. Also, based on the fact that the clay layer was remolded to some extent, a minimal 10% reduction was applied to its strength parameters. The results of the limit equilibrium analyses clearly indicate that, even without the effect of crushed rock layer above the slope face, the slope is on the verge of sliding with a lower FS compared to that during the initial conditions before any remediation work took place.
Figure 8. Analysis of the second slide using existing conditions

Based on the slope stability problems summarized above, a new remediation project, which is an extended and surely more expensive version of the previous one was undertaken. The details are illustrated in Figure 9.

Figure 9. Final remediation project for the slope
4. Summary and Conclusions

This study exemplified the importance of designer-contractor communication and the significance of attention to design details by a relatively small-scale slope failure. It was clearly demonstrated that not following the recommended procedure of performing the excavation at a maximum of ten-meter long sections, thus elongating the open excavation time, decreased the FS against slope stability failure to a value even less than the originally existing conditions. In addition, a well-meant slope stabilization measure that was taken without the consent of the designer, which is clearly a lack of communication issue, aggravated the conditions even more. Design details and communication clearly become more important when there is limited amount of geotechnical data, which is the usual case for small-scale projects like the one described herein.

References

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[2] Rocscience Inc. 2018 Slide 2018 (Toronto, ON, Canada)