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EXPERIMENTAL STUDY OF FAILURE HISTORY IN JOINTED ROCK MASS

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Abstract: Failure of rock mass is not a static process, but has its own history. Its duration varies from several seconds to several years. Movements of rock mass are often hundreds of metres in length and significantly change its original shape. Failure mechanics can be studied experimentally. On inhomogeneous models we can observe the onset of failure (prior to and during the failure, deformations increase on sliding surfaces), the chronology of various stages of failure (cavings, slides), and the final shape of rock mass, after the discontinuation of the failure. We can also observe influences, exerted by modelled joints, adits and other features, upon the failure history and shapes of cavings and slides.

Key words: failure mechanics; failure history; physical model; stability of rock mass; jointed rock mass

1. INTRODUCTION

The mathematical study of fracture history of jointed or fractured rock mass, when individual joint sets have spatial (3D) structure, is as yet very complicated. On the contrary, the fracture history can be studied experimentally on structural physical models (Vacek 1990a, 1991b). As a structural physical model from equivalent materials we regard a model in which, during its construction, sets of joints similar to those existing in nature are made (Vacek, 1990a, 1991a), i.e. their directions and dips are the same as in nature. By doing this we fulfil the condition of similarity of rock mass spatial structure.

2. DEFINITION

The present paper reports on our experimental investigations of phenomena associated with rock mass failure, above all those occurring prior to and during the failure and during the abatement of movements after the failure. The results are valuable from the viewpoint of understanding the mechanism of failure of the discontinuum formed by irregular blocks. They are also of practical importance, in designing mines or underground engineering works, for mining authorities in deciding on an appropriate technology of extraction and, in particular, also for more accurate determination of hazard conditions signalling earth slides or cavings. Therefore, they can also improve the safety of underground workplaces.

We have studied rock mass failure, in accordance with the catastrophe theory, as a dynamic process occurring in a phase space. Under the influence of external (mining, tunnel driving, and change of loading in time, etc.) and internal (change of rocks' mechanical properties in time) conditions, equilibrium is upset, ending with rock mass catastrophe, i.e. failure (caving, slide, etc.).

Already in earlier experiments, prior to failure, various phenomena were observed in the model, i.e. audible creaking or crackling, fall of a part of the overburden, convergence of the hanging wall and footwall, and fall out of weak gangue from steeply dipping veins, etc. These symptoms of an approaching failure were observed 1 – 20 minutes prior to the failure; with an approaching caving they became more frequent and more conspicuous.

It should be pointed out that the more heterogeneous the structure of the model, the more pronounced the symptoms preceding the failure. Moreover, in heterogeneous models, the failure was more complicated and, as a rule, it did not occur instantaneously but proceeded gradually in a series of partial cavings. On the contrary, homogeneous models only exhibit such phenomena rarely. Their failure usually occurs suddenly and definitely.

To record model movements we used either the method of close-range photogrammetry (Vencovský, 1988) or videorecording. The first technique is very precise and able to measure model deformations of 0.01 mm. The accuracy of the second method is not high but it does yield a continuous recording. The best approach is to combine the two methods. Computer analysis of movements is widely used. Programs for adjusting the measured values on surfaces are available.

3. THREE EXAMPLES OF OUR RESULTS

3.1. Caving of underground open space

Figs. 1–4 show the caving of an open space in the Mědĕnec Mine.

The worked-out space is situated in magnesite; in the actual hanging wall there are skarns and further on gneisses. The deposit is crossed by a prominent fault. Its thickness is 6 m and it is filled with migmatites, tectonic clay, etc. In the homogeneous model of this geological mining situation the failure occurred suddenly, the roof of the stope, after falling into the worked-out space, had the shape of a parabola, and the caving did not reach the surface. Figs. 1–4 show the caving of a structural model. The situation prior to the caving is shown in Fig. 1, the first stage of the caving is in Fig. 2, the second in Fig. 3 (it began one minute after the first stage of the caving), and the final stage of the caving (which began approximately 10 minutes after the first caving) is shown in Fig. 4. Before the first caving and in between all the cavings as well, creaking could be heard from the model. In the case of the Mědĕnec Mine, subsidence of the surface did occur.

