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Technical Analysis of Collapse in Tunnel Excavation and Suggestion of Preventing Appropriate Applicable Methods (Case Study: Sardasht Dam Second Diversion Tunnel)

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Abstract

In order to either optimal use of water resource of KELAS river basin and electrical energy generation, Sardasht Dam and power plant are designed. Dam water diversion system includes two tunnels with inner diameter of 7 m. Several collapses have occurred in portal of second diversion tunnel (A2) which has created large cavity in tunnel crown. In order to prevent collapse, various ways such as steel sets installation and also grouting to increase strength of surrounded rock mass, are prescribed but none of technics could not to ban caving in. considering this fact that in order to continue tunnelling process, collapse zone should be passed, a solution or solutions must be suggested to overcome consecutive and dangerous collapses problem. In order to decrease tunnelling risks, in this research, using both experience and knowledge obtained from previous proposed executive solution to similar cases and technically analysis of occurred collapse in current diversion tunnel, it has been tried to suggest a new appropriate solution which defeat the problem. Finally, in order to stabilize of tunnel crown, as an effective and applicable solution, constructing retaining crown by means of rock bolts, was introduced.

Keywords: Sardasht Dam and Power Plant; Diversion Tunnel; Technical Analysis; Collapse; Support System.

1. Introduction

Underground spaces contain several hazards due to their position in an environment with high uncertainty. Reasons for risk development in underground structures are such as unknown ground, groundwater presence, limited available space, logistics issues, unsuitable working conditions, etc. Some of major factors of accidents and damages in underground structures are insufficient pre-construction studies, errors at design and calculation stage, and faults during construction. Review of accidents and damages occurred in underground structures is a key tool to understand unstable phenomena and processes that we encounter during construction of structures [1, 2]. As a result of these reviews, selection of the most appropriate construction method becomes possible for future projects. Tunneling affects stability conditions of environment and, in addition to considerable underground effects, have some consequences on surface, as well. Then, in respect of design and planning, progress aiming to make risks and their impacts least is required. Nowadays, the term 'risk' has various meanings and aspects considering safety, economy, environment and social issues. Literature about risk issue rapidly grew in recent years and it was used in extensive areas.

Luiyan et al. addressed, in an investigation, stability analysis and design of support system for diversion tunnel of Khersan 3 Dam. The tunnel crosses through limestone beds of Asmari Formation. This region is placed in Folded Zagros

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Area, and this is the reason why several faults and discontinuities formed on tunnel route. They designed a support system, after geo-mechanical classification of rock mass of tunnel route [3]. Sejnova et al. studied on risk definition for tunnel excavation process. This study provided a method to define excavation risks relevant to unpredictable events using ETA and FTA methods that might be used as a guide for tunnel design, risk management and decision making in order to deal with these hazards [4]. Niknia et al. evaluated and determined the risks of Ab-yoord water conveyance tunnel by brain-storming during their research. In the study, rock mass classification was done simultaneously with tunnel excavation and proper actions provided caused decreasing risk of hazards such as flood and rock fall in tunnel route [5]. Taromi and Saiedi studied geotechnical hazards existed on the route of Sabzkooh water conveyance tunnel such as several fault zones, great depth, high ground water table, ground water inrush, rocks with high potential of squeezing and rock burst, possibility of a combined face and Karst potential and provided some solutions for these hazards [6]. Khakbaz and Saiedifard studied about arrangements of excavating a water conveyance tunnel through a fault zone having movement potential. In this study, after studying trace and determining location of active faults, displacement boxes designed in order to make water conveyance metal pipe axis and tunnel cover flexible along with implementing a semi-rigid connection at interface of metal pipe and final cover of tunnel that increased tunnel safety factor [7]. Fraldi and Guarracino conducted studies on analytical solutions for collapse mechanisms in tunnels with desired cross section. In this study, an exact solution for the prediction of collapse in tunnels and natural cavities with a generic profile has been presented in the realm of the plasticity theory with the help of classical tools of the calculus of variations.

