Back-analyse of a large-scale collapse of chalk mine (Château-Landon, France 1910)

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Abstract

The paper presents the feedback of a large collapse of an underground chalk mine in France (77). A 2D numerical model, using the distinct element method, was used. It considered the specific characterization of the site, presence of a slope, fault, hard layer, and water. The results of the numerical modelling highlighted the role of those elements, mainly the fault, where tension stresses favorite the sliding of a large mass over the underground mine.

Introduction

The subsidence phenomenon can occur several years after the end of the mining operation. Times to times an exceptional event, such as a large-scale collapse (massive collapse) of the underground mine, can happen and induce severe consequences (Al Heib et al., 2015). The subsidence hazard is generally related to natural, man-made, etc. factors. The large-scale mining collapse is one of these catastrophic events. The prediction of such an event is very difficult. In this paper, we present a historic large-scale collapse of a chalk mine. The objective is to discuss the role of the different factors (natural and man-made) at the origin of this catastrophic event.

Case study description

During the winter of 1910, the Seine and its tributaries overflowed causing a rise in the water table and the flooding of an active chalk mine, located at Château-Landon (Paris Basin, France, Figure 1). The collapse that occurred caused a large landslide, destroying both the nearby waterway and the hamlet and killed 7 persons (Watelet et al., 2016). The collapse occurred after few days of heavy and continuous raining. Gombert et al. (2013) studied the effect of the water which was considered the triggering factor. However, the analysis of the geology and topography of the mine shows (Figure 2): 1) the mine excavated with high extraction ratio, 2) a cliff zone with a slope equal to 24°, 3) the presence of a stiff limestone bed on the overburden and 4) the existing of a fault with a dip equal to 70°. The objective of the paper is to study numerically their effect and to compare the results to the in-situ observations.

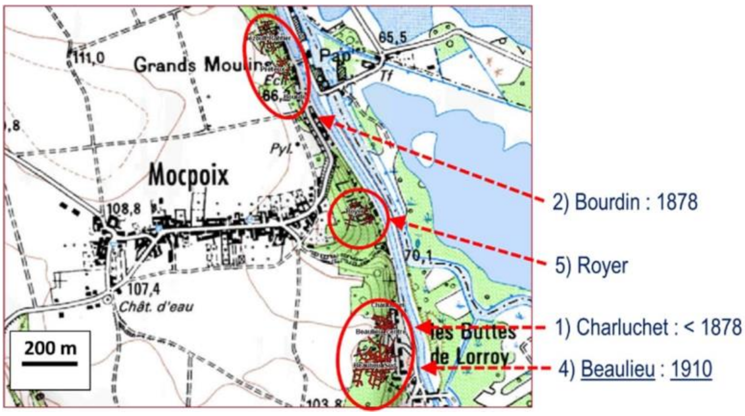

Figure 1 Localisation of the Château-Landon underground chalk mine (France), 1878, 1910: are the dates of the previous collapses

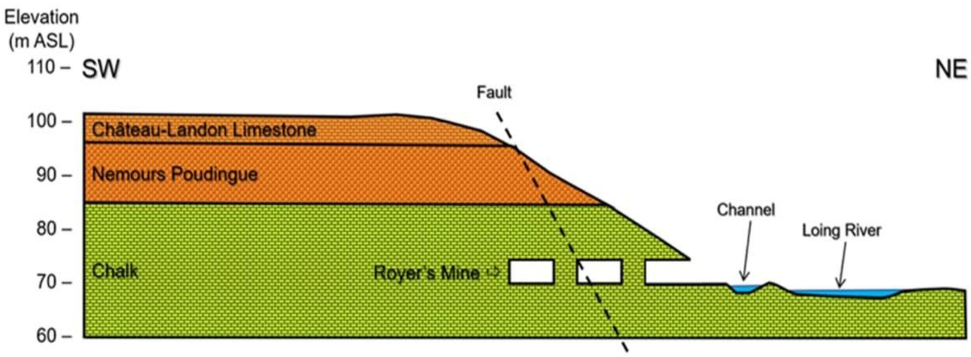

Figure 2 2D section illustrated the position of the chalk mine, the fault and the geology

Back analysis using 2D numerical modelling

Model description

To study the effect of the slope and fault, a 2D model of the mine collapsed in 1910 integrating a fault that cuts the cover and the various benches of the overburden as well as the cliff was produced (Figure 2). This model was based on observations and new data from the Royer mine, which reveal the presence of a fault-oriented North-South, with a slope of 70° relative to the horizontal. The mechanical characteristics of the chalk (Lafrance, 2016) result from laboratory characterization tests and the bibliography. Table 1 and 2 present the geomechanical characteristics of the different layers, joints, and fault (Figure 2).