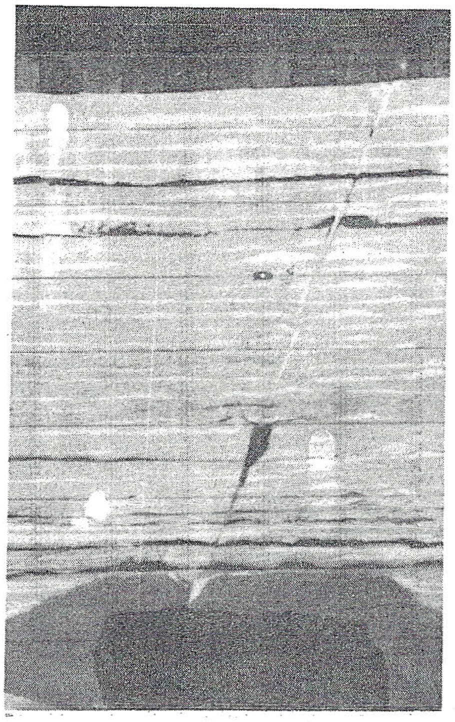


Fig. 1. The Mědĕnec Mine.
The still stable stage.

Fig. 2. The Mědĕnec Mine.
The first stage of the failure.

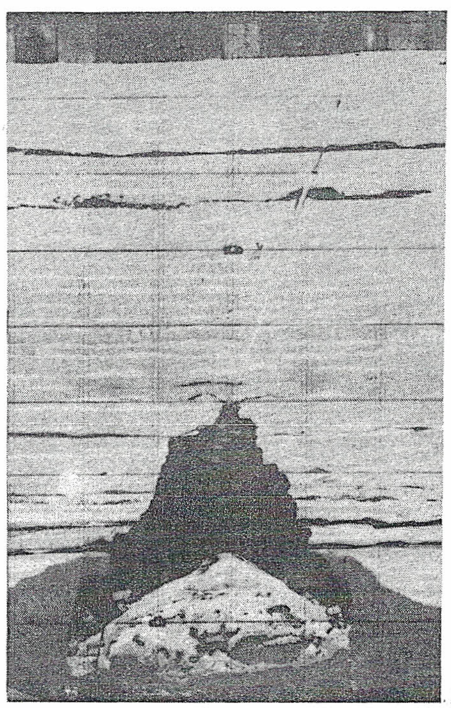


Fig. 3. The Mědĕnec Mine.
The second stage of the failure.

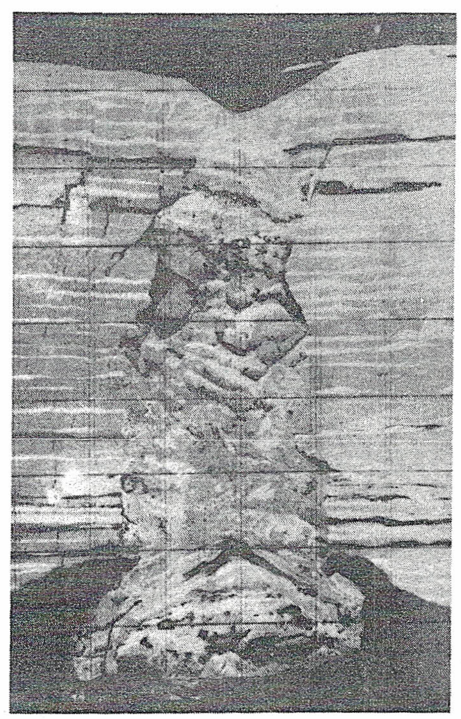


Fig. 4. The Mědĕnec Mine.
The final stage of the failure.

3.2. Slide of a slope with predestinated sliding surface

This problem was studied for the geotechnical conditions on the southern slopes of the Krušné hory Mountains, stripped due to an opencast coal mine. The contact

