A Case Study of Probabilistic Seismic Slope Stability Analysis of Rock Fill Tailing Dam

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ABSTRACT

The article presents the case history of expansion of rock fill tailing dam of the Rampura-Aghucha zinc mine in Rajasthan, India. Before raising the height of the dam from 27 m to 54 m, a detailed seismic stability analysis was performed considering the spatial variability of the soil. The safety values and the probability of failure were calculated using the Monte Carlo simulation method. All the analyses were carried in a 2-D limit equilibrium-based SLIDE software using Spencer's method. The cohesive strength (c), the angle of friction and the acceleration due to earthquakes were considered as the random variable. The final slope geometry was created after the seismic stability analysis of the upstream and downstream slopes. For the critical geometry of the slope, the observed factor of safety values was found to be higher than the values specified in the ANCOLD. The probability of failure value was found to be less than 8%. The newly constructed rock fill dam has already sustained three Monsoon rains and still continues to be performing at its best condition.

KEYWORDS

Limit Equilibrium Methods, Probabilistic Analysis, Rock Fill Dams, Seismic Slope Stability, Spencer’s Method, Tailing Dam

1. INTRODUCTION

The latter half of the last century witnessed a great spurt in the mining activities all over the world. Different milling processes were introduced in the last few decades to extract different metals. In general, the mined ores are finely powdered and subjected to metallurgical processes to extract the mineral values. After the extraction, the remaining part of the mined material will be disposed of usually in the slurry form termed as tailings. In the beginning, when the productions were small, and when environmental concerns were nonexistent, the tailings were discharged into the natural streams and valleys. Such is not the case now, as the tailings discharges are huge, and environmental concerns are very serious since the tailings contain chemicals and contaminants. As a result, large surface impoundments are created for the tailings by constructing an all-round dyke system called as tailings dam.

Three different methods are in use for the construction of the tailing dams namely, upstream method, downstream method and centerline method. The suitable method is selected depending on the availability of land, characteristics of the settled tailings, and the cost of construction. The upstream method is the most cost-effective; but cannot always be adopted due to the stability issues. In this

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method, the new section has to be constructed on the settled tailings with low shear strength and highly variable properties. The downstream methods are known for higher stability; but are costly. The centerline method is in between the upstream and downstream methods in terms of cost and stability. Figure 1 shows the schematic construction sequence of the different methods.

Over the past decades, failures of the large tailing ponds have triggered serious disasters and drawn public attention to the safety of tailings dams (Rico et al., 2008a). The major cause for the tailing dam failure are slope instability, seepage, in sufficient free board, rise in the phreatic surface, foundation failure, excessive rainfall and seismic liquefaction etc. Rico et al. (2008b) carried out the failure analysis of 147 tailing dams and reported that the 85% of the failure occurred in the active tailing dams. Meteorological factors such as uneven rainfall and snow were found to be the major cause. It was also observed that the majority of the failed dams were constructed using the upstream method of embankment raising. The routine stability analyses may not suffice while adopting the upstream method of embankment raising. More robust and comprehensive analysis considering all the critical aspects has to be carried out in those cases. The present study proposes the reliability based seismic stability analysis for the dams. The reliability-based methods consider the spatial variability of the mine tailings and the soil (e.g. Hong and Roh, 2008; Griffiths et al., 2009; Wang et al., 2010; Wang, 2012; Liang Li et al., 2014).

The variations in the soil properties significantly influence the stability of the dams. Apart from the inherent variability, the variability comes by virtue of the field and laboratory testing of the soil. In reliability-based methods, a series of calculations are made by varying the critical design parameters over its maximum credible range to determine its effect on the factor of safety (Xie et al., 2012). In the conventional deterministic analysis, the factor of safety (F) is defined as the ratio of resisting force to the driving force on a potential sliding surface. The slope is considered safe only if the calculated factor of safety exceeds unity (Husein Malkawi et al., 2000). According to Duncan (2000), it is not logical to use the same value of factor of safety to conditions that involve widely varying degrees of uncertainty. Because, the slopes with the same value of safety factor may exhibit different levels

Figure 1. Different raising schemes: (a) Upstream method; (b) Downstream method; (c) Centerline method
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