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Reduction of landslide risk in substituting road of Germi-Chay dam

H. Farshbaf Aghajani
M.Sc in Geotechnical Engineering, Ashenab Consulting Engineers Co., Tabriz, Iran

H. Soltani-Jigheh
PhD of Geotechnical Engineering, Technical Faculty, Azerbaijan University of Tarbiyat Moallem, Tabriz, Iran

ABSTRACT: Germi-Chay dam is an earth-fill dam with central clay core that is underconstruction across the Germi-Chay River in Iran. Due to dam construction, part of the main road, that connects East Azerbaijan and Ardabil provinces together, remains within the dam reservoir. Therefore, it is necessary to construct a substituting road, 5 km long, outside of the reservoir. Part of the substituting road is located on the natural ground slope is susceptible to landslide. In this paper, first, the stability of the road slope is verified by performing a back analysis for the slip surfaces. Then, an appropriate scheme is suggested for construction of the road embankment in order to attain permanent stability of the slope. Evaluation of measured deformations show that the slope displacements have decreased considerably and slipping of the slope have stopped after executing the stabilization treatment.

1 INTRODUCTION

Landslide is one of the most important geohazards in geotechnical engineering that can be a threat for the stability of the structures. The potential of land sliding may increases when the slope is consisting of a weak texture and also subjected to groundwater rising by locating in vicinity of a waterway. Construction of infrastructures, such as the roads and buildings over the mentioned slopes may increases the geohazard risk, and even can lead to slide of the slope and consequently failure of the constructed structures.

To avoid from the unfavorable incidents and to guarantee stability of structures, the landslide risk must be managed and reduced by using the efficient and practical methods as well as with considering of the costs.

Some researchers have investigated the risk assessment and management of the landslides by statistical, analytical and geological methods (Lessing et al, 1983; Fell, 1994; Dai et al, 2002). Some of these methods are appropriate for risk assessment of land slide occurrence. However, a few numbers of methods have been presented for hazard risk reduction and treatment of the slipped slope that are performable in practice with low costs.

In this research, a practical and efficient method is employed to reduce the landslide risk of a slipped slope, as a subgrade of a road, in Iran. The geological formations, landslide potential, and stability of the slope are first investigated. Then, an appropriate methodology is proposed for construction of the road embankment with considering the necessity of current land slide risk reduction. Also, for examining the efficiency of proposed method, slope deformations are monitored at regular intervals during and after embankment construction.

2 SUBSTITUTING ROAD OF GERMI-CHAY DAM

Germi-Chay dam is an earth-fill dam with central clay core that is being constructed over the Germi-Chay River, located about 220 km of north-east of Tabriz city in East Azerbaijan province of Iran. The heights of the dam from bed rock and river bed are 82 and 62 m, respectively. Also, length and width of the dam at the crest are respectively 730 and 10 meters. The maximum water level of reservoir is 1460 meters higher than sea level. The main purposes of the Germi-Chay dam are irrigation of farm lands and supplement of urban drinking water.

Unfortunately, due to dam construction, a part of the main road, that connects East Azerbaijan and Ardabil provinces together, is located within the dam reservoir. For this reason, a substituting road is being constructed, with the length of 5 km, outside of the reservoir. A part of the substituting road at kilometer $2 + 065$ is located in the natural ground slope that is a slipped area and susceptible to landslide.

The geological investigation of the area shows that the slope is comprised of weak shale material located on the igneous bedrock. Furthermore, a waterway has been located in the vicinity of subgrade slope. So that during the rainy seasons, ground water rises within the slope and causes to occur slips and tension cracks in the subgrade slope. Field measurements indicate that the values of horizontal and vertical displacements during 9 months are 714 and 346 centimeters, respectively. A view of cracks and slips occurred in the subgrade slope are presented in Figures 1 and 2, respectively.

With respect to the importance of substituting road from the view point of linking two provinces

Figure 1. Tention cracks near borehole BH 55 due to slipping.

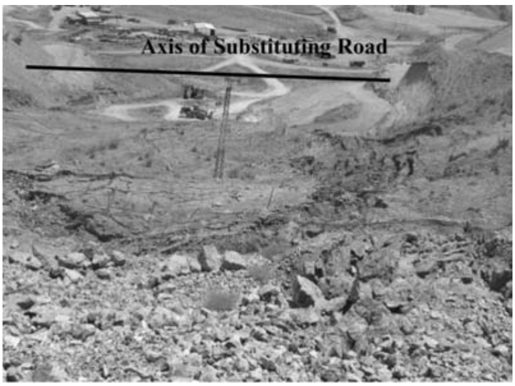

Figure 2. A view of sliped in the subgrade slope as well as substituting road axis.

and its location on the slipped area, the stabilization of the subgrade slope and securing of road safety permanently is concerned in this research.

