MORPHOLOGY AND HYDROMECHANICAL BEHAVIOUR OF A SINGLE NATURAL FRACTURE IN A GRANITE UNDER NORMAL STRESS
- EXPERIMENT AND THEORY -

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ABSTRACT

The aim of this thesis is to analyse the relationship between the morphology of the fracture surface and its hydromechanical behaviour under normal stress. All the studies presented hereafter (morphologic and hydromechanical analysis) are performed on a set of seven cylindrical fractured samples (12 cm in diameter) cored in a single fracture ; the core axis being orthogonal to the fracture surface. The rock is a medium grained granite with a porphyroïd trend and shows a slight planar anisotropy.

After a brief description of the petrographic, physical and mechanical properties of the granitic material, three main subjects are discussed :

- quantitative morphologic analysis of the fracture ;
- mechanical behaviour under normal stress ;
- flow variation in the fracture with normal stress.

structures is confirmed by the bimodal aspect of the height histogram, and that the average range of the smallest structure corresponds to the average radius of curvature. To complete the geostatistical analysis, we have shown that it is possible to draw a map of the fracture surface using kriging (figure 2).

The surface and volume of the entire fracture are studied using 1) pseudosections reconstituted from the profiles recorded on each side of the fracture and 2) plastic prints of the fracture at different stress levels.

The height of the voids are deduced from the pseudosections. The experimental variograms (figure 3) of the height of voids show a range of 6 mm. It appears that the arrangement of the voids is strongly linked to the smallest structure.

The application of stereological methods to the pseudosections to estimate the percentage of contact area under zero stress leads to a value of 10 to 15 %. The prints study, using image analysis, shows that the contact area increases very quickly when the stress increases at low levels, and then stabilizes at a value of 50 to 70 % of the total fracture area for a stress level of 15 MPa (figure 4).

2 - MECHANICAL BEHAVIOUR

During laboratory testing, the major difficulty we encountered was the adjusting of the relative position of the two sides of the fracture. Although the two sides of the fracture fit well together, the fracture is always slightly mismatched. An evaluation of this mismatching is possible by using the following testing procedure (figure 5) :

A preloading is applied to the fractured sample. Then it is submitted to several sets of increasing loading and unloading cycles. A residual closing is obtained at the end of each cycle when the sample is only submitted to the preloading. This residual closing decreases with the number of cycles and is inversely proportional to the maximum value of the charge applied during the cycle. Then the sample is totaly unloaded. This last operation enables us to measure the final irreversible residual closing due to the whole experiment. The repetition of such a set of cycles (named "experiment") shows a decreasing of the final irreversible residual closing until it almost disappears (0 to 5 µm) after the third experiment. After this third experiment, we observe a complete reversibility of the fracture closing for stress levels up to 80 MPa.

It seems that, for the fracture we studied, it is possible to adjust the two sides and to avoid in this way during the tests, the bias due to the manipulation of the sample.

The relative displacement between two points one in each side of the fracture is plotted against the normal stress level. Such a measurement integrates the properties of the fracture itself and of the rock. The results confirm what we found in the literature. We obtain a non linear relationship at stress levels of less than 15 MPa (figure 5). At higher stress levels, the curve is linear with a slope almost equal to the one expected from the Young modulus of the intact rock. One can conclude that the closure of the fracture dominates for low stress levels, whereas the elasticity of the rockdetermines the global behaviour for high stress levels. Beyond 15 MPa, the fracture does not close any more. Its maximum closure is in the order to 30 to 40 % of the average aperture under zero stress.

The mechanical and morphologic data have led to two possible theoretical models of mechanical behaviour. In the first model the basic equations of which were developped by Hertz (1880), we assume that the asperities are spherical with variable height and that the behaviour of the asperities is elastic. This model cannot be fitted to the experimental results. So we have build another model in which the fracture is represented by two rigid planes, one of which carrying teeth of variable height. The difference between two contiguous teeth being small, we consider that any loaded tooth will always be surrounded by unloaded teeth. These surrounding teeth will cause a confining pressure on most of the height of the loaded tooth. The behaviour is assumed to be elastoplastic. This model is based on the aperture distribution obtained from morphologic data. It is this model that gives the best fit to the experimental data (figure 6).

3 - HYDROMECHANICAL BEHAVIOUR

The tests are performed with a divergent radial flow. The testing procedure is based on the results of the mechanical tests with repeated cycles (figure 7). The intrinsic transmissivity decreases quickly when the stress level increases until a level of 10 MPa, and then becomes stable. After the third experiment, the variations are reversible, which agrees with the mechanical results.

