Features of the earthquakes’ manifestation intensity formation in mountainous areas

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Abstract. Analysis of the destructive earthquakes’ consequences engineering macro-seismic survey data shows that the earthquakes manifestation degree is in close correlation with the peculiarities of geomorphological conditions. Moreover, this dependence is not of a simple character: there is a clearly expressed multifactorial nature of correlations. The work shows that the earthquakes intensity is determined not only by the relief slope magnitude, but also by the specific location of the site in the mountain range hierarchy. The results of the experimental studies analysis (field and laboratory experiments) are presented. It is noted that from a physical point of view, the relief has a certain potential energy. To estimate the indicated energy, a phenomenological indicator was introduced in the form of the so-called "relief factor", which is the product of the relief inclination angle by the corresponding height. It is noted that upon reaching the value R=650 (degrees m) the intensity increment is one point. The use of a new relief parameter, which makes it possible to fully take into account the specific conditions of the location of the investigated area, increases the establishment validity of the mechanisms for the earthquake intensity formation in mountainous regions.

Introduction
In recent years, the list of studies, in which instrumental measurements are very actively used in various, very different fields of geophysics, has significantly expanded. This undoubtedly raised the quality of the results obtained as well as their reliability [1-10]. In this regard, it became possible to directly study such subtle effects as the relief influence on the amplification of vibrations under strong dynamic influences, which is clearly manifested during macro-seismic and other field surveys of various hazardous natural and man-made processes’ manifestations. It is known that most of the seismically active zones, which are characterized by a large rugged relief and various engineering and geological conditions, are located in mountainous areas. The results of an engineering survey of the strong and destructive earthquakes’ consequences show that it is precisely these features that largely determine the earthquakes intensity. The issues of relief influence adequate consideration and the engineering-geological structure of the area on the intensity of the destructive earthquakes’ manifestation is the basis for carrying out the corresponding anti-seismic measures in the developed and newly developed territories. At the same time, traditionally, scientists and engineers pay more attention to the study of the influence of the engineering-geological structure of the area on the earthquake seismic effect.

Analysis of the engineering macro-seismic survey data of the destructive earthquakes consequences shows that the earthquakes manifestation degree is in close correlation with the peculiarities of
geomorphological conditions. Moreover, this dependence is not of a simple character: there is a clearly expressed multifactorial nature of correlations. This circumstance imposes certain restrictions on the direct use of macro-seismic survey data, which is superficial to a certain extent. This is facilitated by the tight deadlines allotted for the direct study of various engineering and geological situations and reducing the earthquakes consequences analysis to a statement or descriptive form, etc. This leads to the need for special sorting of survey data based on corrective information. This approach will clarify the reasons for the change in the earthquakes’ intensity in each case.

The seismic effect or the intensity of an earthquake is formed by a certain alignment of the factors considered above. This refers to the physical phenomena formed by a specific set of factors: strengthening or weakening of the incoming seismic waves by the soil layer, uneven precipitation, the phenomenon of resonance in the soil-structure system, etc.

The facts of the area geomorphological conditions’ influence on the earthquake intensity manifestation are well known from the macro-seismic survey strong earthquakes data. In particular, during the Rachinsky earthquake (Georgia, 1991) in Ambrolaur and Onsky districts, a large number of rural-type buildings located at the base of the hills received minor damage (0-1 degrees) [14]. At the same time, the buildings located on the slopes exceeding 20 degrees were damaged significantly more (2-3 degrees). When vast territories are located on high plateaus, the seismic effect is often formed solely by the relief influence, but this is rarely paid attention to. At the same time, due to the proximity to the epicenter, partial and complete building collapses may prevail. For example, in the village of Bokva, during the 1991 Rachinsky earthquake damage of 4-5 degrees predominated, i.e. - partial and complete collapses of buildings and structures were observed. Here, when analyzing the reasons for the seismic effect formation, the influence of the relief, namely the building location height, was not taken into account.

Analysis of seismic norms of different countries in the world [13] shows that they take into account the seismic properties of soils, mainly due to their physical and mechanical properties. The influence of the relief is not even considered in them. An exception is the building codes of France [13]. In the early building codes of the former USSR (SNiP-II-A; 12-69), the influence of the relief was taken into account [11]. In subsequent Norms (SNiP - II-7-81), for the unknown reasons, this provision was excluded [12]. Moreover, the current Recommendations for seismic microzoning [16] recommend increasing the expected intensity of sites with a steepness of more than 15 degrees by one point. This simplified principle of intensity estimation is not at all typical for seismic microzoning. This is due to the lack of a reliable methodology to quantify such estimates. Hence, the question of assessing the contribution of relief features to the generated vibration intensity during earthquakes is of great scientific and practical interest.

