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ABSTRACT

Vanyar dam is located near Tabriz city, North West of Iran. The side channel overflow spillway of this dam is located on the left side of dam body with discharge capacity of 1330 m^3/sec. To construct this spillway a soil-rock slope with height of maximum 140m is excavated. After about three years, some surface cracks and slides started to develop.
This research tries to study the reasons of these instabilities and some approaches are presented to stabilize the slope. This slope is located on too weathered and crushed igneous rocks and weak sandstones. The field studies indicated that the most important reasons of these instability events were rainfall penetration, weathering, freezing and melting cycles, static and dynamic loading conditions, increase in slope height, tectonic conditions and shotcrete covering.
To stabilize the slope meanwhile doing back analysis, many methods evaluated and considering to advantages and disadvantages of each method and available equipment, some approaches such as: adjustment of the slope gradients, improvement of drainage system, construction of retaining structure, vegetation and stabilizing instable parts of rocks are recommended as remedy works in this case.

INTRODUCTION

Site of Vanyar dam (Shahid Madani), is located in 5 km to North East of Tabriz, North West of Iran.

Fig. 1. Situation of Vanyar dam project

This project aims to control the seasonal spates of Aji Chai River and to store the extra water of the river in full-water seasons in order to develop the farmlands downstream of the river. It has special importance to construct this dam due to its site near to upside of Tabriz, with about 2.5 million in population, and in a region of high risk of seismicity and near to main fault of North Tabriz. Figure 1 shows the situation of Vanyar dam project.

This dam has 93 meters in height from base and 277 meters in crest length and its type is Rockfill with vertical Clay Core (ECRD). The soil volume of its body is about 1.7 mcm.

Total reservoir volume of Vanyar dam is predicted as 360M m^3 and in normal water level, it will has 28 km in length and 37 km^2 in area. Basin for this dam will be 7700 km^2 in area and annual input rate for Aji Chai River is 445 mcm.

Appurtant structures in this project include spillway, irrigation intake tower, diversion tunnels, inspection and grouting gallery and bottom outlet located around the dam body (GNCE, 2002).

This paper analyzes the reasons for start of slides and failure happening in great trench near to spillway after some years of excavation, and then, evaluates the different methods of stabilization and in finally recommends some approaches to control the instability and slide in this slope.

LANDSLIDE AND ITS TYPES

Landslide always causes many financial and human damages, in the way that it is accounted as second most dangerous phenomenon in the century after earthquake (Alfors et al., 1973).

Figure 2 shows a typical type of landslide which occurred in La Conchita, coastal area of southern California. This landslide and earthflow occurred in the spring of 1995. People were evacuated and the houses nearest the slide were completely destroyed.

