ԳԵՈՄԵԽԱՆԻԿԱՅԻ ՊՐՈԲԼԵՄՆԵՐ, ԵՐԵՎԱՆ
ПРОБЛЕМЫ ГЕОМЕХАНИКИ. ЕРЕВАН
PROBLEMS OF GEOMECHANICS, YEREVAN

1971, 5 : 100—112

УДК 624. 131.37

MODELS OF BLOCK SYSTEMS

BLAHOSLAV KOSHTAK, C.E., C.Sc.[1]

SYNOPSIS. Photoelastic models were analyzed to find characteristics of stress distribution in a system of blocks. The research was motivated by megageological considerations directed to the Earth's crust block systems. The most simple schemes of blocks were investigated in two dimensions under compressive load acting in the plane of the system. The models confirmed that the load is supported in the system by a bearing skeleton formed by rigid blocks. Thus some blocks are overloaded while some others relieved. Configuration of the bearing skeleton is due to the original irregularities in the blocks system. In the Earth's crust natural irregularities are to be expected. It is argued therefore that a similar situation with a system supporting load through stress concentrating blocks is likely to occur in the Earth's crust. Besides, relieved blocks are expected as well as other features that were observed. Actual deflections from rigidity of blocks are expected to modify the configuration of the bearing skeleton but not to change the basic behaviour of the system.

INTRODUCTION

Any geotectonic hypotesis represents a serious simplification of nature which results in a selection of factors that are assumed to be important in the involved problems. To compare the effeciency of different factors their role must be evaluated. This task, which is sometimes very difficult to achieve by making observations in the field, can be solved by such means like models.

In spite of the fact that the factor of mechanical discontinuities in the rock mass is generally considered of the utmost importance, there is a lack of imformation about its role. This is why this model study was made as an attempt to follow the effect of one chosen factor—set of mechanical discontinuities to the stress distribution in the Earth's crust. The effort was concerned with megageological problems. However, the interpretation is believed to be found in different scales.

Not all types of discontinuities were taken into account, but preferably those that allow a massif to be considered as an assembly of blocks that are more or less distinct. Thus one of the basic geotechnical views (Thadeu, 1967) upon a rock massif is followed. It is expected that the discontinuities may be often more important than the properties of the rock substance itself. While increasing volume of mass new and different systems of discontinuities become efficient. At the limit, the

[1] Senior Scientific Worker, Dept. of Engineering Geology, Geological Institute, Czechoslovak Academy of Sciences, Prague.

idea of a continental block system (Moody, 1966), as of giant fragments of the Earth's crust, is foreseen.

To see the function of discontinuities more clearly, highly simplified models were employed. They were not intended to characterize any particular region of the Earth's crust but to represent a structured medium contradictory to contiuum.

PRELIMINARY EXPERIMENTS

In preliminary experiments with block systems it became apparent that it was very difficult to achieve a perfect match of individual blocks in models. The dimensional variability due to production of individual blocks followed the laws of statistics and had a basic influence on the stress distribution. It was recognized that the phenomenon cannot be regarded as aparasitic effect only.

Dantu (1957) who introduced a new photoelastic procedure for visualization of the !oad transfer in granular media, pointed out the formation of load-bearing chains of grains as a physical nature of the load transfer in such a medium. He has shown also that the similar nature of stress transfer can be traced in the highly heterogeneous medium like concrete. Not dissimilar mode of load transfer was recently postulated by Voropinov (1967) in his description of failure mechanism in rocks. There is an idea of „bearing skeleton", transformation of which governs the trength behaviour of rock in the process of plastic deformation. Beyl (1951) analysed the practical influence of „bridging" due to competent beds of rock on mining operations. All these authors refer to the same phenomenon seen from different standpoints. Their common finding is the formation of a „bearing skeleton" that may be a response to the mismatch of grains as well as to the heterogeneity or competency of the material or to the differential movements due to plastic deformations in a granular medium.

Having this in mind it was decided not to prevent the natural mismatch of blocks in the models but rather to follow its consequences. So the original idea of discontinuity of the mass was accepted as closely related to that of inhomogeneity of the mass. This aspect is reflected in the proposed interpretation of the experiments as well as in the basic approach. In this broad approach the block systems can be considered as different forms of granular media or the concept of granular media is considered appropriate even for block systems.

GENERAL APPROACH

Consider, on the surface of the Earth's body, an idealized crust as a single uniform layer cut into blocks[2]. The crust is relatively rigid con-

[2] Tabular composition of the Earth's crust has been recently postulated by Moody (1966). According to his view „the fundamental building blocks of the Earth's crust as it now exist are polygonal tabular blocks of continental composition and of varying size and shape and similar blocks of oceanic composition".

trary to the ductility of the Earth's body, and different processes in the body may cause movements in the system due to horizontal forces, and horizontal stress field[3] will take place in addition to the confining pressure due to force of gravity. The crust is on the surface of Earth and it may well dilate laterally, in the vertical direction. There is some justification therefore to consider the crust as a two-dimensional system; a cracked shell in a state of compression.

The horizontal stress field will be affected by the configuration of the discontinuities between blocks and their frictional properties, as well as by rheological behaviour of the block substance. Considerable variation of block properties can be expected[4]. There is not enough evidence about the frictional properties[5] on block boundaries. The dimensions of blocks are estimated at 100 km diameter and at 40 km thickness[6]. The arrangement of blocks is indicated by the linearity of large faults and hypothesis about shear[7] patterns (Moody, 1966). The idea of rectangular joint system can be derived from, although many irregularities are to be expected.

Such were the few hypothetical assumptions combined with some considerations and data which formed the basis for the design of models. Hence it was concluded that:

(*a*) A two-dimensional model would be appropriate to the situation of a limited section of the Earth's crust block system on the surface of the Earth's body;

---

[3] New evidence about the general horizontal stress field in the Earth's crust and about serious variations in the field was given by Hast (1967) and Van Heerden and Grant (1967).

[4] Heterogeneity of the Earth's crust was indicated by the small scale measurements (Kosminskay and Riznichenko, 1954; Melchior, 1967). Variation of rock behaviour due to inelastic deformational properties of rock is considered by Birch (1963) and Robertson (1953), and due to factor of time by Scheidegger (1963).

