SIMULATION OF THE CRACKING OF MARBLE SAMPLES RESULTING FROM THE CORING PROCESS USING IRAZU SOFTWARE

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Abstract: In the field of mechanical engineering, FEA (Finite Element Analysis) is widely used to solve structural, vibration and thermal problems, and its versatility and numerical efficiency have imposed the finite element analysis method on the engineering analysis software market over time, while other methods have become niche applications. The finite element method is mainly used in the activity of simulating and modeling some phenomena in geo-mechanical engineering. In this sense, the simulation of the crushing phenomenon of rocks used in construction, such as marble, is of particular importance. Finding suitable methods for simulating this phenomenon can shorten the design period of rock coring tools, and regarding the actual crushing phenomenon, by validating the results obtained in the simulation process, preliminary conclusions can be drawn, so that laboratory tests are only needed in the final phase of a research. Starting from the characteristics of a core drill, a model of a marble specimen was created in the SOLIDWORKS application, a model that I later subjected to the compression request simulation using the Irazu application. The obtained results will be compared to the actual results gathered in laboratory tests.

Key words: Simulation, model, finite element, compression, velocity

1. CORING HEAD MODEL, SPECIMEN MODEL

In order to simulate the compression of a Ruşchiţa marble specimen, we considered the coring head model from figure 1. It is equipped with diamonds and has the constructive elevations from figure 2.

As can be seen in figure 3, the marble specimen has a diameter of 57 mm (imposed by the geometry of the coring head) and a height of 120 mm. In this figure I also presented the two plates (upper and lower) between which the marble specimen is subjected to a compressive effort. Under the conditions of the Rock Mechanics

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Laboratory of the University of Petroşani, the press with which the test was carried out has a fixed upper plate and a mobile lower plate.
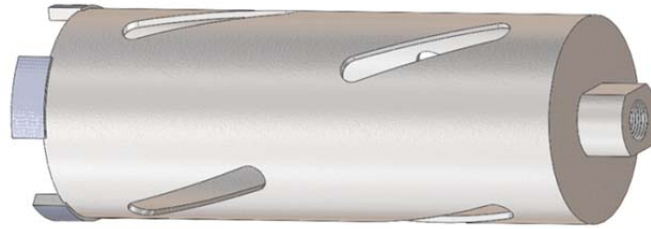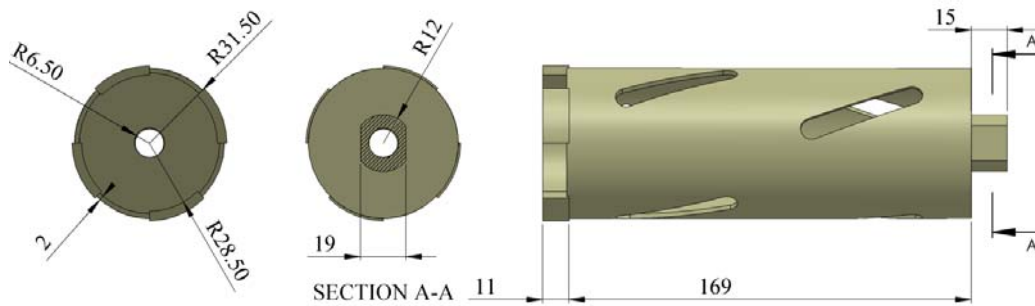