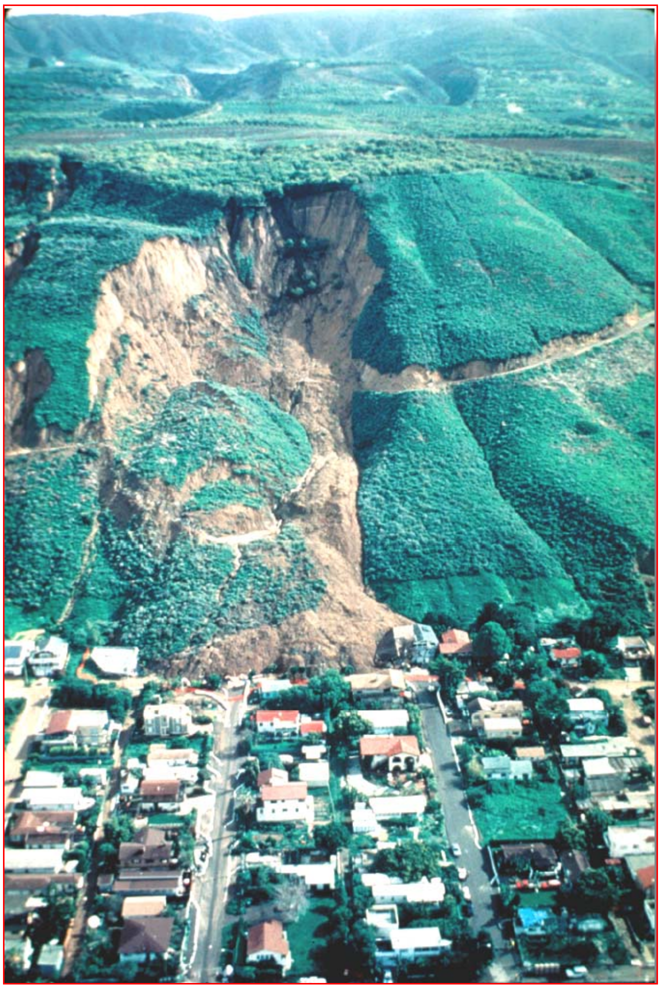

Fig.2. A typical type of landslide in La Conchita, California, 1995

The various types of landslides can be differentiated by the kinds of material involved and the mode of movement. A classification system based on these parameters is shown in table 1.

Table 1. Types of landslides. Abbreviated version of Varnes classification of slope movements (Varnes, 1978)

<table>
<tr><th rowspan="3" colspan="2">Type of Movements</th><th colspan="3">Type of Materials</th></tr>
<tr><th rowspan="2">Bedrock</th><th colspan="2">Engineering Soils</th></tr>
<tr><th>Predominantly Coarse</th><th>Predominantly Fine</th></tr>
<tr><td colspan="2">Falls</td><td>Rock Fall</td><td>Debris Fall</td><td>Earth Fall</td></tr>
<tr><td colspan="2">Topples</td><td>Rock Topple</td><td>Debris Topple</td><td>Earth Topple</td></tr>
<tr><td rowspan="2">Slides</td><td>Rotational</td><td rowspan="2">Rock Slide</td><td rowspan="2">Debris Slide</td><td rowspan="2">Earth Slide</td></tr>
<tr><td>Translational</td></tr>
<tr><td colspan="2">Lateral Spreads</td><td>Rock Spread</td><td>Debris Spread</td><td>Earth Spread</td></tr>
<tr><td colspan="2" rowspan="2">Flows</td><td rowspan="2">Rock Flow (deep creep)</td><td>Debris Flow</td><td>Earth Flow</td></tr>
<tr><td colspan="2">(soil creep)</td></tr>
<tr><td colspan="2">Complex :</td><td colspan="3">Combination of two or more principal type of movement</td></tr>
</table>

Vargar and Gorbushina (1998) by collecting and analyzing the geological information of 350 cases of landslides in various dam sites showed that more than 50 percentage of landslides occurred because of geostructural factors.

Harp et al. (2006) used a simple infinite-slope analysis together with a historical landslide data set collected for the city of Seattle, Washington, to establish a reliable correlation between a slope-stability measure (factor of safety, FS) and the locations of shallow slope failures that form debris flows.

The resulting FS map of the city showed the lowest FS values were in areas where slopes are steep and where geologic units had low shear strengths.

Landslide is usually resulted from some motives such as earthquake, flood and volcano. Earthquake in May 1960, for example, in South and central seashores of Chili caused the numerable main land slides and thousands surface ones (Davis & Karzulovic, 1963).

Earthquakes in Reventador in 1987 in North of Ecuador also happened after one month hard raining, bringing about thousands small landslides in the steep hillsides (Schuster et al., 1996).

The term “landslide” describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing.

Figure 3 shows a graphic illustration of a landslide, with the commonly accepted terminology describing its features.

