Rock Specimens Destruction Regularities under Uniaxial Compression

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Abstract. Modern approach to the stress-strain state assessment of a mining structure design, especially when it is non-linearly deformed and areas of local destruction appear, should be based on the principle of step-by-step loading in the form of small increments of the loading factor. At each such step, due to fracture, the deformation properties of the materials composing the region change, forming a generally non-uniform and, possibly, non-linear deformation medium. The modelling results of the rock massif state within this approach may differ significantly from the results for one-step loading, which is usually used in researches.

The article discusses the use of an iterative process of loading and destruction as applied to the simplest design, namely, for one-dimensional loading of a homogeneous rock specimen. It is shown that under the "rigid" loading conditions, the described approach makes it possible to simulate the characteristic features of damage localization in the sample and the nonlinear nature of the deformation as a whole, including post failure deformation.

1. Introduction

The research, connected with the identification of features of destruction a design, especially in geom mechanics, makes an important group of tasks. The approaches to the solution of such tasks are various. However, today they are absolutely inadequate and, mostly, do not reflect the real processes in the destroyed environment. Some assumptions, considerably simplifying the mathematical description of the nature of deformation and destruction (for example predetermining zones of the destruction emergence and the nature of its subsequent process) became the cornerstone of such methods [1, 2, 3, 4, 5]. The destruction in the massif of rocks is often connected with the formation of a certain surface or narrow extended zone, in which this destruction is localized and which location is determined by the properties of material and by the conditions of loading of a mining structure. Practically all the methods of the assessment of stability of the pit boards slopes are based on the specification or on the search of a certain surface of displacement with the subsequent assessment of the power balance on it at the best [6, 7, 8].

However the location of such surface or zone (especially in homogeneous and isotropic environment) is not predetermined by anything in the space, i.e. they are formed during the destruction directly, both in the dynamic and quasi-static mode in the conditions of constantly changing configuration of the destroyed area and, perhaps, under variable loads [9, 10, 11]. That also applies to
the subject of this article, which is the consideration of durability of the samples, tested for the monoaxial compression.

Let us consider the method of the destruction areas definition, constructed on the basis of numerical modelling with possible more general assumptions on the character of the material destruction.

Nowadays the most widespread approach to the studying of quasi-static destruction consists in the use of this or that criterion of the destruction from a very extensive set and in the choice of the proper criteria values of the parameters entering this criterion. After finding of the intense deformed condition of the studied area and the use of the chosen criterion, a certain area, in which the material is considered to be destroyed, is defined. This area is the destruction area. It would be more accurate to call it a zone of initial destruction because of the fact that the material in it changes its deformation and strength properties to some extent, and the operating loadings remain invariable. In case of repeated calculation, the received destruction area can change its size and configuration.

The offered approach is just based on the consecutive, iterative tracking of the development of this zone. As a result, it can develop unrestrictedly, leading to the destruction of the whole structure, otherwise it can be stabilized areas some measures, having created the final destruction area.

Let us note that this idea is not new, but earlier it could not be realized because of the technical difficulties of tracking of the consecutive increments of the destruction area. It is important that these increments were as small as possible for ensuring stability and unambiguity of calculations. The approach, described schematically is presented in figure 1, where the settlement area, typical boundary conditions and loadings are shown. The consecutive growth of the destruction area is also shown.

![Figure 1. Schematic image of the destruction area development](image1.png)

Let us consider that the used criterion of destruction includes a set of parameters of the intense deformed condition (tension, deformation) and has dot character, i.e. we deal with destruction in a point.

2. **Algorithm and computational method**

Further consideration is connected with the numerical model operation of an intense strained condition of the explored area with the use of the method of final elements. Then let us suppose, that the parameters of the intense strained condition are localized in the final elements. I.e. in this case the actual point is this or that final element within which the realization of the chosen criterion of destruction is checked. At the same time the extension of the border of the destruction zone happens element-wise (or by groups of elements). So, it is clear that the elements are to be rather small.

The following circumstance should be noted. The deformation properties of material change somehow in the destroyed zone. It is apparent that they decrease: the material becomes less rigid and less strong, but it is unknown how less. They can vary, ranging from the properties of a starting material (i.e. it is destroyed slightly) up to the final destruction with zero straining-and-strength properties.
Their values cannot be received as a result of the pilot studies. However, it is quite possible to count on the solution of the reverse task, i.e. by comparison of the calculated and measured parameters to define properties of breed in the destruction zone. Varying their value during the calculation one can receive a variety of the results of modelling, including those, which are suitable according to some criteria.