It was found that the adopted limit approach allows estimating the load as an independent variable and contributes a guidance founded on simple and sound mechanical bases about the overall collapse mechanism. Therefore it can represent a useful complementary tool to numerical analyses. It is also felt that the discussed examples may contribute to a better understanding of the role of the parameters characterising the rock bank [8]. Chen and Wu also cared out studies to causation Analysis of Collapse of Some Tunnel and Treatment Measures. Based on the analysis of working face status and review of the construction process for several months, it has been shown that the improper emergency measures adopted were the direct cause for the collapse. However, improper longitudinal distances among the working faces and quality defects of the support structures were the root causes. After the causation study, an integrated treatment program has been proposed, including improving support parameters, grouting in the surrounding rock, reinforcing arch abutment and adopting combined engineering measures etc. Finally, multi-point inclined temporary support with I-beams has been also proposed [9]. A study on stability analysis and monitoring for tunnel in loose soils during construction was also conducted by Also Wang et al. that the according to this study First, FEM is used to analyze the stability of the shallow tunnel section, and soil nails are used to improve the upper soils. Second, monitoring work is done deliberately. The collapse of local face is predicted successfully. The monitoring results show the influence of the aquifers in the loose surrounding rock on the stability [10].

Aforementioned researches are mainly in the field of risk determination and management, but some hazards, however with little possibility, might be encountered during excavation operations. The tunnel, studied in this research, collapsed during excavation. It should be noted that some arrangements were predicted to control collapses but they failed in practice. This decelerated the progress of operation. Hence, it is important to suggest a new solution in order to put an end to this type of hazards.

The remainder of this study is organized as follows. Section 2 introduces the investigation of dam site and some technical characteristics of Sardasht Dam. In Sect. 3, an explanation of technical analysis of tunnel collapses is presented. Section 4 presents a brief outline of collapse prevention. Section 5 discusses and proposes a suitable solution. Finally, Sect. 6 concludes the paper and presents some suggestions.

2. Dam Site Investigation

Sardasht Dam is being constructed on Kelas River (Small Zab) located in West Azarbayjan Province, Northwest of Iran. Kelas River is one of western border rivers of Iran and the second high runoff river of the region, after Sirvan River. Regarding Geographical position, it runs mainly in West Azarbayjan Province and Piranshahr and Sardasht townships and a minor part of it, at southwest of the watershed, namely bouin and Baneh branches, is located in Kordistan Province and finally flow into Iraq. Zab (Kelas) River, which formed after joining Lavi, Avajer, Badinabad Rivers and some other minor branches, flow in Piranshahr Region of West Azarbaijan Province [11]. After integration of Lavin and Avajer Branches, the river is called Zab, Zeh, or Kelas. Sardasht Dam site is among the sites considered to construct hydropower project and to transfer water. River diversion will be done by two tunnels with inner diameter of 7 meters which is designed on right abutment. The length of tunnel A1 is 627m and tunnel A2 is 638m and operational cross-section area is 63 to 80m^2. Inlet portal of A2 Tunnel, from 18+0 to 32+0 km, suffered some collapses which hindered excavation operation and project progress. Main characteristics of Sardasht Dam and Hydropower are summarized in Table 1.

Table 1. Technical characteristics of Sardasht Dam and Power plant [12]

Water Diversion Tunnel (2 No.)	Total Length: 1031 m, Diameter: 7 m
Dam Type	Earth Dam
Dam height	116 m

Sardasht Dam site is located among areas of a slate rock unit with inter-beds of sandstone which are metamorphosed. This area, which, in fact, is a salty belt (Figure 1), played an essential role in morphological evolution of the studied area along with major and minor faults. Regarding that almost same geological and stratigraphically conditions dominate all over the area of dam site and water conveyance tunnel to hydropower plant, same geomorphological elements are taken into account for the areas as well. However, proportion of these elements in various parts of the site shows some differences [11]. According to elevation map of Iran, the mountainous region of the studied area mainly consists of lands with elevations of 500- 2000m and areas with elevations more than 2000-3000 m are very rare. These high-rise areas are compatible with lands located in the left side of Kelas River. These areas are complied with western and southern mountains of Iran and Zagros and Makraan are considered as subdivisions of this classification [12].