[5] Jeager (1959) after triaxial experiments with very different joints in rock concludes that „measured coefficients of friction lie in the range 0,5—0,8 and differ but surprisingly little between the various surfaces." A similar result can be only roughly assumed with megageological objects. Archard (1958) after theoretical and experimental verification concludes that the simple Amonton's law of friction is applicable in case of higher loads either for elastic or plastic contact deformations. On the other hand Brace and Byerlee (1967) and Maurer (1965) conclude that the coefficient of friction must change as the stress changes. The presence of water in joints reduces frictional strength and makes the problem even more complex. The results indicate that not too much gain can be expected at present by introducing intricate frictional conditions to the models.

[6] The bottom of blocks need not be necessarily identical with the Moho-discontinuity but rather lithosphere-asthenosphere boundary. The estimate of block dimensions which resulted from many discussions in the Geological Institute of the Czechoslovak Academy of Sciences is not considered critical in the experimental design and wide deflections are expected. Yet, any result should be interpreted with respect to the realistic sizes of blocks.

[7] Horizontal shear in considerable depth is usual while vertical shear is exceptional. This has been found by Hast (1967).

(*b*) Blocks of quadratic shape would be the simplest approximation of the block geometry;

(c) Uniaxial horizontal loading in coaction with plane confining pressure[8] would be representative for Earth's crust loading conditions.

(*d*) The major deformations or movements are to be expected at the boundaries of blocks, where contacts take place, and at the vicinity of ductile blocks. The blocks are mostly regid[9] while block properties may vary seriously. Consequently, the energy of elastic deformations of many crustal blocks can be comparatively high, though plastic deformations will be more evident. Therefore, elastic models generally, but combined with plastic insertions, would be designed for the study.

(*e*) The uniform frictional properties throughout the joint system could be assumed. The joints can be either closed or open differentially[10]. The action of hydrostatic pressure would not be introduced in the joints because of the experimental difficulties. Instead, the action of plane confining pressure[8] should be introduced on the model boundaries.

(*f*) The lack of data makes the definition of model conditions incomplete and similitude in its technical sense cannot be well established. Only qualitative results would be interpreted and the model would be seen as a scheme only.

EXPERIMENTAL WORK

Two-dimensional photoelastic models made from rectangular or circular blocks were employed. Different materials were used, namely glass, plexiglass, epoxy resin, gelatin and elastoplex[11]. Since models were mosaics, forces were transmitted from block to block through contacts; and actual deformation due to material characteristics, played an important role in stress distribution. Individual blocks of any particular model were originally made from one particular material. Later some models were produced where the influence of a plastic insertion amidst rigid grains was studied.

Individual blocks in a system were usually of the same shape and size but small and random differences in dimensions were present. This was found to be of extreme importance.

Models were deformed in special loading frames. The first frame allowed uniaxial loadings of a square area of mosaic. The load could act against the faces of blocks (Fig. 1,a) or diagonally (Fig. 1,b). The latter

---

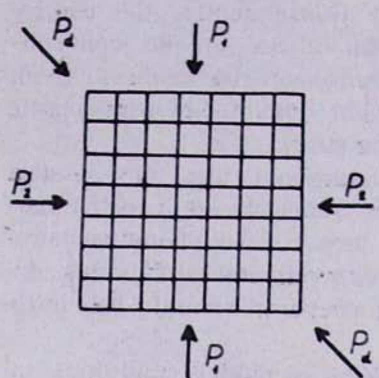
8 Meaning of this term according to loading scheme of Fig. 2.

9 Morgan (1968) concludes that the evidence presented in his paper favours the existence of large „rigid" blocks of the crust.

10 Besides the many tensile features on the surface of the Earth, cracks functioning as open cracks in the depth can be foreseen (Secor, 1968). Pore pressure can be an important factor in it (Brace, 1968).

11 Optically sensitive benzyl acrylic resin of the Czechoslovak production.

condition meant that the block system was forced to follow the change of shape of the frame from square to rhombus. Slipping along block boundaries was an essential feature of deformation. The action of forces $P_1 = P_2$ created a state of „plane confining pressure" and, consequently, it conditioned friction in joints which were bare, not cemented. The action of P_d had to overcome this friction in order to cause movement along the joints. Slipping proceeded in jumps.

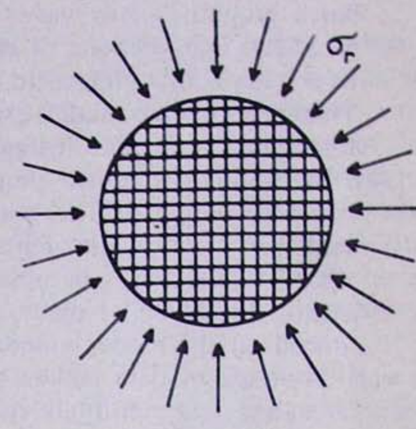


a) $P_1 > O$; $P_2 = O$; $Pd = O$
b) $Pd > P_1 > O$; $P_1 = P_2$

Fig. 1. *Square frame loading conditions* a) uniaxial loading; b) diagonal loading.

Նկ. 1. Բեռնավորման պայմանները՝ քառակուսի շրջանակում. միառանցքային բեռնավորում. անկյունագծային բեռնավորում։

Рис. 8. *Соотношение между системой, ратной рамке:* а) одноосное нагружение; в) диагональное нагружение.



$\sigma_r = const$

Fig. 2. *Round frame loading conditions:* plane confining pressure.

Նկ. 2. Բեռնավորման պայմանները՝ կլոր շրջանակում՝ հարթ սահմանափակող ճնշում։

Рис. 2. *Условия нагружения в круглой рамке: плоское ограничивающее давление.*

Soft rubber packing preventnd boundary block corners from damage due to contact with the steel frame and simultaneously acted as a compressive medium for the mosaic. Thus the loading condition Fig. 1,b created shear conditions in the area of mosaic, that resulted in the stress transformation and slipping of blocks.

The second loading frame was designed for the pure „plane confining pressure" condition. On the boundary of a round area of mosaic, uniform concentric pressure σ_r was created (Fig. 2) using air-pressure loading system. Either cylindrical or square block mosaics could be tested in this frame.

The mosaics were analysed in polarised light. Isochromatics recorded on photographs represent the principal-shear contour lines. Dense fringe and bright colour areas can be interpreted as highly stressed while dark zones and shadows mean relief of shear. Photos in circulary polarizated light which follow, show isochromatics without interference of isoclinals which would be present at plane polarilation. The results would be better seen in colours than in the black and white version in which the isochromatic fringe order is hard to be distinguished.