The simplest configuration, namely, compression of the sample of breed between rigid punches, i.e. the test on an axial compression was chosen for modelling. The scheme is presented in figure 2.

![Figure 2. Schematic representation of an axial compression of a sample of breed](image)

The general view of a sample and the loading device (where 1 is a punch, 2 is a sample) and the corresponding calculated scheme with the corresponding boundary conditions is schematically given in the Figure. The problem is solved in flat statement for the simplicity of reflection and interpretation of the received results. According to the symmetry of the task the calculated scheme includes only one fourth part of the considered configuration. The total size of the sample made up 6*4 cm. Contacts of the punches with the exemplar were considered as ideal for simplicity, i.e. the complete coupling without slippage was supposed. Let us note that such simplified problem definition at the first stage allows to avoid the need to analyze a set of features of the received results during more detailed consideration of the task. At the same time that allows to reveal the main features of deformation of the sample in the mode of "rigid loading".

The settlement of final element grid during the test calculations varied. In the area occupied with the sample it consisted of ~ 60000 elements (in separate options up to 600000 elements). At the same time the size of an element can be estimated as 0.1*0.1 mm.

When calculating it was supposed that all the components (the loading punch and the sample) are elastic with Jung modules and Poisson's ratios, respectively: 1*109 Pa, 0.25; 1*106 Pa, 0.28. I.e. The punch material is three times more rigid, than the sample. In this connection its deformation can be not taken into consideration.

It should be noticed that modelling did not pursue the aim to receive values of rated parameters for any concrete material. In this regard the original values of deformation strength parameters for all the materials were taken rather randomly. The task consisted in testing of the offered approach and obtaining the general regularities of deformation with the least possible expense of computing resources.

On the least upper bound of the punch vertical movements were set sequentially: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 10.0 mm. In other words, the deformation was 1.67, 3.3, 5.0, 6.7, 8.3, 10.0, 13.3, 16.7, 20.0 and 33.3%. Let us note that most of these deformations are too big for the linear elastic theory, which allows no more than 3-4% of such deformations. However, if the geometrical nonlinearity is considered during the calculation, i.e. the calculated stressed condition of the sampler is considered to be the deformed condition, then any deformations are allowed in practice. So, 10 options of loading were calculated and all the components of the intense strained state in the sample were received.
Actually, this or that shift was instantly put to the end face and the condition of the sample was estimated (without taking into account the dynamic effects).

It is important that the loading of the sample occurred at the expense of the task of shifts, i.e. in the mode of "rigid loading". Such approach, unlike the task of pressure at the end face ("soft" mode), allowed to trace various phases of destruction of the sample in the quasi-static mode. At the same time the lateral area of the sample remained free.

The intensity of the tangential stresses was chosen as the criterion of durability, as it is the scalar value, which is not connected with any direction but which characterize the shift deformation of the material, usually prevailing during destruction by compression. The material destruction was considered to exist in case of the excess of some criteria value by intensity of tangent tension (this value was 1.5*10^5 Pa according to the calculation). As it was already mentioned earlier, the starting material in the destruction zone is replaced with the replacing elastic material with the elastic module of 1*10^5 Pa, which is less, than the elastic module of the starting material.

3. Results and discussions
Let us note that the realization of the durability criterion was not observed at the first four steps of loading up to 6.7%, and the destruction zones, which were traced by the corresponding iterative procedure described above, began to appear only further. As it could be expected, originally they were localized, and then they developed from point S (the point of coupling of the punch and the sample (see figure 2).

Figure 3 gives the example of the final distribution of the tangential stress intensity at the general deformation of the sample of 10.0%. Figure 3a presents the corresponding isolines, and Figure 3b presents the spatial representation of distribution.