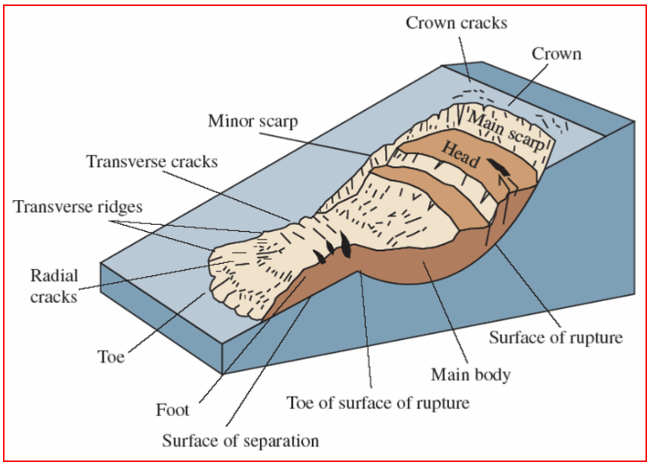

Fig. 3. A graphic illustration of a landslide, with the commonly accepted terminology describing its features

The most common types of landslides are described as follows and some of them are illustrated in Fig. 4.

Slides

Although many types of mass movements are included in the general term “landslide”, the more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are rotational slides and translational slides.

Rotational Slide. This is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide.

Translational Slide. In this type of slide, the landslide mass moves along a roughly planar surface with little rotation or backward tilting. A block slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move downslope as a relatively coherent mass.

Falls

Falls are abrupt movements of masses of geologic materials, such as rocks and boulders, which become detached from steep slopes or cliffs.

Topples

Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks.

Flows

There are five basic categories of flows that differ from one another in fundamental ways:

Debris Flow. A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as slurry that flows downslope.

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Debris Avalanche. This is a variety of very rapid to extremely rapid debris flow.

Earth Flow. Earth flows have a characteristic “hourglass” shape. The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.

Mud Flow. A mudflow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles.

Creep. Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure.

Lateral Spreads

Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain. The dominant mode of movement is lateral extension accompanied by shear or tensile fractures. The failure is caused by liquefaction, the process whereby saturated, loose, cohesionless sediments (usually sands and silts) are transformed from a solid into a liquefied state.

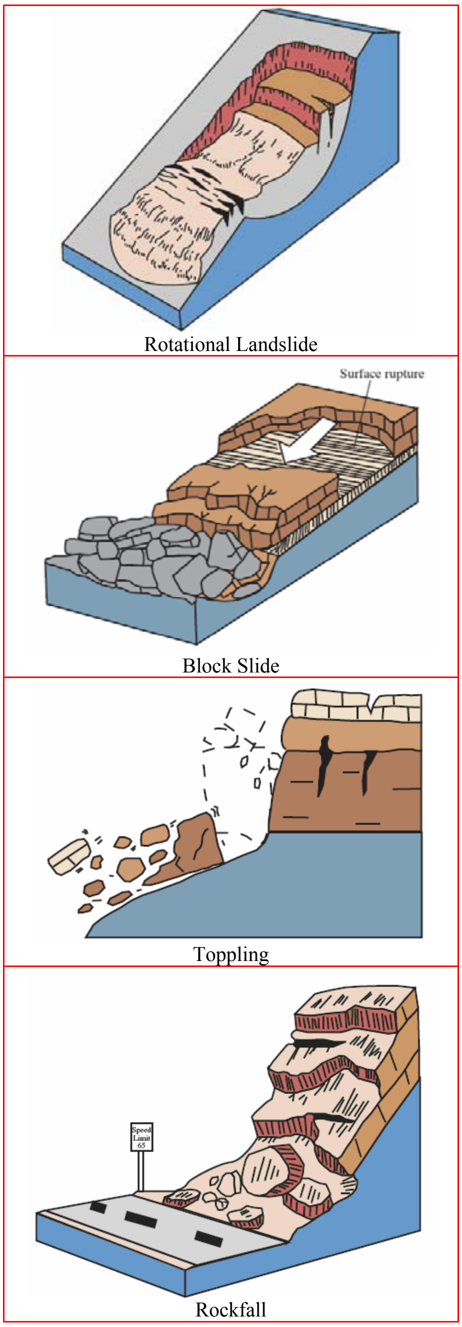

Fig. 4. Some common types of landslides

THE SPILLWAY AND ITS ADJACENT SLOPE

The spillway is located on the left abutment of dam body and its type is side channel overflow spillway. Discharge capacity of this spillway is 1330 m^3/sec. Its channel length is 41m and the chute length is 96m. Ogee level of this concrete spillway is 1498 meters above sea level (masl) and its stilling basin is selected as USBR, type II of 59 m in length (GNCE, 2002).