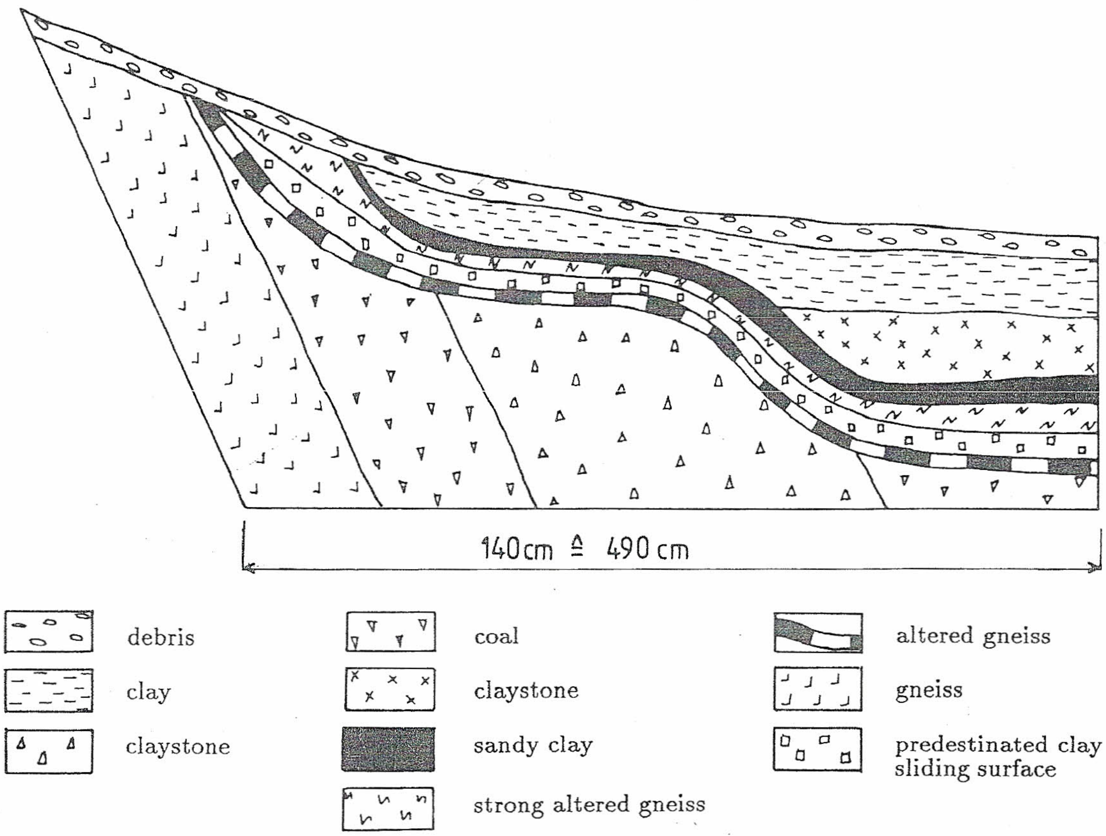


Fig. 5. Mine ČSA, scheme of the model.

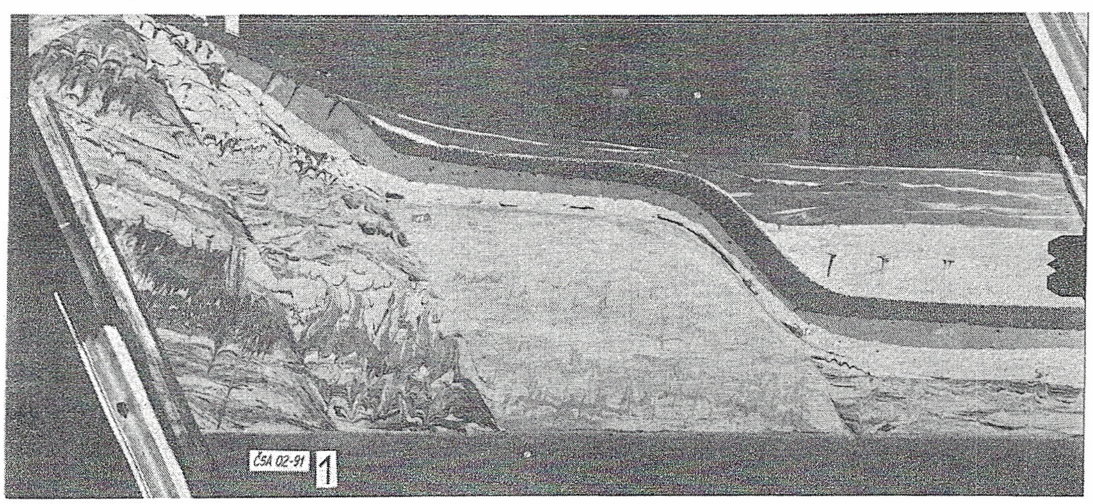


Fig. 6. Mine ČSA, the model before testing.

between the fundament and sediment consist of special very weak clay strata with cohesion of 2 – 3 kPa and angle of internal friction 2–3°. The scheme of Model ČSA 02 is presented in Fig. 5. Fig. 6 shows the model prepared for testing. Fig. 7 shows the still stable stage of mining. Various stages of the slide are shown in Figs. 8–10. In Fig. 11 the surface of the slide is shown. Blocking of the slide on its picked-up