The injection of dyed water during hydromechanical tests has made it possible to localise the flow outlets around the sample. It appears that the dyed water exits at a precise number of locations ; each outlet has a size in the range of a millimeter. It seems that the flow does not happen in all the fracture surface, but is concentrated in channels. The systematic counting of these outlets at different stress levels (figure 8) shows that their number decreases fastly when the stress level increases up to 10 MPa, and then levels out. The average distance between these points is 6.5 mm at zero stress and 18 mm at a stress of 15 MPa. These two values are the physical expression of the structures found during the geostatistical study. The attempts to fit the experimental curves with empirical relationships found in the literature show that the flow cannot be modelled with any one on the entire stress interval. These empirical relationships are suitable only at low stress levels. The assumption of a quasi generalized flow in the fracture plane is sustained at this stress level by the high number of outlets. However this assumption is not acceptable at higher level.

Louis (1967) introduced in the cubic law a roughness coefficent C defined from the geometry. We attempt to fit the cubic law to the experimental results by varying the parameter C. The values of C we obtain are not compatible with its geometrical definition.

Finally the coupling of the "confined teeth model" and the cubic law enables us to reproduce qualitatively the experimental behaviour for only one half of the samples. The shape of the curves can be fitted, but in any case, the calculated values of the transmissivity are 10 to 100 times greater than the experimental values.

CONCLUSION

We have shown that it exists a relationship between the morphology of the fracture surface and its hydromechanical behaviour under normal stress. It appears that the most promising methods to quantify the morphology are the geostatistical method (variograms and kriging) and the possibility to reconstitute the angular distribution in 3D to approach the mechanical behaviour in shear. Although the technique of the plastic prints is still rudimentary, it shows that it is a possible way to better known the flow in the fracture plane.

Further, although the "confined teeth model" enables us to fit the mechanical behaviour of the fracture, the establishement of a hydromechanical model requires to have a law of flow which reflects well the reality of the flow in channels.

