ORDERS OF TECTONIC CRACKS

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A model is presented for the formation of tectonic cracks.

Determination of the order to which tectonic cracks belong is a required condition for description (modeling) of the tectonic jointing of rock masses to solve problems of hydro-technical construction. If it is not predetermined to what order cracks of a single orientation belong, complexities arise in determining the length, width, spacing, wall roughness, and type of filler of in tectonic cracks. With respect to determination of the length, width, and spacing of the cracks, the complexities are governed by the fact that empirical distributions of these parameters differ greatly from a normal distribution in connection with their rigorous asymmetry. Approximation of the plots by functions of familiar distributions will not solve the problem, since the mode of the plots of these distributions is not always an objective characterization of the jointing, but characterizes the degree of detail of the crack survey. In certain specific rock masses, cracking will tend to zero as the degree of detail of investigations of the mode of the distribution of crack spacing increases [1].

The division of a set of tectonic cracks into orders will make it possible to construct plots of the form \( m = f(r) \), where \( m \) is the number corresponding to the order of cracks, and \( r \) is a generalized geometric parameter (for example, length, width, etc.). This kind of plot would make it possible to obtain an objective characterization of crack parameters, which is independent of the degree of detail of the scale of the investigations.

Accumulation of data on jointing in connection with hydrotechnical construction has permitted specialists in this field to establish overall characteristic features of tectonic cracks of different dimensions, develop an order classification for cracks, and include it in regulatory documents. The classification recommended in Construction Rule and Regulation 2.02.02–85 for rock masses “based on orders of breaks in continuity” is presented in Table 1.

The purpose of this paper is to analyze situations that have arisen in connection with the absence of a single approach to classification of orders of tectonic cracks in the scientific literature.

**Review of Classifications of Orders of Tectonic Cracks.** The classification presented in Table 1 cannot be treated as an order classification for tectonic cracks in general, since its caption unambiguously indicates that we are speaking precisely about those cracks and fractures that lead to a break in continuity of the medium. Consequently, we are not speaking about cracks and fractures that are inclusions and defects of the medium, which do not disrupt its integrity. Moreover, the caption indicates that we are speaking of a classification of masses. The classification thereby automatically established correspondence between the expanse of the break in continuity and the limiting dimension of the geo-

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**TABLE 1. Classification of Rock Masses by Order of Breaks in Continuity**

<table>
<thead>
<tr>
<th>Characteristic of break in continuity of mass</th>
<th>Thickness of crushing zone, or width of cracks</th>
<th>Extent of break</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order-I fractures — deep, seismogenic</td>
<td>hundreds and thousands of meters</td>
<td>hundreds and thousands of kilometers</td>
</tr>
<tr>
<td>Order-II fractures — deep, nonseismogenic, and partially seismogenic</td>
<td>tens and hundreds of meters</td>
<td>tens and hundreds of kilometers</td>
</tr>
<tr>
<td>Order-III fractures</td>
<td>meters and tens of meters</td>
<td>kilometers and tens of kilometers</td>
</tr>
<tr>
<td>Order-IV fractures</td>
<td>tens and hundreds of centimeters</td>
<td>hundreds and thousands of meters</td>
</tr>
<tr>
<td>Large order-V cracks</td>
<td>&gt;20 mm</td>
<td>&gt;10 m</td>
</tr>
<tr>
<td>Medium order-VI cracks</td>
<td>10 – 20 mm</td>
<td>1 – 10 km</td>
</tr>
<tr>
<td>Fine order-VII cracks</td>
<td>2 – 10 mm</td>
<td>0.1 – 1 m</td>
</tr>
<tr>
<td>Narrow order-VIII cracks</td>
<td>&lt;2 mm</td>
<td>&lt;1 m</td>
</tr>
</tbody>
</table>

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logic body, the continuity of which is broken. Voluntarily or
involuntarily, the authors of classifications of masses, which
are based on orders of breaks in continuity have defined two
problems (classification of the dimensions of the cracks, and
their enclosing medium), and proposed a solution to these
problems for the area where they intersect.

The classification under consideration is not a universal
classification of tectonic cracks. Actually, it is a classifica-
tion of lump (block) structures, since in a jointed medium,
geologic bodies, which are thought of as a unified whole
(seams, benches, dikes, etc.), are usually distinguished from
the enclosing medium by petrographic composition and
physico-mechanical properties, and this difference, as a rule,
will result in the formation of tectonic disturbances at the
interface of the two media. The set of disturbances, which
restrict the geologic bodies, form a complete lump (block)
structure.