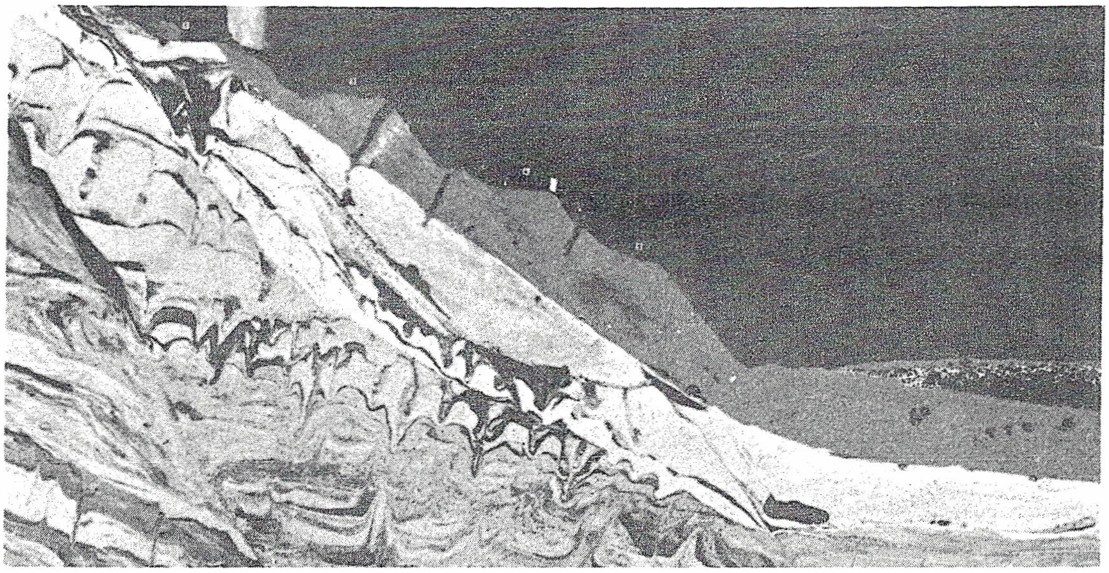


Fig. 7. Mine ČSA, detail of the last stable phase of mining.

Fig. 8. Mine ČSA, development of the slide.

front and the uncovered sliding surface behind its top can be seen. In Figs. 12 and 13 two possibilities of analysing the results are presented. The contrasting colouring of the model in Figs. 5–10 should facilitate orientation during photogrammetric measuring of the model.

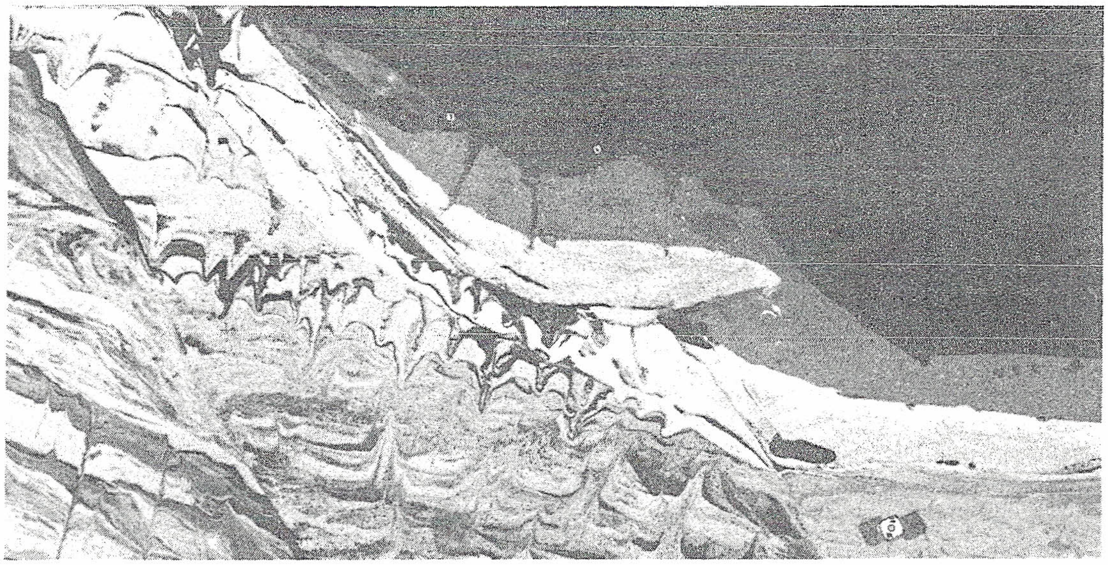


Fig. 9. Mine ČSA, next stage of the slide.

Fig. 10. Mine ČSA, final stage of the slide.

