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Received on 22.11.2006

UDC 551.242

## INVESTIGATION OF INITIATION CONDITIONS OF RELATIVE DISPLACEMENTS OF THE FAULT-BLOCK MEDIA UNITS UNDER VIBRATION LOADING

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*On the basis of computer modeling by the method of movable cellular automata the theoretical investigation of initiation conditions of relative displacements along the interfaces of complex stressed geological media blocks in the complex intense condition under local vibrating loading has been performed. It is shown, that defining factors at formation of unstable shift on the interblock border of fracture-block geological environments are the relative value of shift stresses and also the frequency of vibrating loading, i. e. time of impulse energy allocation. Low in power, but long-continued loadings on influences on high-voltage borders of section are the most effective in respect to power inputs.*

### Introduction

It is known that geological environments possess the hierarchical multilevel organization of their block structure [1]. Any part of the earth's crust represents a set of structural elements divided by continuity infringements of different scale. Block interfaces have lower strength and deformation characteristics than material of blocks itself. Therefore continuity infringements of various scales are one of the ways of mountain massif existence at greater irreversible deformations [2]. Realization mechanisms of complex stressed geoenvironment elastic energy can be various [3]. The main one among them is localization of irreversible deformations along interfaces of the earth's crust blocks. The mode and speeds of block relative displacements on active fractures are defined by features of structure and the local stressed condition, and also by the external natural and technogenic factors [4, 5]. Values of displacement speeds can fluctuate from several mm/years (crypic mode) up to the first m/s at strong earthquakes. One of the earthquake mechanisms is relative shift movement of blocks. Its realization is connected with achievement of limiting value of shift stresses along the interface. Therefore the relevant problem of geophysics is the definition of initiation conditions of unstable displacement by active interfaces of the earth's crust.

In the present work, on the basis of computer modeling by the method of movable cellular automata (MCA) [6], the investigation of initiation conditions of block dynamic sliding along the interface located in a complex stressed condition under vibrating loading has been carried out. We shall note that during number of

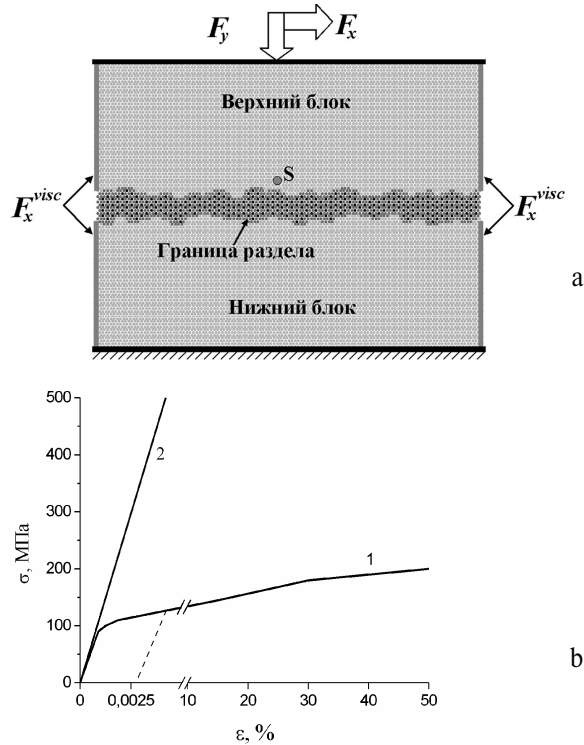
years the MCA method is successfully used for studying of response features of complex heterogeneous materials and environments [7, 8].

### Problem statement of numerical modeling

For solution of stated tasks on the basis of MCA method the qualitative bidimensional model of section interface of structural elements of block environment, Fig. 1, *a*, has been developed. The model sample consisted of two high-strength blocks divided by the interface area for which the mechanical properties of broken down substances were set. Response functions of block automata and the interface are shown on Fig. 1, *b*. It is visible, that for block automata the response linear function was set, and for the interface the response function had a long irreversible area. Continuity infringements in the interface area, size of which is much smaller than the size of cellular automata, were modeled implicitly through the response function (curve 2 on Fig. 1, *b*). Infringements of greater scale were modeled by setting of unbound pairs of cellular automata in the interface material.

