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Interaction between a crusher, a MSE Wall and stockpile at mine in Peru

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Abstract. This paper describes two numerical models that were performed to study the dynamic interaction between a crusher, a mechanically stabilized earth wall and a stockpile for the primary crusher at important mining project in Peru. The models were implemented in the finite element program Plaxis 2D AE and were aimed to evaluate the interaction between crusher and earth fill, the effect of the of the position of stockpile on the behavior of the structure, and the safety factor for different positions of the stockpile with respect to the crusher station. This article presents the details and results of these models.

Keywords. Soil-structure interaction, numerical methods, computational geomechanics, mechanically stabilized wall, dynamic analysis

1. Introduction

SRK Consulting, as a part of its activities, dealt with a difficult project located in the central part of Peru. The primary crushing station of the mining project in evaluation, which is an important part of the mine operation processes, interacts with a stockpile of ore located on the surface behind the crusher wall. The static and dynamic behavior of the primary crushing station is of great interest to the mine due to the complex interaction between the crusher and the stockpile located behind the structure.

To evaluate the interaction between the described components, the authors developed numerical models in the finite element program Plaxis 2D AE. The objective was to evaluate: i) the contact pressure between the MSE Wall and the primary crusher for different positions of the stockpile; ii) the displacements of the structure as a result of the static loading of the stockpile and after seismic loading, including the effects of the earthquake shaking on the stockpile itself; iii) the safety factor for each scenario by the strength reduction method available in Plaxis; and iv) to provide design elements for the operational optimization of the location of the stockpile with respect to the crusher station.

2. Model geometry

The problem of the interaction between crusher and reinforced earth wall surrounding it is three-dimensional in nature, as shown in Figure 1, and therefore it cannot be reduced

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to a single 2D problem without a serious compromise of predictive capacity. However, for the accuracy required for this study, the authors considered that the evaluation of the interaction could be achieved through the analysis of two representative sections, those shown in Figure 2.

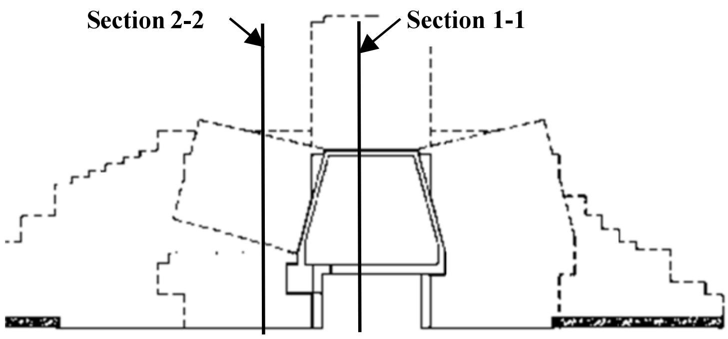

Figure 1. Plan view of the crusher and the reinforced earth wall.

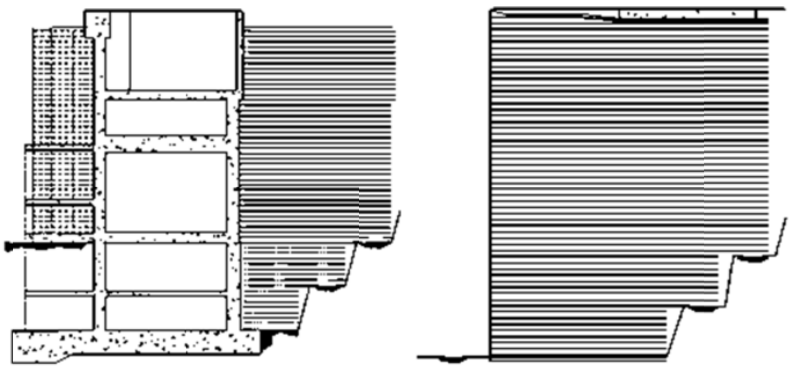

Figure 2. (left) Section 1-1 (include crusher). (right) Section 2-2 (MSE wall)

The model dimensions are 350m x 80m for Section 1, and 350m x 100m for Section 2. The crusher has a maximum height of 39.5m, from its foundation to the top of the concrete structure. Several construction stages were modeled. First, the crusher reaches the level 4706 masl, followed by the MSE Wall afterwards. After that the entire structure of the crusher is built up to the level 4721 masl and finally the backfill of the MSE wall is built in layers of 30 cm up to the level 4719 masl. The primary crusher, the MSE wall and the stockpile rest on quartz-monzonite rock, which was modeled as a linear elastic material. The concrete building was modeled as a linear elastic cluster with axial and bending stiffness equivalent to the real structure. Figure 3 shows the model geometry for Section 1 and Figure 4 shows the geometry of Section 2.