Fig.1 Diamond coring head
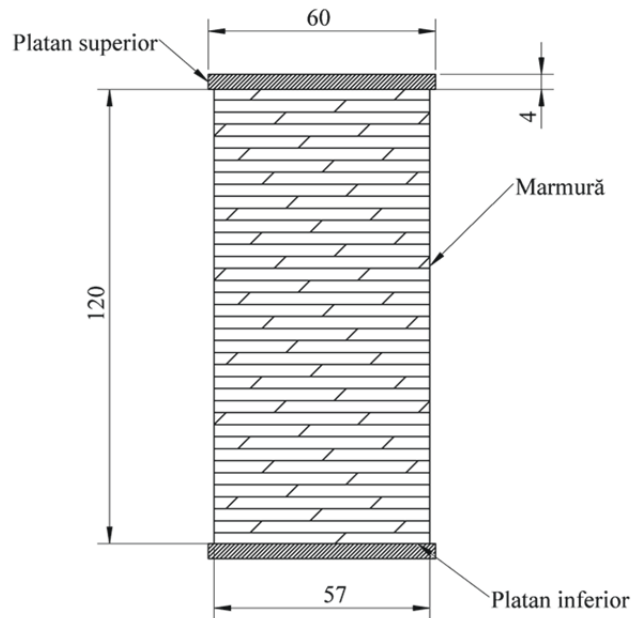

Fig.2 The dimensions of the coring head

Fig.3 The dimensions of the marble specimen

Figure 4 shows the actual way in which the compression plates and the marble specimen were made in two sketches.
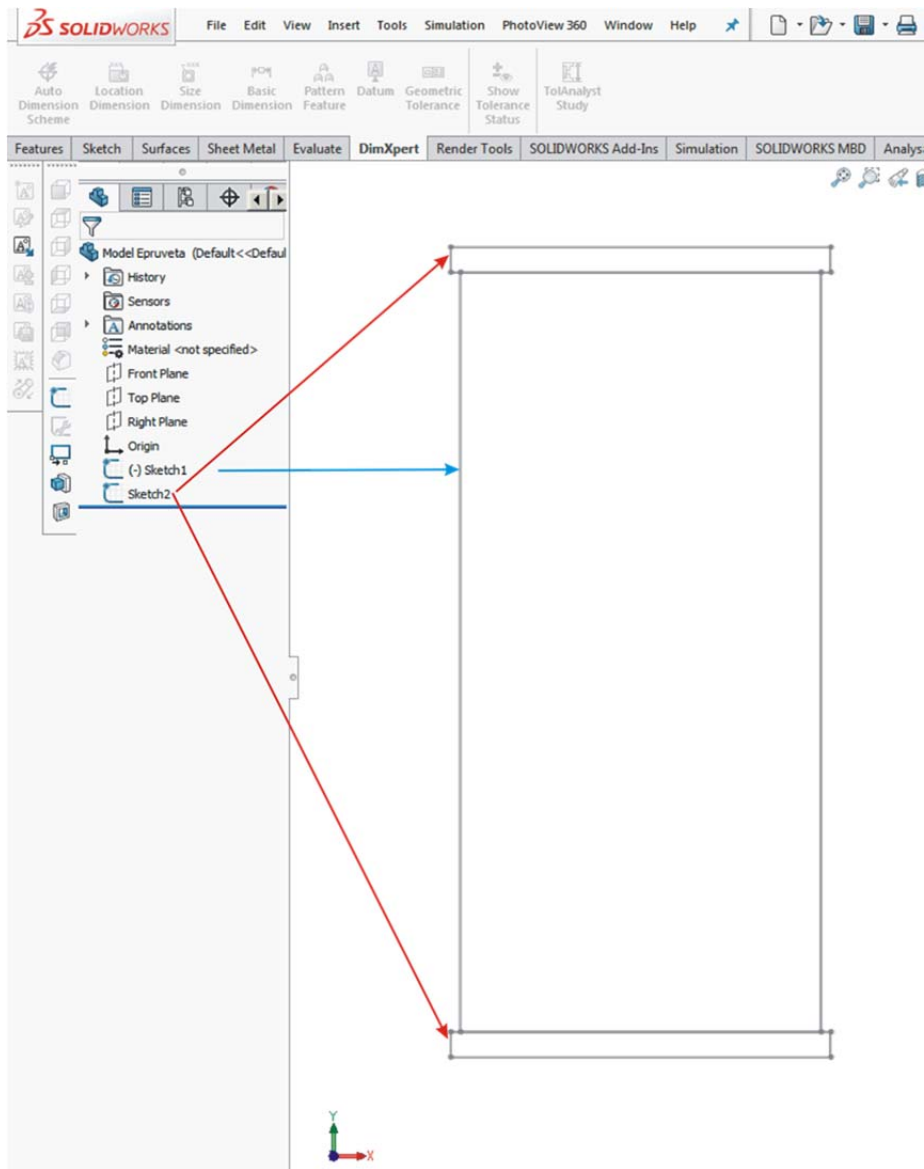

