Macroseismic intensity attenuation equations for Central Asia earthquakes

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Abstract. Based on macroseismic survey data for strong earthquakes in Central Asia, the coefficients of attenuation of seismic intensities with distance in the Blake-Shebalin- and Kovesligethy-type equations were refined. A new generalized dependence of macroseismic intensity attenuation on distance, taking into account the depth of the earthquake hypocentre, were obtained. Relations between the minor and major axes of the ellipse approximating real isoseists depending on the shaking strength, source depth and earthquake magnitude were found. With the example of the territory of eastern Uzbekistan, the influence of the choice of the law of seismic intensity attenuation with distance on the obtained seismic hazard assessments is investigated.

1. Introduction

Estimates of seismic intensity at the macroseismic scale still play an important role both for investigating the historical seismicity of seismically active territories and for compiling and specifying different-scale maps of seismic zoning because the current construction standards of a number of post-Soviet countries are significantly based on this characteristic of seismic effects. When strong earthquakes occur in the region, prompt forecasting of their macroseismic intensity allows rescue service actions to be planned even before the beginning of field macroseismic surveys.

To date, many macroseismic field equations have been obtained for the entire territory of Central Asia and its different regions based on analysing the macroseismic consequences of appreciable and strong earthquakes [1–6, etc.]. The most common types of dependencies on macroseismic attenuation $I$ with increasing hypocentral distance $R$ from an earthquake with magnitude $M$ are the Blake-Shebalin-type [1] $I = aM - blgR + c$ and Kovesligethy-type [7] $I = aM - blgR - dR + c$ due to their simplicity and stability of the inverse problem of finding their included coefficients. At the same time, each of these relationships insufficiently takes into account the peculiarities of macroseismic effects caused by different depths of earthquake source locations. In particular, the empirical fact that the attenuation of seismic intensity with distance from the source for shallow-depth earthquakes is faster than for deep-depth earthquakes is not reflected in the Blake-Shebalin- and Kovesligethy-type formulas, in which the coefficient $b$, which characterizes the decrease in the intensity with distance, is a constant value.

Based on a large volume of macroseismic data, along with refinement of the coefficients in the Blake-Shebalin- and Kovesligethy-type equations for the territory of Central Asia, a generalized dependence of macroseismic intensity attenuation with distance was obtained in the article, taking into account the specifics of seismic effects. The relationship between the minor and major axes of the
ellipse, which approximates real isoseists, depending on the shaking severity, source depth, and earthquake magnitude, was also found.

2. Initial macroseismic data and methodology

The information for the study was the database of macroseismic data created at the Institute of Seismology, Academy of Sciences of the RUz; the information includes schemes of isoseists of strong earthquakes in Central Asia and tables of "point values" of the earthquakes studied [2]. The electronic version of the macroseismic database began to form in the late 1980s, when the efforts of specialists from seismological centers of the Central Asian republics unified macroseismic materials for each territory to solve problems related to seismic hazard assessment. This base was supplemented by schemes of isoseists of strong earthquakes that occurred in the territory of Uzbekistan and in the regions bordering it over the last 25 years. The total number of earthquakes for which information on macroseismic surveys was available was 171 events (Fig. 1), 122 of which had data on the epicenter earthquake intensity \( I_0 \). The magnitude range of the earthquakes in the database varied from \( M=3.7 \) to \( M=8.4 \). The distribution of earthquakes with \( M \geq 4.5 \) by magnitudes and depths of hypocenters is shown in the Figure 1 histogram. To homogenize the initial data for the following constructions, the magnitudes of all seismic events were converted to the unified \( M_S \) magnitude. The conversion of magnitudes was carried out according to the dependences of A.S. Mukambaev and N.N. Mikhailova for the Central Asian earthquakes [8].

![Figure 1. Map of Central Asia earthquake epicentres for which macroseismic survey data were available.](image-url)
For each investigated seismic event, the sizes of isoseists of different ballast sizes were taken along the major and minor axes of the ellipse approximating the real isoseists, as well as the sizes of the central radius. For seismic events whose isoseist shape differed significantly from the ellipsoidal shape, the maximum and minimum dimensions of the closed curve-limiting zones of different macroseismic intensities were measured. The coefficients in the equations relating the intensity of shaking at the epicenter of the earthquake and at different distances from it, depending on the earthquake magnitude, source depth, and hypocentre distance, were calculated by the least squares method.

3. Results and discussion

3.1. Shaking intensity in the epicentre $I_0$.

Figure 2 shows the experimental values of the shaking intensity in epicenter $I_0$ depending on the earthquake magnitude $M$. Without taking into account the distribution of earthquakes by depth, the dependence of the shaking intensity in epicentre $I_0$ on magnitude $M$ is as follows:

$$I_0 = 0.92 \cdot M + 2.08 \ (\sigma = 0.62) \quad (1)$$

Figure 2. Dependence of the intensity of earthquake $I_0$ on earthquake magnitude $M$ for different ranges of depths.