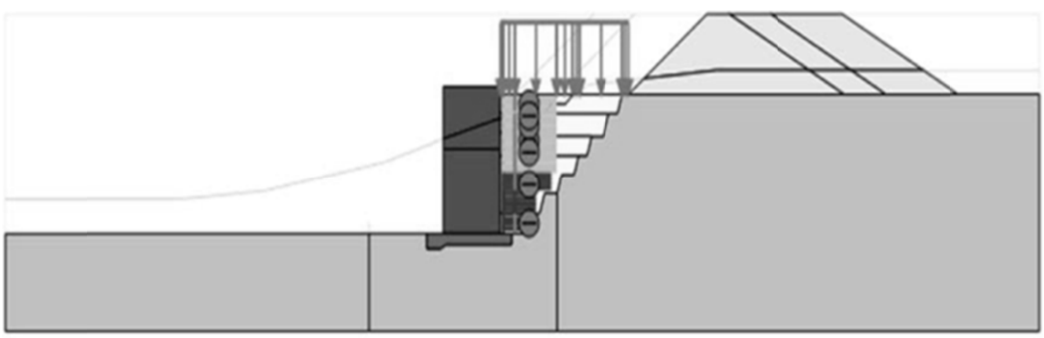

Figure 3. Sketch of the model geometry of Section 1.

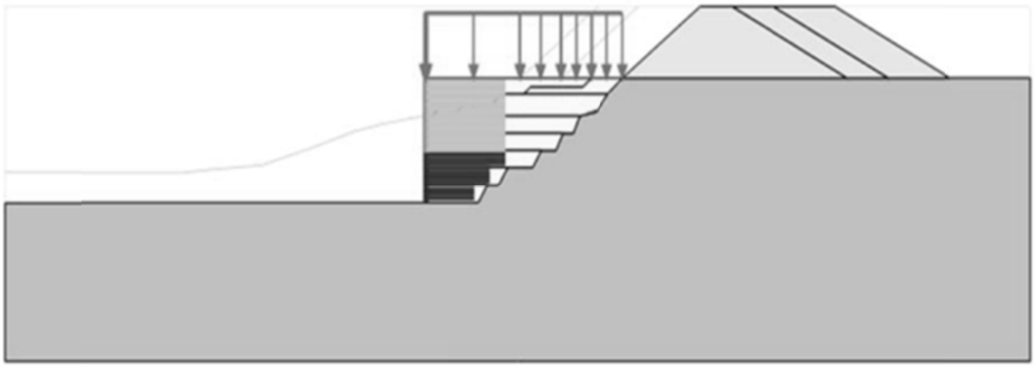

Figure 4. Sketch of the model geometry of Section 2.

3. Mesh and boundary conditions

The mesh has a design which is standard for ground-interaction problems with the following particular features: i) horizontal reinforcing geogrids have a vertical separation of 0.60m but were modeled with a separation of 1.20m as a compromise between predictive capacity of the model and numerical quality of the mesh; ii) one polystyrene layer installed between the concrete structure of the crusher and the backfill was modeled as an interface element of equivalent thickness and mechanical properties; iii) the geogrids are not connected to the concrete structure and, consequently, are not connected to the concrete block in the numerical model, meaning that behind the concrete block there is a big concentration of very small soil and interface elements that hinder the numerical solution and require manual tuning of numerical parameters for optimal and fast convergence; iv) the stockpile was modeled as a material - a necessary strategy for dynamic analyses – and also a load– a conservative strategy for the calculation of the global safety factor. In Figure 5, details of the mesh of the Section 1 for the two of analyses are shown.

