ON INTENSITY OF EARTHQUAKES ON ROCKY GROUNDS

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A theoretical foundation for an engineering and statistic conclusion is given on anultimate force of earthquakes on rocky grounds. As an estimation of this force a simple correlation has been obtained for determining maximum velocity of particle vibrations during a violent tremor. The correlation is based on an ultimate magnitude of flow of seismic energy and a destructive stress of rocks. A comparison is drawn between obtained data and the instrumental observation.

1. When designing buildings and structures in seismic regions one should have data on the movements of ground on the earth surface during violent earthquakes. These data result form the velocity spectrums or accelerations of particle vibrations of various grounds whose nature during strong movements has not been studied well enough as yet. Up to the present time the recordings of the seismic vibrations in the epicentral zones of the earthquakes force 7, 8 and 9 are very rare. Owing to this the basic source for reliable information on the movements of grounds in such cases is next to none.

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A thorough engineering analysis of damages and destructions caused to buildings and structures located on various grounds during violent and destructive earthquakes which occurred on the globe during various periods of time testifies to the fact that the earthquake force 7 may prove destructive on rock. This was observed during the Lisbon earthquake in 1755, Andizhan earthquake in 1899, California earthquake in 1906, Messina earthquake in 1908, the Crimean earthquake in 1927, Fukui earthquake in 1946, Ashkhabad earthquake in 1948, Khait earthquake in 1949 , etc.

Many concrete examples of such kind can be cited to show similar situation, they are given in the works (1) dealing with the investigations of the consequencies of violent earthquakes. These have been used to derive the above engineering and statistic conclusion.

2. Following is an attempt to produce a theoretical background for this engineering and statistic conclusion. For this purpose let us analyse seismic energy developing from a seismic focus to the earth surface using a method of geometric seismology (2, 3). Let us assume that the earth crust in the vicinity of the seismic focus in homogeneous and isotropic whilst near the earth surface the zones of sandy-argillaveous formations are likely to occur along with the rocky zones. The energy passing from the seismic focus along the seismic rays can come up to the earth surface either only along the rocky grounds or following the

rocky grounds through a layer of a sandy-argillaceous deposits. In such a case, the energy flow reveals some changes on the boundary line between the layer and the half-space. It can be taken into account if one use laws of refracrion and reflection of seismic waves.

With the aid of a method of geometric seismology it is possible to establish that the intensity of a wave travelling along a seismic ray can be estimated by a product

$$V^2 C \rho = F = \text{Const} \qquad (1)$$

where V is a velocity of vibration of medium particles, C is a velocity of wave propagation and ρ is a medium density.

If acoustic rigidity data are plotted as abscissa as they increase and the square velocities of particle vibration are plotted as ordinates the graph of this dependency will take a form of a hyberbolic curve, Fig. 1. According to this curve, loose grounds having small values of acoustic rigidity are characterized by high velocities of particle vibrations. With passing over to dense rocks acoustic rigidity increases whilst particle vibration velocity drops. As long as acoustic rigidity tends to a maximum value particle vibration velocity to a certain constant value. Hence

$$\underset{C\rho \to \infty}{V^2} = f(C\rho) \longrightarrow \text{Const} \qquad (2)$$

According to the recent views the stresses in the earth crust are distributed irregularly. In the regions of prospective violent earthquakes there is a process of gradual accumulation of stresses which come up to the limit of temporary resistance and then bring the material of earth crust to destruction which is accompanied by an earthquake. Seismic waves which are formed in these rocks as a result of an earthquake are such that they cannot cause stresses exceeding the strength of material where they propagate. On the other hand, we have a graph at our disposal, Fig.2, showing a recurrence of violent earthquakes made up by Guttenberg and Richter (4) for a depth of from 0 to 60 km. In this, a frequency N of earthquakes of the same force occuring annually is plotted as ordinates whereas earthquake intensity or magnitude is plotted as abscissa. From this figure it follows in the region of the most violent earthquakes this graph inclines inside and towards the direction parallel to the ordinate axis. It looks as if it were tending to cut off an ultimate value of energy of a violent earthquake, which it never exceeds, on the abscissa.

Thus, it can be taken for established that energy of an earthquake determined through ultimate destructive stresses of rocks cannot rise infinitely. Owing to this an earthquake force has some boundaries and cannot be in excess of a certain limit. In accordance with this a flow of energy cannot be larger than a predetermined value though it may alter from earthquake to earthquake.

Owing to the above the formula (1) can be written down in another form, i.e.

$$V^2 c\rho = F \leq F_o \qquad (3)$$

Besides, stress in the passing seismic wave is equal to

$$Vc\rho = \sigma \qquad (4)$$

To avoid rook destruction due to dynamic stresses of varying signs it is necessary to introduce a certain safety factor n. Then we shall get

$$Vc\rho = \sigma \leq n\sigma \qquad (5)$$

where n for dense rocks is normally of the order of from 5 to 10.