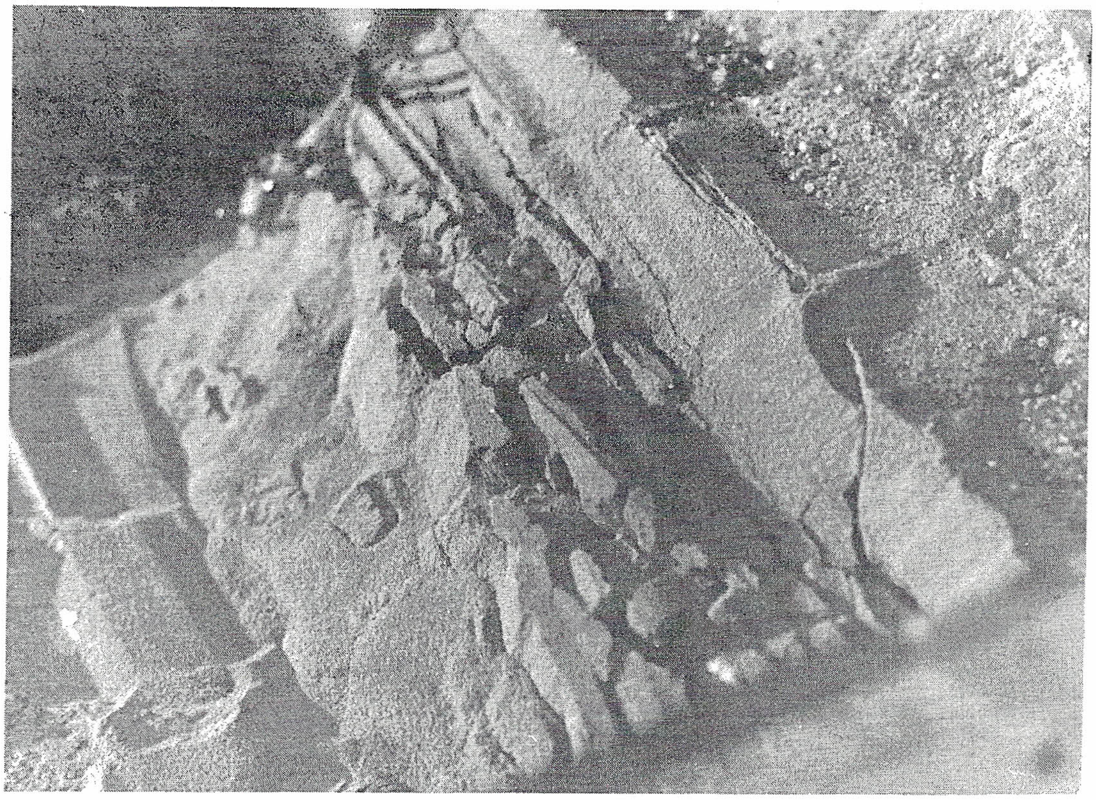


Fig. 11. Mine ČSA, view of the surface of the slide.

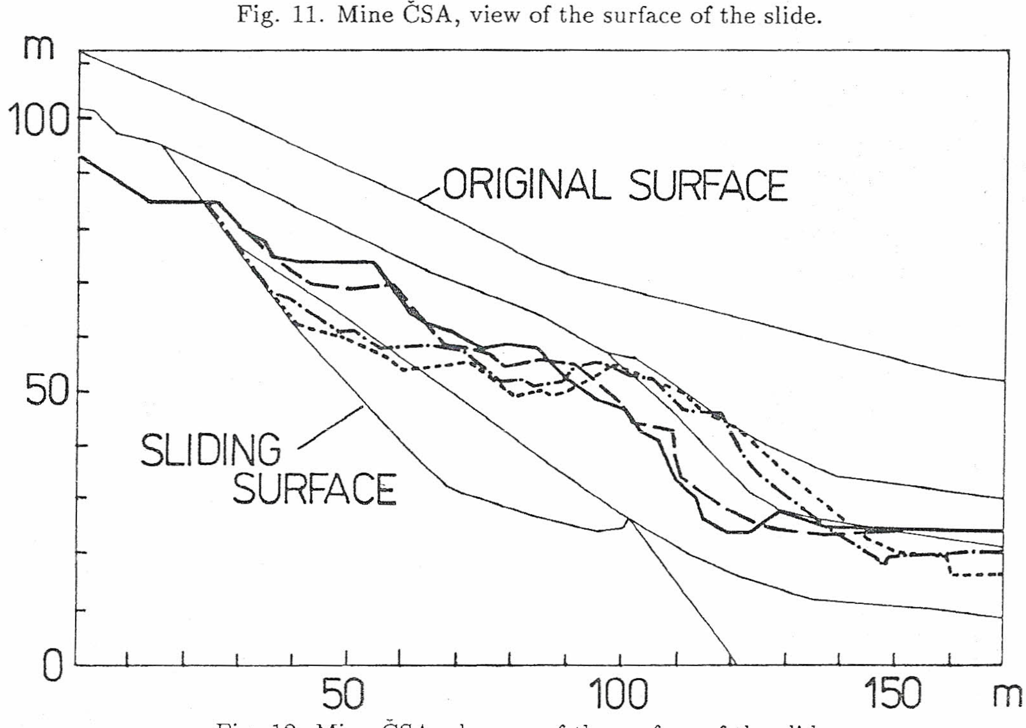


Fig. 12. Mine ČSA, changes of the surface of the slide.
—— surface according to Fig. 7; – – – surface according to Fig. 8;
-·-·- surface according to Fig. 9; - - - - surface according to Fig. 10.