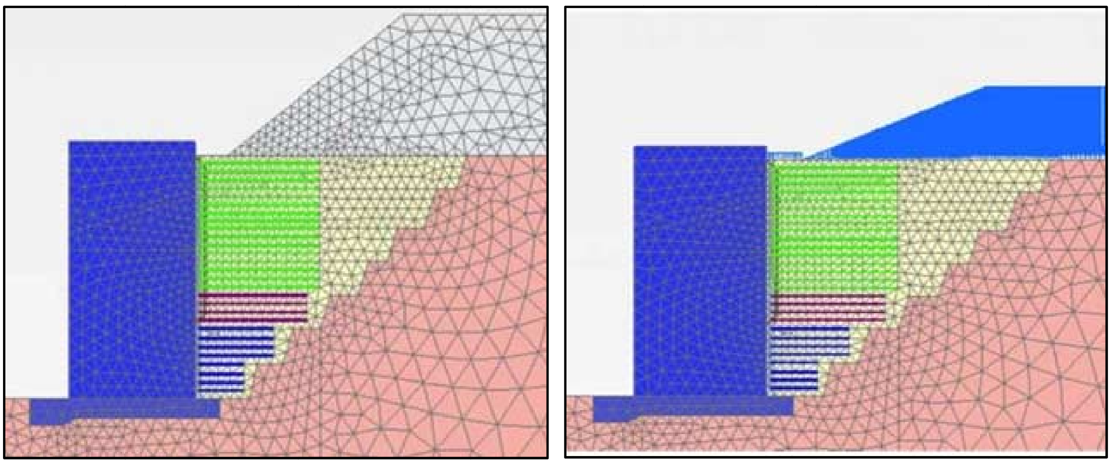

Figure 5. Detail of Section 1 with stockpile as material (left) and as a load (right).

For the static analyses, conventional boundary conditions were employed, whith horizontal full restraint at the base and vertical restraints on both sides of the mesh. For the dynamic analyses, absorbent lateral borders were employed. A "compliant base" was used in the base, the default option for the seismic analyses in Plaxis AE [2].

4. Materials

A geotechnical exploration program was performed to characterize and identify the materials involved in the model, including excavations in the compacted fill material and stockpile, geomechanical characterization, field density tests and representative sampling. The results were complemented with the information provided by the client, including the compaction records of the MSE wall, the rock drilling records, the geophysical lines and the structural plans of the primary crusher.

With the information outlined above, the following geotechnical units were identified: U1) reinforced ground and structural backfill, classified as (GC-GM) with 66% of gravels, 20% of sands and 14% of fines; U2) stockpile, classified as (GP-GM) with 77% of gravels, 17% of sands and 6% of fines; U3) rock mass composed of hard quartz-monzonite.

The strength properties of Units 1 and 2 were determined from triaxial testing of remoulded samples. For Unit 3, point load and simple compression tests were performed in the intact rock samples and it was concluded that this unit would have a linear elastic behavior for all conditions analyzed. The properties of compacted backfill, reinforced soil and stockpile were based on field tests, laboratory triaxial tests and compaction records during the construction phase.

To represent the behavior of soils (Units 1 y 2) the model HS-Small available in Plaxis was used [3]. This is an elastoplastic constitutive model with isotropic hardening for shear and compression. In its current formulation, the model reasonably reproduces: i) the increase in stiffness with confining pressure; ii) elastic behavior at low deformation; iii) pre-failure hardening with a hyperbolic stress-strain curve; and iv) a limited amount of hysteretic damping [1].

The structural elements were modeled as linear elastic materials. The geogrids of the MSE wall were represented as flat elastic elements without bending stiffness. The vertical face of the wall does not have rigid elements, so it was not subject to a special analysis in the models. The material parameters are shown in Tables 1 and 2. For the dynamic analysis, the same parameters of the static case were used.

Table 1. Constitutive parameters for Units 1 and 2.