Layer	Density	Young Modulus	Poisson ratio	Cohesion	Friction angle	Compression strength*	Tensile strength
Unit	kN/m^3	MPa		MPa	(°)	MPa	MPa
Unsaturated Chalk	20	500	0.22	1	30	3.5	0.2
Saturated chalk	20	100	0.23	0,35	30	0.9	0.2
Poudingue	22	2000	0.30		Elastic		
Limestone	25	4000	0.30				

Table 1 Geomechanical characteristics of the different rock layer

Joints/fault	Normal stiffness	Tangential stiffness	Cohesion	Friction angle	Tensional strength
Unit	MPa/m	MPa/m	MPa	(°)	MPa
Fault	298	205		30	
Degraded fault	298	205		10	
Horizontal joints	2500	1150	5	45	5

Table 2 Geomechanical characteristics of the joints (discontinuities) and fault

Five configurations were tested (Figure 3): • The first corresponds to a reference configuration (mine excavation without fault and slope); • The second corresponds to a configuration in the presence of a cliff but without fault; • The third corresponds to a configuration with a cliff cut by a fault at the front of the mine; • The fourth corresponds to configuration 3, but the fault cuts the mine in the middle; • The last configuration (configuration 5) is similar to configuration 3, but the fault is located at the border of the mine. The position of the fault was chosen to illustrate the role of the fault without necessarily corresponding to the exact configurations of the mine of Beaulieu (40 m) and Royer (60 m). A parametric study will be conducted to clarify the influence of the dip.

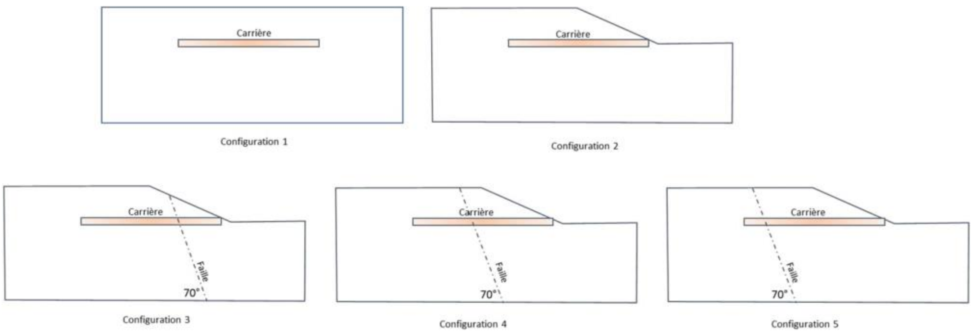

Figure 3 Different configurations for studying the effect of the slope and the fault

Results and conclusion

The stress, strain and displacement distributions are obtained thanks to the numerical modelling. The analysis herein is focused on the specific stress distribution related to two geometric and geologic aspects (slope and fault). The results highlighted the role of the reduction of the friction angle of the main fault and of the strength of the chalk layer (Figure 3).