In performed calculations the lower surface of the model sample was fixed, and loadings were applied to the upper surface, Fig. 1, *a*. It is important to note that geological environments are located in the constrained conditions limiting volumetric deformations of blocks, and freedom of their relative moving along interfaces. The pair of environment elements, environment influence of which was brought to increase inertia movements and also to intensive absorption of mechanical loading energy was considered in the work. For imitation of these environment properties on automata of la-

teral surfaces of blocks the additional viscous force was acting, directed on axis  $X$ ,  $F_x^{visc} = -\alpha V_x$ , where  $V_x$  is the component  $X$  of the respective automata speed.



**Fig. 1.** Structure and scheme of model interface loading (a), response functions of block automata (curve 1) and interface material (curve 2) (b). Dashed line corresponds to unloading

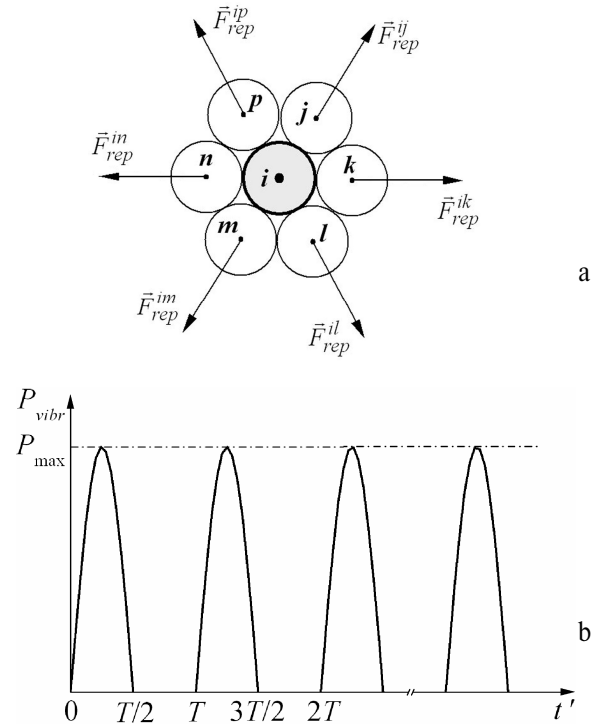
In works [8, 9] it is shown that influence of vibrating effects is essential when stress level along interfaces is close to integrated value of fluidity limit. Therefore the preliminary loaded samples were considered in the work. The initial stressed condition was set by the application to the sample upper surface of the external force having normal ( $F_y$ ) and tangential ( $F_x$ ) components (Fig. 1, a). Value  $F_y$  was fixed and its specific value made 20 % from the fluidity limit of border material. Under vibrating loading the important role is played by natural frequencies connected with distribution of longitudinal and cross-section of elastic waves on the sample [8]. For the given system (Fig. 1) they are concluded between values  $v_L^+$  and  $v_H^+$ , respective to distribution of cross-section and longitudinal elastic waves on length  $L$  and height  $H$  of the sample.

The important criterion for seismic danger estimation of geoenvironment fragments stressed condition is «stability» of current condition of active interfaces to vibrating influences. The following calculations are performed in the work for studying of vibration influence. After setting the initial stressed condition of the interface (Fig. 1) the local vibrating influence was applied to the system, the **automaton S** of the upper block, located near the interface Fig. 1, a, was used as a source. Local cyclic loading was set as follows. In all the pairs of the **automata S** with neighbors besides «classical» potential and viscous forces of interaction [6] operated the additional periodically fluctuating normal force of repulsion