Fig.4 Creation of sketches for plates and the specimen

Since the GEOMECHANICA Irazu 2D Suite application with which the compression simulation was performed allows the import of a 2D geometry that has the .DXF format, created in other applications, it is necessary to save the part made in SOLIDWORKS in the supported format as can be seen in figure 5.
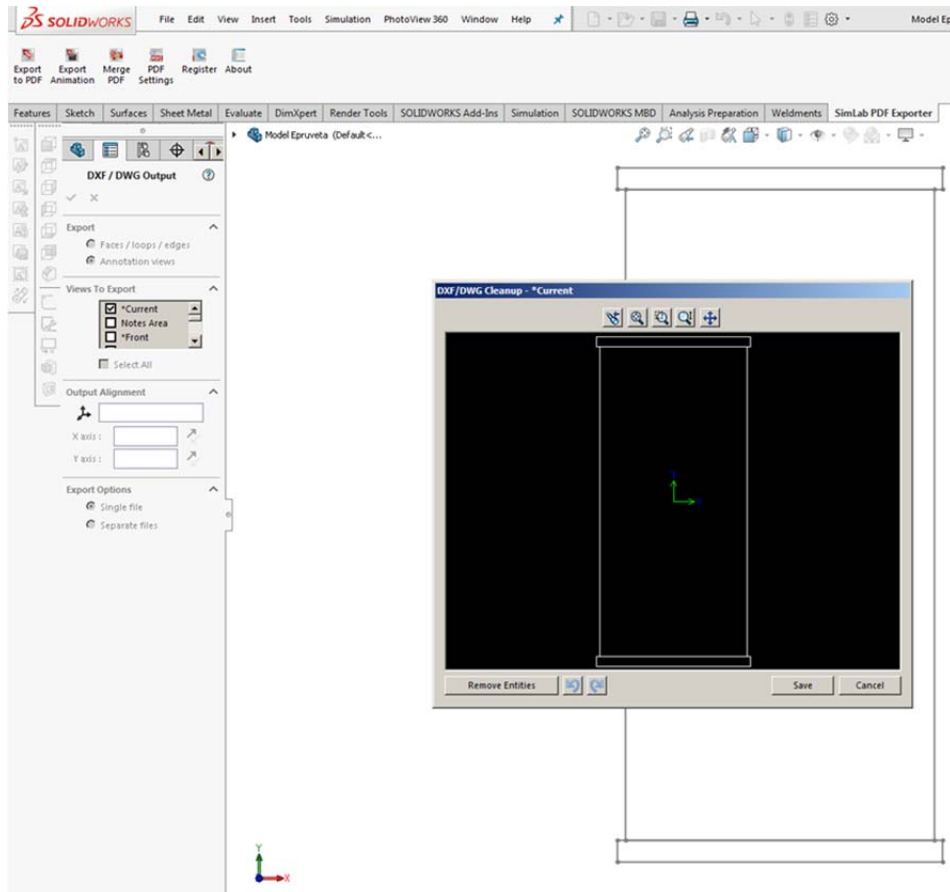
Fig.5 Generating the DXF format of the sample created in SOLIDWORKS

2.   COMPRESSION SIMULATION OF THE MARBLE SPECIMEN

2.1 Presentation of the Irazu program package

The Irazu software package is a versatile 2D or 3D geomechanics simulation based on the finite discrete element method (FDEM). A distinctive feature of Irazu software is the ability to explicitly model fracturing and fragmentation processes in brittle materials with complex, non-linear behavior. These processes can be highlighted and calculated only by simulation using numerical methods. Characteristic of this application is the highlighting of the evolution over time through stages of the process of fragmentation and fracturing of the material.

The software allows the analysis through simulation and modeling of the compressive stress of a cylindrical specimen, the tensile stress of a cylindrical specimen (Brazilian test), the stress of slopes due to pre-fracturing, the stress of hydraulic fracturing, the simulation of rock cutting with cutting knives.