According to the topography of area and relative high gradient in left side of the spillway, it is bound to construct a high soil-rock slope. In this slope, with maximum height up to 140m, in initial step of excavation and stone cutting, there are built some horizontal berms in distances of 15m to make possible to do the operations for slope construction and necessary transports. Layout plan of the slope spillway and body of dam are shown in Fig.5.

With accordance to locating the slope near the spillway and dam body, any possible destruction and slide, during construction and service can be a factor for considerable human and financial damages. Any slide in the slope during service time may causes to obstruct the spillway, makes waves in the reservoir, overflow water above the body and cause to damage in rock-fill body of dam, making the security of total project in danger. It is important, therefore, to prepare the required stability for the slope. Two view of the slope are shown in Fig. 6 and Fig. 7.

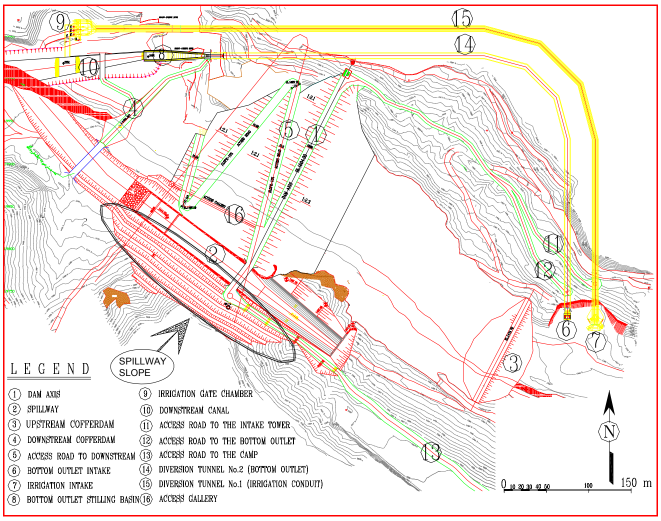

Fig. 5. Layout plan of spillway and body of dam

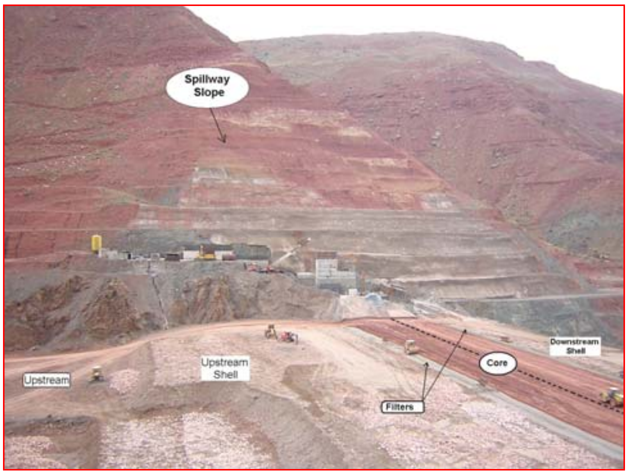

Fig. 6. A view of the slope and Dam body (front view)

Fig. 7. A view of the slope (side view)

Based on the primary design, the slope gradients are assigned around 1V:1.2H in lower parts of the slope to 1V:0.7H in upper parts in it. Critical section of the slope is shown in Fig. 10.

To control local slides, trench surface is covered from lower levels to level 1523 by shotcrete cover and steel meshes. Analyzing the results of bore holes in this area and study of geological situation indicate that the ground layers in slope are as following:

- Between sections 1 to 6, sandstones in relatively loose position;
- In lower levels of slope, weathered igneous rocks;
- In upper levels of the slope, clay stones with high resistance.