3 GEOLOGY OF LANDSLIDING AREA

To investigate the geological and geotechnical properties of the studied area, a number of six boreholes, denoted by BH-53, BH-54, BH-55, BH-56, BH-57, and BH-R1, are drilled in the subgrade slope.

The results of the subsurface explorations and laboratory tests showed that the geological structure of the subgrade slope consist of the recent alluvium (TR), quarternerary traces (TA), crashed red rhyodacite (RhD), quartz diorite & quartz monzo-diorite (QD & QMD) and alternation of grey shale with yellow sandstone (Sh & S). Details of these formations have been illustrated in Figure 3 (Ashenab, 2005).

The recent alluviums have located at the sides of waterway and comprised of silt and sand mixtures. The thickness of this formation is less than 3 meters. The quarternerary traces comprise mixtures of fine-grained soils and some sand and gravel.

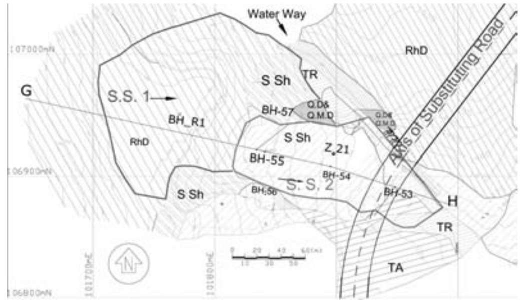

Figure 3. Geological map of studying area as well as land sliding mass with substituting road axis.

Sedimentary formations consist of shale and sandstone materials frequently have been repeated with depth within the slipped zone, and exposed at the kilometer 2 + 065 of the substituting road. At deep levels, amount of sandstone mass increases and sometimes the sedimentary layer is alone consisting of sandstone. Shale mass is in the forms of claystone and siltstone. In order to investigate properties of shale material, a number of experimental tests were carried out on the samples obtained from BH-54 and BH-55 boreholes. The results indicated that these materials have low shear strength with average liquid limit (LL) and plasticity index (PI) of 42 and 17, respectively. Also according to Unified Soil Classification System, the majority of samples are categorized as CL (ASTM 1997). Because of weak texture of sedimentary formations, precisely determination of layers strikes and their dips is difficult. However, site explorations show that the slip plane of slope does not coincide to the dip direction of sedimentary layers of shale materials.

At the right hand of the waterway, geological formations have been made from the rhyodacite mass. Also, at the upper elevation of subgrade slope, rhyodacite mass with almost 50 meters depth is located over the shale layer. The rhyodacite formation has good quality and strong property which the fragments are used as concrete aggregates.

Bedrock formations of quartz diorite & quartz monzo diorite materials have been embedded under the mentioned layers. The bedrock has relatively good quality and high strength with a few joints. According to the site explorations, the depth of bedrock at BH-53, BH-54 and BH-55 boreholes are 10, 14.8 and 3.5 m, respectively.

The slope has slipped because of seasonal raining and weak condition of shale mass. Figure 3 illustrates the boundary and direction of slips. Also, a geological longitude profile of the slope along the slip direction (i.e. G-H cross section in Figure 3) is presented in Figure 4.

As illustrated in this figure, the slipped area can be divided into two separate portions. The first portion, specified by S.S.1 area, includes the land slips in the upper elevations of the slope occurred due to the movement of rhyodacite mass on the shale layer. The values

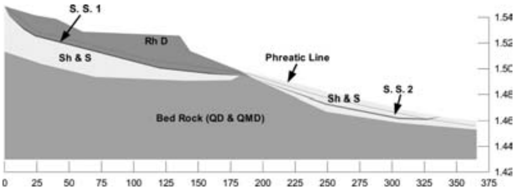

Figure 4. Geological profile of slope (G-H), locations of slip surfaces of 1 and 2 as well ground water level.

of displacements at benchmarks installed on the rhyodacite mass are about a few centimeters. This fact is due to existence shallow bedrock in front of rhyodacite mass, which withstand against the movements.

The second portion of the slips is ground movement in the lower elevation of the slope through the shale material, i.e. S.S.2 area shown in Figures 3 and 4.

Field observations indicated that the amount of movements progressively have increased during rainy seasons. Also, subsurface explorations determined the depth of sliding about 10 m. This relatively low depth is related to the non-conforming of shale lamination and slip direction as well as increasing of fraction of sandstone at lower depths. Although the strong sandstone has extended up to considerable depth, the amount of horizontal movements is much more, about 714 centimeters during a period of nine months.