2.2 Creating a new Irazu simulation study

The Irazu application allows the import of a DXF type geometry as can be seen in figure 5.1. In our case, it is the virtual sample made in SOLIDWORKS (figure 6). Once the CAD geometry is selected, the auto-identification and creation of surfaces option is chosen (figure 7).
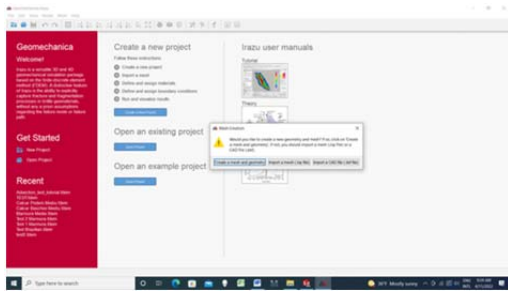

Fig.6 Importing a CAD DXF geometry into Irazu
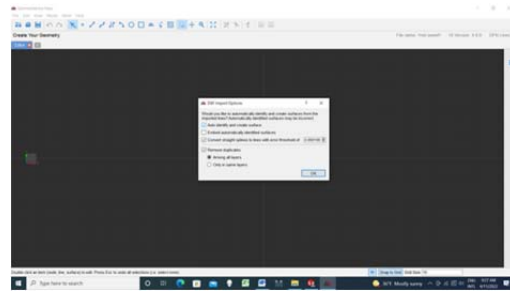

Fig.7 Auto identification and creation of model surfaces

Figures 8, 9, and 10 show the surfaces corresponding to the geometric components of the project (upper plate, lower plate and marble), as well as the characteristic dimensions of the finished elements to be created. For plates we opted for a size of the finite element equal to 2, and for marble equal to 1.
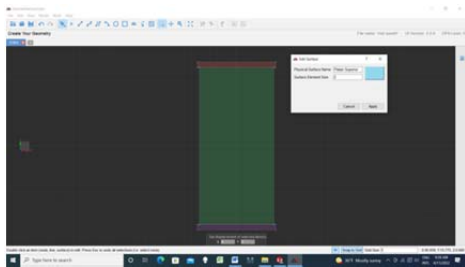

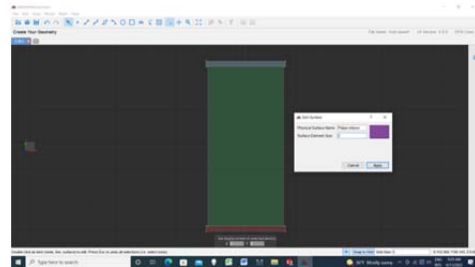**Fig.8** Defining the surface of the upper plate and the size of the finite elements

Fig.9 Defining the surface of the lower plate and the size of the finite elements
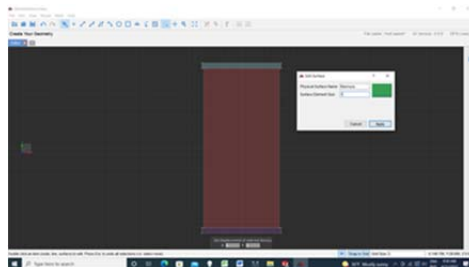

Fig.10 Defining the surface of the marble and the size of the finite elements

It should be remembered that the Irazu application does not have a module to generate them, but it allows the use of specialized applications in this sense. In this case, the free gmsh.exe software was used. The mesh of finite elements generated with the help of this program is presented in figure 11.
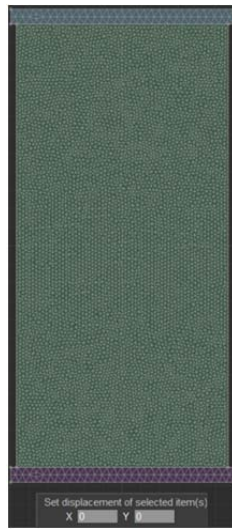