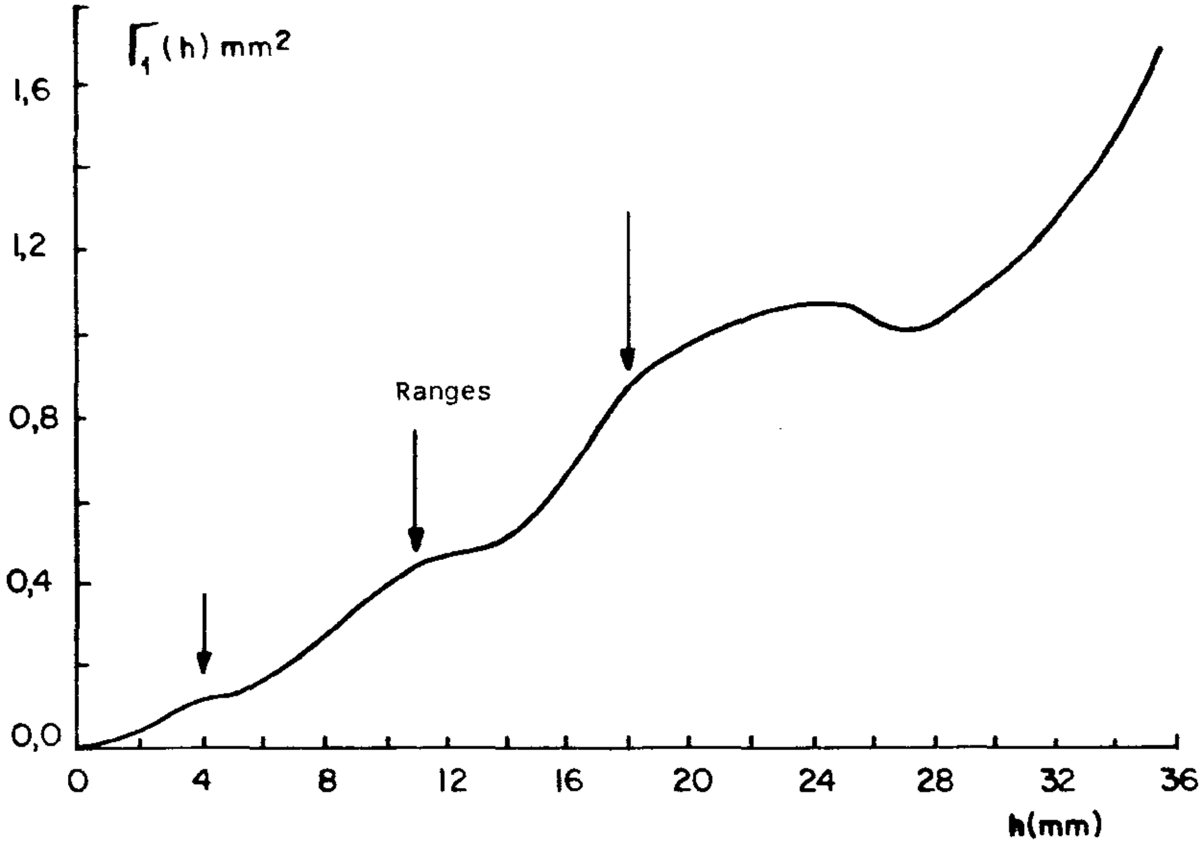

Figure 1 - Experimental variogram of the height of the fracture surface

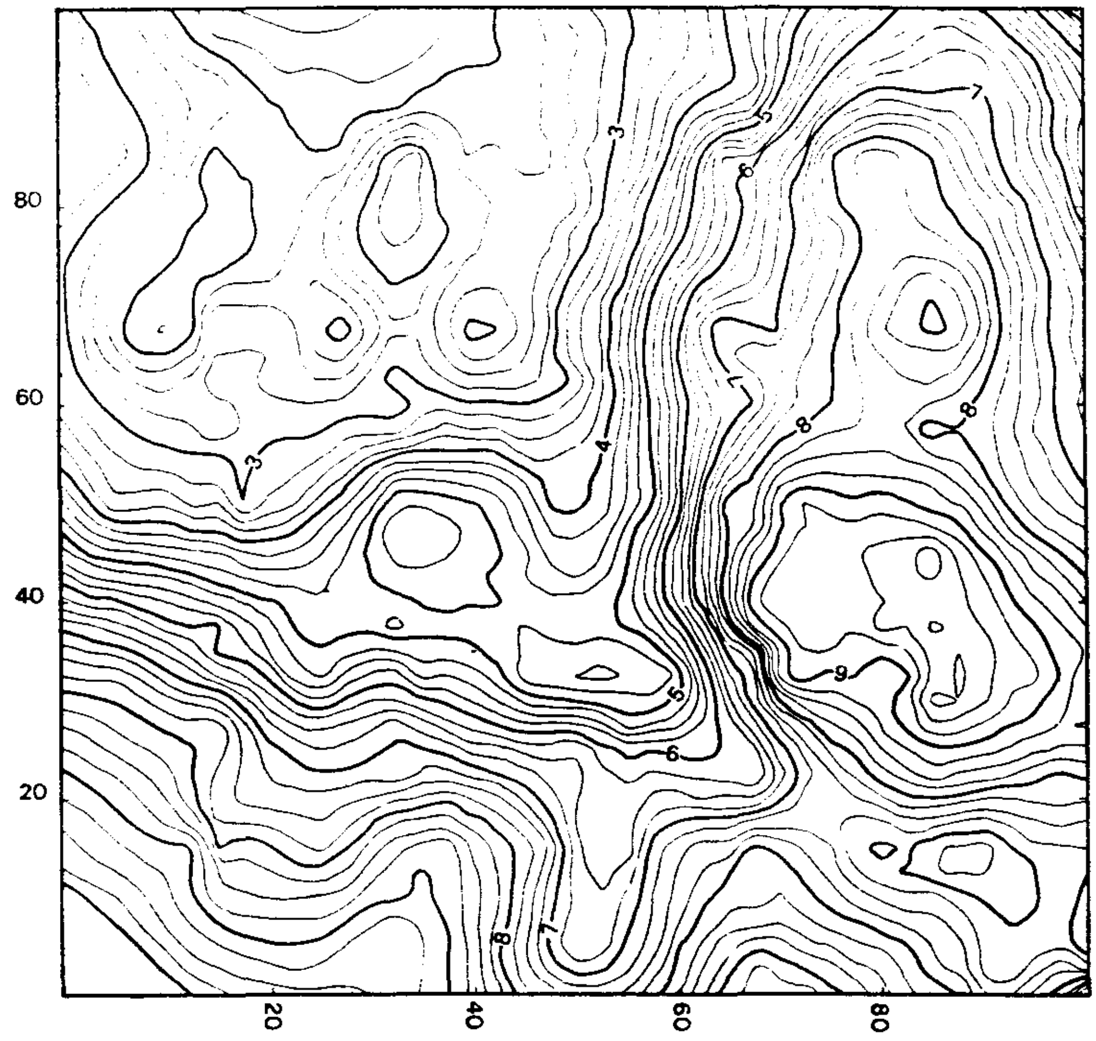

Figure 2 - Kriging of the fracture surface