![Figure 3. Distribution of the tangential stress intensity in the sample: isolines (a), 3D-image (b)](image)

It is possible to note that under absolutely smooth boundary conditions, and in case of absence of any inhomogeneities within the settlement area, a legibly localized zone of the increased values of intensity of the tangential stress was formed in it. It can be interpreted as a zone of shift destructions; in other words, it is the surface of displacement.
It is apparent that under any circumstances the global equilibrium of the area occupied with the sample has to remain. It in particular means, that the integral from the distribution of vertical tension according to any horizontal section within the considered area is to have the same value, which is the average value of the squeezing tension. Such tension was calculated at different steps of loading on two pieces which location is shown in Figure 3a. One piece (2) coincides with the lower bound of the area, and the second (1) is located apart in 0.5 mm from the upper bound, i.e. from the line of interaction of the sample and the punch.

The corresponding distributions of the squeezing tension on these pieces (lower and upper) at the first step of loading are given in Figure 4 (if \( \Delta h=0.5 \) mm or 1.67\%). Average values for them coincide practically (they are shown as straight lines); that demonstrates the existence of power equilibrium of the sample.

![Figure 4. Distribution of the squeezing tension according to horizontal sections of the sample if \( \Delta h=0.5 \) mm](image)

Figure 5 presents the same tension on lines 1 and 2, but for the loading step in case of deformation of the sample in 10.0\%, (like in Figure 3).

The distribution on the lower bound has a smooth appearance, which can be judged about according to Figures 3a and b. It is visible from the Figures, that the localized indignation of the intense strained condition on the considered step of loading does not reach this zone.

Distribution on the top piece has oscillatory character at least on the part of the piece, as it gets to the zone of oscillating values of the tangential stress intensity within the obtained zone.

![Figure 5. Distribution of the squeezing tension according to horizontal sections of the sample if \( \Delta h=1.67 \) mm](image)
Nevertheless, the corresponding average values of tension are very close to each other; that is also reflected in Figure 5. Their distinction is estimated as shares of percent.

The obtained oscillations are most likely connected with the loss of stability of the relevant decisions. However, they arise in the proper place and are not accidental in size at all. Such fluctuations also develop in case of larger loading shifts. At the same time "crests", similar to those, presented in Figure 3b, are formed in all settlement area, breaking it into separate blocks (Figure 6) with intensive movements on their borders (deformation in 16.7%).

![Figure 5](image)

**Figure 5.** Distribution of the squeezing tension according to horizontal sections of the sample if \( \Delta h = 3.0 \text{mm} \)

The value of deformation of the sample is known for each of steps of loading and as it was made earlier, the average value of tension can be calculated. Thus, there are ten points, describing the nature of deformation of the sample in case of "rigid loading". The corresponding schedule is presented in Figure 7. Let us note that the typical diagram of the ultraboundary deformation of the sample is obtained except the part of the curve in the field of greater deformations.

![Figure 6](image)

**Figure 6.** Distribution of the intensity of the tangential stresses in the sample: 3D- image for the deformation in 16.7%

![Figure 7](image)

**Figure 7.** The generalized chart of deformation of the sample in case of "a rigid loading"
Here it has an asymptote with the elastic modulus equal to \(\sim 1.1 \times 10^5\) Pa. That corresponds to the elastic modulus of the replacing material approximately. Such replacement happens during the development of destruction of a sample.

4. Conclusions
The results of the study show the fundamental importance of the correct formulation of the geomechanical problems, especially with the nonlinear nature of the rock massif deformation as a result of man-made impact on it. Under massif deformation, its properties are constantly changing, which leads to urgency of problems solving using loading parameter increments. This approach is typical for solving plastic problems, however, in the case under consideration, the target is complicated by the changing geometry of the region under examination due to the appearance of fracture zones with lost bearing capacity.

In article it is shown as an example of iterative method application for calculating stress-strain state in solving the simplest problem of deformation and fracture of a rock sample.

In the end, we should note that the result obtained is fundamentally differ from the results obtained in the framework of traditional approaches. Just according to the scalar criterion of the durability, applied in the iterative process of calculation of the destruction areas, and replacement of the destroyed material with a softer replacing material, we was succeeded to receive the localization of destruction in the sample and the ultraboundary nature of its deformation. At the same time, both the main material, and the replacing one are elastic on all extent of the deformation. That allows to consider ultraboundary deformation to be not a property of material, but a property of the structure, (of the sample in this case).

To obtain the general chart of deformation with the ultraboundary branch of deformation, aspiring to some residue durability, the procedure of replacement of the material is to be more adequate. In particular, the module of elasticity of the replacing material is to be variable, gradually decreasing up to zero. That will allow to avoid the site of growth on the ultraboundary branch of the chart.

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