Rock slope stability analysis with a kinematical method for the Nam Phoun dam site project, Laos

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Abstract. Rock slope stability is one of the major challenges in the rock engineering. In this paper, kinematical analysis on the right bank slope of Nam Phoun Hydropower station dam site project has been performed according to the planar sliding and wedge sliding. Field investigation was realized and geometrical properties of rock mass collected, the objective in this paper is to evaluate the stability of the dam site and predict the probable mode of failure; Lower hemisphere stereographic projection of different joints set was realized using a commercial Rocscience program called Dipv6. Planar sliding and wedge sliding failure performed, show that no probable planar sliding and wedge sliding failure can occur on the right bank slope and for the excavation process; the slope face is stable for dip angle equal to 45°.

1. Introduction

Rock slope stability in the fractured rock mass is one of the problems in rock engineering, and various engineering project in mountains area requires the excavation of rocks and the geological units used may be of sedimentary, magmatic or metamorphic origin. In most cases, these rock masses have a large number of discontinuities of the varying extent [1]. These discontinuities include bedding planes, joints, fractures and schistosity [2] resulting from the phenomena that affected the massif during the geological period. In relation with free surfaces, these discontinuities cut the rock masses in blocks around the excavation zones, influencing the stability of the massifs. On the rocky slopes, geotechnical engineers and geologists are often confronted with these problems of instability. The consequences often lead to loss of human life, and economic resources. [3] discussed the importance of structural geology in the ruptured rock slope mechanism and how these structures control slope stability. In similarly, [4] demonstrated how geometry and rock slope composition are determining factors in the potential mechanism of failure from complex multi-mechanism to complex fracture. Among the methods of analyzing slope stability problems in rock masses, the kinematic method is considered as one of the appropriate approaches.

This paper presents a stability analysis of the right bank’s slope of Nam Phoun hydropower project dam site in Laos. However, the dam site area includes varying slopes and lithologies; in order to ensure the safety of the dam, the main objective in this paper was to evaluate the stability of the dam site and predict the probable mode of failure by using the conventional kinematical analysis method.
2. Geological feature of the study area

The dam site is located at Nam Phoun River near the Nam Phoun Village in Paklay District of Xayabury Province in Northwestern Laos (figure 1). The latitude and longitude coordinates of the dam project location are 18°27'48.23"N and 101°28'04.45"E, approximately 2.6km upstream the convergence points of the tributary Nam Gnam River (figure 1). The reliefs of both banks are symmetrical with a broad valley which is cross-section and “V” shaped.

Lithologically, the area under investigation is composed of clastic rocks (Mz1) aged from the Middle Triassic to Middle Jurassic which are mostly continental sedimentary, including argillaceous clastic rock and, thin coal seams and conglomerate; acidic-neutral - basic intrusive rocks (vPz3) of Permian age are also present.

The sedimentary rocks (CPz2) present in this area date from the Upper Devonian to the Lower Carboniferous. The dominant lithology is composed of tuffaceous slate, tuff, tuffaceous sandstone and tuface phyllite. The dam site area has the major presence of Quaternary overburden which is mostly composed of alluvial and deluvial-eluvial deposits. The upper part of overburden on both banks is composed of deluvial-eluvial gravelly clayey soil and lower part eluvial gravelly soil.

![Figure 1. Location of the study area](image)

According to the discontinuity survey performed on the natural bank slopes, no major fault and fold were observed in the dam site area but the minor fissures or joints are presents. The structural surface is class V-structural surface that mostly appears as the bedding surface or tectonic fissure. The data on strikes, dip, dip direction, of each discontinuity were recorded.
3. Kinematical analysis

By definition, Kinematic analysis is the motion of the body without reference to the forces that cause them to move [5]. It allows understanding the influence of discontinuities on stability by studying the relationship between the orientation of discontinuities and the slope face [6]. Different authors have used this method to evaluate the problems related to slope instability successfully [7-10]. In this paper, the kinematical analysis described by [5], [11] was applied. In order to accomplish this task, structural data collected in survey discontinuities on the dam site were analyzed by stereographic projection technique according to two types of failure’s mode: sliding plane and wedge sliding, using Rocscience program Dip 6.0 [12].

Firstly, the contours of ten (10) different joint’s orientation including bedding plane were obtained on a lower hemispherical equal area stereographic projection as illustrated by figure 2. It shows the maximum density of the pole’s plans at 14.62 %. Details of dominant joint’s set orientations obtained by Dip program are provided in table 1.

During construction’s phases, excavations process will be realized on the slopes and modify the slope geometry. For reasons of safety of the slopes, the analysis of the blocks was studied by considering the geometrical characteristics of the slope face expected for the excavation on the right banks. The dip angle of the natural slope varying from 10° to 25° and the dip direction of the rock slope face at the right bank under excavation will be 45/110.

![Figure 2. Contours of poles discontinuities, Stereographic projection, equal area, lower hemisphere](image)

| Joint’s orientation | Dip | Dip direction |
|---------------------|-----|--------------|
| J₁                  | 65  | 156          |
| J₂                  | 25  | 125          |
| J₃                  | 66  | 355          |

Table 1. Different joint’s set orientation
4. Result and Discussion

This section as mentioned above present the results and discussion of the slope stability study carried out at the dam site of Nam Phoun hydropower station project; the conventional Kinematical analysis has been carried out according to possible planar sliding and wedge sliding on the left and right banks. The main objective was to evaluate the stability of the dam site and predict the probable mode of failure of slopes. Thus, the stereographic projection of the different joint’s collected in the study area was analyzed using Dip program 6.0 [12].

Figure 3 shows the results of planar sliding performed on the right bank of the dam site. It shows the intersections I (J1, J3), I (J1, J2) and I (J2, J3) of all the joints. I (J1, J3) plunges to 16° E, I (J1, J2) plunges to 68° E.

Figure 4. Kinematical analysis, wedge sliding at the right bank

Figure 3 shows the results of planar sliding performed on the right bank of the dam site. It shows the intersections I (J1, J3), I (J1, J2) and I (J2, J3) of all the joints. I (J1, J3) plunges to 16° E, I (J1, J2) plunges to 68° E.
and I (J2, J3) plunges to 81° E. According to [13] and [7], planar sliding is possible if the discontinuity plane daylight into the slope face and the difference between the strike of the discontinuity plane and that of the slope face is 20° or less. But in figure 3, all of these intersections are outside of the potential rupture zone which is located at the West. Therefore, there are no critical conditions and no possibility of planar sliding failure.

Figure 4 shows the result of the wedge sliding analysis performed. There is wedge failure if the discontinuity intersection vector falls within the critical wedge region, which is bounded by the great circle representing the dip of the slope face and the circle representing the angle of internal friction (ϕ). According to figure 4, the envelope of failure is located at the East and the different intersection of set’s joints is outside of the critical wedge region. In these conditions, wedge sliding failure cannot occur in the right bank’s slope.

5. Conclusion

Based on the kinematical analysis performed on the right bank’s slope of Nam Phoun hydropower station project, the following conclusions can be drawn:

1. For two modes of failure realized, precisely planar sliding and wedge sliding, there is no probable failure mode on the right bank’s slope.

2. For the excavation process at 45°, the slope angle is safe.

3. Given that the rock mass of the study area has a state of alteration advancing, rocks and a large amount of overburden in the upper part, it will be necessary to conduct further studies on numerical analysis for reasons more safe and also assess the influence of rainfall on the stability of the dam site.

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