Experimental research.
At the Institute, at different times, special studies were carried out to assess the influence of relief on the seismic effect of an earthquake. These studies were based on the materials of macro-seismic survey of a number of strong earthquakes. The studies were carried out on-site and on models. Field observations, in particular, were carried out in the area of the monastic cave complex David Gareji when solving the protection tasks of a historical and cultural monument near the military training ground (1988). In this case, the explosions were used as vibration sources [15].

In this work, as an example of the enhancement of the seismic effect caused by the features of the relief, the results of physical modeling are given on the example of the territory of Sukhumi [17]. A 3-D model of Sukhumi, the constancy of the wave propagation velocities, Poisson’s ratio and soil density in the corresponding layers of nature – model was examined as the main conditions for simple similarity when creating a physical three-dimensional.

The territory of the city in the plan was 9x9 km. The scale of the model was M 1: 10000. The most dangerous vibrational frequencies for the city are the frequencies of 1-10 Hz, which for a model measuring 0.9 x 0.9 m corresponds to the frequencies 10 ÷100 kHz. The bedrock of the corresponding mountain range is represented by highly weathered from the surface, fractured limestone. Gypsum was
used as a model material. The wave field of Rayleigh surface waves propagating from the earthquake source in the shelf zone near the city of Sukhumi was simulated.

The experiments were carried out on a setup consisting of a generator of ultrasonic vibrations with a period $T=3-20$ m sec and the receivers (piezoelectric acceleration sensors TsTS-19). During the research, the frequency of the vibrator was 62 kHz. This corresponds to a natural vibration frequency of 6.2 Hz. When using a pulse with $T = 15$ msec, when the propagation speed of Rayleigh waves in gypsum was $V_R = 1.21$ mm / s, the vibration wavelength for the mode was $\lambda = 18$ mm.

**Figure 1.** General view of the model

The source of ultrasonic vibrations was located on the model surface in the shelf area at the reference point. The surface of the model was divided into 96 squares and the wave field of Rayleigh waves was studied at 67 nodal points (Figure 3.). At each picket 7 measurements were made and the results were averaged. The experiments took into account the possibility of reflections from the side faces of the model (the phenomenon of reverberation).

The influence of the relief features on the Rayleigh wave passage was estimated relative to its amplitude on a reference circle, i.e., relative to vibration amplitudes at corresponding distances on a similar model with a homogeneous topography.

The increase coefficients in the amplitude level were determined by sequential movement along the profile on the model surface and compared with the amplitude at the reference point.

Data analysis showed that at an angle of inclination $\alpha \geq 20^\circ$ gain reached $k=2.0$, which corresponds to an increment of 1 point. Sometimes the increment reached 2 or more points. It should be noted that these points corresponded to detached peaks. In some cases, when $\alpha<<20^\circ$ the gain, however, was large and also corresponded to 2 points. The analysis showed that this phenomenon is due to the location of these points between the dominant peaks. Hence, we can conclude that the inclination angle use as a characteristic of the relief is clearly insufficient. Moreover, this parameter does not always adequately correspond to the actual results of macro-seismic survey of the destructive earthquakes’ consequences.

**Figure 2.** Carrying out the experiment
Further, it was found that depending on the inclination angle, the intensity increase varies significantly (0 \( \div \) 3.0). On the other hand, the cross-sections (almost parallel to the coastline) show that, in addition to the observation angle, the amplification effect is significantly influenced by the observation height itself. Moreover, even in the absence of local tilt, the gain was nevertheless quite significant.

Analysis of the corresponding dependencies showed that to increase the reliability of observation results, it is necessary to take into account both factors simultaneously. This led to the introduction by the authors [15] the so-called coefficient of “relief” \( R \) in 1989 which makes it possible to take into account both factors.