In the interpretation of patterns, the optical sensitivity of materials must be taken into account. While glass or plexiglass show only light, at the same load epoxy resin and gelatin show rich colour fringe patterns. Rich patterns cannot be therefore interpreted always as indication of high load. The square frame was used for high sensitivity models; the circular frame for low sensitivity ones. The shape of models on photographs indicates the type of loading used, and even the structure of mosaic can be also distinguished.

OBSERVATIONS

Results are given by the isochromatic patterns on Figs. 3 to 6. Fig. 3 and Fig. 4 show epoxy resin and gelatin models respectively, Fig. 5 glass models, and Fig. 6—plexiglass models.

The inspection of photographs shows a large variety of patterns which likely indicate complicated behaviour. The models can be conveniently described in two separate groups. The first group deals with only square block models loaded in square frame and the models represent details of mosaics. The second group represents mosaics containing more individuals so that the phenomena can be investigated as a whole. In mosaics the distribution of the individuals with respect to the dimensional deviations, is random.

Square block models under unixial loading conditions

At a glance, Fig. 3 show extremely complicated patterns. Several blocks are in a serious non-uniformity of loading.

Fig. 3,a an uniaxialy loaded mosaic, shows non-uniformity in loading of different sets of blocks and stress concentration along „vertical" block boundaries. The latter may be explained as a consequence of an eccentricity of load. Namely, the second left set is overloaded with relatively low excentricity but the right sets show high excentricity of loading, e. g. the second right shows the excentricity to the left. The third right set bears comparatively less load, expecially at its lower part. No slipping occurs.

Diagonal loading induces the blocks to slipping (Fig. 3b). While some blocks slip along the „vertical", the others slip along the „horizontal" joints. Hitching of corners stops slipping and causes extremely high stress concentration Some blocks seem to be free from load, some loaded diagonally, some bearing intensive edge load. The load distribution is very unbalanced.

Progress in slipping excludes hitched corners by shearing them off. This is connected with sudden change in stress pattern. Eventually, slipping occurs only in one direction, „vertical" or „horizontal", regarding the Figures. Fig. 3,c is an example of slipping in „horizontal" direction but the chances are the same for either direction. While several slipping blocks are relieved, other retain typical patterns indicating „diagonal" or "edge" load.

A somewhat different effect can be found with the last model (Fig. 3,d). One joint, namely the third „vertical" from the left, allowed an extreme slip. Hence, the transmission of forces in the system is extremely unbalanced. Actually, the load is transmitted by the diagonal set of blocks from the right lower corner of the system to the centre where it splits to „horizontal" and „vertical" components. This leaves the other regions of the system almost completely unloaded. Despite this extreme effect, the internal stress patterns of loaded blocks are very similar to those in previous pictures. No new type has appeared.

While Fig. 3 represents models made from epoxy resin, which is relatively hard material with small deformations in comparison with the slips that take place in the mosaics, Fig. 4 represents models made from gelatin, relatively much more deformable material. The ratio of elastic moduli of these two materials is about 10^3:1. Accordingly the behaviour is different. Deformations of the gelatin models are of the same order as the slips in mosaics.

Fig. 4,a shows a model with easy slipping joints as a result of low friction conditions. The transmission of load due to the high deformation is well balanced by individual blocks. The diagonal loading prevails in spite of the actual slipping of blocks along the „horizontal" joint system. During the process of slipping the joints remain completely closed along their length.

Fig. 4,b shows a model of the same kind but with high friction in joints. The friction was high enough to stop slipping. All the energy of loading is stored by the strain of blocks. Several disconnections in joints can be regarded as rare failures. It is not surprising that the state of stress is almost the same as in the case of an one-piece model (Fig. 4,c) representing continuum. While the deformed square net as seen on Fig. 4,b means real joints between blocks, the net on the continuous one-piece model as seen on the Fig. 4,c is drawn on the surface only and does not mean joints.

To recapitulate, the continuous media (Fig. 4,c) may be split into a block sysiem without any serious change of stress distribution as long as the friction in joints is high (Fig. 4,b). Once the bonds between blocks are destroyed, slipping may proceed and stress and strain is considerably redistributed (Fig. 4,a). The load transmission may still be well balanced between individual blocks. The situation becomes extremely complicated with rigid materials. Joints tend to open during the deformation. Any difference in slipping or in shape and size of blocks results in extremely unbalanced transmission of load through the system (Fig. 3).

It should be noted that this set of experiments shows models ranging in behaviour from the continuous and homogeneous media right through the mosaic of rigid blocks.