Since the right-hand portion of (5) cannot exceed the destructive stress σ_R of rock material it will be true to put down

$$n\sigma = \sigma_R \qquad (6)$$

Hence, the combination of (3), (5) and (6) results in

$$V \leq \frac{F_o}{\sigma_R} \qquad (7)$$

In this we do not take into account possible cases of refraction and reflection of energy flow passing from the seismic focus to the earth surface.

We mean herein the ultimate strength during a dynamic destruction of rock. Its amount can estimated as follows. The earthquakes are known to produce seismic waves which propagate from the source to the environment medium and cause a number of changes in pressure of a limited duration in it. The number of such changes normally numbers from 100 to 1000. Since no experimental data are available on the breaking strength of rocky ground during the action of seismic loads we shall believe it equal to the breaking strength valid for static destruction. Judging from some indirect experimental data a deflection in this case is about 20 per cent.

This appeares to account for the fact that the period, when pressure grows to maximum during the passing of a seismic wave, is much longer than that of the rock vibration proper which means that the effect of this pressure can be considered as static and, consequently, a destructive dynamic stress can be assumed to be equal to a static destruction.

The formula (7) can hold true not only of rocky but also of other looser grounds which are characterized by a stable value of an ultimate destructive stress. Let us analyse how the formula obtained can be applied to these cases. Since a flow of seismic energy in the focus or at two observation points close to it keeps constant for different kinds of groud, the expression (7) at coordinates (V, σ_R) is a hyperbola. It shows that with small destructive stresses which correspond to loose grounds velocity of particle vibration proves to be the greatest one. With a pass over to large stresses which correspond to solid and rocky grounds this velocity drops and within the limit, when $\sigma_R - \sim$, it keeps constant and is the least one of all possible velocities of particle vibration on various types of ground at violent earthquakes. Thus, when deciding upon a construction cite one can estimate beforehand what tremors are likely to occur during the earthquakes to be expected. This , however, calls for a sufficiently accurate value of a destructive stress of ground under a structure to be built.

3. Assuming the least strength of a rock to be equal to 50 kg per sq.cm we can calculate an ultimate value of velocity of particle vibration on the surface of rocky ground of a considerable thickness during destructive earthquakes. According to instrumental observations the most common maximum value of energy of destructive earthquakes is 10^{25} ergs. It is related to the energy flow through a formula

$$E = \iint_{ST} F_0 \, ds\,dt = F_0 S T \qquad (8)$$

Assuming that $S = 2\pi R^2$ where R is a hypocercal distance and $T = \sum_i \tau_i$ is a duration of the vibration process at the observation point due to a number of consequent tremors of a violent earthquake.

Let a hypocercal distance R be 30 km and a duration T of the seismic vibration process at a violent earthquake of the order of 5 min. The latter is based on the fact that a duration of a vibration process at the Vernon earthquake in 1887 was 5 min and that the Japan destructive earthquake lasted over 4 min. Hence the value of an energy flow is equal to F_0 = 600 kg/cm per sec. Using (7) we shall obtain $V \leq 12$ cm per sec. which approximately corresponds to the strength of the earthquake force 7.

Neumann (5) belives the velocity of particle vibration at the earthquake of such force to be 9 m per sec. According to instrumental observation, when in a Pribaikal (near Lake Baikal) expedition, the author of the present paper observed a tremor force 6 on August 29, 1959, which occurred on limestone, and recorded the velocity of particle vibration within 5 to 6 cm per sec that corresponds to 10-12 cm per sec for force 7.

From numerous investigations into the effects of explosions upon structures it has been found that with the velocity of particle vibration of 12-14 cm per sec plaster cracks and falls off in buildings and structures, chimneys fall down, sometimes main walls reveal cracks. Such destructions usually refer to a tremor force 7.

Instrumental estimation of force intensity on various grounds are extremely scarce. Neumann (6) cites the accelerations of ten violent earthquakes on various rocks. He stated that the maximum intensity recorded on granite at violent earthquakes in Helen, El Centro and Olympia was force 7.2 with a period of 0.3 sec and force 6.7 with a period of 2 sec and over. A period of 3 sec at all distances corresponded to the maximum acceleration measured.

Thus, a comprehensive study of the discussed problem leads us to belief that the force of earthquakes on rocky grounds may be as high as force about 7.

In the case of fractured and weathered rocky grounds and complex relief the ultimate force may slightly rise. There can be no fault movements, landsliedes or collapses.

