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KARST SINKHOLES STABILITY ASSESSMENT IN CHERIA AREA, NE ALGERIA

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ABSTRACT

This research work deals with the problem of karst sinkhole collapse occurring in the last few years in Cheria area. This newly revealed phenomenon is of a major constrain in land use planning and urbanization, it has become necessary to assess the stability of these underground features before any planning operation. Laboratory testing and field work were undertaken in order to determine both intact rock and rock mass properties. All the rock mechanics testing and measurement were undertaken according to the ISRM recommendations.

It has been found that under imposed loading, the stability of the karst cavities depends on the geo-mechanical parameters (Rock Masse Rating; RMR, Geological Strength Index; GSI, and Young Modulus; E) of the host rock as well as the depth and dimensions of the gallery. It increases with RMR, GSI, E and depth and decreases as the cavity becomes wider. Furthermore, the calculation results show that a ratio (roof thickness to gallery width) of 0.3 and more indicate, a stable conditions.

The results obtained in this work allow identifying and assessing the stability of underground karst cavities. The methodology followed in this paper can be taken as a road map in the establishment of a hazard map related to the studied phenomenon. This map will be a useful tool for the future urban extension planning in Cherea area.

Keywords*:* Karst, Rock Mass Rating (RMR), sinkhole collapse, Tebessa.

INTRODUCTION

The catastrophic collapse of residual soil covers overlaying solution cavities in karstic limestone areas constitutes a serious geological hazard around the world. It is a well known phenomenon related to the occurrence of underground solution cavities in limestone, dolomite and gypsum terrains. It is a challenge for land use planners and engineers as it affects seriously the foundations stability and performance. In urban areas, generally the sudden collapse causes damages to properties, infrastructures, and even lives. This research work deals with the problem of karst sinkhole collapse occurring in the last few years in Cheria area. The last sinkhole collapse has caused severe damage to several houses, roads, water main supply, and sewages. It has caused a widespread panic among the population mainly those living too close to the crater. This time, as the phenomenon starts to affect the security and the economy of the population. The collapse is due to a sudden rupture of the roof of a large underground karst cavity. Karst cavities are in fact widespread in the Eocene limestone forming the upper formation under the quaternary cover in the Cheria syncline.

GENERAL SETTING

Cheria basin which takes the name of the village located in its center is located to a 50 km to the SW of Tebessa city. It is a wide plateau of a triangular shape with an area of around 800Km^2. The altitudes vary from 1050 to 1500m.

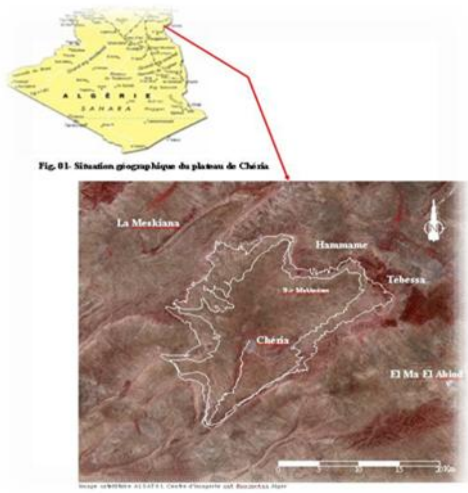

Figure 1: Location of the study area.