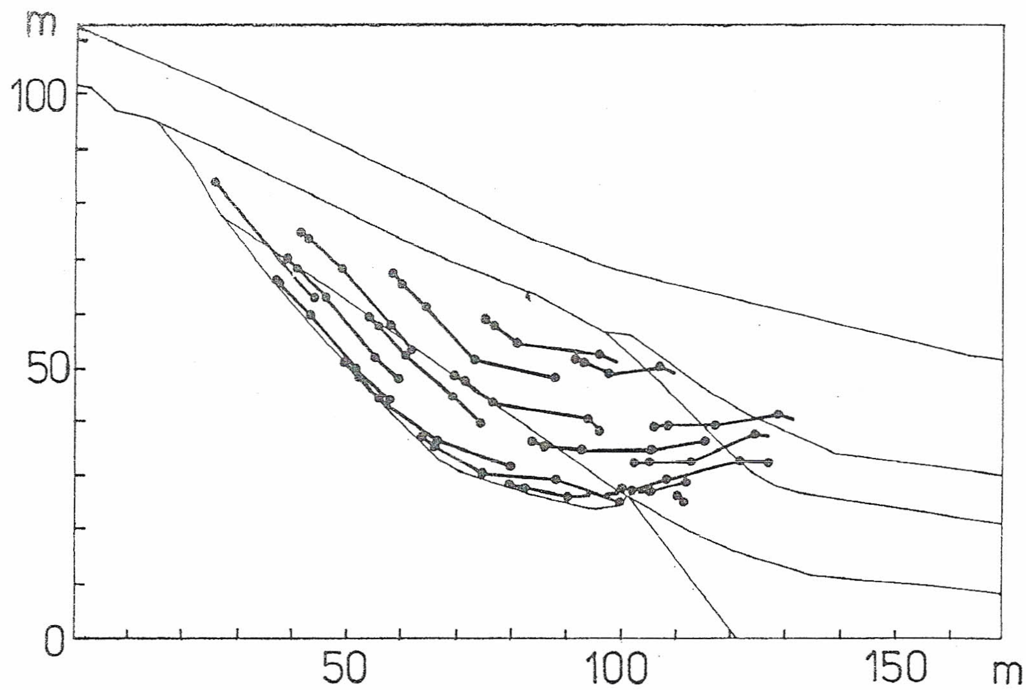


Fig. 13. Mine ČSA, movements of selected points.

3.3. Rock mass pillar with cracks and an adit

The last figures show the failure history of a pillar with an adit in its centre and three joints (Fig. 14). The dimensions of the actual pillar are height 50 m, width 10 m and length 20 m. The width of the adit is 2.4 m. The rock mass is magnesite. Joints with sand filling were made in the model.

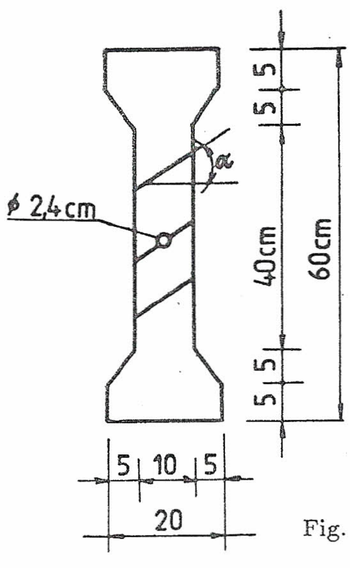


Fig. 14. Scheme of Pillar 4.1.

Fig. 15 shows the model before testing. Figs. 16–19 show successive stages of the failure. A similar situation on the model from magnesite after testing can be seen in Fig. 21. The differences between the homogeneous (Fig. 20) and inhomogeneous pillars are clearly visible. The failure of the homogeneous pillar was sudden, with

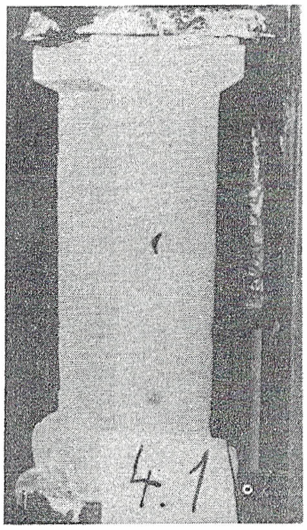


Fig. 15. Pillar 4.1, prepared for testing.