**Figure 3.** Dependence of the ground vibrations amplification on the relief inclination angle.

**Figure 4.** Dependence of the ground vibrations amplification on the observation height.
Figure 5. Dependence of the ground vibrations amplification on the relief factor

Analysis of the data obtained as a result of the experimental studies, as well as a result of the Rachinsky earthquake macro seismic examination showed that the relief influence on the seismic effect of an earthquake is most fully taken into account by the indicated indicator:

$$R = \alpha \times H$$

where $\alpha$ is the relief inclination angle, degrees;
$H$ – height, m.

For example, for $\alpha = 10^\circ$ and at height $H = 65 \div 70$ m, i.e., at $R = 650-700$ (degrees m) the increment in the intensity will be 1 point.

Summary

The experimental observations’ results analysis shows that to characterize the influence of a terrain on the seismic effect of an earthquake, such indicators as the angle of inclination or only the height are clearly insufficient. At the same time, both factors undoubtedly form the seismic effect during earthquakes and dynamic impacts.

It is necessary to use an indicator that would allow taking into account both of these factors at the same time. From a physical point of view, the relief has a certain potential energy. To estimate the indicated energy, a phenomenological indicator was introduced in the form of the so-called "relief" coefficient which is the product of the angle by the corresponding height.

The work shows that the intensity is determined not only by the magnitude of the relief slope, but also by the specific location of the site in the mountain range hierarchy. The results of the analysis of previously conducted studies related to the need for practice, as well as the special experimental studies (field and laboratory experiments) are presented. The impact, in this case, was carried out in the form of explosions and monochromatic vibrations in the ultrasonic range, etc. Despite the significant differences in research conditions, the research results were generally characterized by a high degree of compliance.

Consideration of the geomorphological conditions’ influence in the area should be carried out by using the so-called "relief" coefficient. It is noted that upon reaching the value $R = 650$ (degrees m) the intensity reaches 1 point.

The use of the introduced parameter in the practice of earthquake-resistant construction makes it possible to fully take into account the specific conditions of the studied area location. The latter
circumstance increases the establishment validity of the mechanisms for the earthquake intensity formation in mountainous regions.

References
[1] Zaalishvili V, Melkov D, Dzeranov B, Morozov F and Tuaev G 2018 International Journal of GEOMATE 15 (47) 158-163.
[2] Zaalishvili V, Kanukov A, Melkov D, Makiev V and Dzobelova L 2018 International Journal of GEOMATE 15 (51) 160-166.
[3] Zaalishvili V, Melkov D, Kanukov A and Dzeranov B 2016 International Journal of GEOMATE 10 (1) 1656-1661.
[4] Zaalishvili V and Rogozhin E 2011 Open Construction and Building Technology Journal 5 30-40.
[5] Zaalishvili V 2016 International Journal of GEOMATE 10 (2) 1706-1717.
[6] Gorbatikov A, Rogozhin E, Stepanova M, Kharazova Yu, Andreeva N, Perederin F, Zaalishvili V, Melkov D, Dzeranov B, Dzeboyev B and Gabaraev A 2015 Physics of the Earth 1 28.
[7] Zaalishvili V, Nevskaya N, Nevskii L and Shempelev A 2015 Journal of Volcanology and Seismology 9 (5) 333-338.
[8] Zaalishvili V B, Melkov D A 2014 Izvestiya. Physics of the Solid Earth 50 (5) 707-718.
[9] Khulelidze K K, Kondratyev Yu I, Zaalishvili V B, Betrozov Z S 2016 Sustainable development of mountainous areas 8 (1) 46-51.
[10] Grigorkina G S, Ramonova A G, Kibizov D D, Kozyrev E N, Zaalishvili V B, Magkoev T T, Fukutani K 2017 Solid State Communications 257 16-19.
[11] SNiP II-A; 12-69 Building Codes and Regulations (Stroyizdat, Moscow).
[12] SNiP II-7-81 Building Codes and Regulations (Gostroyizdat, Moscow).
[13] Paz M 1994 International Handbook of Earthquake Engineering. Codes, Programs and Examples.
[14] Gogmachadze S, Zaalishvili V, Kipiana D and Odisharia A 1991 UNESCO report 141-145.
[15] Zaalishvili V and Gogmachadze S 1989 Report of ISMIS Academy of Sciences of Georgia № state reg. 01.9.00.016412 25-40.
[16] Recommendations for seismic microzoning in engineering surveys for the construction, Moscow, 1985 72.
[17] Gogmachadze S 1993 Cand. Dissertation (ISMIS) 156.