Gravel (GP-GM)	Symbol	Unit	Unit 1	Unit 2
Unit weight	γ	kN/m^3	24.0	23.0
Moisture content	ω	%	4.0	5.0
Void ratio	e	-	0.17	0.24
Critical friction angle	ϕ_c	°	40.0	41.0
Maximum friction angle	ϕ_{max}	°	42.0	41.0
Dilatancy angle	ψ	°	4.0	0.0
Cohesion	c	kPa	1.0	1.0
Reference shear deformation	$\gamma_{0.7}$	-	10^{-4}	10^{-4}
Stress exponent	m	[1]	0.50	0.50
Failure ratio	R_f	-	0.90	0.90
Reference pressure	ρ_{ref}	kPa	100.0	100.0
Small strain shear stiffness	G^{ref}_0	MPa	200.0	180.0
Unloading/reloading stiffness at 100 kPa	E^{ref}_{ur}	MPa	100.0	90.0
Secant stiffness at 100 kPa	E^{ref}_{50}	MPa	33.0	30.0
Oedometric stiffness at 100 kPa	E^{ref}_{oed}	MPa	20.0 a 33.0	18.0 a 30.0
Poisson ratio for unloading-reloading	υ_{ur}	-	0.20	0.20
Rayleigh damping parameters	α	1/s	0.1047	0.1047
(damping ε=1% between 1Hz and 5Hz)	β	S	0.000531	0.000531
Pre-overburden pressure	POP	kPa	200.0	200.0

Table 2. Constitutive parameters for the Units 3, foundation and the structure of the crusher.

Gravel (GP-GM)	Symbol	Unit	Unit 3	Foundation	Crusher
Unit Weight	γ	kN/m^3	26.0	24.0	10.7
Young's modulus	ω	GPa	9.5	21.7	12.7
Void ratio	e	-	0.20	0.17	0.17
Rayleigh damping parameters	α	1/s	0.05236	0.04712	0.04712
(damping ε=1% between 1Hz and 5Hz)	β	s	0.000265	0.0003979	0.0003979

5. Seismic analysis

Regional seismic catalogs (CISMID) and (PEER) were analyzed; a set of seismic records compatible with the seismic demand of the project in terms of magnitude (M), hipocentral distance (R) and with a PGA value were selected and scaled to the design seismic parameters of the site. The preselected records were grouped and ordered in terms of Arias intensity and duration for a PGA similar to the design PGA, which was calculated based on a probabilistic study of seismic demand, where a return period of 2475 years for the design earthquake was established, due to the importance of the structure in the production process of the mine. Finally, the two seismic records that showed the maximum duration and maximum Arias intensity were chosen to perform 2D dynamic analyses. Figures 6 and 7 show the two seismic records used in the models, scaled to the design PGA. In total, four analyzes for the static case and three scenarios for the dynamic analyzes were considered, these are shown in Figures 8 and 9.

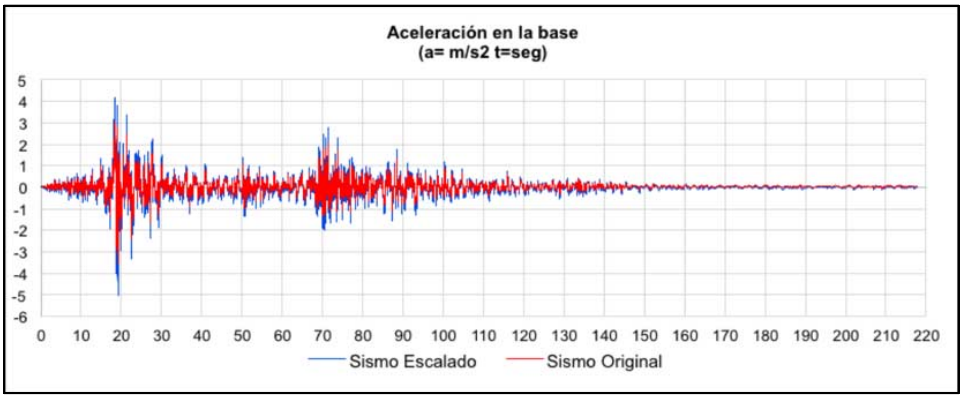

Figure 6. (a) Pisco earthquake (2007).