(Fig. 2):

$$F_{rep}^{ij} = \begin{cases} S^{ij} P_{max} \sin(2\pi\nu(t-t_{start})), & (n-1)/\nu < (t-t_{start}) < (n-1/2)/\nu \\ 0, & (n-1/2)/\nu < (t-t_{start}) < n/\nu \end{cases}$$

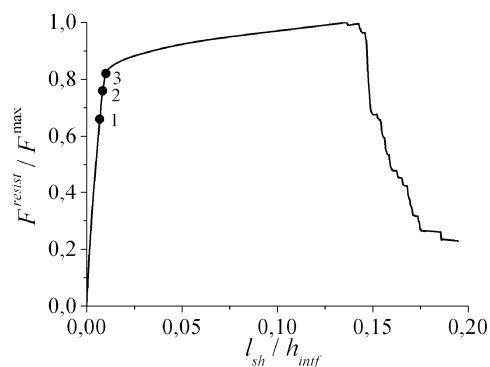
where  $S^y$  is contact area of automata pair,  $\nu$  is frequency,  $t_{start}$  is time of the cyclic loading beginning,  $t$  is present time,  $P_{max}$  – fluctuation amplitude of «vibrating» pressure,  $n$  is cycle number.



**Fig. 2.** The scheme of action (a) and the law of «vibrating» pressure fluctuation (b) of «dotted» source of vibrating influences (in figure  $T$  is period of vibration)

On Fig. 3 the dependence of resistance force of the sample  $F^{resist}$  to shift deformation with constant speed under value of tangential displacement  $l_{sh}$  is resulted. On the graph the variables  $F^{resist}$  and  $l_{sh}$  are normalized respectively on the maximal resistance force  $F^{max}$  and border thickness  $h_{inj}$ . It is visible that the curve of resistance to shift is characterized by three basic stages: quasi-resilient, quasi-plastic current and beyond (areas of softening and residual durability).

Frequently geoenvironments function in conditions of constant influence of vibrations of various nature. Gradual accumulation of small irreversible deformations on the most loaded interblock borders (in the end of the quasi-resilient and in the beginning of the quasi-plastic stages on Fig. 3) can lead to occurrence of block dynamic sliding. We shall note that influence of weak indignations on geodynamic processes (including preparation of earthquakes) is one of the most discussed problems in geophysics [10]. Therefore the investigation of initiation features of unstable shift along block interfaces under cyclic influences with controllable parameters (frequency  $\nu$  and amplitude  $P_{max}$ ) is carried out in the work. The interfaces being in various stressed conditions, shown by dots 1–3 on Fig. 3, were considered.



**Fig. 3.** Dependence of resistance force to tangential displacement of the model fracture active wing  $F^{resist}/F^{max}$  from displacement value  $l_{sh}/h_{inf}$ . Dots on the diagram mark the allocated levels of stress  $F^{resist}/F^{max}$ : 1) 0,66; 2) 0,76; 3) 0,82

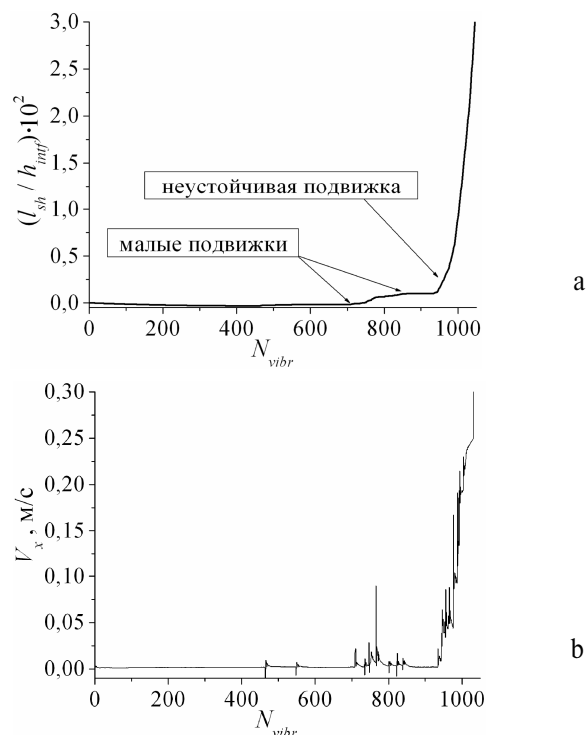
### Laws of unstable shift formation under local vibrating influences

