Back Analysis and Rectification of a Failed Cut Slope in the Southern Expressway

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ABSTRACT: A failure occurred in a cut slope of the southern expressway where all the surface drainage measures had been implemented. The failure surface was shallow but it has disrupted three levels of berms. The debris of failure were quite dry. A close examination indicated that a cascade drain has cracked and water is leaking to the slope. There were five systems of joints in the rock and adversely oriented relict joints were identified during rectification work. The failure could have been triggered by infiltration of rainwater through relict joints, reduction of matric suction and development of pore pressure. Rectification process involved installation of soil nailing and cable anchoring together with long sub horizontal drains.

1 BACKGROUND

A failure occurred in a cut slope at chain edge 42+340 to 42+400 in the southern expressway after few days of rain. As illustrated in Fig. 1 tension cracks were noted in the slope around 9 AM and the traffic on that side was diverted. Complete failure occurred by 5 PM on the same day (Fig. 2). The failure surface was quite shallow (Fig. 3) but it destroyed the system of berm drains and cascade drains over three levels of berms. The debris of the failure were quite dry. The ground water table is quite low. Close examination indicated that one cascade drain had cracked sometime prior to failure and water had been leaking into the slope. Whitish clay of low shear strength was seen at some locations in the failure surface. (Fig. 3).

The slope is formed of residual soils where the parent rock is metamorphic. Due to weathering under high ambient temperature and high rainfall conditions and the differences in the lithology of the parent rock the weathered product is highly variable. Rocks with no or slight weathering were embedded in a matrix of soil (boudinage structures). Five different joint systems were identified in the rocks in the area (Fig. 4) and adversely oriented relict joints filled with water were identified during the rectification process. Kulathilaka and Sujeevan (2011) illustrated the infiltration of rainwater and associated reductions of matric suction and pore pressure development due to a rainfall. Kulathilaka and Kumara (2011) illustrated how the changes in the pore pressure regime are minimized by surface drainage and surface protecting vegetation. Analyses were done with GEOSLOPE (2007) software. In the case of this slope all such measures were implemented. It appears that the loss of matric suction had been facilitated by the presence of adversely oriented relict joints and leaking drains. When the back analyses were performed with different values of apparent cohesion the critical failure surface given in Fig. 5 was obtained for a value of 7 kN/m^2. A detailed study modeling the infiltration with relict joints is currently in progress.

2 RECTIFICATION PROCESS

Analysis indicated that the slope profile that remains after failure is not safe unless high matric suction values prevail. As such a rectification design was done using saturated shear strength parameters and assuming that the slope is made of residual soils completely. The rectification

Fig. 1 Tension cracks on the verge of failure

Fig. 2 After the catastrophic failure

Fig. 3 Failure surface is shallow. Whitish clayey is seen at some locations

proposal involved; strengthening the existing scar of failure by soil nailing after removal of the