$I_0$ values from different depth ranges earthquakes were shown by different colors points. The linear approximation $I_0=f(M)$ for each seismically active layer was shown by the same colors lines. $\sigma$ value of the linear approximation standard deviation for different layers varies from 0.57 to 0.96. However, as shown in the Figure, these lines are almost parallel. This shows that the increasing rate of $I_0$ with increasing magnitude is practically independent from the chosen range of earthquake source depths. At the same time, the level of these plots for different ranges of earthquake source depths is different. The level of these plots decreases with increasing earthquake source depth. Thus, for seismic events with the same magnitude, a greater macroseismic effect in the source region is observed for earthquakes with smaller source depths. Based on the totality of experimental data, we obtained the following dependence by the least squares method, which relates the intensity at epicentre $I_0$ to earthquake magnitude $M$ and hypocentre depth $H$:

$$I_0 = 1.14 \cdot M - 1.28 \cdot \lg H + 2.28 \ (\sigma = 0.57) \quad (2)$$

3.1.1. Peculiarities of macroseismic intensity attenuation with distance.
For the entire set of Central Asian macroseismic data, the Blake-Shebalin-type dependence for disturbance propagation along the mean radius is as follows:

\[ I_0 = 1.32 \cdot M - 3.01 \cdot \lg R + 3.55 \ (\sigma = 0.7) \]  

(3)

The dependence of the Kovesligethy type, constructed from the same experimental data, is given by the expression:

\[ I_0 = 1.33 \cdot M - 2.37 \cdot \lg R - 0.00205 \cdot R + 2.24 \ (\sigma = 0.73) \]  

(4)

Figure 3 shows the attenuation curves of macroseismic intensity with an increase of the epicentral distance \( \Delta \) for the Central Asian earthquakes with magnitudes \( M=5.5–7.5 \) according to the above Blake-Shebalin- and Kovesligethy-type relationships. Constructions were made for earthquake source depths of \( H=15 \) km and \( H=25 \) km. For comparison, the same Figure shows the character of the curve attenuation by N.V. Shebalin's dependence [1], constructed from world data:

\[ I_0 = 1.5 \cdot M - 3.5 \cdot \lg R + 3 \]  

(5)

Figure 3. Comparison of different dependencies of macroseismic intensity attenuation with an increase of the epicentral distance \( \Delta \) for Central Asian earthquakes.

As follows from the Figure, for the considered range of earthquake magnitudes and focus depths, the Kovesligethy-type relation gives the lowest intensity in the near zone, while the author's relation in the form of the Blake-Shebalin equation gives the highest values in the far zone. Discrepancies in the values of macroseismic intensities with different attenuation laws are approximately 0.5 points in the near zone and approximately 1 point from the earthquake epicentre.

Analysis of experimental data indicates that the coefficient of attenuation of macroseismic intensity with distance significantly depends on the depths of the originating earthquakes. Figure 4 shows the average values of the lengths of observed isoseists of different macroseismic intensities for earthquakes with magnitudes \( M=5.0 \) to \( M=7.5 \) with a gradation of a half magnitude for different ranges of earthquake focus depths.

Practically in all magnitude ranges (except \( M=7.0 \), where event statistics are not very large), the lengths of "younger" isoseists (I=4–6 MSK) for earthquakes with greater depths of origin have greater lengths than for earthquakes with shallower origins. This means that the attenuation of macroseismic intensity with distance for shallower-depth earthquakes is faster than that for deep earthquakes. Therefore, the dependences of attenuation of macroseismic intensity with distance of the Blake-Shebalin and Kovesligethy types, in which the attenuation coefficient \( b \) is a constant value, do not adequately characterize the real seismic effect.

Attempts to take into account the peculiarities of seismic effects caused by different depths of earthquake focus locations have been made in some studies (e.g., D. Bindi [9] for the territory of Central Asia). In this paper, the relationship between the intensity value at the epicentre and at different hypocentre distances \( R \) was considered as follows:
\[ \frac{I - I_0}{\lg R - \lg H} = -(dM - e\lg H + f), \text{ where } I_0 = aM - b\lg H + c \]  
(6)

Figure 4. Mean values of observed isoseist lengths of different macroseismic intensities (\(\Delta_I, \text{km}\)) for earthquakes with magnitudes \(M=5.0–7.5\) and different earthquake focus depths.

On the left side of this equation is the ratio of the increment in intensity to the increment in the logarithm of the hypocentre distance, and on the right side is the attenuation coefficient, i.e., it was assumed that the latter depends on the magnitude of the earthquake \(M\) and on its depth \(H\).

