Seismic Evaluation of Tailing Storage Facility

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Abstract

In connection with the possibility of increasing seismic activity in southwest Western Australia (SWWA), it is important to consider the seismic stability and reliability of mining facilities already existing, including tailings dams. Not many years ago, tailing dams were designed using a simple pseudo-static approach. However, the pseudo-static method suffers a number of drawbacks including the assumption that dams are absolutely rigid bodies fixed on their foundation and thus experiencing a uniform acceleration equal to the underlying-ground acceleration. It is currently understood that dams behave as deformable rather than rigid bodies. The response of dams to ground shaking is determined by the properties of the constituent material, the geometry, and the nature of the ground motion. Hence, an updated assessment of the performance of tailing dams in response to possible earthquakes is necessary. In this study, the responses of two typical tailing dams built using different construction methods (i.e. upstream and downstream construction methods) to design earthquake ground motion are investigated using numerical dynamic analysis. Seismic performance of these dams is presented.

Keywords: seismic response, tailing storage facility, deformation

1. Introduction

Disposal of tailings is commonly considered to be the most sensitive environmental issue confronting the mining industry as failure of tailing dams may result in uncontrolled spills of tailings and other materials, potentially leading to environmental catastrophes, losses in terms of property and human life and negative company image. The seismic safety of tailings dams has drawn much attention over past decades since a significant number of this type of earth structure have suffered severe damage or even total failure during strong earthquakes. In connection with the possibility of increasing seismic activity in southwest Western Australia (SWWA), the seismic design of a tailings storage facility has become an important aspect for all mining operations.

Embankments can be raised using either the upstream or downstream method of construction. The construction of an upstream designed embankment begins with a pervious starter dyke foundation. The tailings are usually discharged from the top of the dam crest creating a beach that becomes the foundation for future embankment raises. The upstream method of tailing dam construction is a standard method for tailings disposal because it is economical. However, studies of world wide dam failures indicate that the upstream method is more susceptible to instability from seismic loading compared to downstream method. This is because embankment raised by upstream method is founded directly on existing tailings typically with low relative density and high water saturation and therefore a high risk of liquefaction during earthquake shaking. Accordingly, the upstream method is used less frequently in high seismicity zones of the world. In contrast, dam embankments using the downstream method have larger seismic capacity as each raise is structurally independent of the tailings and its behaviour is similar to water retention dams. The main disadvantage is the large volume of fill material required to raise the dam which leads to a dramatic increase in the cost of this construction method. In the past, upstream-type embankments were the most popular embankment of tailing dam in SWWA as seismic risk in Western Australia has been considered quite low. However, the upstream-type embankments might be vulnerable to destructive ground shaking.

Not many years ago, the seismic analysis of tailing dams was commonly performed using a simple pseudo-static approach. This was also called seismic coefficient method. The effect of seismic shaking is represented by a factor of safety against sliding with the addition of a horizontal force. The additional horizontal force is equal to the product of a seismic coefficient (k_h) and the weight of the potential sliding mass. In the analysis using pseudo-static approach, dams are assumed to be absolutely rigid bodies fixed on their foundation and thus experiencing a uniform acceleration equal to the underlying-ground acceleration. The use of seismic coefficient is conservative mainly because the PGA exists for only a very short time and the use of a constant lateral force is unrealistic since in one instant the acceleration may be de-stabilising the dam but in the next instant, when the direction of the acceleration reverses, it has the effect of stabilising the dam. Seismic coefficients vary significantly from study to study, e.g., k_h of 0.1-0.5 in Terzaghi (1950), k_h of 0.1-0.15 in Seed (1979), and k_h of 0.5 in Hynes-Griffin and Franklin (1984). However, it lacked a rational basis for choosing this seismic coefficient and there are no hard rules for selection of seismic coefficient. Furthermore, it is currently understood that dams behave as deformable rather than rigid bodies. The response of dams to ground shaking is determined by the properties of the constituent material, the geometry, and the nature of the ground motion. Hence, in this study, a more accurate assessment of the performance of tailing dams in response to possible earthquakes is carried out by using numerical dynamic analysis. The responses of two typical tailing dams built using different construction methods (i.e. upstream and downstream construction methods) to design earthquake ground motion are investigated. Seismic performance of these dams is presented.

2. Design Earthquake Ground Motion

The design event is assumed to be a ML7.5 event with an epicentral distance of 50km in the analysis. The peak ground acceleration (PGA) is estimated to be 0.32g based on Liang et al. (2008) model. The estimated duration of an earthquake of ML7.5 at an epicentral distance of 50km is about 17sec. The duration is measured by integrating squared acceleration and adopting 95 percentile time interval (Trifunac and Brady, 1975). To investigate performance of tailings dams under earthquake ground motion, seismic ground acceleration time history corresponding to design event is generated in this study. The design response spectra defined in Australian Code (AS 1170.4-2007) is used as target response spectrum in ground motion simulation. The simulated time history and the comparison of the response spectrum of the simulated motion and the target response spectrum are shown in Figure 1.