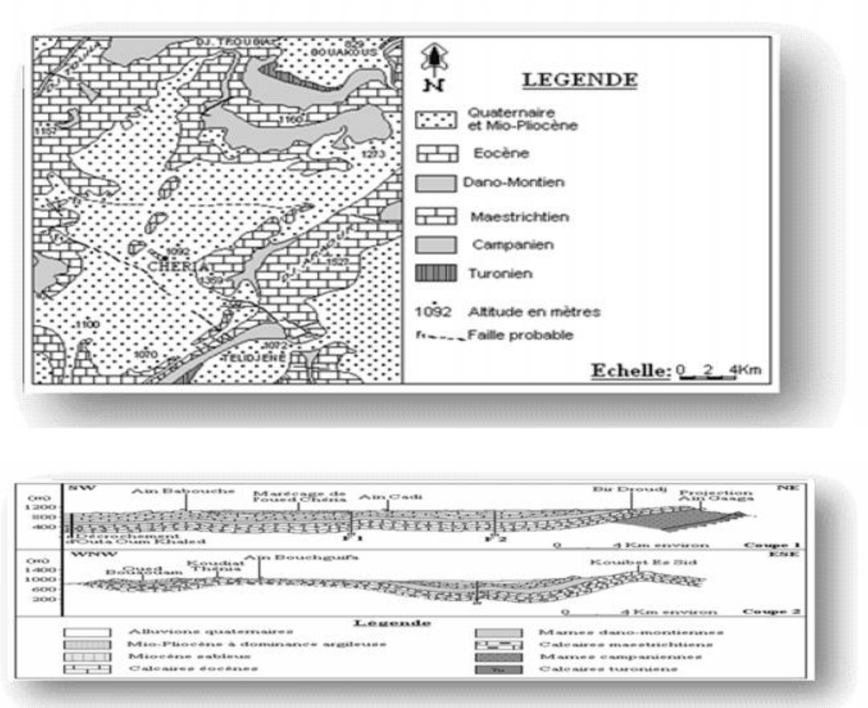

Figure 2 : Geological cross section of the studied region

From a geological point of view, the studied area is a syncline structure oriented 30° to the North. It has been studied by several authors among the first stand (Durozoy 1948; Flandrin, 1959). Cheria syncline consists of a stratigraphic succession of more than 1000 meters thick. Trias, Cretaceous and Eocene constitute the main formations. The later occupy more than 80 %, the resting 20 % are composed of the Mio-Plio quaternary filling deposits (Chaffai et al., 2003). In its central part, Eocene limestone is intensively fractured and karstified and covered by a mantle of varying thickness constituted of a mixture of gravel sand, clays and limestone crusts. Eocene limestone outcrop in the centre of the basin and form small troughs on either side. These latter are covered by the aforementioned recent detrital materials.
The basin is dissected by two major sets of fractures trending N E-S W and N W-S E cut by a sub-orthogonal third set of N-S direction. The drainage pattern in the basin is highly controlled by these sets of fractures. It appears from a first glance at the air photographs that the distribution of karst cavities is also controlled by the fractures; more precisely they occur at the intersection of the fractures.
From a hydrogeological point of view, Eocene limestone formation constitutes the most extensive aquifer in Cheria basin. The perennial water availability in the study area is related to the great potential of Eocene limestone aquifer. The marly–limestone bedrock forms the lower boundary of the groundwater

reservoir (Fig. 2). The thickness of the Eocene limestone aquifer increases towards the central part of the basin (Chaffai et al. 2003). The alluvial aquifer is not appreciably used for drinking water, as it used to be, because of its relatively poor quality acquired recently by agriculture, domestic and industrial pollutants. Compared to the Eocene aquifer, this later remains of limited extent and thus limited reserves. The general flow direction for both Eocene and Quaternary aquifers is from the north to the south guided most of the time by the fractures and the morphology (Fig. 3)

Karst processes are one of the most important post sedimentary factors that contribute to landscape evolution in the studied area. Unfortunately most of the Eocene limestone of Cherea area is covered by quaternary deposits, which do not allow karst features (sinkholes, pineacles, cavities…etc) to be apparent. Nevertheless, at Youkous valley, which is not far from the study site and located at the northern periphery of the basin, karst features such as cheminies, pinnacles and cavities are well exposed.

Figure 3: boundary condition map for the study area.

CHARACTERISTICS OF THE CHERIA SINKHOLES

Sinkhole collapse is a well-known phenomenon in Cherea area, N E Algeria (Fig. 4). It has been reported that during the last century small diameter sinkholes appear from time to time in Cheria area without making any harm to people or infrastructures. They were not considered as a challenge to security or safety and so they were not of some concern to population or of local

authorities.
The water level was then vey close to the surface, mainly in the southern part of the basin. The wells drilled for underground water extraction show that voids were encountered at a depth between 1 to 50 m. The voids vary in height, between 1 m to several meters throughout the area. In recent years, two large events of cover collapse sinkholes were recorded (Fig. 4).

Figure 4: boundary condition map for the study area.

STABILITY ANALYSIS OF KARST CAVITIES

Several authors have studied the condition of stability of underground cavities in natural and man made cavities. Abdelllah and Goodings (1996, 2002) have used geotechnical centrifuge to replicate full-scale sinkhole development over underground cavities in weakly cemented sandstone. He showed that when the ratio of roof thickness (T) to cavity width (W) is less than 0.25, failure occurs. While When T/W was greater than or equal to 0.31 a stable arch is formed and the roof is stable. Swift and al. (2004) used plaster scale models and Finite Element models (FEM), in order to simulate failure mechanisms and ultimate failure loads. Insitu testing was carried out using full-scale test, where a cavity roof in triasic sandstone was loaded to failure in Nottingham (Waltham et al. 2004). This experiment was then used to validate the numerical results obtained considering material of the same properties as Nottingham sandstone using Flac 2D (L. Zhengxin). Several other authors such as Davis et al. (1980), Tharp (1994) and   have used with success the limit analysis technique to study the stability of underground openings in an undrained state.
The effect of underground water fluctuation is also of a paramount importance, Sowers (1975) described the occurrence of two large sinkholes after three days of pumping. In Florida, Benson and Lafontaine (1984), Currin and Barfur (1989) reported that sinkhole frequency increases during spring dry season. The