Fig.11 The network of finite elements

In the next stage of the marble breaking simulation, the settings are selected. The measurement units (in this case mm and ms) as well as the type of stress (mechanical) were chosen, as shown in figure 12.
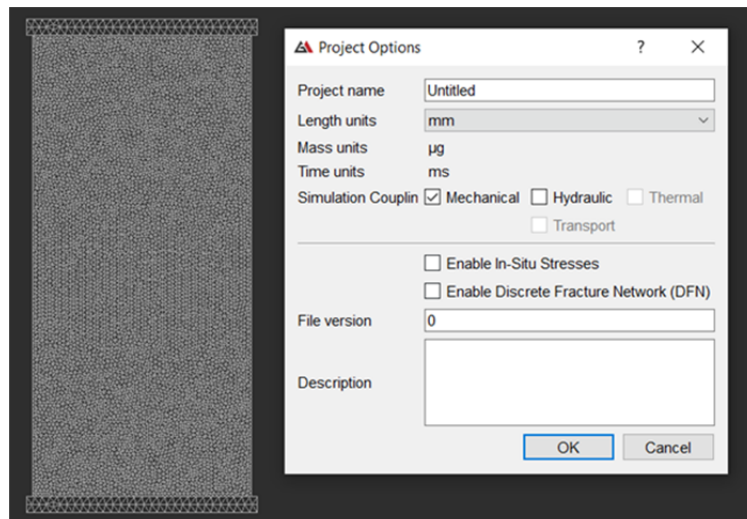

Fig.12 Choosing the simulation settings

For the calculation parameters, a number of 600,000 iterations were chosen with a time step for each iteration of 5×10^{-6} ms. Under these conditions, the request will take 5×10^{-6} ms x 600,000 iterations = 3 ms.

2.3 Running the simulation, results

Figure 13 shows the evolution cursor of the performed calculations. We specify that a simulation like the one performed has a solution time that exceeds 30 minutes.
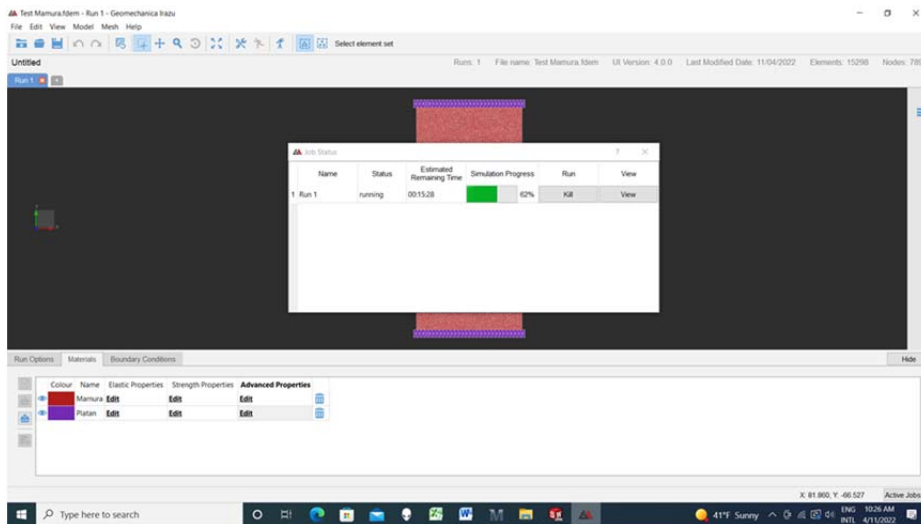

Fig.13 The evolution of the calculation cursor

The graphic image of the end of the simulation (corresponding to a displacement of the lower plate of 0.3 mm) in which the displacements and fracturing of the sample were highlighted is presented in figure 14.
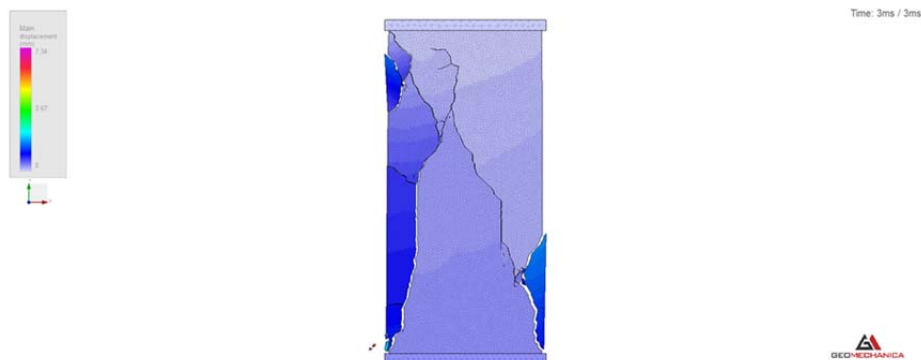

Fig.14 Graphical image of the end of the simulation (3 ms or 0.3mm)

Since the Irazu application allows saving the graphic results in sequences of images, we used this facility to determine the moment when the cracking of the specimen begins. As can be seen in figure 15, the crack appears after 2.7 ms, which corresponds to a compression of the marble of 0.27 mm.

