Determination of earthquake magnitude and intensity in the USSR

E. F. SAVARENSKY

The determination of earthquake magnitude in the Soviet Union is based on instrumental observations using the international magnitude scale.

The estimations of M for distant earthquakes usually involve observations of amplitudes and periods at the maximum phase of surface waves. To simplify the work seismic stations use nomograms (fig. 1, N. V. Shebalin and S. L. Solovyov [6,17]). In estimating the seismic energy for near and weak earthquakes recorded by highly sensitive instruments the Galitzin method [1] is used. Such estimates for local earthquakes are made at the Institute of Seismology of the Academy of Sciences of Tadjikskaya SSR (V. I. Bune [9,10]). Work is proceeding to improve methods of determining M from observations of body waves as well as to find regional corrections of M depending on the location of earthquake epicentres (S. L. Solovyov [3,14,17,19,21]). Devices recording energy flux of earthquakes are now being designed which will make M determinations more reliable.

In determining instrumental magnitude M in the Soviet Union the scientists do not confine themselves to the instrumental seismic investigations and to the connection of these with tectonic processes (E. F. Savarensky [4, 8, 11, 15, 20]) but consider the practical problem of connecting the intensity near the epicentre with the magnitude M. This is important for earthquake-proof construction especially in cases when formerly non-inhabitant regions of seismic activity are considered.

The first stage of this problem deals with the determination of the connection between the intensity I_o, the magnitude M and the focal depth H. This dependance was found by interpreting a few hundreds of earthquakes and comparing the intensity at the epicentre with the magnitude M. Finally the following empirical formula was deduced:

$$I_o = 1.5\,M - 3.5\,\lg H + 3.$$

Nomogram for determination of M

$$M = \log \frac{A}{T} \cdot f(\Delta)$$
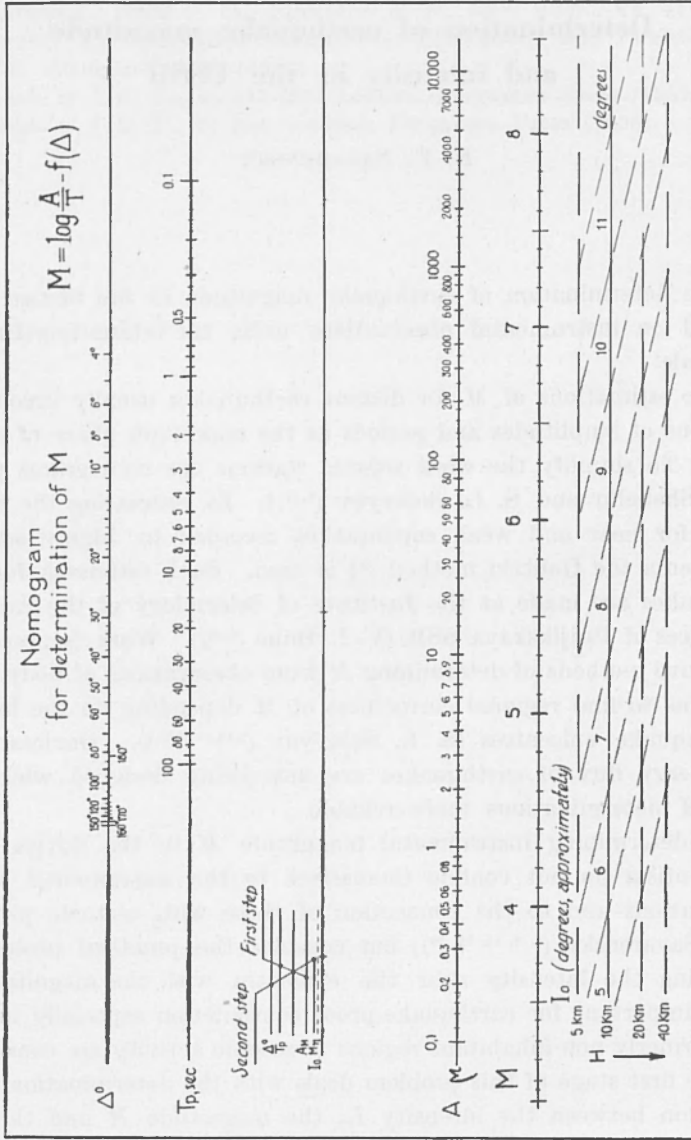
The formula is true for earthquakes with focal depths of no more than 60 km. At greater depths the influence of a layer with a lowered velocity (asthenosphere) is being exerted. (N. V. Shebalin [6, 19, 22]). The determination of I_o by M is seen from the above nomogram (fig. 1).