4 BACK ANALYSIS OF SLIP

Prior to stabilize the subgrade slope, it is necessary to known the mechanical parameters of materials located among the sliping surfaces. The most efficient method for determine these parameters is performing a back-stability analysis for slipped slope (Sabatini, 2002). With respect to the progressive movement of the subgrade slope, it can be concluded that the shale material along the slip surface have reached to the residual condition. In this condition, the soil cohesion is negligible and the effective friction angle may be determined by performing a stability analysis assigning safety factor of 1.0 (USACE, 2003). The back-analysis was performed with the limit equilibrium method by using SLOPE/W software. Mohr-Coulomb criterion is utilized for modeling of material.

Since the slip surface is known in the field, it must be defined carefully for back-analysis. Therefore, the slip surfaces (S.S.1 and S.S.2) with identified situation are considered as a narrow band made of weak material with unknown friction angle and differ from the other material of slope. It is necessary to note that the SLOPE\W software is unable to model the interfaces between different materials in order to define slip surfaces. Thus, by applying this approach, it is not necessary to reduce the parameters of whole slope.

The Mohr-Coulomb parameters of other materials, such as cohesion and friction angle, are obtained from conducting triaxial and direct shear tests on the samples retrieved from boreholes. Density, cohesion and friction angle of the slope materials are presented in Table 1.

Table 1. Strength parameter of slope materials.

Material type	Friction Angle	Cohesion (kPa)	Density (kN/m^3)
Rhyodacite	30	10	22
Shale	23	100	20
Slip Surface 1*	15	20	19.5
Slip Surface 2*	15	15	19.5

*Obtained from the back-analysis

Subsurface explorations determined ground water level 2 m below the ground surface. Two dimensional geometry of the slope, materials of layers, locations of slip surfaces as well as ground water level are shown in Figure 4.

The values of the friction angle and cohesion of slip surface materials obtained from the back-analysis are presented in Table 1. Comparison between the obtained results and recommended values in literature shows the accuracy of back analysis (Bowles, 1996).

5 A SCHEME FOR SUBGRADE SLOPE STABILIZATION

Since the safety of substituting road was threatened by future probable sliding of subgrade mass totally due to large deformations expected in S.S.2 area, it is necessary to seek a remedial treatment for stabilizing of the subgrade slope with considering practical and economical feasibility.

In last decades, many approaches and methodologies have been introduced for stabilizing and treatment of the slopes. These methods can be categorized in the following groups: slope geometry modification, control surface water and internal seepage control, provide retention, increase soil strength with injections and soil reinforcement (Hunt, 2007, Cheng & Lau, 2008). Selection of appropriate method is based on several factors such as practical feasibility, economy and available facilities.

In Germi-Chay project, utilizing the slope geometry modification method required enormous excavation and thus high cost. Because of slipped and weak texture of shale mass, the efficiency of soil reinforcement also is unconfident.

As mentioned in geological description, bedrock embedded under the slope at S.S.1 area has been located at shallow depth. Thus this feature is utilized to construct a retained system along with appropriate drainage capacity.

Therefore, to stabilize the slope, it was proposed to excavate the foundation of road embankment up to the bedrock level. Then, the foundation trench was filled with rockfill material to reach to the identified level of road embankment and, finally, the road embankment was completed. It expected that the road embankment plays role as a barrier against slope sliding and

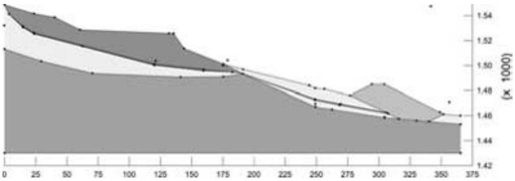

Figure 5. Geometry of the slope after stabilization and road embankment.

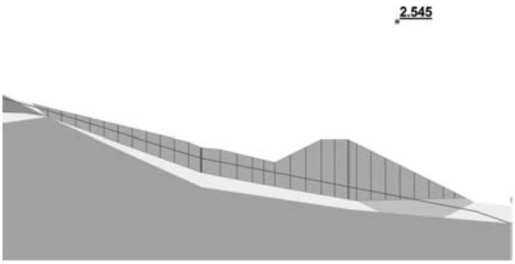

Figure 6. Potentially slip surface after stabilization.

decreases the movement of the upper mass because of high strength and stiffness of rockfill material used in the embankment and its appropriate geometry. Figure 5 illustrates the stabilization scheme of subgrade slope after stabilization process as well as road embankment section.

The proposed scheme for stabilization was modeled and analyzed using SLOPE/W software for evaluating safety of the slope and road as well as for determining supposed slip surfaces. Also, the factor of safety of S.S.1 surface was determined by stability analysis of the proposed geometry. As indicated in Figure 6, the results of the analysis show that in the presence of the road embankment, the safety factor of S.S.1 surface increases from nearly 1.0 (as a threshold condition in stability analysis) to 2.545. Moreover, the safety factor of the embankment constructed on the bedrock is about of 3.85. Since the embankment material is comprised of rockfill material with high drainage property, the phreatic line locates in a lower level and the safety factor becomes more than theoretical calculation.