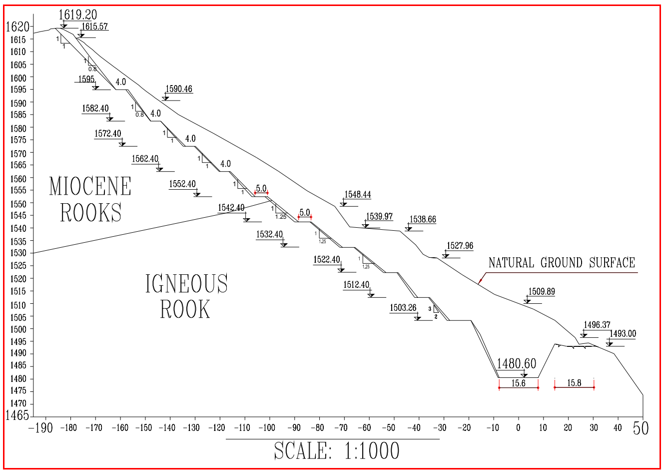

Fig. 10. Critical section of the slope

OCCURING INSTABILITY IN THE SLOPE

After three years of excavation and stone cutting, there was observed some local and global instabilities and slides in some parts of the slope. The study of instabilities determines the conditions and features of slides as following (GNCE, 2002):

- Instability mechanism and slide in the slope are assigned in most areas as rotational slide;
- Almost of slides are made in discontinuity surfaces between two lithologies of igneous rocks and sediment sandstones;
- Completely formation of slide surface around levels of 1513 masl to 1543 masl is through gradual growth of local cracks;
- Cracks in shotcrete cover area recognized as horizontally and vertically, along the wire mesh.

Figure 8 shows a global slide that occurred in a part of the slope in winter and in Fig. 9 is shown some occurred cracks in shotcrete cover.

Fig. 8. Global slide occurred in the slope

Fig. 9. local cracks that occurred in shotcrete cover

STUDY OF INSTABILITY FACTORS

According to the long passed time from excavation of the slope trench, and studies of the instability factors, the results showed that the instability factors can be divided as following:

Raining Water Penetration into Soil and Rock Areas

Hydrostatic pressure of soil and rock areas increases due to water penetration, decreasing the shear strength of area. It also causes to raise the pore water pressure of soil and rock areas, totally increasing in slide potential on weak surfaces.

Weathering and Cycles of Freezing and Melting

Due to high changes in temperature of the region, sometimes less than -30 °C in winter, icing the water in cracks and holes of rocks causes to open the cracks more and increase in rock and soil volume, and therefore, decrease in strength parameters. Mechanical and chemical weathering, moreover, cause to reduce the cohesion, so then chemical changes and ion exchanges decrease the stability.

Change in Loading Conditions on the Slope

Vibrations in base of the slope and also some explosions for rock and soil excavations and dynamic loading due to crossing the machinery and equipment affect on slope stability. Vibrating loading in coarse sands causes to decrease cohesion and in fine sands, the causes in liquefaction.

Moreover, unloading on upper parts of the slope, due to excavations, causes in swelling in rocks and decreases the strength parameters of rock mass.

Increase in Height of the Soil Slope and Change in steepness

After excavation in upper parts of the slope and after two-year interruption, there was proceeded to excavate the lower parts related to spillway base and stilling basin.

By excavation of the lower parts of the slope, the gradient increases and causes in local instability. Also releasing lateral stresses in lower parts of the slope bring about opening the cracks and instability in some parts of it.

Layering and Geological Conditions Around the Slope

Studies around the slope site represent the severe changes in material types, strength and situation of crushed rocks. Occurring of some failure wedges in weak areas and the areas of weak mid-layers proves it.