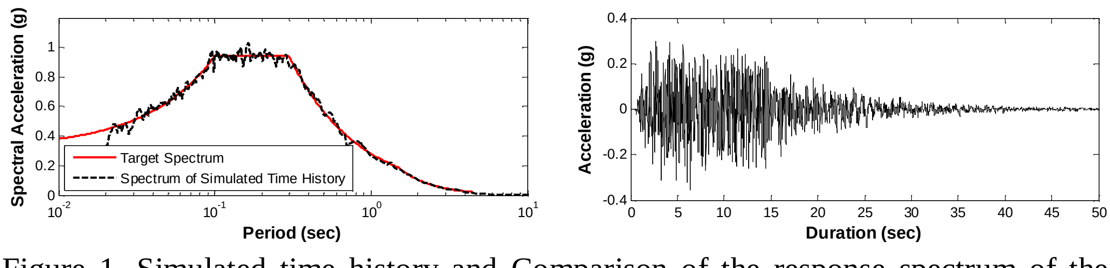


Figure 1. Simulated time history and Comparison of the response spectrum of the simulated time history with the design response spectrum

3. Model Geometry and Material Parameters for Seismic Analysis

The two cross sections examined may be described as Model 1 (Figure 2) a 60m high upstream tailing dam with three upstream raises and, Model 2 (Figure 3) a 100m high downstream tailing dam. The typical section of upstream tailing dam and downstream tailing dam are modelled as shown in Figure 2 and Figure 3, respectively. Two points are selected to track the displacement histories at the crest of dams during the earthquakes. The geotechnical properties adopted are listed in Table 1 and illustrated in Figure 2 and Figure 3 for the sections.

It is well documented that tailing are generally susceptible to liquefaction when they are subjected to strong earthquake shaking. However, there is a significant amount of uncertainty involved in assessment of the liquefaction susceptibility of tailing material. Most research conducted on liquefaction has focused on naturally occurring soils. Some studies (e.g. Ishihara, 1985) indicated that tailings may have differing liquefaction properties to natural soils as often it typically comprises finely ground rock and therefore may not have clay mineralogy. Hence, the performance of dam embankment subjected to non-liquefied tailing and liquefied tailing conditions are investigated. The undrained shear strength of the liquefied tailings is estimated based on the method developed by Olsen and Stark (2002). A degradation factor method proposed in Shanker et al. (2007) study is adopted to estimate Young's modulus of liquefied soil. Based on this approach, a degradation ratio of Young's modulus of liquefied soil to the non-liquefied soil is estimated to be 0.1 in our study.

Description	Colour	Unit Weight (kN/m3)	E	Cohesion (kN/m2)	Friction Angle	Permeability (m/sec)
Clay Core		17	20MPa	0	35	$5x10^{-8}$
Filter		17	25MPa	0	35	$1x10^{-3}$
Tailing		17	3MPa	0	20	$5x10^{-7}$
Compacted tailings		18	10MPa	0	30	$4x10^{-7}$
Rockfill		18	50MPa	0	38	$1x10^{-4}$
TFL		22	100MPa	0	40	$5x10^{-7}$
LFL		25	30GPa	0	40	$1x10^{-7}$

Note: TFL is top foundation layer; LFL is lower foundation layer

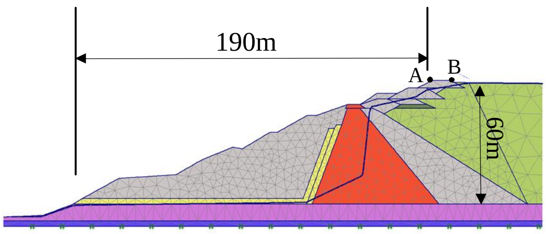


Figure 2. Model 1 Upstream tailing dam

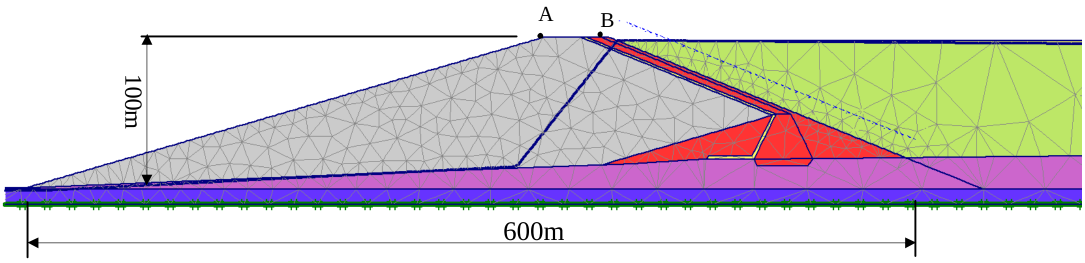
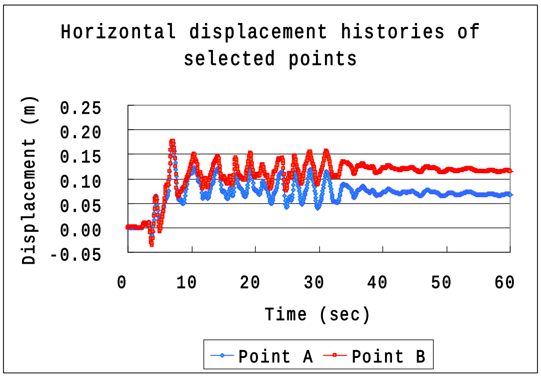