As a result of solving a system of 6 linear equations with 6 unknowns, the following dependence of seismic intensity attenuation on distance along the central radius was obtained:

\[ I = 1.475 \cdot M - 2.646 \cdot \lg H + 1.905 - 0.498 \cdot M \cdot \lg \frac{R}{H} + 1.159 \cdot \lg H \cdot \lg \frac{R}{H} - 1.401 \cdot \lg \frac{R}{H}. \]  
(7)

The value of the standard deviation in the obtained dependence is \(\sigma=0.565\).

Figure 5 shows plots of macroseismic intensity attenuation with distance for earthquakes with magnitudes of \(M=5.5, M=6.5\) and \(M=7.5\), which occurred at different depths, and similar plots obtained from N.V. Shebalin's dependence [1].

Figure 5. Comparison of macroseismic intensity attenuation with increasing epicentral distance according to different dependencies: a) by the dependence of N.V. Shebalin [1]; b) by the author's dependence, considering dependence of the attenuation coefficient on the focus depth.
It is evident from the Figures above that both according to the author's dependence of attenuation and N.V. Shebalin's dependence plotted from world data, a greater macroseismic effect in the near zone is observed for earthquakes with shallow source depths. However, based on distance from the source, the character of attenuation of seismic intensity is different for the compared dependences. N.V. Shebalin's dependence on the attenuation of macroseismic intensity with distance is the same for earthquakes with different focus depths. According to the author's dependence, a decrease in the seismic effect with distance for earthquakes with shallow focus depths occurs faster than for earthquakes with greater focus depths, which better corresponds to real empirical facts.

3.2. Consideration of the ellipticity of isoseists.

Following [6], the compression coefficient of ellipse \( k \), which approximates real isoseists, was considered a parameter characterizing the degree of ellipticity of observed isoseists, which is equal to the ratio of the length of the minor axis of ellipse \( b \) to the length of its major axis \( a \). We investigated the dependencies of ellipse \( k = b/a \), which approximates the real isoseists, on the value of macroseismic point \( I \), the focal depth \( H \) and the earthquake magnitude \( M \). Each of these relationships is individually characterized by a low correlation coefficient. Using a set of parameters, the following equation of the relationship between the ellipse compression coefficient \( k \) and the parameters \( I, M, \) and \( H \) was obtained by the least squares method:

\[
k = 0.05 \cdot I + 0.002 \cdot H + 0.04 \cdot M + 0.73
\]

4. Influence of the attenuation laws of seismic impact intensity with distance on the resulting seismic hazard assessments

![Figure 6](image)

**Figure 6.** Maps of the territory of Eastern Uzbekistan seismic hazards on a macroseismic scale for a probability \( P=0.98 \) of not exceeding seismic level during 50 years at different laws of seismic intensity attenuation with distance: a) N. V. Shebalin dependence based on world data; b) Blake-Shebalin-type dependence obtained in this work; c) Kovesligethy-type dependence; and d) author's dependence, in which the attenuation coefficient depends on the focus depths of occurring earthquakes.
Figure 6 (a-d) shows the maps of seismic zoning of the territory of eastern Uzbekistan for a probability \( P=0.98 \) for not exceeding the level of seismic impact over 50 years. With uniform parameters of earthquake recurrence and values of seismic potential of focal zones, they were calculated under the different attenuation laws discussed in this article.

The highest hazard values are obtained when choosing the N.V. Shebalin’s dependence obtained from world data as the attenuation law, and the lowest values are obtained when adopting the Kovesligethy-type dependence constructed from macroseismic data of Central Asian earthquakes. According to the author's attenuation dependence that takes into account the depths of occurring earthquakes, the indicators of seismic hazards were \( \Delta I=0.7 \) points lower than the Blake-Shebalin-type dependence and \( \Delta I=0.3 \) points higher than the Kovesligethy dependence obtained from the same macroseismic data.

5. Conclusion
As a result of the study, the following main results were obtained.

1. Based on the analysis of a large volume of macroseismic data for the territory of Central Asia, the regional dependence of the shaking intensity in the epicentre on earthquake magnitude and focal depth was obtained. The attenuation coefficient intensities of seismic effects with distance in Blake-Shebalin- and Kovesligethy-type equations were clarified.

2. Experimental data show that the coefficient of attenuation of macroseismic intensities with distance depends on the earthquake depth. A new type of attenuation equation taking into account this effect is proposed, and its coefficients are determined by the least squares method. The correlation between the minor and major axes of the ellipse approximating real isoseists depending on the value of the macroseismic points, the earthquake magnitude, and the earthquake depth, is investigated.

3. Using the territory of eastern Uzbekistan as an example, seismic hazard assessments depend significantly on the choice of the law of seismic intensity attenuation with distance. Even the dependences built on the same experimental data give very significant differences in the resulting seismic hazard estimates (\( \Delta I=0.7 \) points).

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