An ultimate velocity of vibrations on rock allows to construct a spectrum curve of accelerations which can be taken for a standard. Other grounds will show higher velocities of vibrations and the acceleration spectrum will rise respectively. To plot them, use can be made of increment in intensity of seismic vibrations based on instrumental observations during weak close earthquakes.

Thus, in each seismic region and for any distribution of grounds one can predict the ultimate force of tremors during the destructive earthquake. On rocks it will be round about force 7 whereas on loose sandy—argillaceous grounds it may amont to force 9-10.

Experience testifies that such differentiation of tremor forces between various types of ground will hold true even when a violent but not a destructive earthquake occurs. In this case an earthquake force on rock may prove to be less than ultimate one and respectively it will drop for sandy-argillaceous grounds but there it will always be higher than on rock. This testifies to a certain pattern in distribution of intensity of seismic vibrations in different grounds during earthquakes.

It appears important, therefore, to establish for every seismic area, using the above method, standard spectrums of accelerations of violent earthquakes attributed to different grounds and use them for calculating seismic loads acting upon structures.

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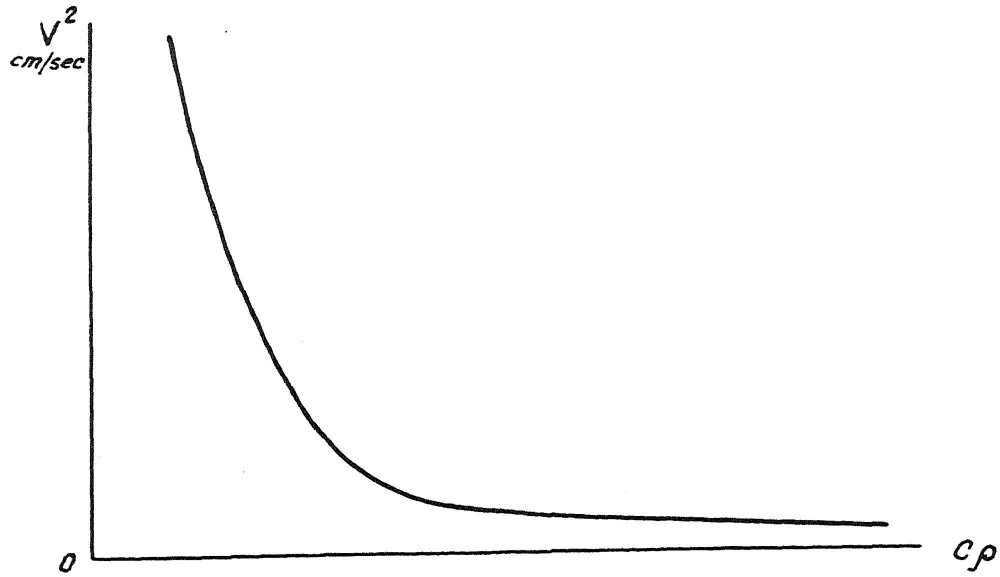
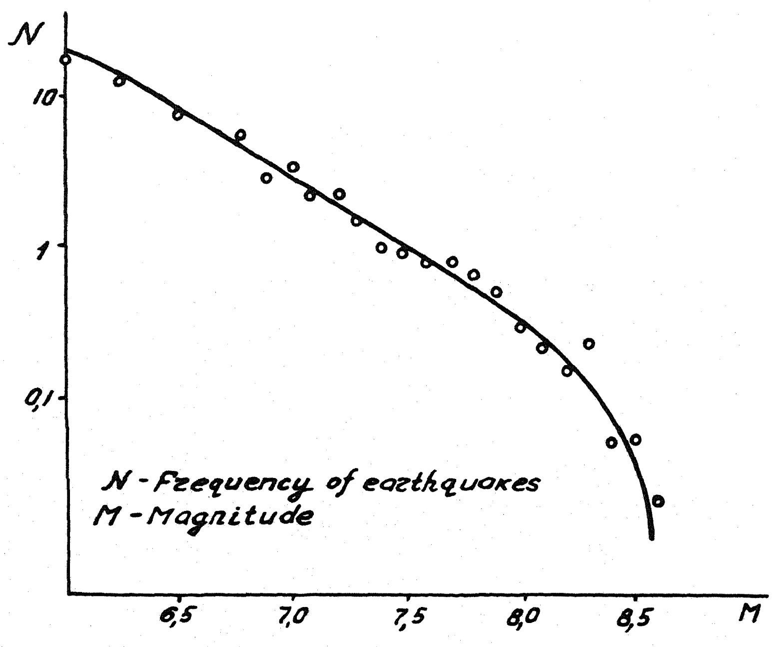


The decrease of the particle velocity with the variation of acoustical rigidity of the media. Fig. 1.



Mean annular of earthquakes per 0,1 unit of magnitude. The deep of shocks are 0 - 65 km. Fig. 2.