Shotcrete Cover in Lower Parts of the Slope

The studies showed that covering external surface of the slope by a wire mesh and shotcrete layer, although causing to prevent surface slides and contact of rainfall and surface weathering, prevents drainage of water in slope body. Therefore, increasing in internal water level of soil and rock mass, and increasing the pore water pressure were recognized as some factors of instability.

STABILITY ANALYSIS of EXISTING SITUATION of the SLOPE

Precise stability analysis of the spillway trench, using computer software, requires to carefully determining the geomechnical parameters of soil and rock mass. Experienced studies and primary design of the slope showed that the strength parameters were assigned based on the boreholes results, laboratory tests and finally engineering judgment. These values are described in Table 1.

Table 1. Primary parameters of the slope materials

Claystones	Igneous Rocks	Sandstones	Material / Parameter
200	200	10	C (kN/m^2)
30	35	30	φ (°)
22	24	23	γ (kN/m^3)

To evaluate the slope stability and review in assumed strength parameters, the back analysis was performed on two-dimensional model of the slope.

According to the happened slides in the slope, strength parameters of these materials are amended in frequent processes of back analyses in a way that safety factor of the slope reaches near to 1, as well as failure mechanism is like real situation. Prepared model for back analysis of the slope is shown in Fig.10.

According to the different geological layers and various mechanisms of occurred failures, two different areas were considered between sections 1 to 8 and sections 9 to 16 for failures. The results of back analysis assigned the strength parameters of two different areas as in Table 2.

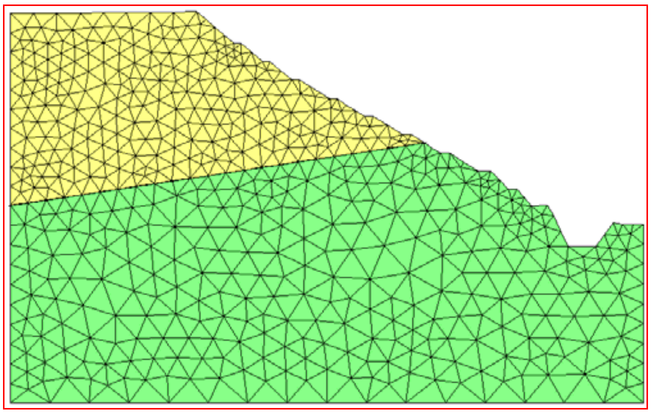

Fig. 10. Finite element model of the slope

Table 2. Amended strength parameters of the slope materials after back analysis

Claystones		Igneous Rocks		Sandstones		Material / Parameter
Section		Section		Section		
9 to 16	1 to 8	9 to 16	1 to 8	9 to 16	1 to 8	
26	80	28	100	25	7	C (KN/m^2)
26	160	28	160	26	10	φ (°)
20	19	21	20	20	18	γ (kN/m^3)

EVALUATION OF THE SLOPE STABILITY APPROACHES

In order to control any instability and slide in the slope, there was studied to use any or a collection of following methods:

- Changing and amending gradient or height of the trench;
- Using structures such as retaining walls, soil nailing, anchors or flexible wire meshes and shotcrete cover;
- Protecting the slope surface to weathering and frequent cycles of freezing and melting;
- Control and decrease of the destructive static and dynamic loadings;
- Improve the slope drainage to decrease in the pore water pressure and amplify the strength parameters of soil and rock mass.

According to the above approaches and special conditions of the dam site, the following approaches were suggested to stabilize the slope. Based on the instability conditions, suggested approaches are divided into two separate groups in order to control the global and local slides as following:

<u>Control of Local Slides</u>

To stabilize surface and local slides in external surfaces of the slope, some approaches are suggested as following:

<u>Control of Loose Parts of Rocks</u>. Loose parts of rocks, that may fall and slide in some external parts of slope, and with accordance that lower parts of the slope are place of passing workers and machinery, probably falling the loose stones can cause in some human and financial damages.