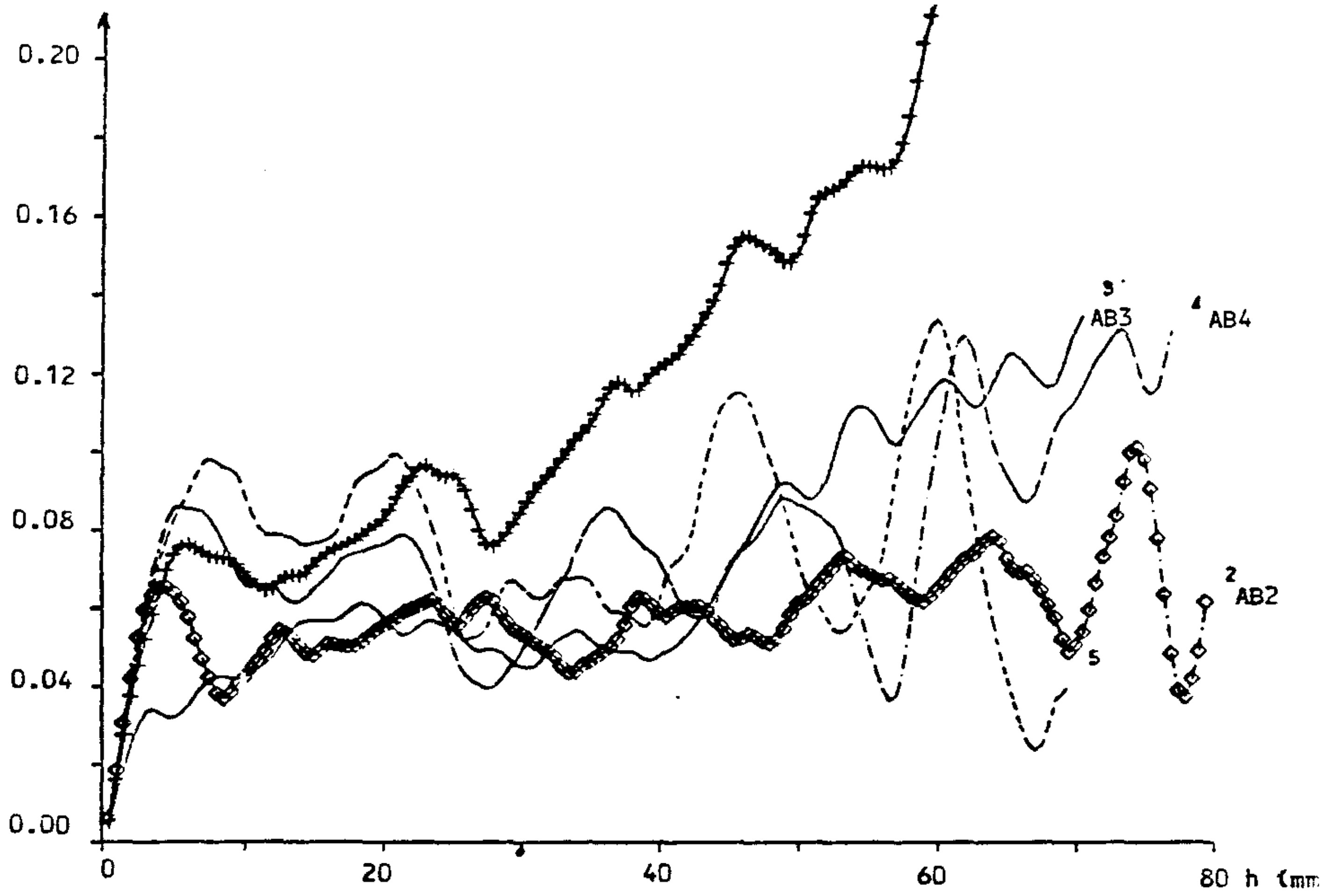

Figure 3 - Experimental variogram of the height of the voids

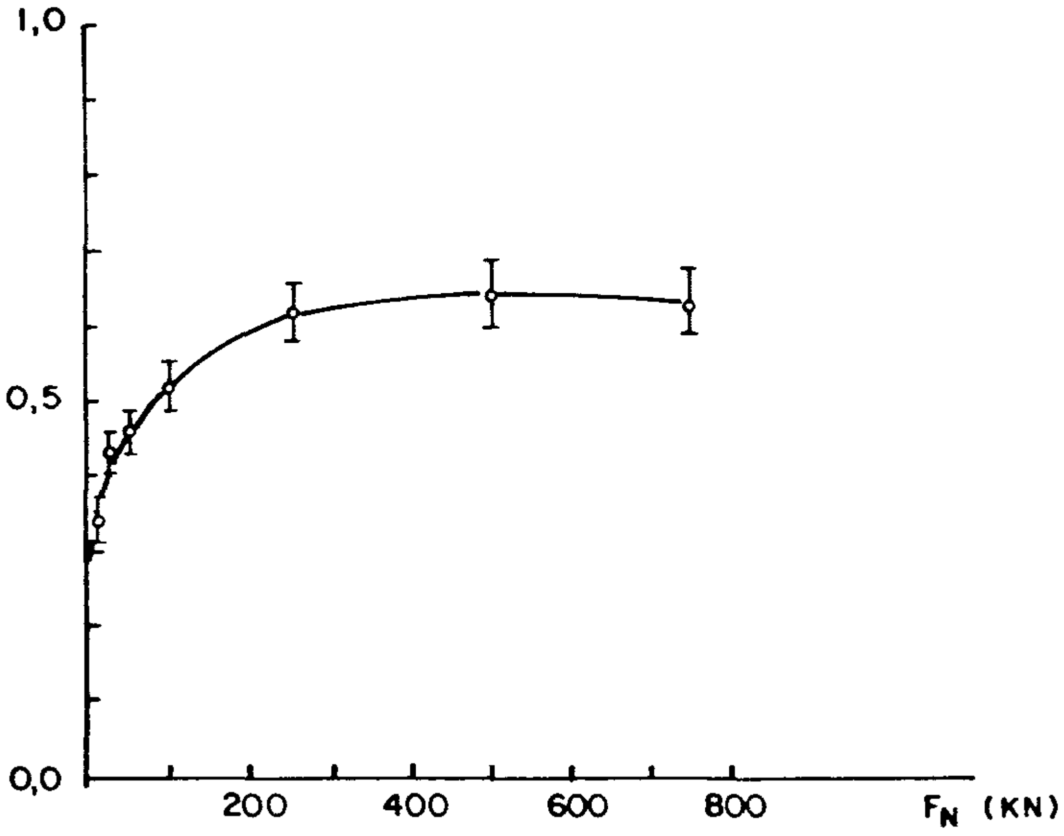

Figure 4 - Variation of the percentage