The estimates assume that average properties between the focus and surface of the Earth are obtained everywhere.

In conclusion mention is made on the systematization and cataloguing of earthquakes by magnitude.

When compiling seismicity maps of respective zones of the USSR (E. F. Savarensky [20]) according to their magnitude all earthquakes are divided into 5 groups:

Group	M and I_o--intensity (at normal focal depths)		Distance of registration
I	7 1/2	9 and more	recorded by the most stations of the world
II	6.5-7.5	8-9	
III	5 1/4-6.5	ca. 7	60° and more
IV	4 1/4-6 1/4	—	20-60°
V	4 1/4	—	up to 20°

Thus, the first three groups are based on practical considerations. To some extent they include destructive earthquakes considered to be the most violent in the USSR. The lower groups include weak earthquakes which are of interest for a general study of seismicity. In some cases M is determined from the distance of registration. The catalogues attached to the seismicity maps are compiled according to the form:

Date	Time of earthquake h.m.s.	Epicentre coordinates	Focal depth	Magnitude group	M Distance of registration and name of the most distant station.	Notes (Information on intensity

Accuracy class: A – epicentral error is less than 25 km.,
                B – less than 50 km.

To make a more accurate determination of I_o by M it is necessary to take into account the influence of the local geologic structure in the epicentral region upon the amplitude of oscillations. This influence is witnesses by the results of numerous investigations of destruction caused by earthquakes. The main principal problem is to determine the interval of periods in which we must take into account the influence of the layer of comparatively sedimentary rocks.

Let us make but a simple estimate of the effect of direct from any direction SH waves and vertical P waves. Observations show that such waves are most dangerous.

Let us consider plane waves of unity amplitude. It should be recalled that at the surface of a semi-space the amplitude of the oscillations considered is equal to 2. If a layer with thickness H is situated on this surface, then, as Rayleigh showed, waves coming from the semi-space and reflected many times in the layer will interfere.

For P waves the amplitude magnification takes place each time when the ratio of the layer thickness to the wavelength is multiple of the odd number of quarters. At these ratios the surface amplitude is equal to $2 \dfrac{m_o}{m_1}$, where m_1 and m_o are the acoustic rigidity of the layer and of the semi-space.

With the wavelength λ considerably exceeding the layer thickness H, when $\beta = 2\pi \dfrac{H}{\lambda}$ is small, the amplitude of oscillations at the layer surface will be near to 2 and to the influence of the layer can be neglected. This error will be determined by the difference:

$$\sin \beta - \beta$$

Thus, the maximum value of the period in the interval is determined.

We shall further take into account the absorption of the energy oscillations by the layer assuming that the absorption is inversely proportional to the wavelength or to the period, which fact is confirmed by observations. In this case the amplitude changes with distance Z by the formula:

$$e^{-2\pi\varkappa_2 \frac{Z}{\lambda}}$$

where $\varkappa_2$ is the damping coefficient and the amplitude decrease with the increase of $\dfrac{Z}{\lambda}$, or with the reduction of the wavelength. This damping lowers resonance maxima at the layer surface.