Results of calculations show that local vibrating influence leads to accumulation of irreversible deformations in the interface and generation of damages. As stressed condition of the interface zone is defined by action of forces from structural blocks, then with accumulation of damages these forces begin to surpass the force of interface shift resistance. Thus the upper block begins to be displaced in a direction defined by the force  $F_x$  until the force  $F^{resist}$  does not become equal to  $F_x$  because of interface material hardening, and performance of the environment will not lead to a supper. Such displacement can be considered as a small steady shift. The further influence leads to occurrence of new damages and shifts. Such shifts in addition accelerate the process of deformation accumulation along the interface. With increase in number of damages the value and speed of displacement of the upper block increases. At the certain stage the effective shift durability of the interface becomes lower than specific value of the applied force which leads to unceasing movement of the upper block with acceleration which can be associated with unstable shift.

Dependences of block displacement values along the border  $l_{sh}$  and instant speed of displacement  $V_x$  from quantity of vibration cycles of vibration  $N_{vibr}$  is shown on Fig. 4. It is visible that, since some moment, the upper block begins to make small displacement along the interface, Fig. 4, a. Gradually, the amplitude of shifts increases and time intervals between them decreases and becomes comparable to duration of shifts itself. At the certain stage another shift becomes unceasing and the dynamic slipping is happening, Fig. 4, a. The analysis of speed time dependence of the upper block shows that at the lowest average speed of the initiated by vibrations displacement ( $V_x \sim 1,6 \cdot 10^{-30}$  m/s) «splashes» of speed, which amplitude increases with increase in amplitude of shifts and at late stages of loading 10 sm/s, Fig. 4, are connected with areas of shifts. The unceasing growth of speed occurs at the stage of unstable shift.

It is possible to draw an analogy between «splashes» of the upper block movement speed (Fig. 4) and seismic waves radiated by centers of earthquakes. If to consider shifts along the border as analogues of seismic events then

the whole process of cyclic loading represents final stages of earthquake preparation. It is obvious, that small «steady» shifts answer to foreshocks, and dynamic sliding of the upper block to the main event. Apparently from Fig. 4, between the end of the last «foreshock» and the beginning of the main event there is a long time interval (about 10 % from full time of «earthquake preparation») during which unstable shifts are absent. This effect in certain respects is similar to the phenomenon of seismic calm which quite often takes place before large earthquakes [11]. In particular, the long seismic calm lasting about 40 years is revealed before the Chuiskiy (Altay) earthquake on September 27<sup>th</sup>, 2003 [12]. Low seismicity of highly stresses areas of environment is explained by action of powerful dissipative processes, and also by various mechanisms of hardening [3]. Exhaustion of their resources leads to fragile destruction. Duration «calm» area depends on parameters of vibrating influence ( $\nu$  and  $P_{max}$ ) and affinity of the interface intense condition to limiting value.