<u>Creating Vegetatation</u>. By vegetation in external surfaces and soil areas, plant roots can cause in reinforcing the external surfaces of soil and practically operate like a natural reinforcement. This reinforcement can prevent both the surface slides and control surface erosion.

<u>Retaining Structures</u>. By construction of retaining walls or flexible metal meshes in horizontal berms among the slopes, the possible surface slides and locally falling the stones can be controlled.

<u>Control of Global Slides and Downfalls in the Slope</u>

To control and restrain any global slides and downfalls in the slope, according to the site and executive operation of the project and also equipment and machinery, following methods were suggested:

<u>Adjustment of the Trench Embankment Gradients</u>. as mentioned before, geotechnical parameters of the mass were assigned in back analysis method according to the failure wedges of the soil and rock slope. Accordingly, to determine the permanent gradients in stability analyses, gradients values

were amended in various sections using the parameters obtained in such a way that safety factor of the slope from suggested allowable values in static and dynamic states increased. In other words, according to the allowable least safety factor, maximum gradient of the slope was determined in various sections.

To amend the gradients according to doing construction operation of the spillway in base of the slope, there was suggested in first step that shotcreted slopes (lower than level 1523m) don't changed, and higher slopes be amended by a horizontal-14-meter berm in this level. Amending the slopes lower than level 1523 were postponed to second step and after stopping the construction of the spillway. Additionally, according to the changes in specifications and strength of ground in different parts of the slope (in plan and height), some various gradients assigned.

Amended gradient of the slope in different parts were determined from 1V:0.9H to 1v:1.5H. Based on the new suggested gradients, the volume of excavation and stone cutting to adjust the gradients in first step was predicted as 320000 m^3.

<u>Control and Reduction of Water Level in the Slope through Drainage System</u>. As shown by primary studies, one important factor of instability in the slope was the water penetration from rainfall into the soil and rock, causing decrease in strength parameters of the slope mass. So, suitable drainage systems were proposed as one of the main approaches of stability control. Drainage system is divided into two surface drainage to control the raining water on external surfaces of the slope and deep drainage to control the water inside the soil and rock mass.

For a surface drainage system, there were suggested the linear channels at the base of horizontal berms, suitable concrete cover on channels surface and transferring the upstream water of berms to downstream of the slope by a collecting pipe. In addition, were proposed deep drainages to control the water inside the soil and rock mass through gravity horizontal drainages. Accordingly, about 1.3 m down of any slope (near to any horizontal berm), relatively horizontal bores (of small gradient for gravity drainage) of 3 inches in diameter and about 5 m in length (or equal to horizontal width of fractured area) of 10m in distance from each other was suggested. To conduct the water, flexible pipes of PVC are put into drilled bores.

The studies show that using the above approaches to control the slides and global instabilities of the trench, and economic based on equipment and machinery of contractor and seasonal limitations of working in the site is operationally faster and more suitable.

CONCLUSIONS

Vanyar rockfill dam is located in North West of Iran with 93m height from base, on seasonal river Aji Chai. Soil and rock slope near to spillway of this dam with maximum 140m height during construction of dam body and after several years of excavation was infected in slides and instability. The reasons were studied in this research.

According to the topographical and geological conditions of the slope site and based on the studies, the main reasons of slides and instabilities in the slope include: increasing level of underground water, rainfall penetration, surface weathering, frequent cycles of freezing and melting, changes in loading conditions, increasing height of the slope through excavations at its base, presence of hard cracked areas and weak mid-layers and shotcrete cover in lower parts of the slope.

After many analyses and studies, the possible ways to stabilize the slope, according to the geological conditions of the region, situation of executive operation, facilities and machinery of contractor, and seasonal limitations of working in the area due to hard coldness and also economically assessing the different approaches, and some of them were selected to stabilization in this case.

In order to control the stability and slides in the slope, based on back analyses, there were chosen and suggested amendment the gradients, amending and completing the drainage system, retaining structure with wire meshes, control of loose parts of rocks and stabilize instable parts of rocks and making vegetation on the slope surface.

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