reason is more probably the lowering of the water table. It is in part due to the loss of the buoyant support as a result of water table lowering. They also occur as a result of rainfalls that come after prolonged period of draught. The reason this time is the downward, force induced by the percolating water.
In this study, the stability assessment is carried out using Falc 2D software and considering karst cavities with varying dimensions. The reason is that in Cheria area, underground cavities exist in varying dimensions, from one meter to more than 50 m across. They also occur at a depth of less than a meter to several tens of meters with varying rock mass properties. Hence, cavity width and roof thickness are varied in order to model all the possible scenarios. For rock properties, Young Modulus (E), Poisson Ratio (μ), Uniaxial Compressive Strength (UCS), Uniaxial Tensile Strength (UTS), Rock Density, and Shear Strength, expressed as Cohesion (c) and Friction Angle (φ) were determined. The rock mass rating, RMR (Beniawski, 1973) was also determined as we are dealing with rock mass. The RMR is used to account for rock mass properties rather than intact rock properties. The available data were based upon laboratory and full-scale tests. Table 1 shows the initial mechanical properties assumed for modeling.

Table 1: Measured mechanical properties of the Eocene limestone

C MPa	Φ°	E MPa	μ	**UCS MPa**	**UTS MPa**
0.2	35.5	5620	0.25	105- 91.2	3.5-7.5

RESULTS AND DISCUSSION

In this study the above intact rock, strength parameters are kept fixe throughout the modeling procedure. The RMR is however, varied according to the local rock discontinuity conditions.
In the FLAC 2D software, the geometry model is set first with the appropriate boundary conditions. Then material properties and material model are specified. The failure criteria used is the Mohr-Coulomb fitted to the studied rock mass by way of it's RMR to obtain a rock mass failure envelope (Beniawski, 1976).
The geometry model consists of a rectangular cavity located at a depth (D) with a roof thickness (T). The roof thickness, the cavity width, the imposed load and the rock mass rating (RMR) are varied in order to assess the influence of every parameter on the overall stability of the cavity.
The modeling results show that for a given RMR and a cavity width the resistance to failure increases as the roof thickness increases (Fig. 5). When the roof thickness, the imposed load and the cavity width are kept fixe the resistance to failure increases as the RMR increases. For instance, a 6 m wide cavity with a roof thickness of 2 m, the resistance to failure increases from 4

MPa when RMR equals 20, to 10 MPa when RMR becomes 40 (Fig.5).
The results also show that when the imposed load, 1 MPa, and the RMR are kept fix (Fig. 6), the relationship between cavity width and roof thickness, at failure, is of a linear form. For an RMR of 40, the ratio of roof thickness to cavity width is about 0.30. This ration is of almost 0.40 for an RMR of 30 and around 0.75 for RMR = 20 (Fig. 7). It can be easily seen that in the case of Cheria Eocene limestone where RMR is 40, an underground cavity can be considered stable if the ratio of the roof thickness to the cavity width is above 0.30 under an imposed load of 1 MPa (10 tones over an area of 1 m^2).

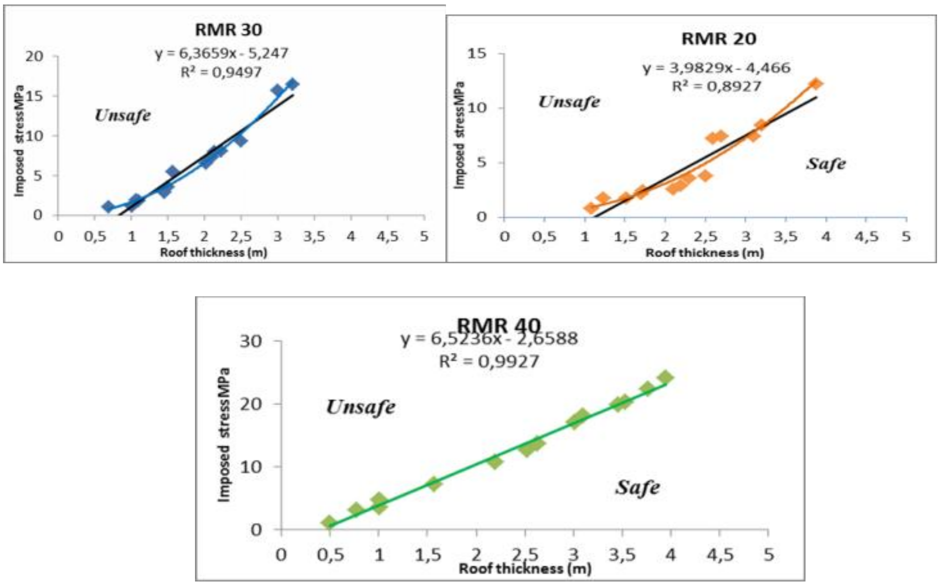

Figure 5: Graphs showing the relationship between imposed loading and the critical roof thickness for different values of RMR.