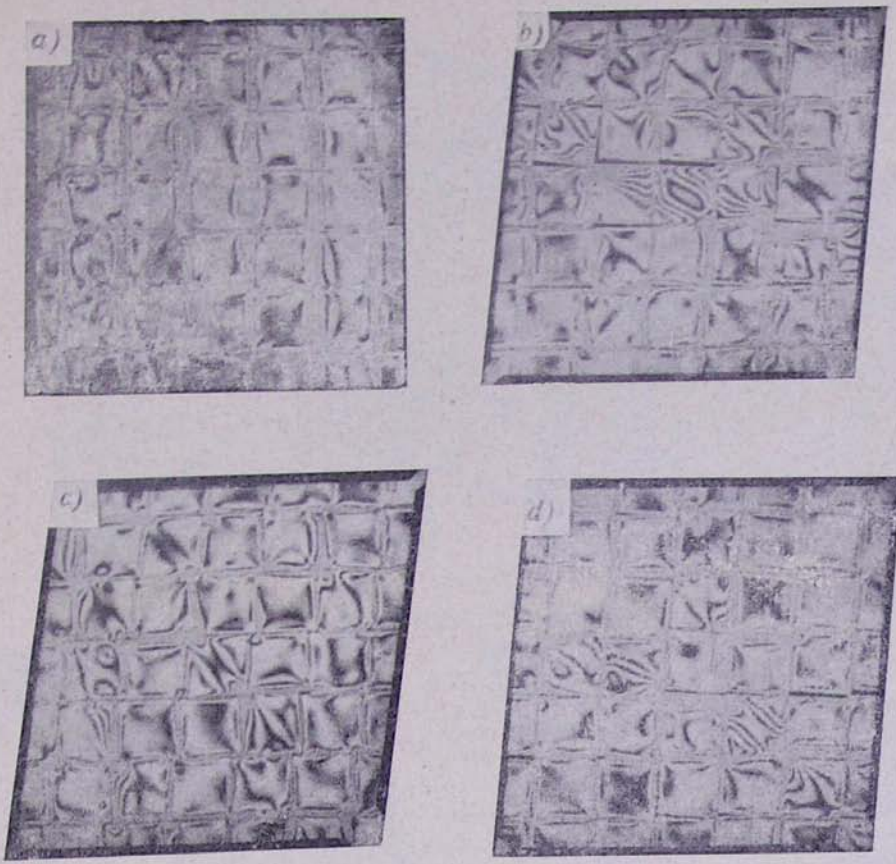


Fig. 3. *System of square (epoxy) rigid blocks in circulary polarized light*; shear stresses are visualized by isochromatics. *a*) Uniaxial loading („vertical" in the photo) results in an assymetrical and non-uniform distribution of stress in individual block-sets. *b*) Diagonal loading produces slipping of blocks; first stage—hitching of corners results in high stress concentrations. *c*) Next stage—the hitched corners are cut off; uniform slipping of block-sets. *d*) Boundaries of uniform slipping zones show extremely overloaded blocks (densely fringed) and completely unloaded ones (dark or shadowed).

Նկ. 3. Կոշտ (էպօքսիդային խեժ) քառակուսի բլոկների սիստեմ շրջանաբևեռացված լույսում. *Շոշափող լարումները երևում են իզոխրոմներից։ a) Միառանցքային բեռնվածք (լուսանկարի վրա («ուղղաձիգ») առաջացնում է առանձին բլոկներում անհամաչափ և անհամասեռ լարումների բաշխում. b) Անկյունագծային բեռնվածքը առաջացնում է բլոկների սահում. առաջին փուլ՝ անկյունների կառչումը բերում է լարումների բարձր կենտրոնացմանը. c) Հաջորդ փուլը՝ կառչած անկյունները կտրված են. բլոկների հավասարաչափ սահում. d) Հավասարաչափ սահող բլոկների սահմանները ցույց են տալիս գերբեռնված բլոկներ (հաճախակի զոլերով) և բոլորովին բեռնաթափված բլոկներ (մուգ կամ մգացված)։*

Рис. 3. *Система жестких (эпоксидная смола) квадратных блоков в кругово-поляризованном свете;* касательные напряжения видны по изохромам. *a*) Одноосное нагружение («вертикальное» на фотографии) вызывает асимметричное и неоднородное распределение напряжений в отдельных блоках. *b*) Диагональное нагружение вызывает скольжение блоков; первая стадия—зацепление углов приводит к высокой концентрации напряжений. *c*) Следующая стадия—зацепленные углы срезаны; равномерное скольжение блоков. *d*) Границы равномерно скользящих зон показывают перегруженные блоки (с частыми полосами) и совершенно разгруженные (темные или затемненные).

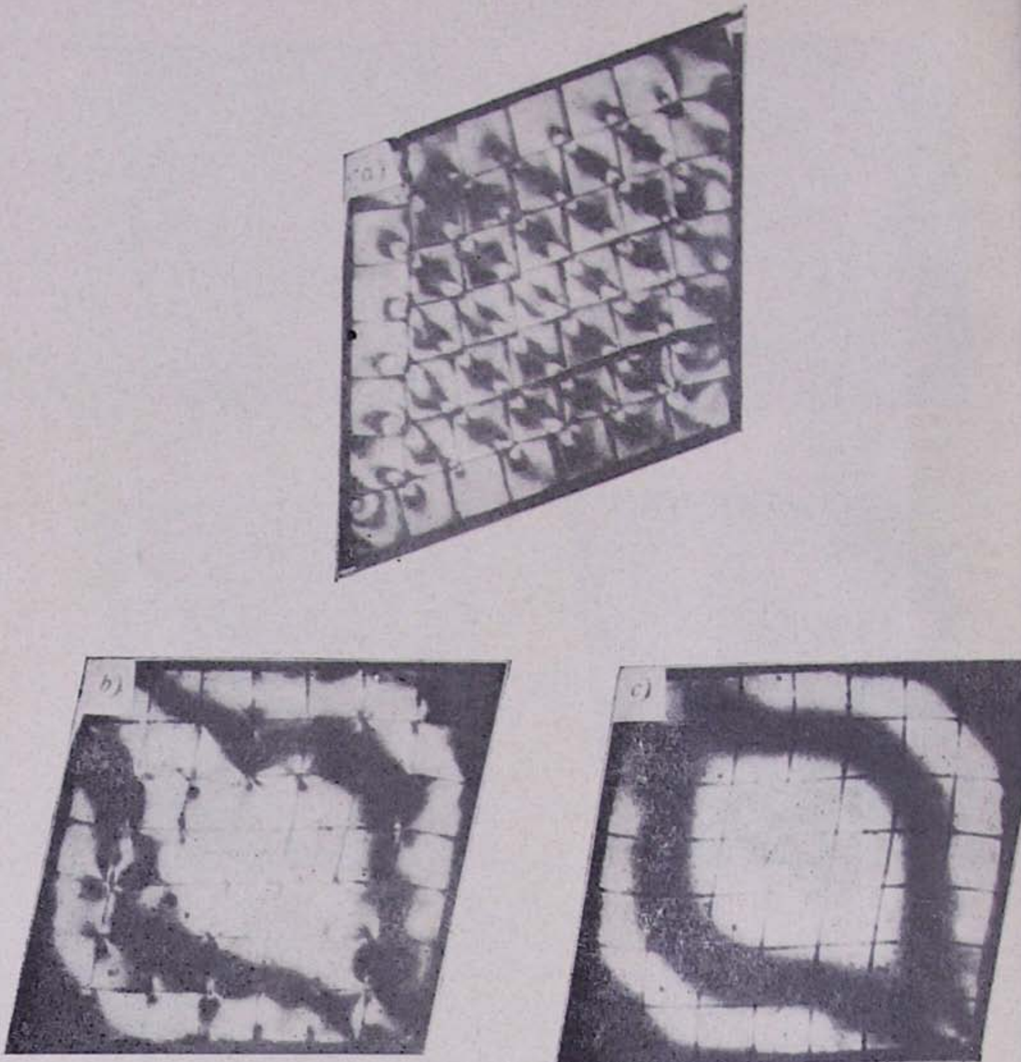


Fig. 4. *System of ductile (gelatin) square blocks under diagonal loading in circulary polarized light.* a) Low friction in joints results in block slipping; well balanced transmission of load through diagonal zones of blocks. *b)* High friction in joints stops slipping. *c)* Continuous medium for comparison with the previous block system with high friction in joints; square net drawn on the surface.