Fig.15 The moment of the appearance of the crack

To be able to draw diagrams related to the simulation parameters with the help of this software, a point on the surface of the specimen must be selected. In figure 16 I have depicted a point in the area of the primary crack of the marble.
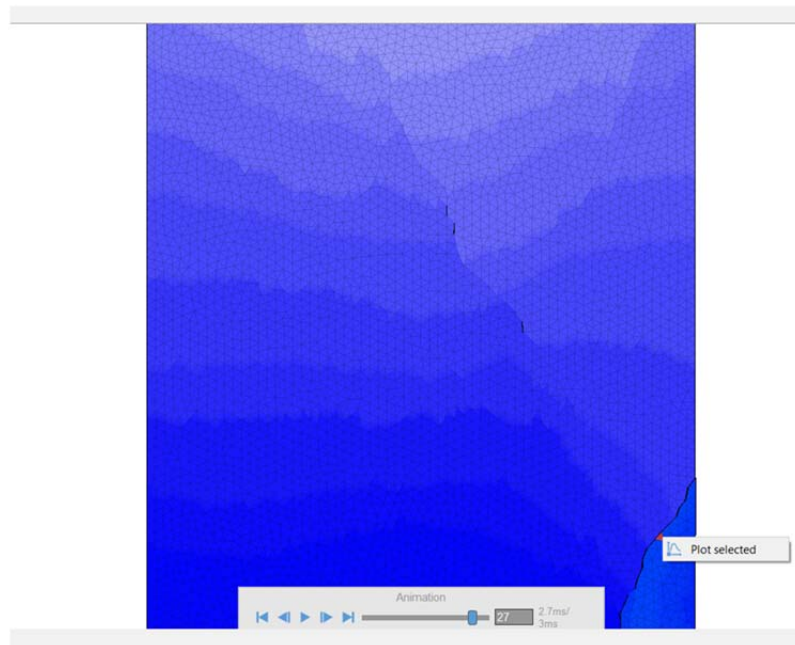

Fig.16 Choosing the point in the primary crack area

For this point we drew the stress variation diagrams for the xx and xy directions. We can see that both have maximum values in the mode at time 2.7 ms. The maximum value is 1×10^7 Pa for the xy direction (figure 17).
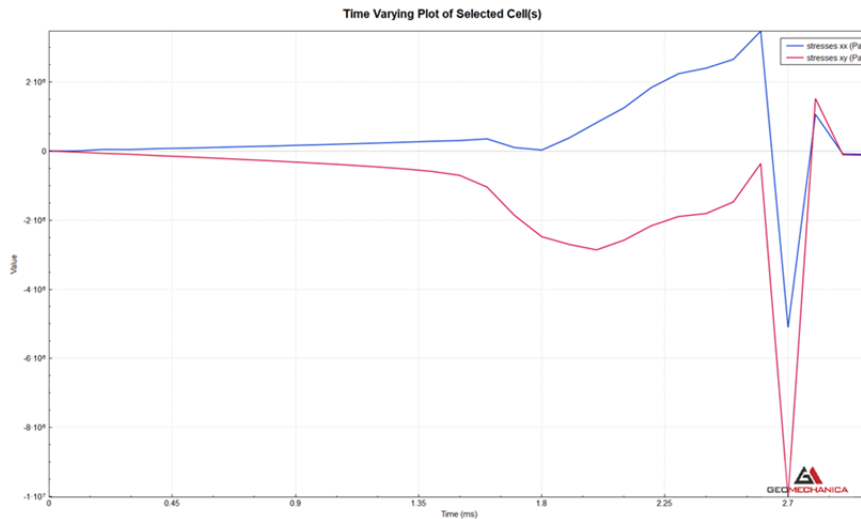
Fig.17 Stress variation in the xx and xy directions