of the contact area with normal stress

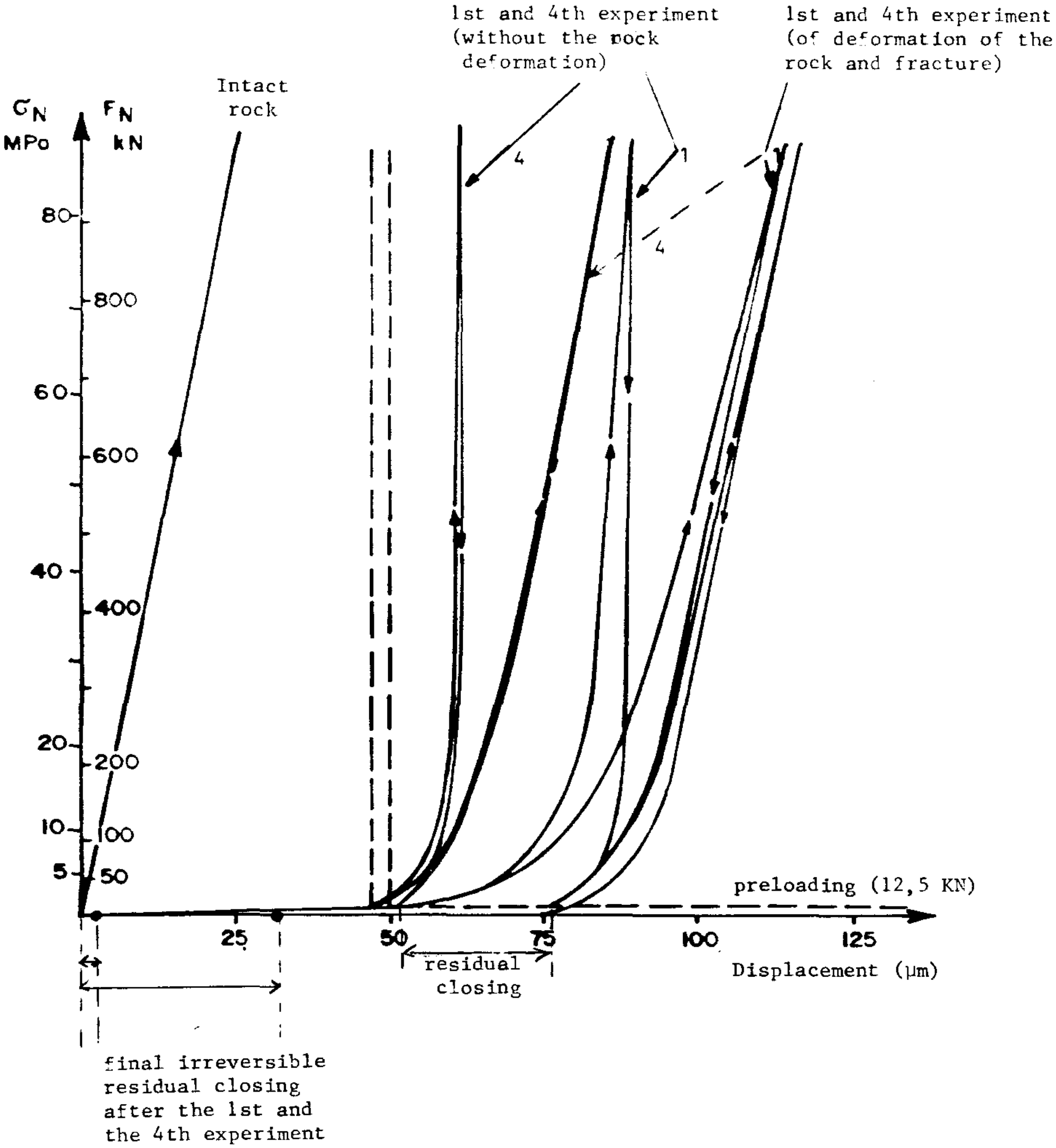

Figure 5 - Curves of experimental data : displacement versus normal stress

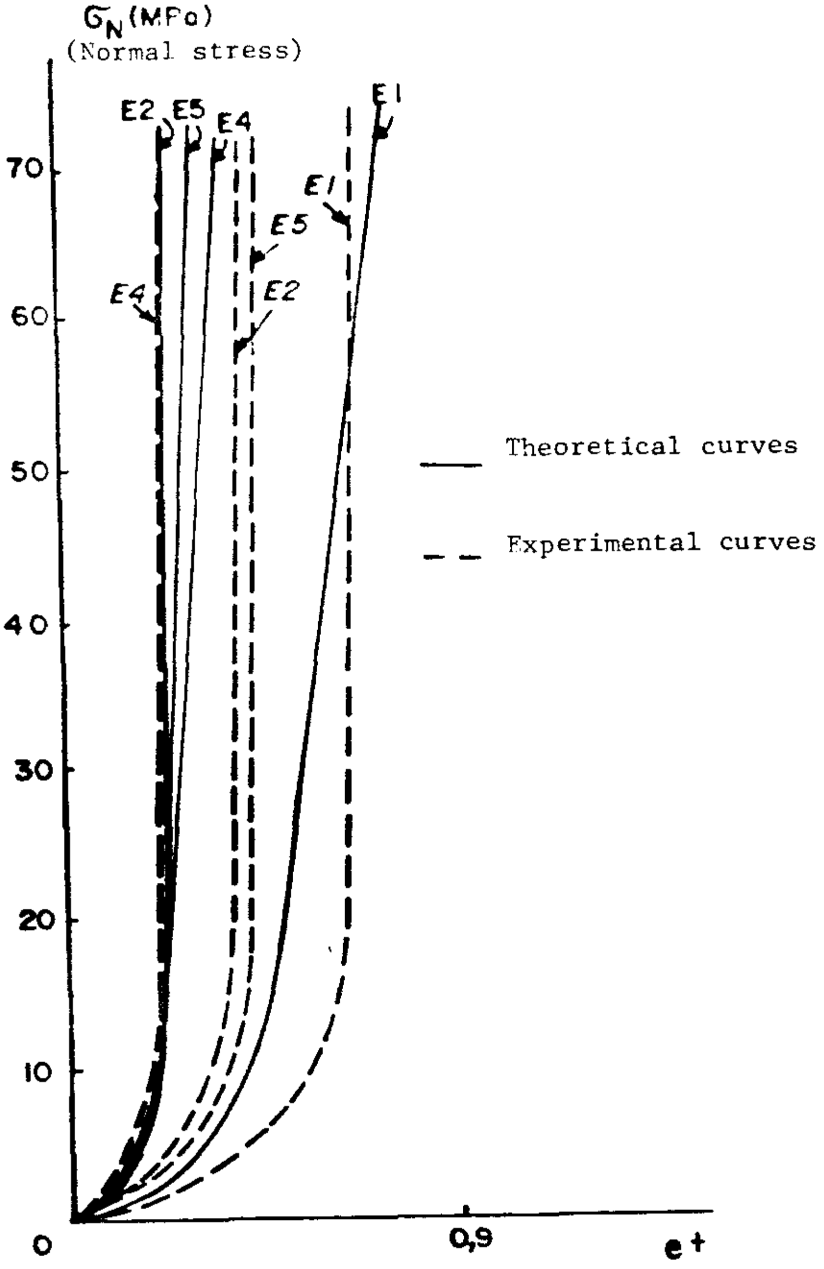