Նկ. 4. Ձգելի (ժելատինե) քառակուսի բլոկների սիստեմ անկյունագծային բեռնավորման դեպքում շրջանաբևեռացված լույսում: *a) Ցածր շփումը կցվածքներում առաջացնում է բլոկների սահում բեռնվածքի լավ հավասարակշռված փոխանցումը բլոկների անկյունագծային գոտիների միջով. b) Բարձր շփումը կցվածքներում կանգնեցնում է սահումը. c) Անընդհատ սիստեմ՝ կցվածքներում բարձր շփումով նախկին սիստեմի հետ համեմատելու համար. մակերևույթի վրա նշանակված է քառակուսային ցանց։*

Рис. 4. *Система тягучих (желатиновых) квадратных блоков при диагональном нагружении в кругово-поляризованном свете.* *a)* Низкое трение в стыках вызывает скольжение блоков; хорошо уравновешенная передача нагрузки через диагональные зоны блоков. *b)* Высокое трение в стыках останавливает скольжение. *c)* Непрерывная система для сравнения с предыдущей системой блоков с высоким трением в стыках; на поверхности нанесена квадратная сетка.

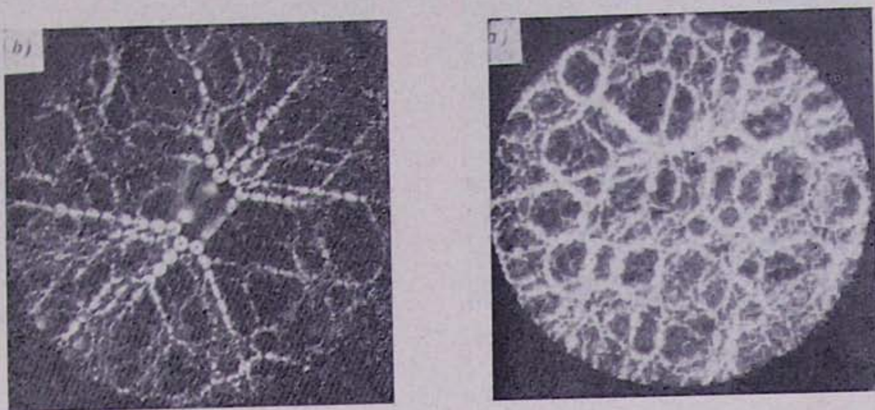
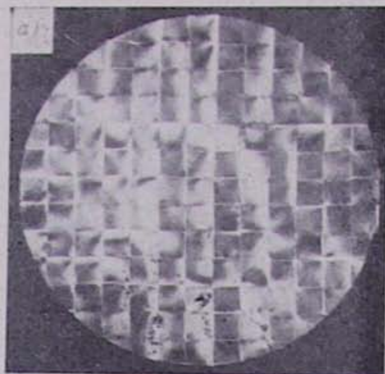


Fig. 5. *System of cylindrical (glass) grains under plane confining pressure in circulary polarized light.* *a*) interna. arching visualized by astress net cutting through zones of relieved blocks. *b*) Square alock insertion in the system occasions uniaxial stress concentration.

Նկ. 5. Գլանաձև (ապակե) հատիկների սիստեմը հարթ սահմանափակող ճնշման տակ շրջանաբևեռացված լույսում. *a*) *Ներքին կամարային էֆեկտը տեսանելի է լարումների ցանցից, որը հատում է բեռնաթափված բլոկների գոտիները.* *b*) *Սիստեմի մեջ քառակուսի բլոկների ներառումն առաջացնում է լարումների միառանցքային կենտրոնացում։*

Рис. 5. *Система цилиндрических (стеклянных) зерен под плоским ограничивающим давлением в кругово-поляризованном свете.* *a*) Внутренний арочный эффект видим по сетке напряжений, пересекающей зоны разгруженных блоков. *b*) Включение квадратных блоков в систему вызывает одноосную концентрацию напряжений.



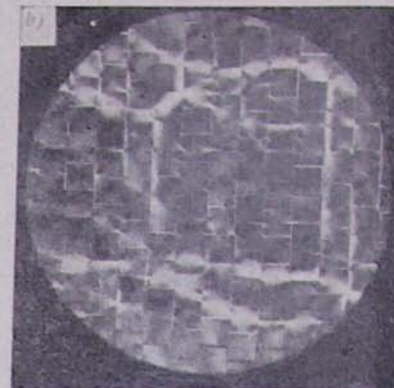


Fig. 6. *System of rigid (plexig.lass) square blocks under plane confining pressure in circulary polarized light. a)* Formation of a stress net with relieved zones in a regular system. *b*) Narrow stress concentrations across the bonds in a „brick-bond" system.

Նկ. 6. Կոշտ (պլեքսիգլասե) քառակուսի բլոկների սիստեմը հարթ սահմանափակող ճնշման տակ շրջանաբևեռացված լույսում: *a*) *Կանոնավոր սիստեմում բեռնաթափված գոտիներով լարումների ցանցի առաջացում: b*) *«Կարակապ սիստեմում» լարումների նեղ կենտրոնացում կարերի լայնքով:*

Рис. 6. *Система жестких (плексиглазовых) квадратных блоков под плоским ограничивающим давлением в кругово-поляризованном свете. a)* Образование сетки напряжений с разгруженными зонами в правильной системе. *b*) Узкая концентрация напряжений поперек перевязок в системе с «перевязкой швов».