Hence it follows that at sufficiently large values of the absorption will be so great that the layer effect will not be important. These data help to find the minimum value of the period in the interval.
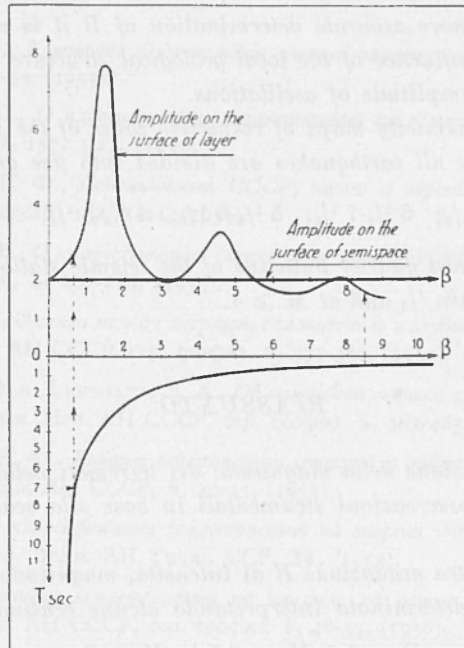

Fig. 2

To calculate amplitudes on a layer surface (dry loess sandy soil, etc.) a 1 km deep, lying on a granite semispace and where ratio of acoustic rigidities $\dfrac{m_2}{m_1} = 10$ and damping coefficient $\varkappa_2 = 0.1$ (E. V. Karus $(^{23})$,)) the influence of the layer should be taken into consideration within the interval of periods from 0.5 to 7 seconds fig. 2).

ABSTRACT

The determination of earthquake magnitude in the Soviet Union is based on instrumental onservations under the international magnitude scale.

The dependence between intensity gradation B, magnitude M and focal depth H was found by interpreting a few hundreds earthquakes:

$$B = 1.5 \ M - 3.5 \ \lg H + 3.$$

The formula is true for earthquakes with focal depths of no more than
60 km (N. V. Shebalin).

The estimates assume that medium properties between the focus and
surface of the Earth are everywhere equal.

To make a more accurate determination of B it is necessary to take
into account the influence of the local geological structure of the epicentral
region upon the amplitude of oscillations.

Compiling seismicity maps of respective zones of the USSR according
to their magnitude all earthquakes are divided into five groups:

$$\geqslant 7\,1/_2; \quad 6\,1/_2\text{-}7\,1/_2; \quad 5\,1/_4\text{-}6\,1/_2; \quad 4\,1/_4\text{-}5\,1/_4; \quad \leqslant 4\,1/_4.$$

In the published quarter bulletins of the seismic stations of the USSR
M is given to within $^1/_4$ and at $M \geqslant 4$.

RIASSUNTO

La determinazione della magnitudo dei terremoti nella Unione Sovie-
tica è basata su osservazioni strumentali in base alla scala di magnitudo
internazionale.

La relazione tra gradazione B di intensità, magnitudo M e profondità
focale H è stata determinata interpretando alcune centinaia di terremoti:

$$B = 1.5\,M - 3.5\,\lg M + 3\,.$$

La formula è vera per terremoti con profondità focali non superiori a
60 km (N. V. Shebalin).

Si presume che le caratteristiche del mezzo tra il fuoco e la superficie
della terra siano ovunque eguali.

Per effettuare una più precisa determinazione di B è necessario tener
presente l'influenza della struttura geologica locale della regione epicentrica,
rispetto all'ampiezza delle oscillazioni.

Preparando le mappe della sismicità delle rispettive zone dell'U.R.S.S.
secondo la loro magnitudo, tutti i terremoti sono stati suddivisi in cinque
gruppi:

$$\geqslant 7\,1/_2; \quad 6\,1/_2\text{-}7\,1/_2; \quad 5\,1/_4\text{-}6\,1/_2; \quad 4\,1/_4\text{-}5\,1/_4; \quad \leqslant 4\,1/_4\,.$$

Nel bollettino trimestrale pubblicato dalle stazioni sismiche dell'U.S.S.R.
M è dato entro l'intervallo compreso fra $M - {}^1/_4$ e $M \geqslant 4$.

REFERENCES

(¹) Голицын Б. Б., *О землетрясении 18 февраля 1911 год*, Изв. Имп. АН, 991-998, (1915).

(²) Косенко С. И., *К вопросу о вычислении энергии землетрясений*. Тр. Геофиан. **21**, 148, 3-15 (1953).