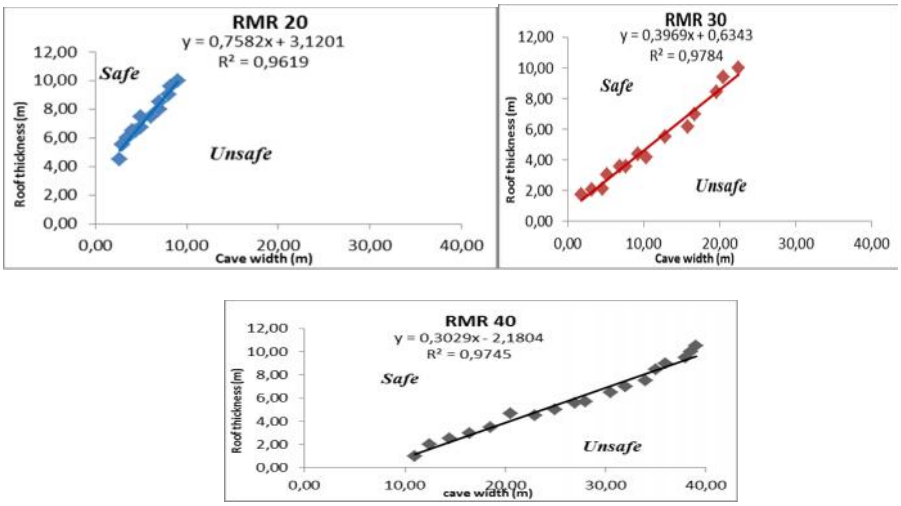

Figure 6 : Graphs showing the relationship between roof thickness and width of the cavity for different values of RMR.

For a cavity with varying width and an RMR of 20 the roof displays more resistance to failure as it thickens. Fig. 8 shows that as the cavity width increases roof thickness at the onset of failure, also increases in a linear fashion. The same relationship is applicable for all the RMR values covered by this study. It has been reported that ground water fluctuation causes sinkhole to form in karst environment. The principal mechanism of water effect lies in the lake of buoyancy as water table drops. The pressure caused by moving water, towards the cavity as a result of drawdown or rainfall also contributes significantly to failure. The effect of ground water fluctuation is modeled in this study; the results show that when the piezometric head decreases rapidly from a level above the cavity roof to another below it, failure occurs (Fig. 7).

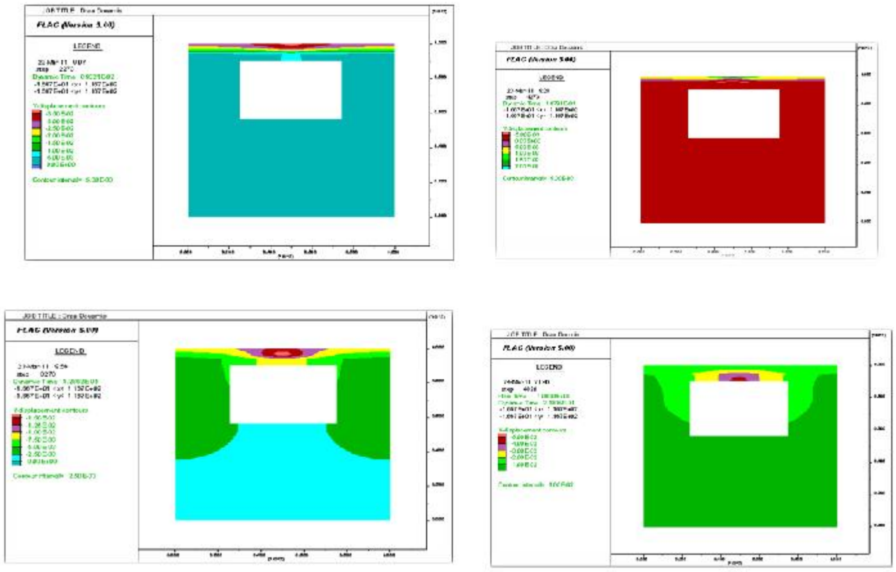

Figure 7: Figures showing the influence of ground water fluctuation on the stability of an underground cavity.

CONCLUSION

The results presented in this paper illustrate that under an imposed loading, the stability of the karst cavities depends on the geo-mechanical parameters (RMR, GSI, and E) of the host rock as well as the depth and dimensions of the gallery. It increases with RMR, GSI, E and depth and decreases as the cavity becomes wider. The calculation results shows that a ratio (roof thickness to gallery width) of 0.2 and more indicate a stable conditions.
The results obtained in this work constitute a road map in identifying and assessing the stability of underground karst cavities. This study allows, thus, the establishment of a hazard map related to the studied phenomenon. This map will be a useful tool for the future urban extension in Cheria area.

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