Figure 1. Slates rock mass and discontinues [12]

To excavate diversion tunnels, in addition to excavation from inlet portal, four new openings were developed by drilling an access adit and then excavation operation is simultaneously done in six faces. After completion of open excavations in outlet portals, two other faces will be added to these faces. Along the tunnel, presence of bedding planes and joint groups and developed wedges resulted in collapse. Also, due to high rate of weathering after excavation, foliation and, consequently, collapse occurs [11]. A topography map and geometric characteristics of the tunnel can be seen respectively in Figure 2 and 3.

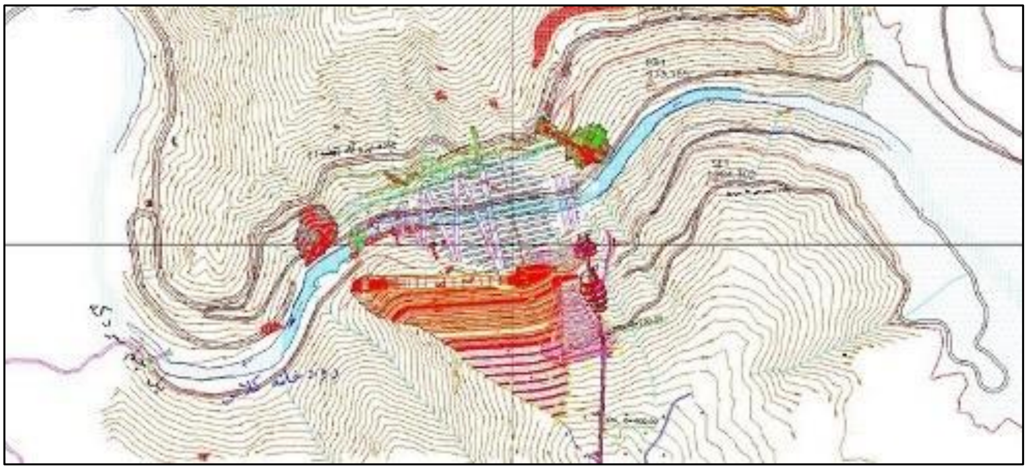

Figure 2. Sardasht dam topography map [15]

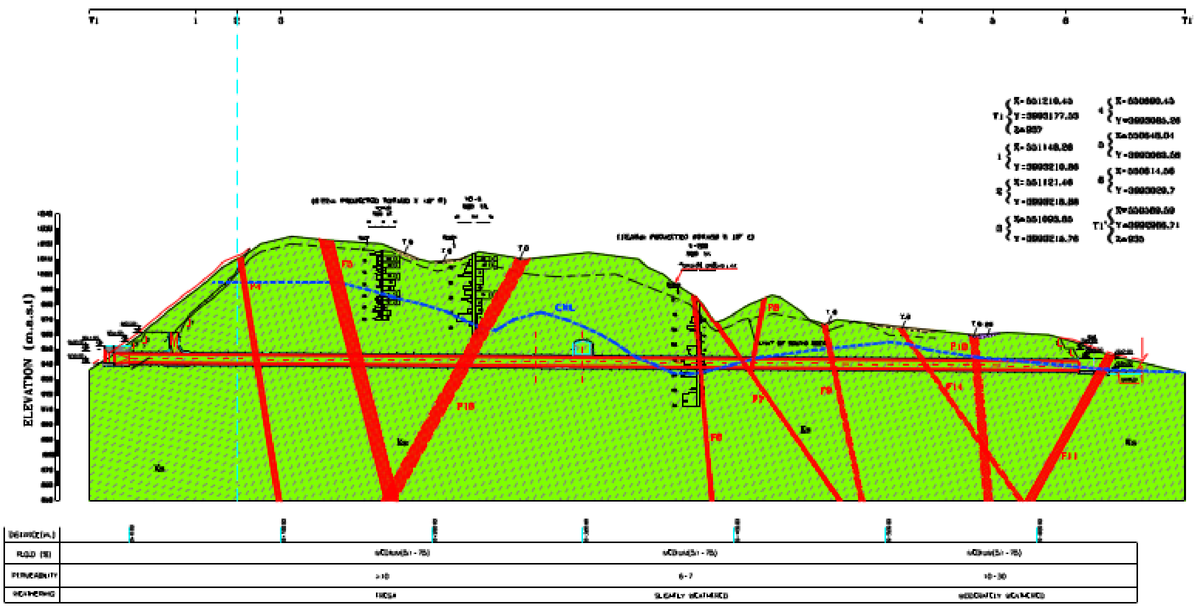

Figure 3. Geometric characteristics of the Sardasht dam tunnel [13]

Based on what was said, first a Pilot according to Figure 4. drilled by drilling and blasting from top to the bottom. The pilot diameter is largely influenced by the main shaft diameter and pilot run method (especially the type of equipment used).

