Instability mechanisms of chalk mines in presence of water : feedback from the collapse of the Baulieu mine (France)

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Introduction :

The weakening of chalk mechanical characteristics under the influence of ageing and flooding/unflooding cycles may be at the origin of dramatic collapses. For illustration, in January 1910, the collapse of the underground chalk mine known as "Beaulieu" (Chateau-Landon, France) caused a large landslide, leading to the death of seven people and destroying several houses. The sudden nature of the event and its concomitance with the flooding of the mine by the nearby “Loing” river have raised the hypothesis that the collapse was caused by the degradation of the mechanical properties of the chalk induced by the increase of saturation degree.

To investigate this hypothesis and more generally, to better understand the mechanisms at the origin of instabilities in chalk mines, a large program including a laboratory characterization, in situ instrumentation and numerical modelling, was set up in 2011. Three underground chalk mines of the Paris Basin (France), including Chateau-Landon, were selected to study the geomechanical behavior of chalks subjected to changes in water saturation degree. Various series of laboratory tests have been undertaken, which allowed to advance in the understanding of the physical and mechanical water-chalk interactions. However, the extent of the phenomenon observed in Chateau-Landon could not be explained only by the reduction of the mechanical properties of chalk in the presence of water. In this context, it was decided to study the behavior of a neighboring and still accessible mine known as "Royer", located less than 500 m from the Beaulieu mine. This mine appeared as the ideal site to get further insights into the mechanisms responsible for this collapse. Indeed, this mine has extracted a similar material, and showed signs of instability in 2016 following exceptional climatic events for this region (177 mm of precipitation for the month of May and important flood of the Loing).

Modelling approach

A first phase of study confirmed similarities between the mines Royer and Beaulieu and the interest to proceed to numerical modelling and instrumentation of the mine Royer in order to better understand the behavior of the works and the mechanisms that led to the sudden collapse in the mine Baulieu.

Given the particularly complex geometric configuration of the site (surface topography with hillsides and valleys, heterogeneous galleries), geometric modeling would not have been possible without prior digitization of mine galleries by 3D laser scanner. Then, the numerical model was built with a 3D numerical code integrating a fault and the geological layers with their geomechanical properties from the laboratory characterization.

The numerical model thus created has 3,500,000 zones spread over 476 m x 387 m horizontally and on a height varying between 57 m and 83 m. The overburden height varies between 1 m and 27 m. The mesh is more precise around the mine (mesh width = 0.2 m compared to 3 m at the model

boundaries) which extends horizontally about 110 m in both directions. A phasing with 15 excavations was made to represent the history of the exploitation. The aspects taken into account by the model are mechanical (excavations + fault) and indirectly hydraulic (rise of groundwater simulated by a reduction of the properties of the chalk and the fault).
Different scenarios were carried out: current state (reference case), flooding with rising water in 11 steps, probable scenario (rise of groundwater without flooding). The aim was to focus on the mechanisms potentially responsible for a collapse after an extremely rainy period: increased lubrication of the fault and rise of the groundwater which rapidly modifies the geomechanical properties of the chalk pillars.

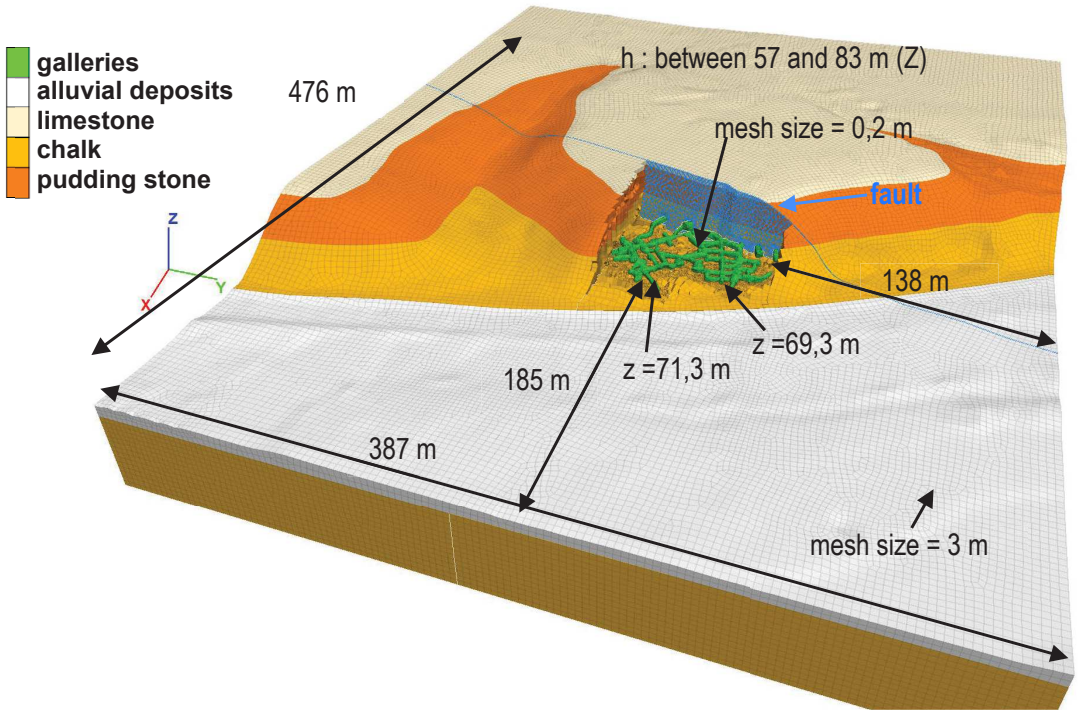

Fig. 1. Mesh of the Royer mine (Chateau-Landon, France)

Results and discussion

Various scenarios have been proposed to understand the primary mechanisms that participated in the collapse of the mine Beaulieu. In this paper the results associated with these scenarios are presented and discussed in light of the observations made in the Beaulieu and Royer mines. Moreover, the construction of a differential state (difference between a probable scenario and the reference state) enabled to identify the zones of maximum variations of displacements, strains and stresses. That information will be used to design an adequate monitoring instrumentation.

Conclusion

This innovative multidisciplinary approach, i.e. feedback from the 1910 collapse, 3D digitization, 3D modeling, instrumentation, opens new roads for the understanding and prevention of collapse risks that may concern other chalk mines in Paris Basin and elsewhere.

References:

Lafrance N. (2016) : Étude des effets de l'eau sur les phénomènes de rupture et de déformation affectant les carrières souterraines de craie. Ph.D thesis of University of Lorraine accepted on 30 March 2016.