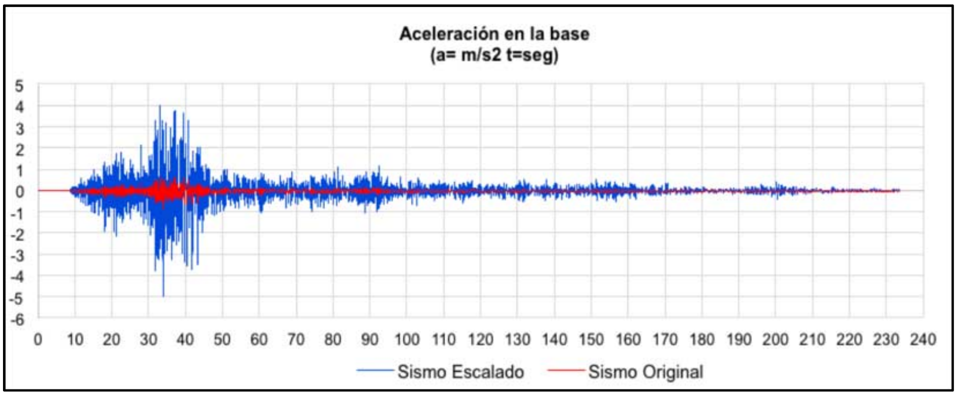

Figure 7. (a) Denali – Alaska earthquake (Fairbanks 2002).

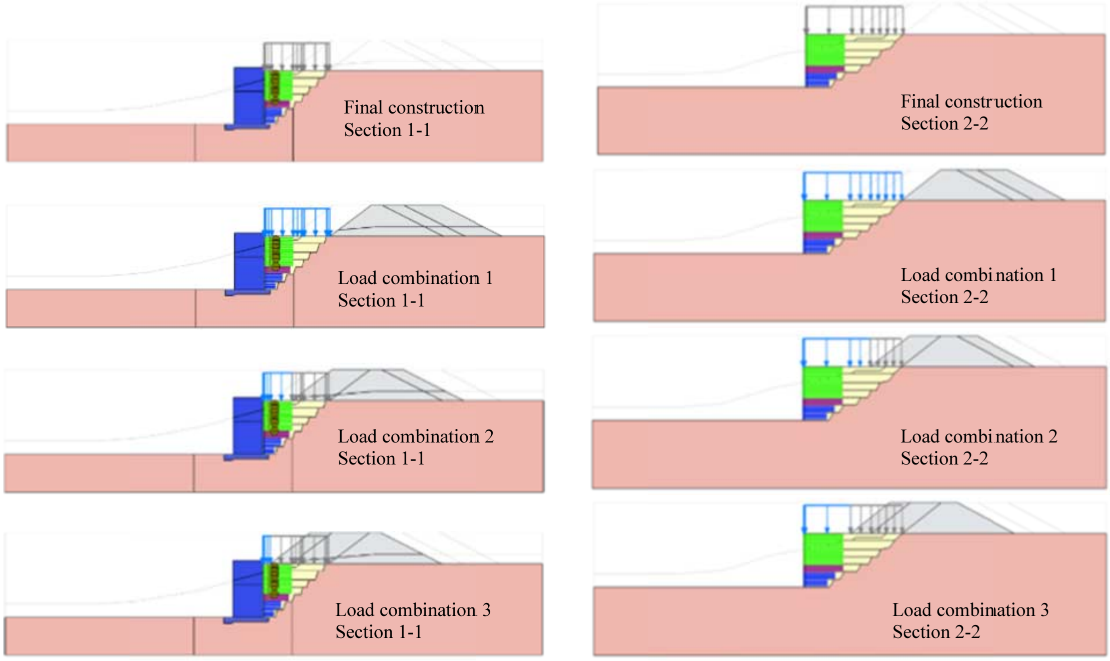

Figure 8. (a) Analyzed cases– Static analysis.