Figure 4. An illustration of the drilling depth of the drain shaft and its pilot position [14]

3. Technical Analysis of Tunnel Collapses

Engineers always face with hazards in tunnel design. Error in design of support system causes some problems. Weak design may result in collapse, compensation of which will be costly. On the other hand, resistant design cause to increase tunneling costs. In this project, presence of groundwater, certain geological situation and presence of surface water, especially in rainy seasons, created conditions that, although several attempts were done to restrain collapses and also, several implementation operations such as shotcrete, filling concrete, pumice, installation of beam and frame and grouting by gravity downward and under pressure through the tunnel, rock mass did not reach a stable status. Hence, due to improper condition of rock mass and lack of a safe and reliable ceiling in collapsible zone, construction process could not be continued. Here we try to propose a new support system considering previous suggested solutions and technical and executional recommendations of experts. Some studies were done about the hazardous events during tunnel excavation and the way of managing and controlling them, which will be referred in the following sections. Next, the way of engineering investigation on collapses, stability analysis of the environment and suggestion of an optimal support system will be addressed.

To study collapses resulted from geological conditions, it is required to survey characteristics of discontinuities (dip, dip direction, spacing, aperture, fillings, joint surface properties, persistence, etc.) along the tunnel route from ceiling and walls. Then, the reasons for collapse are investigated by UNWEDGE software. To do this, characteristics of discontinuities (bedding, fault, joint) such as spatial position, spacing, discontinuity surface properties, are given to Dips software as input and number of joint sets is determined. Then the studied area is divided to homogenous parts and discontinuities of each part included in UNWEDGE to study type of collapse if any wedge is formed. Although, one may observe, more or less, effects of different factors such as strength loss, weathering, discontinuities and their conditions, etc., but for some of the collapses, the most important factors may be determined. To reach this aim, various types of collapses are studied.

- Type 1 collapse (collapse caused by bedding planes): In this type of collapse, impact of bedding may clearly be observed.
- Type 2 collapse (collapse caused by bedding planes and joints functions): In fact, in this type of collapse, which is considered as one of the main types of collapse in the tunnel, discontinuities planes (joint and bedding) are the major factor of these collapses.
- Type 3 collapse (collapse caused by function of key blocks): Falling of a key block results in collapsing other blocks. Although it is similar to previous type of collapse, but, under certain conditions, a key block causes other blocks lock together and releasing this lockage leads to extensive collapse. Regarding dimensions, joints with persistency exceeding tunnel dimensions are main factor of producing blocks. Of course, existence of key blocks should not be ignored. The role of each key block is such that, due to its falling, other blocks and rock fragments relying on it, which are placed in upper levels, are collapsed, in other words, depth of collapse will increase.
- Type 4 collapse (collapse caused by strength loss and weathering): Due to weathering and strength loss, some collapse occur which is usually minor one.
- Type 5 collapse (collapse caused by falling of hanging boulders): Boulders available in rock mass, fall and cause additional excavation [15].

4. Collapses Prevention in A2 Diversion Tunnel

Placement of fragmented zone resulted from a fault located between diversion tunnels 1 and 2 and dip and strike of that fault, which is approximately parallel to tunnels with a little inclination towards the second diversion tunnel, caused left wall of the second diversion tunnel on 0+18km to come near this fragmented zone and initially suffered from limited collapse. After leakage of surface water resulted from raining, the developed cavity, on left side of the second diversion tunnel, enlarged and reached at out of control dimensions. To restrain the instability and the occurred collapse, the following excavation operations have been done:

4.1. Common Reinforcement Steel Set Installation

To pass through the collapsed zone, first, steel frames (rolled 18 girder) were installed and the cavity was filled with concrete, pumice and shotcrete aiming to make a safe ceiling. Due to presence of flowing water at the place of collapse, cohesion of applied shotcrete with rock surface was not significant and practically had no positive effect.