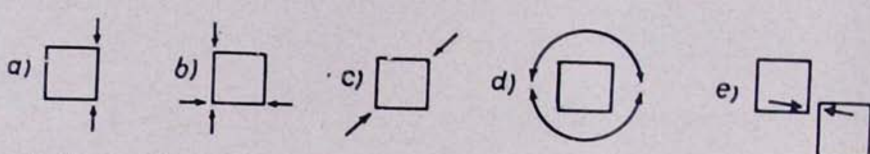


Fig. 7. *Types of load transmission through individuals in a square block system: a*) edge load, *b*) combined, *c*) diagonal, *d*) relieved, *e*) hitching of corners.

Նկ. 7. Քառակուսի բլոկների սիստեմում առանձին տարրերի միջով բեռնվածքի փոխանցման տիպեր՝ *a*) *Եզրային բեռնվածք. b*) *Կոմբինացված. c*) *Անկյունագծային. d*) *Թուլացած. e*) *Անկյունների կառչում:*

Рис. 7. *Типы передачи нагрузки через отдельные элементы в системе квадратных блоков: a*) краевая нагрузка; *b*) комбинированная; *c*) диагональная; *d*) ослабленная; *e*) зацепление углов.

Models loaded by plane confining pressure

Fig. 5,a shows a model formed by glass cylinders. They are all of the same diameter, which vary at random in the range of 5%. During the increase of load a stress pattern appears with an increasing intensity but with a steady form. The same occurs with load decrease. No slipping of particles can be observed.

The theory (Dantu, 1961) assuming the correct uniform size of cylinders and neglecting the second order values due to deformations would lead to the uniform distribution of stress due to particular cylindrical individuals. Contrary to this theory the experiment shows the role of the size and shape variation in the simplest granular medium. An extremely unbalanced transmission of load results. Internal arching concentrates stresses leaving unloaded regions. The stress pattern that may be called „stress net" tends to form hexagons in accordance with the interval geometry of the mosaic. The experiment with the resulting stress net is reproducible if the distribution of individuals in the media does not change.

The next models show the phenomenon of the stress net under more special conditions. Fig. 5,b shows a model of the same kind as the previous but containing square insertion. The regularity of the cylindrical grain structure is in disagreement with the dimensions of an alien object. The stress net transforms in such a way that the insertion is loaded almost uniaxially. So, it may be shown that even the plane confining pressure conditions may result in uniaxial compression of some elements.

Fig. 6,a shows a square block system in the round frame under the conditions of plane confining pressure. There is an appearance of stress net also. Moreover, the same typical stress patterns of individuals can be found as in the models on Fig. 3. In inspection of these photographs the different optical sensitivities of the model materials are to be taken into account.

Fig. 6,b shows a square block system after slipping along the „vertical" joints so that a dissimilar system of „brick-bond" is created. There is also a stress net in such a system but different response in „vertical" and „horizontal" directions may be seen. The transmission of load is better balanced along the slipping direction than across the bonds.

Common features of mosaics

All models show „stress net" as a common feature of compressed mosaics. The stress net means a formation of relatively narrow but continuous zones of high stress concentrations that mediate the force transmission through the medium. Contrary to the stress zones there appear relieved zones that do not participate directly on the force transfer. The stress-net formation can be compared with phenomenon of arching.

A highly homogeneous system of ductile blocks (Fig. 4,a) shows a pattern that can be regarded as an exceptionally regular stress net.

The load transmission is well balanced but concentrated to the diagonal zones of blocks. That may be regarded as a limit case of arching. However, the stress-net formation is not only due to pressence of dicontinuities in the medium. Any irregularities in the shapes and dimensions of blocks cause their differentiation in the system and an uneven stress distribution results. The strees net appears in gross. Some blocks or grains are overloaded while others are relieved of load (Figs. 5,a and 6,b). The geometry of the system is reflected in the geometry of the net as well as in the type of load that can be found at different blocks.

The square block models (Fig. 3) show those types in more detail. There is the „edge load" type which is the most common in the system at any type of external load, and its bi-axial combination; then the „diagonal load" type, an attribute, as a daughter product of arching. Slipping of blocks leads to hitching of corners which is responsible for the very high stress concentrations The described types are sketched on Fig. 7. Their modifications can be found in any block system loaded by any compressional load applied externally.

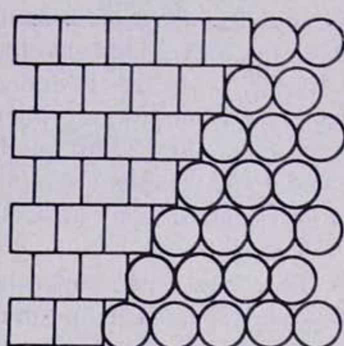


Fig. 8. *Relation between a system formed by square blocks in a „brick-bond" position and a system of cylindrical blocks in a compact, triangular position.*

Նկ. 8. Հարաբերությունը՝ կարակապի դիրքում գտնվող քառակուսի բլոկներից կազմված սիստեմի և կոմպակտ եռանկյան դիրքում գտնվող գլանային բլոկների սիստեմի միջև:

Рис. 8. *Соотношение между системой, образованной квадратными блоками в положении «перевязки швов» и системой цилиндрических блоков в компактном, треугольном положении.*

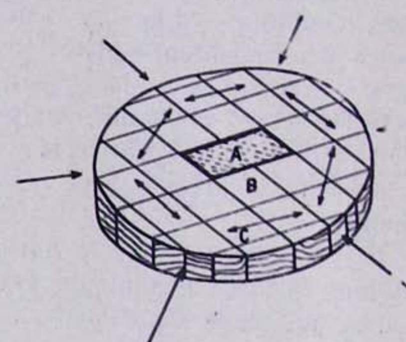


Fig. 9. *Arching due to relaxation of an individual ductile block and formation of a relieved zone*; *A*—ductile block; *B*—relieved zone; *C*—arching zone.

Նկ. 9. Առանձին ձգելի բլոկների ռելաքսացիայի հետևանքով կամարային էֆեկտը և թուլացած գոտիների առաջացումը՝ *A*—ձգելի բլոկներ. *B*—թուլացած գոտիներ. *C*—կամարային էֆեկտ։

Рис. 9. *Арочный эффект вследствие релаксации отдельных тягучих блоков и образование ослабленных зон*: *A*—тягучие блоки; *B*—ослабленные зоны; *C*—арочный эффект.