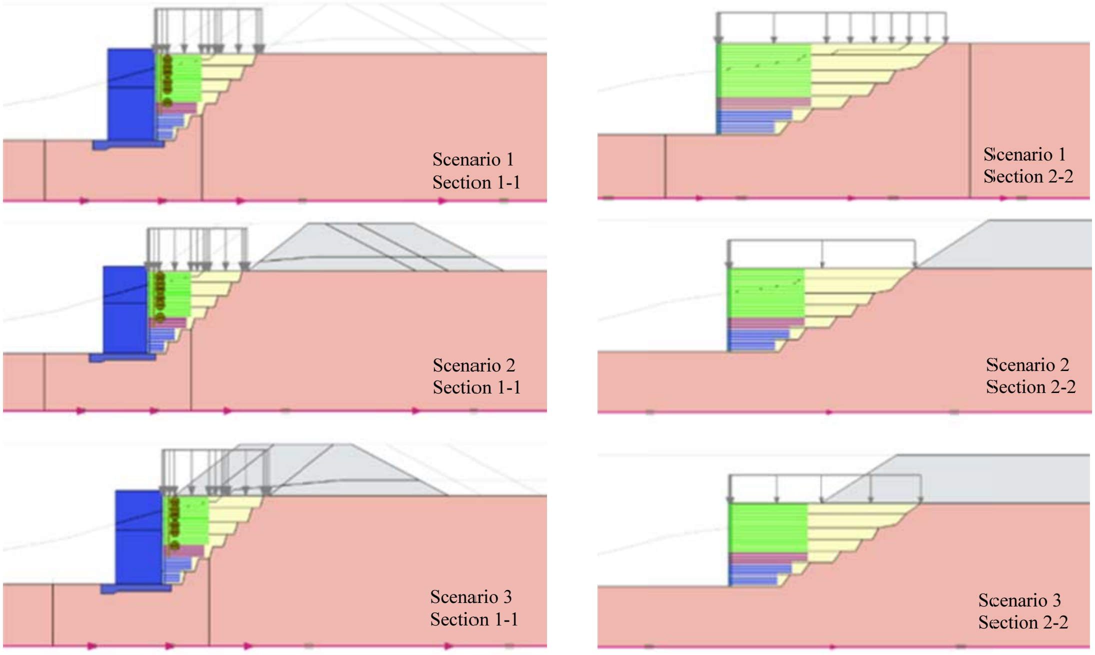

Figure 9. (a) Analyzed scenarios– Dynamic analysis.

6. Results

Wall – crusher contact pressures were evaluated for different positions of the stockpile, under static and seismic conditions. For the static case, the pressure distribution is trapezoidal and the results can be reproduced with sufficient accuracy by adopting the Rankine earth pressure theory with horizontal pressure coefficient K = 0.25|027. The results indicated that the translation of the stockpile form its original position, resting on the upper rock, to a position closer to the crusher, increases the total thrust on the structure by 70%.

The contact pressure distribution obtained for the seismic event was used to calibrate a simplified triangular distribution similar to the method of Mononobe- Okabe [4]. The total thrust capable of reproducing the residual horizontal displacement recorded on the crusher by dynamic analysis performed with the numerical model was calculated.

The upper crusher and MSE wall movements were evaluated on Section 1 and Section 2 respectively, for static and seismic conditions. In the static case, the approach of the stockpile to the front of the MSE wall increased its horizontal and vertical displacements in 40mm and 65mm respectively. These displacements represent a distortion in the front of the wall of 1%. The vertical and horizontal displacements in the highest part of the crusher were not affected by the change of position of the stockpile due to the stiffness of the structure.

Horizontal movements were recorded at the crown of the crusher up to 12mm, in the seismic case. On the front of the reinforced wall, the displacements reached maximum residual values up to 1270mm and 480mm in horizontal and vertical direction respectively. These displacements represent a distortion in the front of the MSE wall of 3.1%. It was noted that the approach of the stockpile to the front of the wall increased the horizontal displacement in 300mm. Figure 10 shows the contour of the horizontal displacements for Section 1 obtained from the seismic analysis.