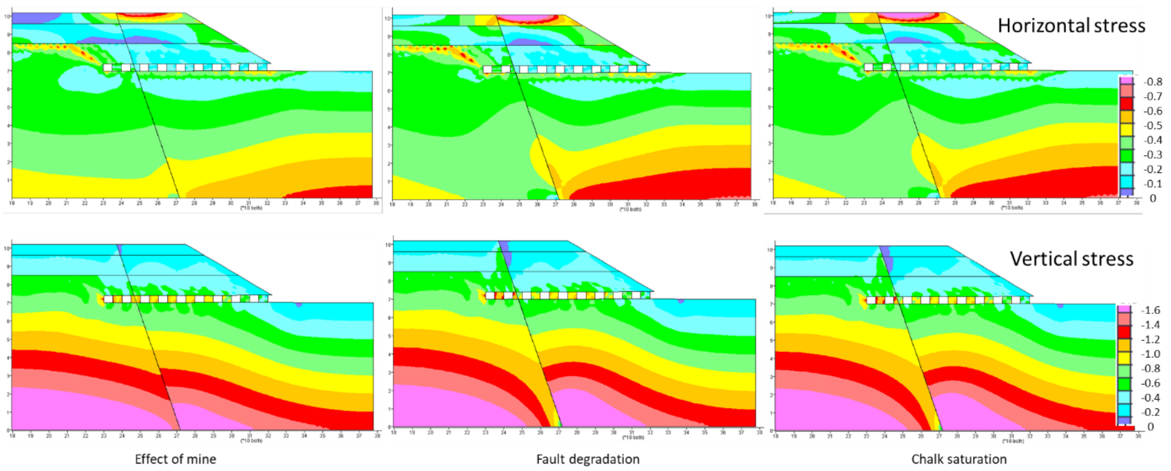

Figure 4 Numerical modelling results, stress distribution (horizontal and vertical) for the configuration (5) and for three scenarios: effect of mine excavation, plus effect of fault degradation and effect of chalk saturation

Figure 4 presents the results for the configuration 5 (effect of mine, fault degradation and chalk saturation). It is noted that horizontal tensile stresses (blue zones) developed in the steeper beds (limestone and puddingstone) are greater in the case where the chalk is saturated. The presence of the fault also changes the stress distribution: significantly lower tensile and compressive stresses are obtained the area behind the fault. The horizontal compressive stresses of the pillars are lower than in the case without cliffs or faults (red zones). On the other hand, the vertical stresses in the pillars located just behind the fault increase. In addition, the vertical stresses at the level of the fault plane are normal tensile or compressive stresses of low amplitude. The relaxation of the fault, or the decrease in the vertical stress, is maximum after the reduction of the friction angle of the fault to 10°. This configuration, which corresponds to a fault crossing the mine and located inside the massif, seems to be the most critical.

Figure 5 presents the suggested mechanism to explain the mine collapse and landslide. The water effect, due to a heavy raining and water table raising, is the main trigger factor. The increasing of the water content decreases the strength of the chalk and the fault.

However, that is not explained the role of the slope and the fault. In fact, the geological and topographic elements induce tensional stresses, the water saturation of the chalk and the presence of the fault increase the tensional stress and contribute to the landslide and the collapse of this old active mine. Based on in-situ observation and the analytical and numerical sensitive studies, one can make the following observation: the collapse is related to the presence of the slope, the fault and the stiff bed which together modify the induced stress. The combination of the geometrical (slope and fault) and the geomechanical modifications (reduction of the mechanical characterisation of the fault and the chalk layer) can explain the collapse.

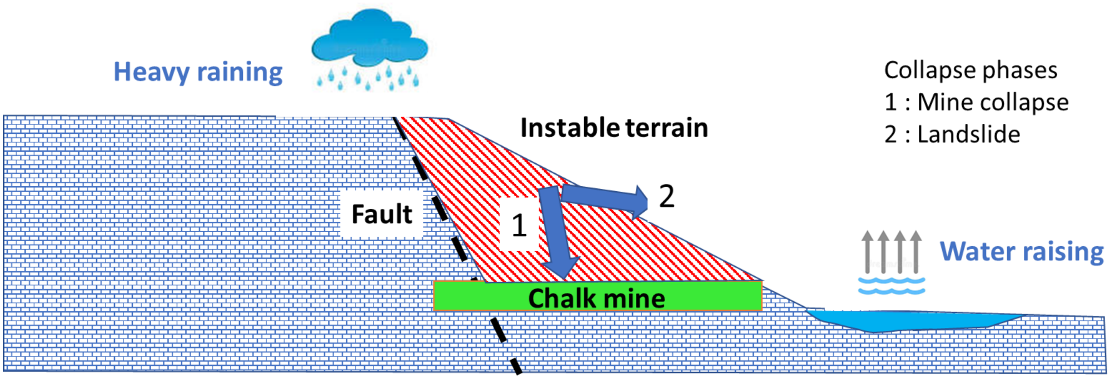

Figure 5 Suggested mechanism and phases to explain the historic collapse of the underground chalk mine

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