Figure 6 - Mechanical behaviour experimental and theoretical curves ("confined teeth model")

$$(e^{+} = \frac{\text{aperture at a given stress level}}{\text{maximum aperture under zero stress}})$$

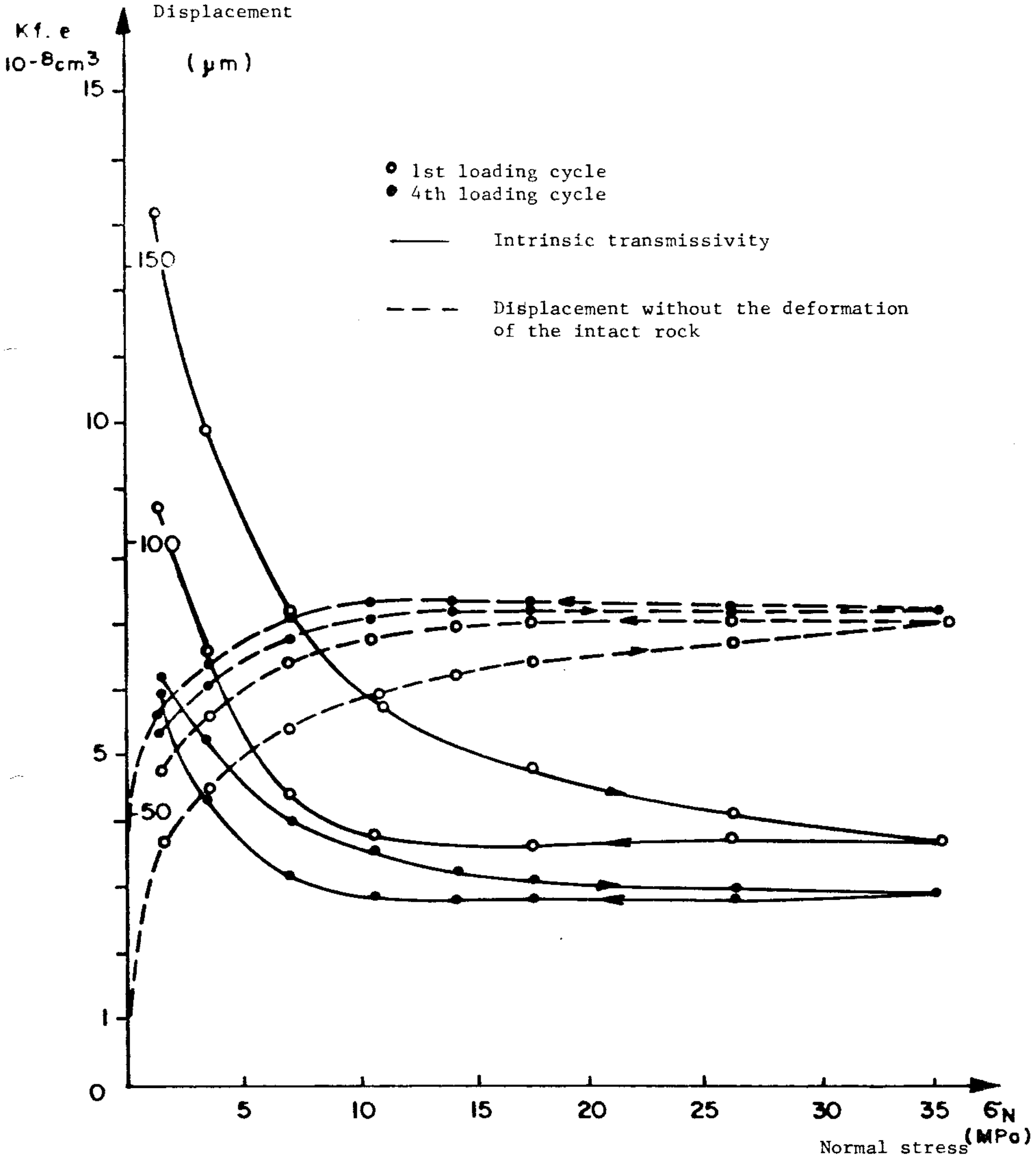

Figure 7 - Hydromechanical behaviour : experimental curves : intrinsic transmissivity and displacement versus normal stress