In addition, a culvert was performed within the road embankment to conduct the surface flows toward downstream; hereby the safety increases from this point of view.

For economic evaluation of proposed stabilization method, the costs of this method was calculated and compared with those of the geometry modification method. The results indicated that in proposed method, the volumes of subgrade excavation and foundation filling are 21650 and 16100 cubic meters, respectively. However, for the second method required excavation is 256000 cubic meters as well as 94000 cubic meters of rockfilling for embankment construction to a level higher than the normal water level of reservoir. Thus, the excavation volume of second method is almost 12 times greater than proposed method.

Figure 7. Excavation and filling processes of the strips during construction.

6 METHODOLOGY OF THE EMBANKMENT CONSTRUCTION

In spite of the current movement of the slope and low strength parameters of shale material, it is expected that the subgrade slope excavation up to the bedrock may lead to instability and hazardous in the slope; particularly that the trench locates at the toe of slope.

As a result, in this research, a comprehensive method was proposed to excavate the road trench down to the bedrock level without occurrence of any instability in the slope.

In the suggested method, first, the material of embankment basin located in the outside part of the slipped region (S.S.1) was excavated to the bed rock and then immediately filled with the coarse grained material.

For excavating road embankment foundation located on the slipped area, it is divided into a number of narrow strips (about 3 meters width) perpendiculars to the longitude axis of road.

To avoid any instability within the slope during construction process, each strip was first excavated from downstream to the upstream of the slope and then filled with rockfill material until reaching to original ground level. Then, the adjacent strip was performed similarly. This operation was executed for all strips until the weak shale material of the road subgrade was substituted with the strong rockfill material. Since the least depth of the bedrock located at the east north of the embankment, the excavation and filling processes was commenced from this situation.

After completing the excavation and filling of all the strips, the road embankment was constructed safely.

Figure 7 shows the excavation and filling processes for one strip of road foundation. Also, the embankment of substituting road after completion is shown in Figure 8.

7 MONITORING OF SLOPE BEHAVIOR

To control the deformations of slope during construction, displacements was surveyed and evaluated

Figure 8. Embankment of substituting road after completion.

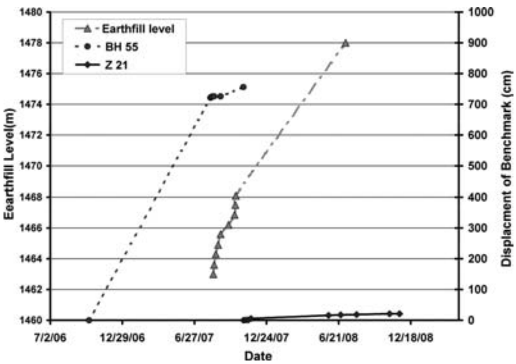

Figure 9. Measured accumulated displacements at benchmarks located on the slope and construction level of earthfill.

regularly at the benchmarks. The investigations showed that the considerable reduction occurred in the deformations after construction of road embankment. For example, variations of displacements during and after construction at the benchmarks located near the BH-55 borehole and Z21 are presented in Figure 9. In this figure, the horizontal displacement of the benchmark located on BH-55 borehole is 721 cm before the road embankment construction (from Oct.-2006 to July-2007). So the average rate of horizontal displacement is equal to 2.38 cm/day. Although during construction of embankment (from July-2007 to Oct.-2007), the displacement of this benchmark shows considerable reduction. Unfortunately, during construction operation, this benchmark is destroyed and inevitably another benchmark (i.e. Z21) was installed in the slip direction and slope behavior was investigated via monitoring displacements in this benchmark.

The site surveying during road construction indicated that the accumulative value of displacements in the benchmark Z21 at the similar rainy season is 16 centimeters (from Oct-2007 to May-2008) and its average rate is about 0.7 mm/day. Comparing the displacements of the two benchmarks at similar time intervals indicates that the deformation of subgrade slope has decreased about 34 times. During embankment construction, the displacement of Z21 increases only about 4 centimeters (from May-2008 to Oct-2008). After embankment completion up to now, the movement of benhmark Z21 and subsequently the slips of slope are almost stopped.

This consequence indicates the effectiveness of embankment in reduction of landslide risk and attainment of permanent stability of substituting road.

8 CONCLUSIONS

In this paper, to reduce the landslide risk and construction of a substituting road, a practical, most effective and economical method was proposed and constructed. Also, the enormous cost of slope modification was saved by applying the proposed method for risk management.

To assure from stability of the slope, as a subgrade of the road, during and after the road construction, it was necessary to monitoring and evaluating the deformations of benchmarks installed on the rhyodacite mass and shale slope (upstream of road embankment). By evaluating the measured data, the slope behavior can be managed and studied continuously, and the critical deformations, led to the hazards, can be predicted.

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