Case study: seismic analysis for slope stability of a very high waste rock dump

Etude de cas: analyse sismique pour la stabilité de la pente d'une décharge de déchets très élevée

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ABSTRACT: In many important mining operations around the world, waste management involves a great complexity and careful analysis to prevent any risks for safety of operations. In seismically active areas such as Peru, the seismic stability of very high waste rock dumps (about 500 m high) becomes a critical component for its design due to the poor understanding of waste rock dynamic properties and behavior during strong seismic events. The authors present a case study that copes with the previous issues by gathering dynamic properties of waste rock such as shear modulus reduction and damping ratio curves and shear wave velocities, and performing nonlinear response analysis for a 500 m high waste rock dump of a copper mine in Peru. As a part of this study, the waste rock dynamic properties were obtained from Anddes´ geophysical tests, resonant column database on waste materials (Pérez, 2015), and correlations (Menq (2003); Darendeli (2001) and Seed & Idriss (1970)). The latter was obtained in collaboration with the University of Austin, Texas, and Anddes geotechnical laboratory. The ground motion amplification was evaluated using of DeepSoil V6.1 (Hashash, 2015), a software specially created for nonlinear deep ground motions response analysis. The results of this study present ground motion response spectra at different height levels of the waste dump to estimate seismic induced displacements by Bray & Travasarou (2007) method.

1 INTRODUCTION

A High Waste Rock Dump (HWRD) is planned for a copper mine in the south of Peru. Site characterization studies conducted in 2014 disclosed colluvial, alluvial and moraine deposits as well as residual soil layer (30 m thick) overlying bedrock. The civil design involved a HWRD of 500 m height, with local and global slopes of 1.33H:1V and 2.5H:1V, respectively. The allowable maximum Seismic Induced Permanent Displacements (SIPD) were established from response analyses to prevent any risks for safety of operations.

This paper evaluates the performance of several 1D non-linear seismic site response analyses to estimate the SIPD for ground motion response spectra at different heights levels (50 m, 100 m, 200 m, 300 m and 400 m) of the HWRD at the base of local and global critical failure surface by Bray & Travasarou (2007) method. Over 9 soil columns consisting of clayey and gravelly soils of colluvial, alluvial and residual origins as well as mine waste were modeled and used in one-dimensional (1D) seismic site response analyses. Then, the response spectrums at the top of each column were used for the HWRD seismic design.

An average Vs profile was estimated using empirical correlations (Seed & Idriss, 1970), a review of Anddes' geophysical tests and a series of Resonant Column and Torsional Shear (RCTS) tests carried on mine waste specimens. Soil dynamic properties included published generic modulus reduction and damping curves with implied strength correction as well as recommended plasticity model parameters based on soil index properties proposed by Darendeli (2001) for competent founding layers and Menq (2003) for waste rock.

These analyses provided the support for the design of waste dump local slopes to prevent any sliding of the waste material that may affect the safety of the operation. Finally, this study suggests a plan to keep updated data for the seismic model of long term operations of high waste rock dumps.

2 CASE STUDY GEOTECHNICAL OVERVIEW AND SEISMIC ANALYSYS

The case study presented is a HWRD design project, located in the southern Peru, developed for a copper mine. The HWRD with a maximum height of over 500 m was needed for the future development of the mine. However, limited information about the waste rock material were available due to the early development of the mine. This issue was taken into account by combining different waste rock materials from the projected sites.

This facility was designed in stages with a maximum height of 50 m and a local and global slopes of 1.33H:1V and 2.5H:1V. Additionally the soil columns are represented in the critical cross-section for reference purposes.

Since the dimensions of this HWRD the waste management plan involved a great complexity mainly because the risks of local failures and even global failures of the facility during its operational life, related to its seismic stability, a careful analysis was carried out to prevent any risks for safety of operations.

The following sections describe the geotechnical features and laboratory tests carried out on the mine waste. A detailed description of the geotechnical analysis performed for this research is presented, which included 1D seismic response analysis and SIPD calculations using Bray & Travasarou (2007) method.