(³) Соловьев С. Л., *О классификации землетрясений по величине их энергии*. Тр. Геофиан **30**, 157, 3-21, (1955).

(⁴) Саваренскии Е. Ф., *Сейсмичность СССР, итоги и перспективы ее изучения*. Тр. Геофиаи **25**, 152, 5-24, (1954).

(⁵) Вешняков Н. В., *О количественной оценке силы землетрясения*. Изв. АН СССР, сер. геофиз., **3**, 207-214, (1955).

(⁸) Шебалин Н. В., *О связи между энергией, балльностью и глубиной очага землетрясений*. IIзв. АН СССР, сер. геофиз. **4**, 377-380, (1955).

(⁷) Соловьев С. Л. и Джибладзе Э. А., *Об изменении потока сейсмической онергии с расстоянием*. Изв. АН СССР, сер. геофиз. **5**, 462-463, (1955).

(⁸) Саваренскии Е. Ф., *Работа сейсмических станций и задачи советскои сейсмологии*. Вестиик АН СССР, **5**, 40-43, (1955).

(⁹) Бунэ В. И., *О классификации землетрясений по энергии упругих волн, излучаемых из очага*. Докл. АН Тадж. ССР, **24**, (1955).

(¹⁰) — *О классификации землетрясении по их силе на основе инструментальных данных*. Изв. АН СССР, сер. геофиз. **1**, 48-55, (1956).

(¹¹) Саваренскии Е. Ф. и Джибладзе Э. А., *О сейсмичности Большого Кавказа*. Изв. АН СССР, сер. геофиз. **5**, 577-583, (1956).

(¹²) Буиэ В. И., *Сравнительно энергетическая характеристика сейсмичности трех районов Таджсикистава*. Докл. АН Тадж. СССР, **19**, 3-12, (1956).

(¹³) — *Об использовании метода Голицына для приближенной оценки энергииблизких землетрясений*. Тр. Мнст. сейсмологии АН Тадж. СССР **1**, 3-27, (1956).

(¹⁴) Соловьев, С. Л. — *О связи энергии и интенсивности землетрясений*. Изв. АН СССР, сер. геофиз. **3**, 357-359, (1956).

(¹⁵) Саваренскии Е. Ф., *Об искажениях в картах сейсмичности*. Изв. АН СССР, сер. геофиз. **7**, 745-754, ₁956).

(¹⁸) Коидорская Н. В. и Постоленко Г. А., *Сейсмичность СССР за 1955*. Изв. АН СССР, сер. геофиз., **2**, 255-257, (1957).

(¹⁷) Соловьев С. Л. и Шебалин Н. В., *Определение интенсивности землетрасения по смещению почвы в посерхностных волнах*. Изв. АН СССР, сер. геофиз. 926-930, (1957).

(¹⁸) — *К вопросу о соотношении между энергиеи об''емных волн и интенсивностью землетрясений*. Бюллетень Совета по сейсмологии АН СССР, **6**, 109-122, (1957).

(¹⁹) ШЕБАЛИН Н. В., *Соотношение между балльностью и иптенсивностью земле-
трясении в зависимости от глубины очага*. Бюллетень Совета по сеисмоло-
гии АН СССР, **6**, 122-127, (1957).

(²⁰) САВАРЕНСКИН Е. Ф., *Об изучении сейсмичности СССР*. Бюллетеиь Совета по
сеисмологии АН СССР, **6**, 16-19, (1957).

(²¹) СОЛОВЬЕВ С. Л., *Некоторые результаты применения шкалы интенсивности
землетрясений на сейсмических станциях СССР*. Студия геофизика н мето-
дика Чехословацкои АН, **2**, 40-45, (1958).

(²²) ШЕБАЛИН Н. В., *Использование соотношения между интенсивностью и балльно-
стью землетрясений для оценки глубины астеносферы в районе Вранча (Кар-
паты)*. Студиа геофизика и геодетика Чехословацкой АН **2**, 86-87, (1958).

(²³) КАРУС Е. В., *Поглощение упругих волн в горных породах при стационарном
возбуждении*. Нзв. АН СССР, сер. геофиз. **4**, (1958).