Figure 3. Model 2 Downstream tailing dam

4. Performance of Tailing Dam Embankment

The tailing dam embankment stability and deformation under the proposed earthquake ground motion are evaluated using finite element (FE) techniques. The numerical modelling was carried out using the Finite Element Package, Plaxis. The program allows for two-dimensional analysis of elastic-perfectly plastic soils with a Mohr-Coulomb failure criterion utilizing 4th order 15-node triangular elements. The calculation consists of two phases. The initial stresses due to soil weight and pore pressures were generated and activated in the first calculation phase. In the second calculation phase, seismic loads were introduced at the model base by applying the simulated ground acceleration time history.

Figure 4 and 5 show the displacements of selected points at the crest of the upstream tailing dam and downstream tailing dam, respectively. Computed permanent horizontal displacement at the crest of the upstream tailing dam embankment (Model 1) at the end of earthquake shaking is about 12cm when it is subjected to design ground motion and non-liquefied soil condition. The corresponding permanent vertical displacement at the crest is evaluated as 42cm.



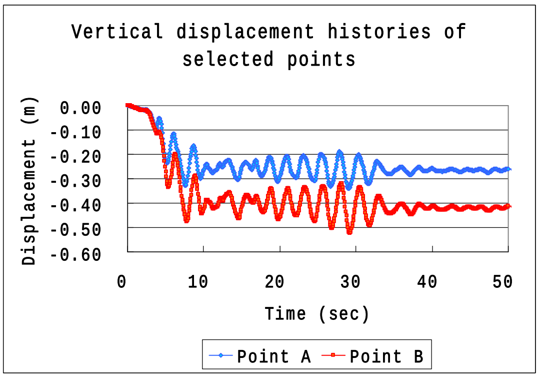
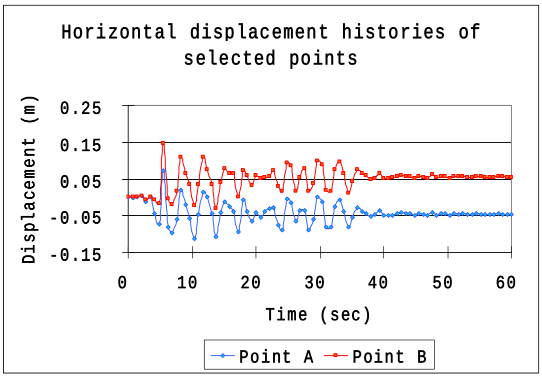


Figure 4. Displacements of selected points at the crest of the upstream tailing dam



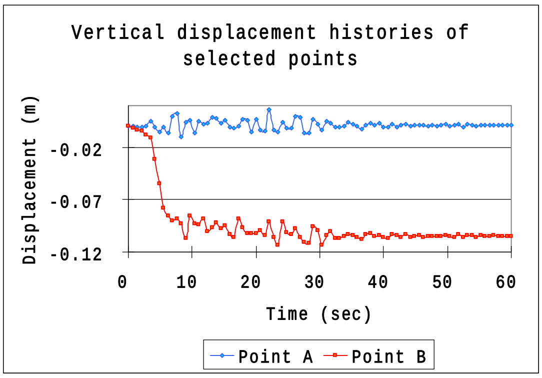


Figure 5. Displacements of selected points at the crest of the downstream tailing dam

The numerical results indicated that the permanent horizontal displacements of the downstream tailing dam embankment (Model 2) are about 5cm. The estimated permanent vertical displacements of the embankment are about 11cm at point B. There is no permanent vertical displacement observed at point A.

Stability conditions are evaluated by progressively reducing the effective cohesion and the angle of shearing resistance by a factor of safety until large displacements of the dam are obtained. Using this procedure the safety factor of post-earthquake stability of the upstream dam (Model 1) and downstream dam (Model 2) are more than 1.5, indicating the tailing dam embankments should not suffer significant damage from the design ground motion.

With liquefied soil condition, the numerical result shows that the upstream dam embankment (Model 1) is not stable in the second calculation phase, indicating that tailing material liquefaction might cause the upstream portion of the dam embankment to fail. The safety factor of stability of the downstream dam (Model 2) is greater than 1.5, indicating that there is no significant effect of liquefied tailing on the stability of dam embankment.

5. Conclusion

The performance of two typical tailing dam embankments, namely upstream-type dam and downstream-type dam subjected to design earthquake ground motion is investigated. The numerical results indicate that the tailing dam embankment should not suffer significant damage from the design ground motion under non-liquefied tailing condition.

Tailing material liquefaction might cause the upstream dam embankment to fail. As the consequences of liquefaction may result in large deformation or failure of the the upstream portion of dam embankment and there are many uncertainty in assessment of the liquefaction susceptibility of tailing material. It is strongly recommended that further research should be undertaken to investigate the susceptibility of the saturated tailing material to liquefy under cyclic loading conditions, e.g. by the use of cyclic triaxial testing.

6. Reference

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