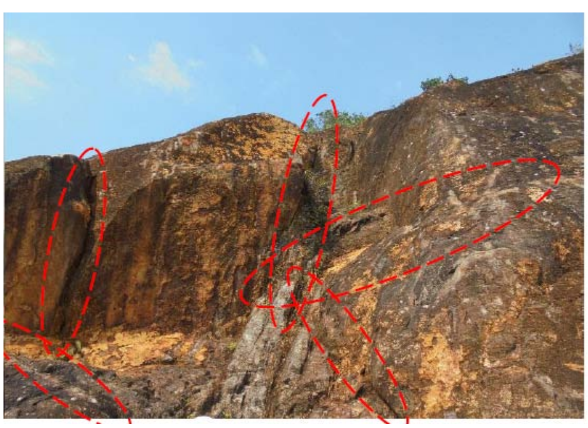

Fig. 4 Joint sets in the bedrock exposed at the top of the slope

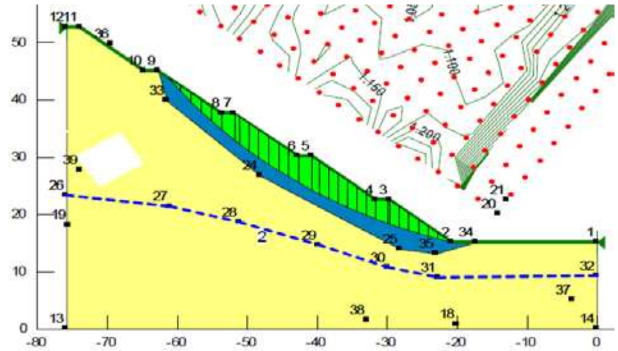

Fig. 5 Simulated failure surface

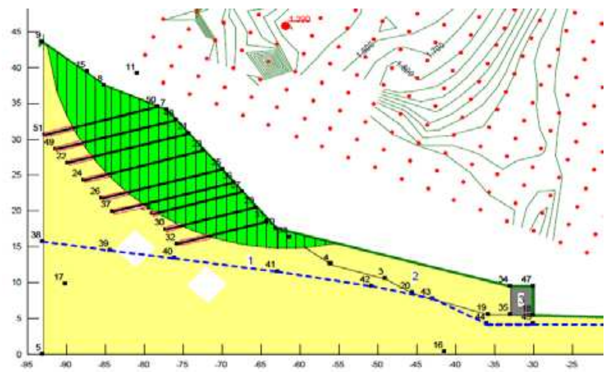

Fig. 6 Proposed stabilization with soil nailing subsurface drainage and toe wall

debris, reconstruction of surface drainage and use of a series of long sub horizontal drains. In addition, a gabion retaining structure is to be constructed at the toe (Fig. 6). Soil nailing design involved nails of 16m length at the highest location. Later it was decided to use cable anchors in place of those long nails. The other nails were of length 12m. During the drilling (Fig. 7) boudinage structures and water filled relict joints were encountered in some drill holes. Water was gushing out at high pressure in those drill holes covering the workers in mud (Fig. 8). During the grouting of boreholes after placement of nails, the grout was coming out from non grouted holes. The volume of grout used was also much greater than the volume of holes which indicates that the systems of joints are interconnected.

Fig. 7 Drilling for soil nailing /cable anchoring

Fig. 8 Water oozing out of relict joints during drilling

A typical system of joints as identified by the evidence surfaced during drilling for rectification work is presented in Fig. 9. This evidence supported the earlier hypothesis that the failure was facilitated by the water entering the slope through relict joints. Water pressure will also built up in relict joints. As such, number of long horizontal drains were done at identified locations of water filled relict joints to facilitate rapid release of water. A typical condition with boudinage structures encountered during drilling is presented in Fig. 10. The location of soil nails, cable anchors and long horizontal drains are presented in the elevation diagram in Fig. 11.

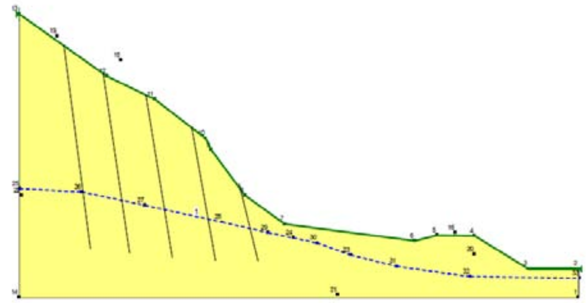

Fig. 9 - Pattern of relict joints identified during drilling

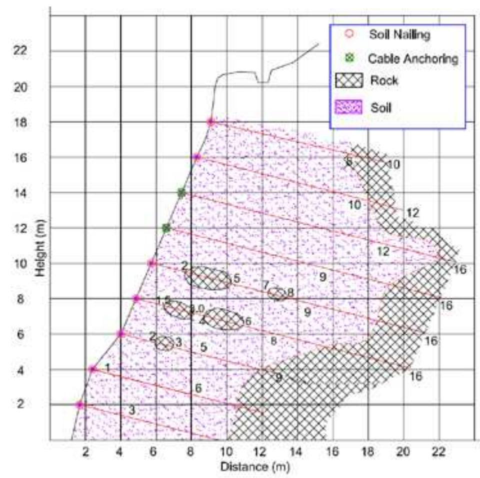

Fig. 10 Typical drilling records indicating boudinage structures

Cable anchors used were pre-tensioned to 180 kN. Thereafter all the nail heads and cable anchoring heads were connected by a system of beams and the complete surface was shotcreted (Fig. 12).

3 LESSONS LEARNT AND CONCLUSIONS

Residual soil formed by insitu weathering of metamorphic parent rocks in tropical climates are highly hetrogenious due to; changes in the lithology of the parent rock, recurrent fluctuations of temperature and frequent rainfall during the period of weathering.