2 .1 *Input motions*

The uniform hazard response spectra for 10% probability of exceedance in 50 years (475 return period), from the site seismic hazard assessment, was employed in all seismic evaluations. Seismic records from both horizontal components used as input for site response analysis were obtained from published motions from Peruvian subduction earthquakes recorded also in Peru. The earthquake motions from the 1974 Lima, 2001 Atico earthquakes were chosen. It is important to mention that the Lima and Atico earthquake motions were recorded near the epicenter of the event, capturing their high energy content, on the other hand, the 2005 Tarapaca earthquake motion, was recorded far from its epicenter and as a consequence, low values of PGA and energy content was registered for this earthquake, being subsequently discarded for the analyses. No other earthquake motions were selected due to the limited database available for Peru. All 4 seismic records (two horizontal components per earthquake) were spectral matched to the 475 years return period response spectra using the SeismoMatch software, which is based in the pulse wave algorithm proposed by Abrahamson (1992) and Hancock et al. (2006).

2 .2 *Seismic induced permanent displacements calculations*

SIPD were calculated for 475 years return period using Bray & Travasarou (2007) method and soil columns were defined from the critical section. To assess the SIPD, representative response spectra were used, considering free field conditions (at the base of local and global critical failure surface) at different heights levels (50 m, 100 m, 200 m, 300 m and 400 m).

All seismic records were used in the analyses. For each column, results of the seismic records were average since no important variations were found. Table 1 shows the characteristics of each column in terms of materials and natural period.

Table 1. Soil Columns.

Case	*Soil Column*	*Soil Material*	*Thick (m)*	*Column natural period (s)*
L*/G**	C1	Waste rock	24 / 24	0.73 / 0.73
		Foundation	30 / 30	
	C2	Waste rock	53 / 24	1.00 / 0.73
		Foundation	30 / 30	
	C3	Waste rock	128 / 68	1.57 / 1.13
		Foundation	30 / 30	
	C4	Waste rock	221 / 110	2.16 / 1.44
		Foundation	30 / 30	
	C5	Waste rock	312 / 149	2.70 / 1.70
		Foundation	30 / 30	

PND: Probability of negligible displacements
*: local critical failure surface
**: global critical failure surface

Table 2 shows the results of SIPD developed along local and global critical failure surface of the HWRD at different heights levels. It can be seen that all local critical failure surface present at least 50 cm of SIPD, which confirms the need for a change in design of HWRD related to its height in order to ensure the safety and serviceability of the facility.

Table 2. Seismic induced permanent displacements obtained for the high mine waste rock dump.

Case	*Return period (years)*	*Seismic record*	*Yield acceleration (g)*	*Displacements*
				Average (cm)
L*/G**	475	Lima and Atico	0.151/0.225	103/41
			0.151/0.301	112/24
			0.151/0.285	79/9
			0.151/0.283	57/14
L*/G**	475	Lima and Atico	0.151/0.28	54/18

3 CONCLUSIONS

For HWRD there is the need for insitu seismic measurements as the HWRD grows to keep updated the design criteria.

Shear wave velocity profiles can be obtained with a certain degree of confidence from RCTS results if geophysical data is available. Additionally, care has to be taken at shallow depths where its logarithmic relationship tend to show higher values compared to geophysical data.

Due to poor understanding of waste rock properties in HWRD, performing response analyses are a useful tool to help establish design criteria, especially at local critical failure surfaces, which in turn enhanced the efficiency of the HWRD by preventing any risk of failure.

In the present paper the SIPD calculations tend to be higher from 0 m to 200 m, compared to those from 200 m to 500 m. From these results design criteria have to be more conservative from 0 m to 200 m by changing the slopes and monitoring during operation and closure.

In this case study, a rational method to establish the seismic coefficient is needed. In other words when evaluating the seismic stability, different seismic coefficients related to its response spectra at different heights should be used. The authors recommend applying Bray & Travasarou (2009) method.

It is important to mention that the calculated SIPD are horizontal and not vertical; in other words displacements due to height and particle crushing process is avoided.

4 REFERENCES

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