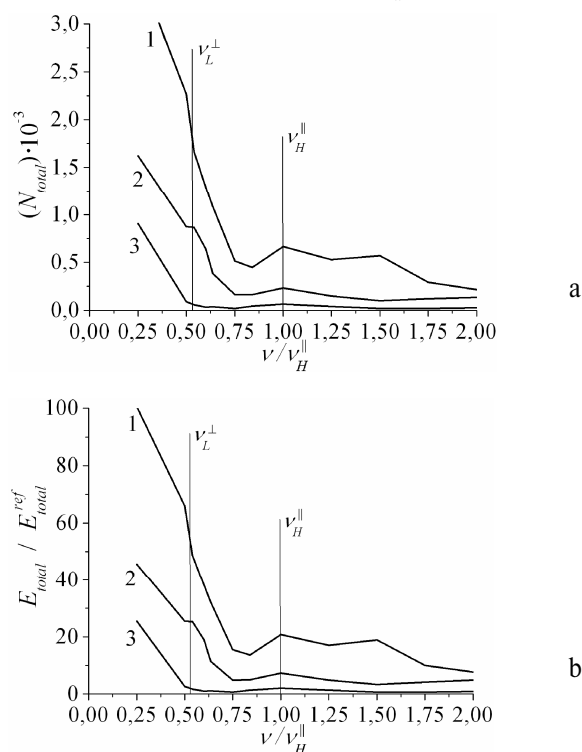


**Fig. 4.** Dependence of tangential displacement value  $l_{sh}/h_{inf}$  (a) and tangential component of movement speed of the upper block upper  $V_x$  (b) from cycle quantity of local vibrating influence at  $F_x/F^{max}=0,66$ ,  $\nu=2 \cdot \nu_{||}$ ,  $P_{max}=122,5$  MPa

### The analysis of local vibrating influences «efficiency» for initiation of shifts under active interfaces

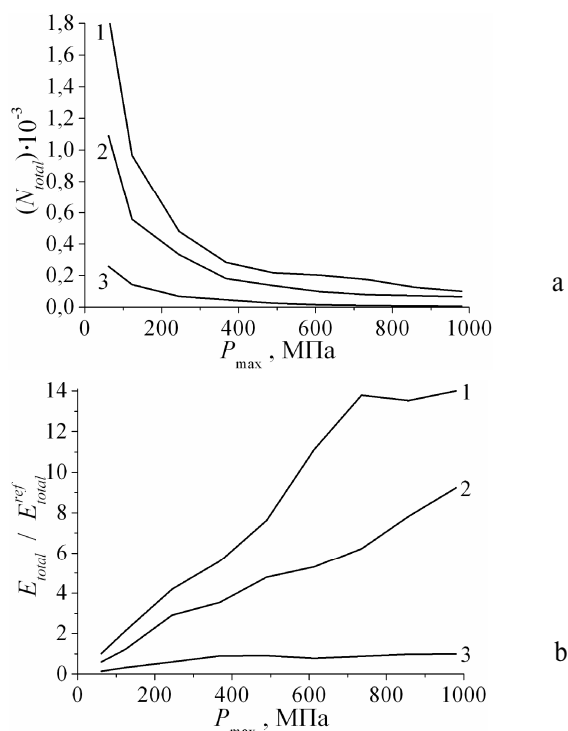
As shown above, local vibrating influences can lead to occurrence of unstable shifts. The analysis of «efficiency» of such influences estimated through quantity of cycles  $N_{total}$  and full energy of vibrations  $E_{total}$ , necessary for initiation of dynamic sliding of blocks is performed in the work. Frequency dependences  $N_{total}$  and  $E_{total}$  for three allocated on Fig. 3 stressed conditions are shown on Fig. 5. Frequency values of vibrating influence  $\nu$  are attributed to maximal natural frequency of the sample ( $\nu_{||}$ ). Values of energy to the value  $E_{total}^{ref}$ , respective to the problem with following

conditions of loading:  $F_x=0,82 \cdot F^{\max}$ ,  $v=2 \cdot v_H^{\parallel}$ ,  $P_{\max}=980$  MPa. It is visible that at  $v < v_L^{\perp}$  the value  $N_{total}$  quickly decreases with frequency growth. In the field of natural frequencies  $N_{total}$  takes on some level and at further increase  $v$  practically does not change, Fig. 5, *a*. Energy of one cycle of vibration  $E_{cycle}$  poorly depends on frequency, therefore dependences  $E_{total}(v)$  repeat curves  $N_{total}(v)$ , Fig. 5, *b*. Thus, under local vibrating influences on the loaded interface with frequencies comparable or exceeding natural for the investigated fragment of the environment, the quantity of energy spent for initiation of unstable shift is defined, mainly, by relative value of shift stresses ( $F_x/F^{\max}$ ).