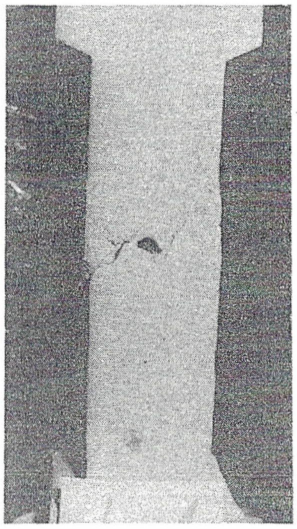


Fig. 16. Pillar 4.1, first stage of the failure.

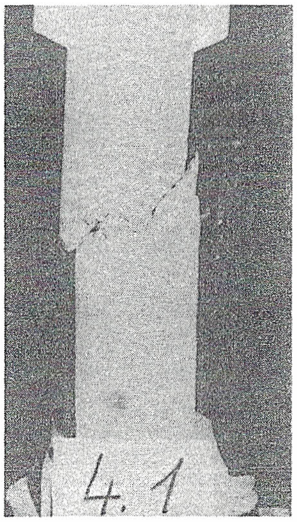


Fig. 17. Pillar 4.1, next stage of the failure.

Fig. 18. Pillar 4.1, next stage of the failure.

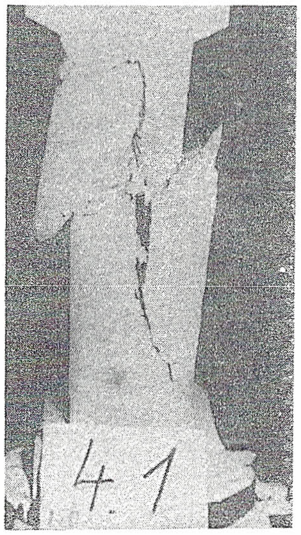


Fig. 19. Pillar 4.1, next stage of the failure.

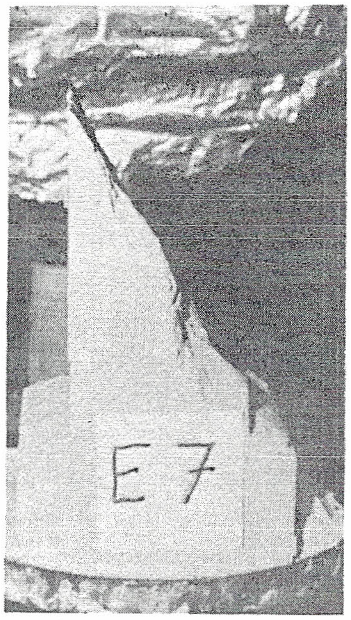
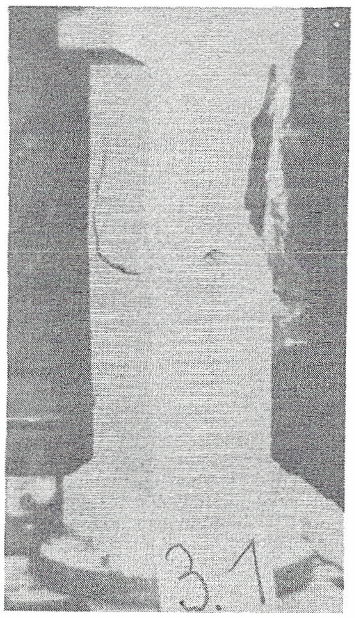


Fig. 20. Homogeneous Pillar E7,
after the failure.

Fig. 21. A magnesite pillar, similar to 4.1,
after the failure.



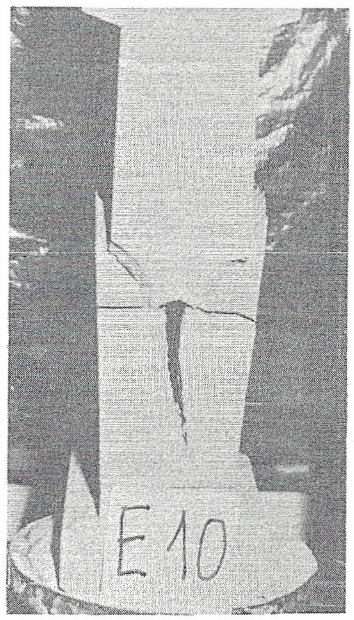


Fig. 22. Another example of a pillar according to the scheme in Fig. 15, after the failure; dip of cracks is zero.

Fig. 23. Another example of a pillar according to the scheme in Fig. 15, after the failure; dip of cracks is zero.