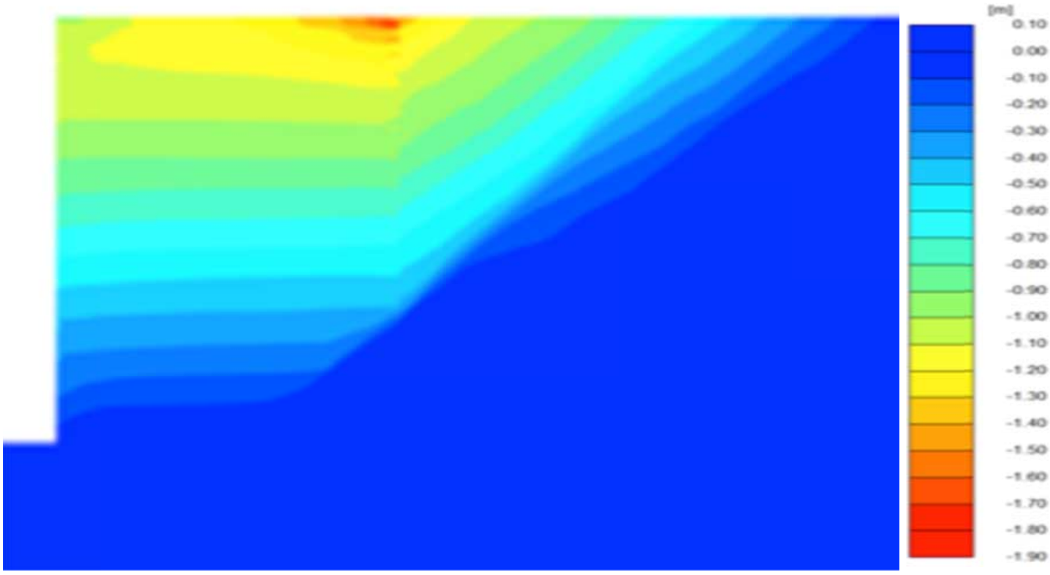

Figure 10. Horizontal displacements contour in the seismic analysis, Section 1.

The numerical factor of safety was calculated in static conditions using the strength reduction method [5]. For Section 1, the potential failure surface is restricted by the structure of the crusher, so the numerical analysis of the safety factor has little interest. The safety factor calculated for Section 2 is bigger than 2.0 for all the load cases and positions of the stockpile modelled.

The distance between the toe of the stockpile and the face of the MSE wall produces small changes in the factor of safety, less than 5% for all the scenarios and loadcases analyzed. Due to the robust design of the MSE wall itself, all modes of failure are of global type, where the MSE wall moves like a rigid block with little distress in its internal structure. Figure 11 shows the total shear deformation contour for the safety factor calculation of Section 2.

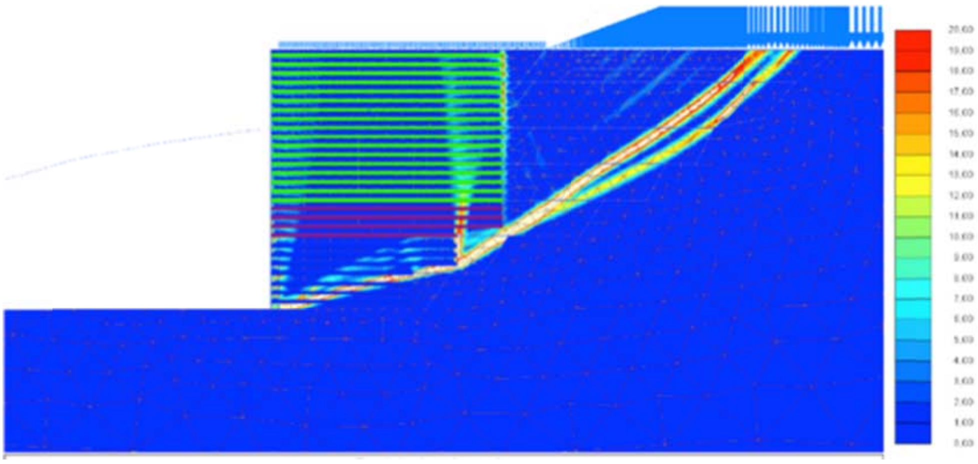

Figure 11. Shear deformation contour in the safety factor calculation – Section 2

7. Conclusions

Numerical models were developed in the finite element program Plaxis 2D AE to study the static and dynamic interaction between a crusher, a mechanically stabilized earth wall and a mineral stockpile.

It was concluded that the geotechnical safety of the construction is adequate and is not affected by the position of the stockpile. From the operational point of view, the structure of the crusher is practically indifferent to the approach of the stockpile in static conditions. The calculated displacements in the front of the reinforced earth wall are tolerable because the front of the wall has no structural covering, on the contrary, the MSE wall is formed with the same wire mesh that serve as a reinforcement grid in the compacted backfill.

For the seismic case, the displacements reported by the model are important, although consistent with the selected method of calculation and the return period of the adopted earthquake for the design.

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