**Fig. 5.** Dependence of full quantity of cycles (a) and energy (b) of local vibrating influence, spent on initiation of dynamic sliding of the active block, from frequency  $v/v_H^{\parallel}$  at  $P_{\max}=490$  MPa and  $F_x/F^{\max}$ : 1) 0,66; 2) 0,76; 3) 0,82

The dependences  $N_{total}$  and  $E_{total}$  from the amplitude of «vibrating» pressure  $P_{\max}$  for various stressed conditions of modeling border are shown on Fig. 6. It is visible that with increase in  $P_{\max}$  the quantity of the cycles necessary for initiation of the unstable shift decreases in inverse proportion to the amplitude. Exception is made with the curve 3 for which the given dependence is fair only at «small»  $P_{\max}$  ( $P_{\max} < 300$  MPa). The dependences  $E_{total}(P_{\max})$  are increasing and can be approximated by direct lines (Fig. 6, *b*). It is connected by that energy of one cycle of vibration  $E_{cycle}$  is proportional to  $(P_{\max})^2$ . With respect to (Fig. 6, *a*) the parity  $E_{total} \sim P_{\max}^3$  is fair. Thus, with reduction of vibration amplitude the number of influence cycles increases but, at the same time, the full value of energy spent on initiation of the unstable shift along the border decreases. It allows to assert, that weak on capacities, but long influences on highly stressed interfaces in block environments in some cases can appear as the most effective (at least, from the point of view of power inputs).

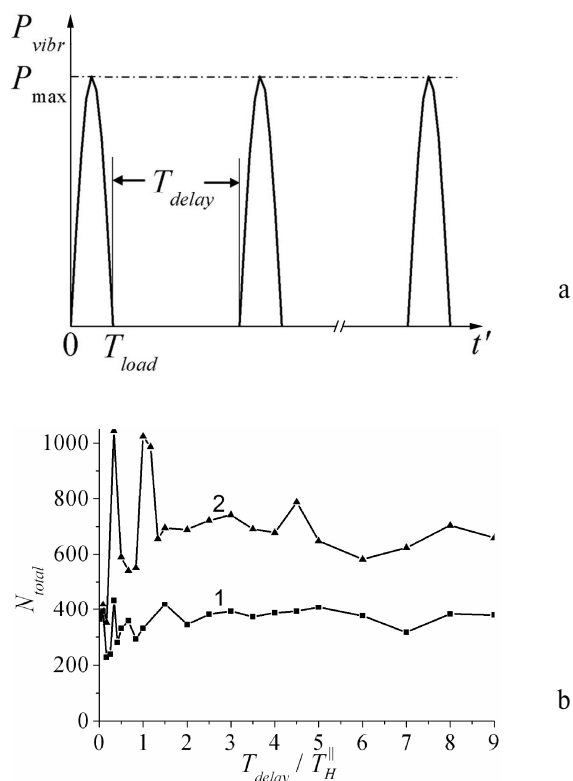


**Fig. 6.** Dependence of full quantity of cycles (a) and energy (b) of the local vibrating influence, spent on initiation of the dynamic sliding of the active block, from the amplitude  $P_{\max}$  at  $v=2 \cdot v_H^{\parallel}$  for  $F_x/F^{\max}$ : 1) 0,66; 2) 0,76; 3) 0,82

It is necessary to note that the interval of «peak» pressure of the vibrating source considered in the present problem is high enough. So, characteristic pressures of wave fluctuations composing microseismic background in the earth's crust are much lower. At the same time, the pressure reaching tens-hundreds of MPa take place under the influence on the studied fragment of explosive infringement by technogenic sources of fluctuations in capacity of which well vibrators can act [13]. Series of high amplitude fluctuations with duration up to several minutes can be radiated also in the centers of strong earthquakes.