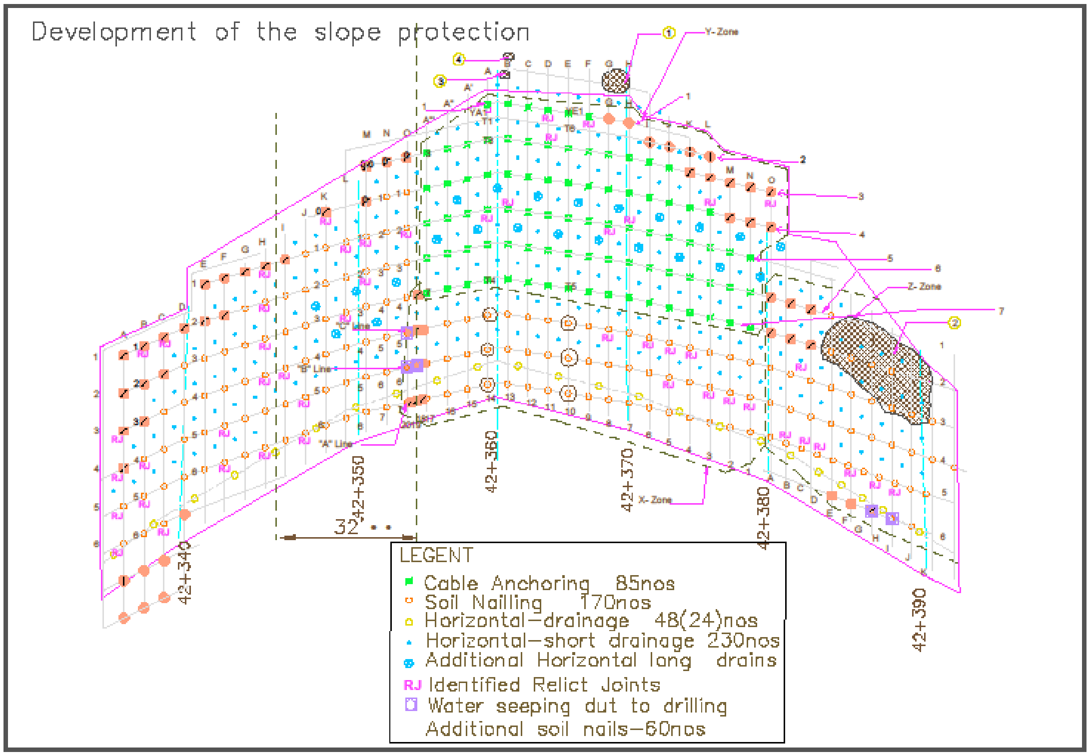

Fig. 11 A front elevation with locations of soil nailing, cable anchoring and sub surface drains.

Presence of relict joints, zones of weaker problematic soils, zones of non-weathered rock are some of the complications that exist. Provision of effective means of surface drains of appropriate dimension and minimizing infiltration is critically important under these circumstances. It is extremely important to monitor and maintain them to ensure that they perform as envisaged during the design. Relict joints would be filled with loose material and water infiltrated into relict joints could facilitate saturation of the slope material. Further, there would be pore pressure built up in relict joints. As such, in addition to the use of structural reinforcing techniques such as soil nailing and cable anchoring to ensure the stability of the profile left behind by the slide, the provision of appropriate surface and sub surface drainage measures becomes very important. Drilling for sub horizontal drains should be done only after the grouting of nailed holes. If the sequence is changed the grout could get into holes through interconnected relict joint systems.

The design of the rectification measures also illustrated the contribution of gravity retaining structures at the toe to restore stability.

Fig. 12 Slope after completion of rectification

REFERENCES

GEO-SLOPE (2007). SLOPE/W User Manual

Kulathilaka S A S and Sujeevan V (2011), Effects of Rainfall on Stability of Cut Slopes in Residual Soils , A paper published in the 14th Asian Regional Conference in Soil Mechanics and Geotechnical Engineering held in Hong Kong in May 2011 pp 518-523.

Kulathilaka S A S, Kumara L M (2011) Effectiveness of Surface Drainage in Enhancing the Stability of Cut Slopes during Periods of heavy rain, Paper published in the Annual Transactions of IESL pp 127-137.