Figure 18 shows the stress magnitude variation. It is observed that for the time interval (0-1.8) ms it increases linearly up to the value of 5×10^7 Pa. In the time interval (1.8- 2.7) ms the shape of the curve is convex parabolic, having a limited increase, the maximum is 5.4×10^7 approximately 2.1 ms from the start of the simulation. At the moment of the appearance of the crack at 2.7 ms, the stress has a sharp drop that tends to 0 in 0.3 ms.
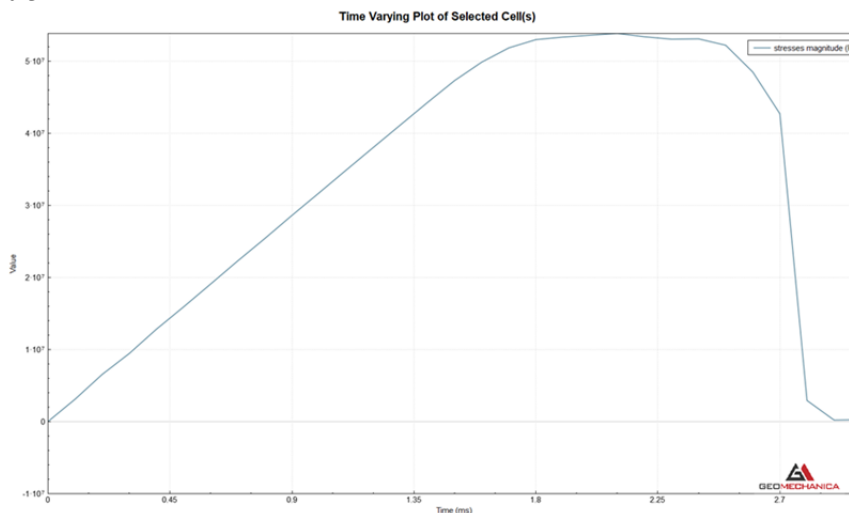
Fig.18 Variation of stress magnitude

Figure 19 shows the model of the corer used for coring of the marble specimens. Figure 20a shows the result of coring, and figure 20b shows a cracked marble sample in the Rock Mechanics Laboratory of the University of Petroşani.

Fig. 19 Core drill model

a   b

Fig.20 Obtaining the sample by coring – cracked specimen

Conclusions

The Irazu software package is a versatile 2D or 3D geomechanics simulation based on the finite discrete element method (FDEM). A distinctive feature of Irazu software is the ability to explicitly model fracturing and fragmentation processes in brittle materials with complex, non-linear behavior.

These processes can be highlighted and calculated only through simulation, with the help of numerical methods. Characteristic of this application is the highlighting of the evolution over time through stages of the process of fragmentation and fracturing of the material.

The software allows the analysis by simulation and modeling of the compressive stress of a cylindrical specimen, the tensile stress of a cylindrical specimen (Brazilian test), the stress of slopes due to pre-fracturing, the stress of hydraulic fracturing and the simulation of rock cutting with chipping knives.

In accordance with calculation parameters, on the time interval of 3 ms in which the simulation takes place, with a movement speed of the lower plate which is 0.1 m/s, the maximum displacement of the lower plate was calculated, which has a value of 0 .3 mm.

Since Irazu allows saving the graphical results in image sequences, this setting was used to determine the moment when the cracking of the specimen starts. The phenomenon occurs after 2.7 ms which corresponds to a compression of the marble of 0.27 mm.

For a point located in the vicinity of the crack at the time of its production, we drew the stress variation diagrams for the xx and xy directions. Both diagrams have maximum values in the mode, at time 2.7 ms, the maximum value is 1×10^7 Pa for the xy direction.

The stress magnitude variation was also plotted. For the time interval (0 -1.8) ms it increases linearly up to the value of 5×10^7 Pa. In the time interval (1.8-2.7) ms, the shape of the curve is convex parabolic, with a limited increase, the maximum being 5.4×10^7 at approximately 2.1 ms from the start of the simulation. At the moment of the appearance of the crack at 2.7 ms, the stress has a sharp drop that tends to 0 in 0.3 ms.

The comparison of the results obtained by simulation with the help of Irazu are consistent both numerically and in terms of shape, with the results obtained in laboratory tests carried out on marble specimens whose geomechanical characteristics were input data of the simulation.

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