The character of vibrations in real environments both natural and artificial genesis, frequently essentially differs from idealized (Fig. 2, *b*). Besides the distinctions concerning forms and repeatability of signals, the important feature of many radiators of mechanical fluctuations is the inequality of time «impulse» influence  $T_{load}$  and time interval  $T_{delay}$  between influences. Thus the ratio attitude  $T_{delay}/T_{load}$  can vary in wide limits. So, the microseismic background represents complex and irregular sequence of extending «wave packages» with various characteristics divided by time intervals of various durations. Therefore the response of model interface (Fig. 1) on local vibrating influences of the source S representing a series of «impulses» of the sine wave form with set porosity (defined by the ratio  $T_{delay}/T_{load}$ ) has been investigated in the work. The scheme of such influence is shown on Fig. 7, *a*. The influence of interval duration  $T_{delay}$  and  $T_{load}$  on the efficiency of vibrating influence defined through quantity of cycles  $N_{total}$  and energy  $E_{total}$  spent on initiation of the unstable shift of the upper block has been analyzed. Results of calculations, in particular, have shown that significant fluctuations of the value  $N_{total}$

occur in a narrow range  $T_{delay} < 2 \cdot T_H^I$  ( $T_H^I = 1/v_H^I$ ). Thus the amplitude of such fluctuations can reach up to 50 % from the average value and more (Fig. 7). With increase  $T_{delay}$  the value  $N_{total}$  «stabilizes», and at  $T_{delay} \gg T_H^I$  becomes practically constant (Fig. 7). We shall note that as energy of one impulse of influence does not depend on  $T_{delay}$ , the dependence  $E_{total}(T_{delay})$  repeats the shown on Fig. 7.



**Fig. 7.** The law of source «vibrating» pressure change at  $T_{load} \neq T_{delay}$  (a) and dependences of value  $N_{total}$  from value of an interval between two influences  $T_{delay}/T_H^I$ : 1) 0,25; 2) 0,67,  $F_x/P_{max}=0,66$ ,  $P_{max}=490$  MPa

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Change of the influence impulse duration (values  $T_{load}$ ) does not lead to qualitative change of the described laws, however can be accompanied by appreciable change of cycle quantity necessary for initiation of the unstable shift (curves 1 and 2). We shall notice that dependence of the «established» value  $N_{total}$  (respective to conditions  $T_{delay} \gg T_H^I$  and  $T_{delay} \gg T_{load}$ ) from impulse duration  $T_{load}$  submits to shown on Fig. 5 law  $N_{total}(v)$ , if to take  $T_{load} = T/2 = 1/2v$  and consider the absence of dependence  $N_{total}$  from porosity of impulses. The reason of decrease in efficiency of vibrating influence (expressed, in particular, in terms  $N_{total}$  and  $E_{total}$ ) at increase  $T_{load}$  is speed reduction of energy allocation by the source.

Thus, efficiency of local vibrating influences on the interface located in loaded condition is defined, mainly, by time of energy allocation during one cycle of influence and practically does not depend on porosity.

## Conclusion

The conducted on the basis of computer modeling by the MCA method studying of laws of initiation under local vibration influences of relative displacements of model blocks along the interface which is being in the loaded condition, has allowed to reveal their generality with final stages of strong earthquakes preparation, which mechanism is connected with relative shift displacement of the earth's crust structural blocks. The analysis of the received results has shown that efficiency of similar dot sources of vibration is defined mainly by relative value of shift stresses and influence frequency or time of impulse energy allocation and practically does not depend on porosity. Thus, long-continued influences with rather small amplitudes on highly stressed interfaces in block environments are the most effective from the point of view of power inputs.

The work has been performed within the limits of integration projects of the Siberian Branch of the Russian Academy of Science 27 and 87, project № 3 of the Presidium of the Russian Academy of Science № 16 program, and also with support of the grant of the Russian Federal Property Fund (06-05-64792-a).

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Received on 26.10.2006