Certain authors, who have come forward with a critique
of the classification in Construction Rule and Regulation
2.02.02–85, propose alternative classifications as a replace-
ment. For example, G. G. Kocharyan and A. A. Spivak have,
based on study of characteristic frequencies and threshold
amplitudes of relaxation pulses in the vicinity of different
ranks of disturbances, come to the conclusion concerning the
existence of a spacing in the hierarchical divisibility of tec-
tonic blocks, which defines the inclusion of a certain number of
(i + 1)th-level blocks in an ith-level block [2]. Based on
their data, the spacing of the hierarchical divisibility is equal
to three, whereupon this fact had been established previously
by geomorphologists (A. Kaye and G. Trikar, 1959).

The correspondence between the spacing of the hierar-
chical divisibility of the blocks s (let us call it so) and k —
the rate of change in the spacing of the orders of cracks that
follow one after the other — should be defined more pre-
cisely. The relationship between s and k is established by the
equation \( k = s - 1 \). These quantities differ from unity, which
is manifested as a result of the fact that for multiple-order
organization of a network of cracks, the “position” of one of
the ith-order cracks is occupied by a large (i − 1)th-order
crack (if the number of the order of the large crack is lower
than the number of the order of the fine crack). For large s
values, this difference no longer exists, but when \( s = 3 \), the
quantity \( k = 2 \). In this manner, therefore, G. G. Kocharyan
and A. A. Spivak recommend that we assume \( k = 2 \). For the
classifications proposed by the Construction Rules and
Regulations and Yu. A. Kosygin (for linear bodies), \( k = 9 \) [3];
for R. M. Lobatskaya and G. L. Koff’s classification, \( k = 4 \)
[4]. M. V. Rats has recommended that \( k \) be assumed equal to
10\(^{3}\), but has mentioned the conditionality of such a division,
and the possibility of varying \( k \) as a function of the problems
being resolved [5].

A review of frequently utilized and competitive classifi-
cations of tectonic cracks and block structures has indicated
that the rate of change in the spacing of orders of cracks fol-
lowing one after the other (a parameter that permits compari-
on of some classifications) is not clearly defined, and is
fluctuated by various authors primarily within the interval
from two to nine (the value of 10\(^{3}\) is egregiously on the high
side).

**Correspondence Between Competitive Classifications
and Actual Data.** To bring lucidity to the problem concern-
ing the rate of change in the spacing of crack orders that
follow one after the other, it is expedient to revert to experi-
ence gained with study of tectonic jointing, which has been
accumulated during the design and construction of hydro-
technical structures. Table 2 presents results of measurement
of the spacing of crack orders VIII – V in rock masses — the
beds of hydrotechnical structures, which are composed of
various lithologic types of rocks possessing different uni-
axial-compressive strengths in the saturated state. The no-
menclature of crack orders was determined in conformity
with the classification from Construction Rule and Regula-
tion 2.02.02–85, although the correspondence is very condi-
tional, since the geologists also took into account specific
characteristic features of the rock masses when dividing a set
of cracks into orders. Data contained in Table 2 were
collected from materials published in the collection “Geol-
ogy and dams,” archival materials held by the institute
Gidroproekt, and on the basis of measurements performed by
the author on several projects.

Analysis of Table 2 indicated that the ratio \( k \) of the spac-
ing of adjoining orders varies over a rather broad range (from
1.17 to 34.09), and is virtually independent of the material
composition of the rocks and their compressive strength.
Figure 1 shows a plot of the distribution. Since the shape of
the distribution curve is highly sensitive to variation in the
grouping interval of the set, its was natural, assuming the
possibility of the existence of a rate of change in the spacing
of adjacent orders, to group a set in a manner such that the
centers of the intervals corresponded to integers 2, 3, 4...
(1.5 – 2.5; 2.5 – 3.5; ...). The mode of the distribution in
Fig.1 is equal to two (this agrees with the view point
expounded by G. G. Kocharyan and A. A. Spivak), but
the mathematical expectancy of the distribution, which is
equal to five, is very similar to the view point shared by
R. M. Lobatskaya and G. L. Koff.

Approximately 75% of the area under the distribution
curve corresponds to a range of from two to nine in the
region used to determine the plot in Fig. 1 (about 75% of
all cases fall within this range). In a large number of the
projects, therefore, results of measurement of the crack spac-
ing for orders VIII through V, which are at our disposal, are
neither inconsistent with any of the competitive classifica-
tions, nor make it possible to surrender preference to any one
of them.

If the same distribution plot is presented as a composite
of even and odd \( k \) values, the overall probability of even \( k
\) values is approximately 2/3, and, accordingly, the overall
probability of odd \( k \) values is about 1/3. Is this disproporti-
ion by chance? Obviously not. The answer to the question “lies
on the surface.” Inhomogeneities of a geologic body may be
the cause of its division by cracks into a certain even or odd