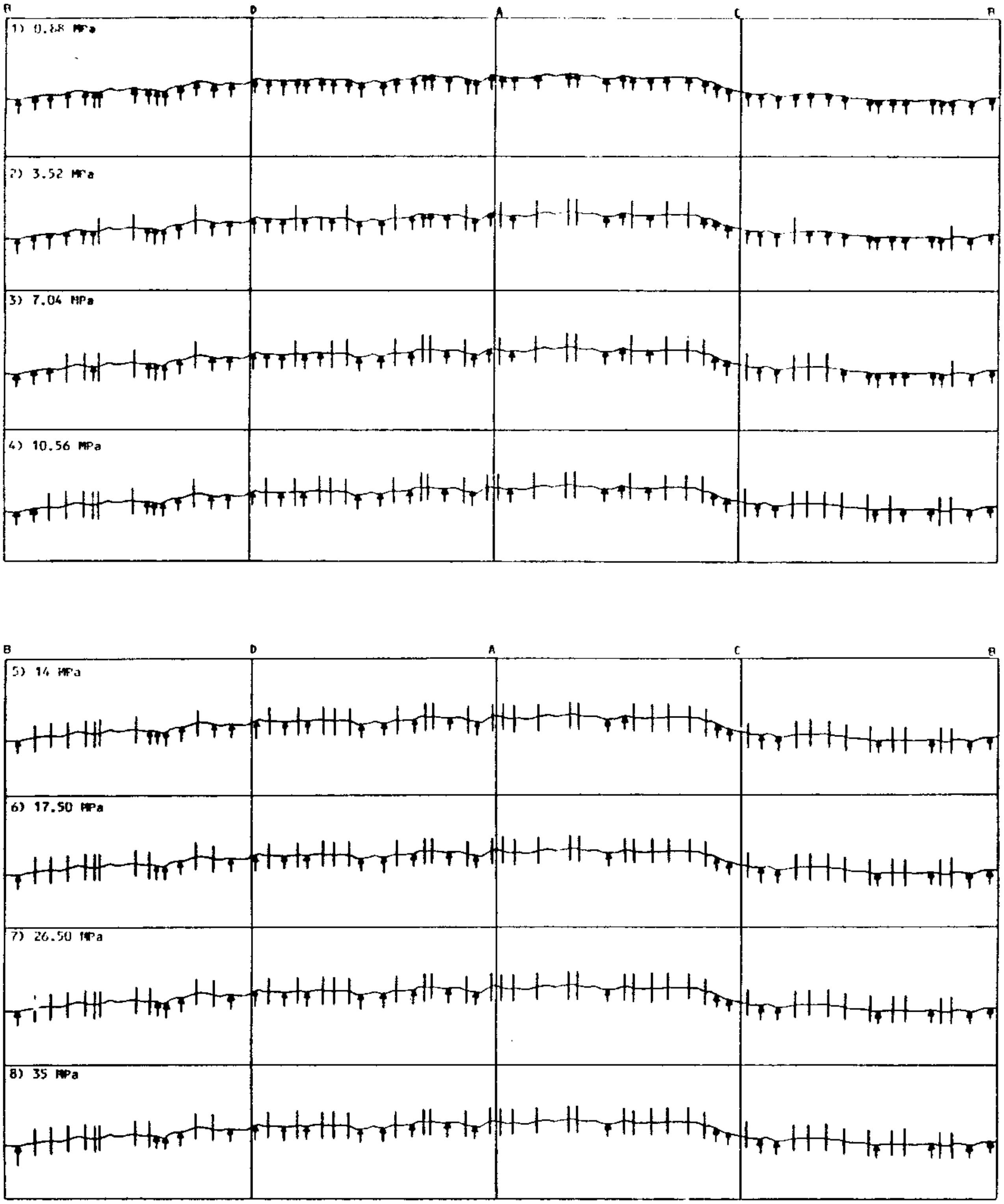

Figure 8 - Outlets around the cylindrical fractured sample at various stress levels

⟶ outlets
—— disappeared outlets