One could imagine a process in which originally a rectangular system slipped to the „brick-bond" position but the stress concentration at corners caused their failure so that the cylindrical-grain system would result (Fig. 8). Due to slipping the dimensional irregularities of blocks were pronounced so that a stress net occurred in gross of the system. Some blocks or grains formed the „bearing skeleton" of the system while others were relieved. According to experiments a ductile block can initiate the formation of a relieved zone which surrounds it containing a large number of rigid blocks[12] (Fig. 9). Thus the formation of the bearing skeleton in the system can be explained as a result of geometrical irregularities as well as of the variation in the rigidity of blocks, and the experiments performed on rigid not matching blocks can be analogically interpreted in terms of variation of rigidity. The shaded i. e. relieved zones of blocks can be seen as more ductile ones and the stressed as the more rigid ones. Consequently a block system has some mechanical properties of two-phase medium like some kinds of plastics formed by skeletons with filling of a more ductile mass[13]. Under different conditions the units of the skeleton are more or less uniaxially stressed. On the other hand there are filling zones which are approaching the state of confining pressure in the process in which the internal balance of the system is to be achived.

INTERPRETATION

In view of the megageological objects the detailed interpretation is a matter of discussion not yet finished. The experimental work, though inspired by certain geological problems, is believed to be virtually independent, having potential application in any problems where the conditions are similar.

The intention was to illustrate the behaviour of a block system. As a result the stress-net formation in gross is observed and the interaction of block geometry and material heterogeneity of the system can be postutated.

The results are presented in terms of the photoelastic stress patterns i. e. isochromatics. To prevent some misleading arguments the Author would like to make several suggestions. First, not to interpret the stress concentrations simply as proportional to deformations. A rigid block can, store much more energy than another one capable of relaxation. As a result there is a tendency of stress concentration in the rigid blocks that are forming the bearing skeleton. Then the rigid blocks can be seen as those highly stressed just because of being competent and their permanent deformation can be relatively small. The largest deformations can be found in the ductile blocks as the results of relaxation. Thus the unstressed blocks in the models may be interpreted as the relieved ones or still relaxing and creeping but highly deformed. On the other hand the ductility and low stress will result in relatively easy slips on boundaries of blocks which are then determined to react swiftly to vertical movement of the subcrustat material. Blocks of the bearing skeleton can

[12] This reminds of the situation around a mine opening in a broken rock (Hobbs, 1966).

[13] Some properties of multiphase materials were discussed by Andrews (1964).

be seen as relatively stable grains, channels of horizontal stresses, that would sensitively react by a temporsry stress increase to such short-term events like tidal loads. The large amount of the stored energy may cause their failure, which can be compensated for only by the transformation of the stress net in a relatively large region of the system. The failure may occur either at the boundary of a block, thus accompaned by a sudden slip at the discontinuity, or inside the block, accompanied by an upheaval of the mass. In both cases an immediate response in the stress net is inevitable.

The difference between the blocks taking part in the bearing skeleton, and between the rest, is essentially in their loading. While the relieved blocks are in the state of confining pressure, or in a stage of a relaxation process leading to it, the block of the bearing skeleton can be in a very complicated state of stress. The possible loading systems are believed to be compatible with those shown in the experiments (Fig. 8). There the uniaxial loadings prevail.

The model apparently fails if the rigid blocks are in such a minority that the bearing skeleton could not get in action, i. e. the rigid blocks would be flowing like islands in a viscous mass. This is the case of process in which the viscous behaviour prevails.

Although the experiments were carried out on elastic blocks, the formation of the bearing skeleton is not conditioned by the unambiguous elasticity of the blocks. A deflection from elasticity does not seem to change the reaction as far as the contrast in deformability of different blocks in the system is significant. Moreover not only effects due to heterogeneity but also effects due to geometrical irregularities in the Earth's crust block system are supposed to be real. This is why the phenomenon of arching with all the consequencies, is excepted to be present in the Earth's crust. Then tectonic forces seemingly coming from „nowhere" could be explained by stress concentrations reflecting processes seated deeper in the Earth. Some effects of the arching could be confirmed by field stress measurements.

CONCLUSIONS

In view of the behaviour of the block-system models it is suggested to see the Earth's crust block system as a two-phase granular medium. Horizontal compression is transmitted through a bearing skeleton of rigid blocks which are in the state of stress resulting from their position in the system as well as from their shape and rheologic behaviour. As a second phase of the system there are ductile blocks either vastly deformed due to relaxation process or relieved in surrounding of the arched rigid blocks. The most rigid blocks concentrate the stresses and play the dominant role in the configuration of the bearing skeleton. Some of the rigid blocks may be relieved of stress in the neghbourhood of ductile blocks. The geometry of the system can be used to determine the typical loading conditions of individual blocks.

The two-phase behaviour of the Earth's crust is dependent on the constrast in rigidity of individual blocks. If ductile blocks prevail there is no chance for the bearing skeleton to be formed and a different model of the Earth's crust should be accepted.

ԲԼՈԿԱՅԻՆ ՍԻՍՏԵՄՆԵՐԻ ՄՈԴԵԼՆԵՐ

Տեխն. գիտ. թեկնածու Բլահոսլավ Կոշտյակ[14]

Ռեֆերատ. *Բլոկային սիստեմում լարումների բաշխման բնութագրերի որոշման համար վերլուծված են ֆոտո-առաձգական մոդելներ։ Հետազոտությունները կապված են երկրի կեղևի բլոկային սիստեմների մեգաերկրաբանական դիտման հետ։ Հետազոտված են պարզագույն բլոկային սիստեմներ՝ երկչափումային սեղմող բեռնվածքի տակ, որը գործում էր այդ սիստեմի հարթություններում։ Մոդելները հաստատեցին, որ բեռնվածքը սիստեմներում ընկալվում է կոշտ բլոկների կողմից կազմված կրող կմախքով։ Այսպիսով, որոշ բլոկներ գերբեռնված են, իսկ մյուսները՝ բեռնաթափված։ Կրող կմախքի ուրվագիծը որոշվում է բլոկային սիստեմների սկզբնական անկանոնություններով։ Ենթադրվում է, որ երկրի կեղևում գոյություն ունեն բնական անկանոնություններ։ Այդ պատճառով գալիս ենք այն եզրակացության, որ երկրի կեղևում համանմանաբար գոյություն ունեն լարումներ կենտրոնացնող նման բլոկային սիստեմներ, որոնք ընկալում են բեռնվածքը. ենթադրվում է, որ գոյություն ունեն բեռնաթափված բլոկներ։ Իրական բլոկների ոչ կոշտությունը ձևափոխում է կրող կմախքի ուրվագիծը, բայց չի փոխում սիստեմների վարքի հիմնական յուրահատկությունները։*