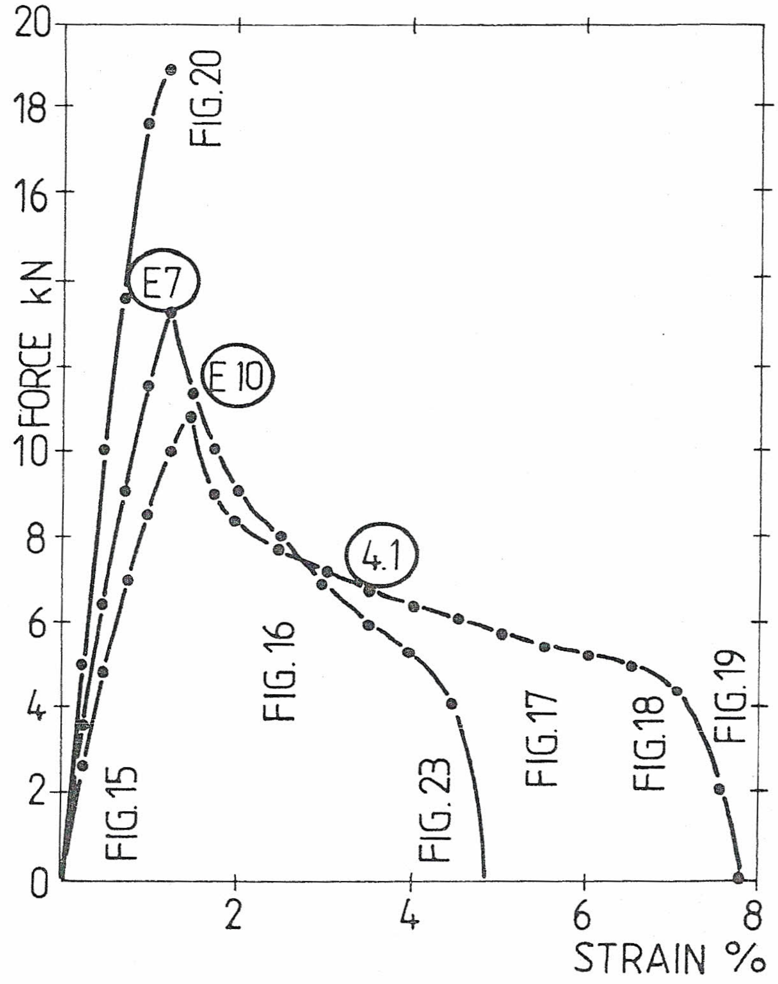


Fig. 24. Load-strain graphs for Pillars 4.1, E7 and E10.

one or two shear surfaces. The vertical deformation before the failure was around 1.5%. The failure of the inhomogeneous pillar was more complex. It was not instantaneous (the duration of failure depends on the loading rate; in the model presented it was 390 s) and the axial deformation amounted to 3–10% (in the model presented it is 8%). It follows that, in spite of a lower bearing capacity (54%), the pillar with an addit was, from the point of view of mining, more advantageous. The model displays an extremely complicated failure. Usually the failure is simpler (Figs. 22 and 23), but it is never so simple as in an homogeneous model. If the homogeneous model has a bearing capacity around 20 kN it is hardly believable that the model, at the stage shown in Fig. 18, can still bear 5 kN, and 1.5 kN at the stage in Fig. 19. The load-deformation curves of Pillars 4.1 (Figs. 15–19), E7 (Fig. 20) and E10 (Fig. 23) are shown in Fig. 24.

4. CONCLUSION

Knowledge of the failure meachnism and its history in jointed rock mass is of great importance to the development of science. An experimental study on physical models makes it possible to investigate a problem continuously in time. The figures showing the failure model demonstrate differences between the types of failures in homogeneous and structured materials. The differences are not only in the geometry of failure but also in its duration and in the final shape of the model after the failure. Continuous videorecording makes it possible to identify failure symptoms and thus to estimate more precisely the deformations that signal hazard conditions. Analogous investigations can be carried out of surface subsidence due to underground mining, and of tunnel-head stability, etc., in structural (jointed) rock mass. If the behaviour of the model is verified on tentative models before the final test, agreement of its results with practical conditions is very good.

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EXPERIMENTÁLNÍ VÝZKUM HISTORIE PORUŠOVÁNÍ V TRHLINOVITÉ HORNINĚ

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Porušování horninového masívu není statický proces, ale naopak probíhá v čase, má svou historii. Doba jeho trvání kolísá od několika sekund po několik let. Pohyby masívu během porušování dosahují často stovky metrů a významně mění původní tvar masívu. Mechanismus (vývoj) porušování je možno zkoumat experimentálně. Na nehomogenních fyzikálních modelech lze pozorovat vznik porušení (před ním a během něho narůstají deformace na smykových plochách) a konečný tvar masívu po skončení porušení. Rovněž lze sledovat vliv modelovaných trhlin, chodeb, atd. na historii porušování a tvar závalu nebo sesuvu.

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