As second step, installation of beam and steel frame and filling of the cavities by pumice, concrete and shotcrete was taken into account. In spite of implementing this procedure, it was not successful in stopping the collapse and allowing passing the collapse zone, because of extension of collapse zone and occurring successive collapses from the tunnel ceiling.

Figure 5. Steel set installation for collapse prevention in occurred void [15]

On the other hand, at upstream of diversion tunnel and on one of upper trenches of tunnel a collapse occurred and a hole was developed due to the collapse from upside of tunnel. At this stage, a forum consisting of different elements of the project was formed and according to a plan proposed by it, initially, working face of tunnel plugged by concrete block wall aiming at preventing more fallings. Then, grout injection was gravitationally done from upper trench to fill joints and cracks. At the same time, the collapsed zone is grouted through drilling grout holes around the collapsed zone.

Objective of all these solutions was to prevent extension of the hole developed at ceiling and wall of the second diversion tunnel and blocking its way towards the area of first diversion tunnel and lower discharge shaft, as well as producing a uniform mass consisting of rock mass and a combination of grout, rock or concrete.

After completion of all proposed procedures, to continue tunnel excavation, the plug of working face was removed, but further collapse, after removing blocks, indicated that desired stability was not reached yet.

5. Proposed New Solution (Retaining Crown Creation with Rock Bolts)

Regarding the observations during excavation operations, one may conclude that main origin of fallings and instabilities is the tunnel ceiling and fallings are going on there. Consequently, construction of a retaining ceiling at the collapsed zone is proposed as a solution for preventing materials of tunnel ceiling from falling. This retaining ceiling will be constructed by rock bolts, as well as grouting around working face of the tunnel. This technique is also used to make a grout curtain against percolated water into the tunnel area by a special procedure. Figure 3. shows a view of carrying out of this technique at a tunnel project:

Figure 6. Steel set installation for collapse prevention in occurred void [15]

To make a safe and strong shield on the ceiling, as mentioned before, first a shotcrete layer of, at least, 7cm thickness is applied on working face to stabilize surface falling blocks. Then bolt holes may be drilled in 30cm distance from each other and 4m long rock bolts of 25 or 28mm diameter will be used, as shown in Figure 6.

Considering the presence of water flowing in the rock surrounding the tunnel at the collapsed zone, in addition to installation of bolts which make a protective ceiling shield at collapsed zone, by grouting of peripheral holes, the developed shield will act as a water-tight curtain, as well. Figures 7 and 8. illustrate grouting system of holes around working face in a similar tunnel project.

Figure 7. Steel set installation for collapse prevention in occurred void [15]

Figure 8. Stope Peripheral boreholes grouting system to create sealing crown in tunnel [15]

By above mentioned procedures, we hope that, after stabilization of rock mass and making a safe environment at the collapsed zone of second diversion tunnel, working faces go through the collapsed zone and excavation operation continue. After passing this zone, excavations will go on with a method containing minimum inductive stresses. Hence, excavation by road-header is suggested for the remaining part of the tunnel. If excavation is faced with hard rock at working face, controlled explosions will be exercised.

6. Conclusion

Stability issue and design of an optimal support system in tunnels are always preferable. In order to investigate the collapse process in the Sardasht water transfer tunnel, studies on the dam site, such as: discontinuity studies, engineering analysis of collapses were carried out by investigating collapses resulting from geological conditions and causing the loss of land using un-wedge software. In addition, various types of incidental collapses, including five types of collapse, were investigated. At the second diversion tunnel of Sardasht Dam some collapses occurred which endangered safety of personnel and excavation environment. It should be noted that, to deal with these collapses, several support designs were proposed such as shotcrete and use of beam and frame as well as consolidating grouting, but, unfortunately all of them failed and fallings continued. In order to introduce a proper support system for tunnel stability, this research addressed way of occurring collapses from engineering point of view, then some arrangements proposed to cope with these collapses and dominated factors on the support systems were reviewed and finally, a new support system introduced, called “developing retaining ceiling by rock bolt”, based on previous observations and experience.

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