МОДЕЛИ БЛОКОВЫХ СИСТЕМ

Канд. техн. наук **БЛАГОСЛАВ КОШТЯК**[15]

Реферат. Для определения характеристик распределения напряжений в системе блоков были проанализированы фотоупругие модели. Исследования были связаны с мегагеологическим рассмотрением блоковых систем коры. Были исследованы наиболее простые схемы блоков в двух измерениях под сжимающей нагрузкой, действующей в плоскости этих систем. Модели подтвердили, что нагрузка в системах воспринимается несущим скелетом, образованным жесткими блоками. Таким образом, некоторые блоки перегружены, тогда как другие разгружены. Конфигурация несущего скелета определяется первичными неправильностями блоковых систем. Предполагается, что в земной коре существуют природные неправильности. Поэтому делается заключение о том, что в земной коре, вероятно, существует подобная же система блоков, концентрирующих напряжения, которая воспринимает нагрузку; предполагается, что существуют разгруженные блоки. Нежесткость действительных блоков видоизменяет конфигурацию несущего скелета, но не изменяет основных особенностей поведения систем.

ԳՐԱԿԱՆՈՒԹՅՈՒՆ — ЛИТЕРАТУРА — REFERENCES

Andrews E. H., 1964. Conference on the Mechanics of Anisotropic and Inhomogeneous Materials, Manchester, April 1964. Brit. J. Appl. Phys., 15: 777—781.

Archard J. F., 1958. Elastic deformation and the laws of friction. Proc. R. Soc. A 243: 190.

Beyl Z. S., 1951. The prestressed state of the Earth's crust, its causes and preservation. Intern Conf. Rock Pressure and Support in Workings, Paper F 2, Liège.

Birch F., 1960—1961. The velocity of compressional waves in rocks to 10 kilobars. J. Geophysical Research, 1960, 65 (4): 1083—1102; 1961, 66 (7): 2199—2224.

Birch F., 1963. Megageological considerations in rock mechanics. State of Stress in the Earth's Crust, edited by W. R. Judd, Proc. Conf. Santa Monica, Calif., Elsevier, New York, pp. 56—82.

---

[14] *Չեխոսլովակիայի Գիտությունների ակադեմիայի երկրաբանական ինստիտուտի ինժեներական երկրաբանության բաժնի ավագ գիտական աշխատող, Պրագա։*

[15] Старший научный сотрудник отдела инженерной геологии Геологического института Чехословацкой Академии наук, Прага.

Brace W. F. and **Byerlee J. D.**, 1967. Recent experimental studies of brittle fracture of rocks. Failure and Breakage of Rock. edited by Ch. Fairhurst. The Am. Inst. of Mining, Met. and Petroleum Eng., Inc., New York, pp. 58—81.

Brace W.F., 1968. The mechanical effects of pore pressure on fracturing of rock. Proc. Conf. Research in Tectonics (Kink Bands and Brittle Deformation), edited by A. J. Baer, D. K. Norris. Geological Survey of Canada, Ottawa, Paper 68—52, pp. 113—123.

Byerlee J. D., 1966. The frictional characteristics of Westerly granite, M. I. T. Ph. D. Thesis, Geology, Cambridge, Mass.

Dantu P. M., 1957. Étude des contraintes dans les milieux hétérogènes. Application au béton. Lab. Central des Ponts et Chaussées, Publ. No 57—6. Paris, pp. 3—25.

Dantu P. M., 1961. Étude mécanique d'un milieu pulvérulent formé de sphères égales de compacité maxima. Lab. Central des Ponts et Chaussées, Publ. No 61—3, Paris, pp. 1—10.

Hast N., 1967. The state of stresses in the upper part of the Earth's crust. Engineering Geology, Amsterdam, 1967/1968, 2(1):5—17.

Hobbs D. M., 1966. A study of the behaviour of a broken rock under triaxial compression, and its application to mine roadways. Int. J. Rock Mech. Min. Sci., Pergamon Press, 3:11—43.

Jaeger J. C., 1959. The frictional properties of joints in rock. Geofisica Pura e Applicata, Milano, 43 (11): 148—158.

Kosminskaya I. P., and **Riznichenko Y. V.**, 1964. Seismic studies of the Earth's crust in Eurasia. in: Odishaw, H., „Research in Geophysics". The M. I. T. Press, Cambridge, Mass., 2, p. 81.

Maurer W. C., 1965. Shear failure of rock under compression, Soc. of Petrol. Eng. Journal, Vol. 5. No SPE. p. 1054

Melchior P., 1967. Oceanic tidal loads and regional heterogeneity in Western Europe. Communications de l'observatoire de Belgique, Série B, No 24, Série géophysique, No 83; Geophys. J. of the Royal Astronomical Soc., 1967, 14: 239—241.

Moody J. D., 1966. Crustal shear patterns and orogenesis, Tectonophysics, 3: 479

Morgan W. J., 1968. Rises, trenches, great faults and crustal blocks. J. of Geophysical Research, 73, (6): 1959—1982.

Robertson E. C., 1963. Viscoelasticity of rocks. State of Stress in the Earth's Crust edited by W. R. Judd., Proc. Conf. Santa Monica, Calif., Elsevier, New York, pp. 181—234.

Scheidegger A. E., 1963. Principles of Geodynamics. Springer, pp. 147—161.

Secor D. T., Jr., 1968. Mechanics of natural extension fracturing at depth in the Earth's crust. Proc. Conf. Research in Tectonics (Kink Bands and Brittle Deformation), edited by A. J. Baer, D. K. Norris, Geological Survey of Canada, Ottawa, Paper 68—52, pp. 3—48.

Thadeu D., 1967. Geotechnical characterization of rock. Lecture delivered at the Superior Technological Institute, Lisbon, pp. 1—22.

Van Heerden W. L., and **Grant F.**, 1967. A comparison of two methods for measuring stress in rocks. Int. J. of Rock Mechanics and Mining Sci., 4 (4): 367—382.

Voropinov J., 1967. Rheological research on rock in shear. Proc. Geotechnical Conf. Oslo, 1: 305—309.