

SOVIET INSTRUMENTS FOR REGISTRATION OF STRONG EARTHQUAKES

by

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SYNOPSIS

Accelerographs with optical registration and devices with galvanometric registration have been elaborated, produced and used in the USSR. They work in a triggering regime and record earthquakes in the intensity range II-X and in the frequency range 0-30 Hz. Three-component accelerograph SSRZ and six-channel light-beam oscillograph ISO-2M, completed with standard seismometers, work autonomously as long as 6 months. Sensitive systems of galvanometers are balanced. Three-component piezoaccelerometer APT-1 with one inertial mass and natural frequency of 2 kHz records accelerations up to 2 g over periods up to 5 sec. The equipment is widely used as at stations and in fields, particularly, under registration of aftershocks in epicentral zones of strong earthquakes. During last 5 years some hundred records of strong earthquakes and their aftershocks have been obtained and treated.

INTRODUCTION

Accurate quantitative data about ground and construction motions near epicentres of strong earthquakes are used while solving the problems of source physics and earthquake engineering.

Instrumental observations carried out by present time allow parameters of ground motions in a neighbouring zone of strong earthquakes [1]. So called earthquake engineering range of periods is from 0.03-0.05 to 4-5 sec. In this range displacements can come up to 80-100 cm, velocities up to 100-500 cm/sec, accelerations up to 2 g. Relative durations of strong earthquakes (time within accelerations exceed 0.03 g [2]) are 10-30 sec in the most cases.

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One should take into account that due to a high complexity of phenomena during strong earthquakes an unequivocal correlation between single parameters of motions and a seismic effect is practically impossible in the nearest zone. Therefore the instruments must provide the obtaining as full as possible information concerning motions with above-mentioned parameters.

The most essential characteristics of instruments are the following: a) frequency range, b) dynamical range, c) maximal value of a signal, registered with permissible errors, d) reliability.

All the instruments used now for registration of near strong earthquakes can be divided into two classes: instruments with direct (mechanical, optical) registration and instruments with distant (galvanometric, magnetic) registration. Parameters of some devices are given in Table 1.

Fig.1 shows amplitude-frequency characteristics of soviet instruments for registration of strong earthquakes.

I. INSTRUMENTS WITH GALVANOMETRIC REGISTRATION

Special or general-utility light-beam oscillographs are used for galvanometric registration of strong motions. Oscillographs N-700, N-010 and others are used in multi-channel devices installed on buildings. In these oscillographs the width of paper is 120-130 mm, paper speed, duration and number of record cycles are regulated in wide ranges.

Six-channel engineering-seismic oscillograph ISO-2M [3] is more common for recording of strong earthquakes in single points of the USSR. The instrument operates autonomously in a triggering regime. The oscillograph is engaged from built in electronic starter, connected with a coil of one of the operating seismometers. The time lost at the beginning of the recording is not more than 0.2 sec. Second marks are passed to one of the operating galvanometers from inner electronic markers. The oscillograph can be equipped with a device which prints an electric clock dial on a film at the end of every cycle.

Channels with galvanometric registration are completed with magnetoelectric seismometers, parameters of which are presented in Table 2 [3].

Comparison of given in Introduction data about maximal ground motion parameters with Table 2 shows that seismographs OSP, APT-1 and to some extent VBP-3, are suitable for recording of the most strong earthquakes in the nearest zone. And one must take into account the parameters of re-

gistering part of a seismograph as well, particularly, those of galvanometers.

To record ground motions with maximal amplitudes (Table 2) by means of a galvanometric channel it is necessary to provide enough strength and balancing of the galvanometer [4]. In any real galvanometer the centre of gravity is displaced with respect to the axis of rotation. In this case the galvanometer, depending on relationship of natural and forced frequencies, operates as accelerometer, velocimeter or displacement meter during an earthquake. The formula connected unbalance δ and maximal registered ground acceleration \ddot{x}_{max} at permissible amplitude y_p of noises in the record with the parameters of the galvanometer having a high natural frequency f_g is presented in the paper [4]:

$$\delta = \frac{2\pi^2 k f_g^2}{M(A/y_p) \ddot{x}_{max}},$$

where K is a moment of inertia of the galvanometer's frame, M is its mass, A is an optical lever.

The method and devices for static balancing elaborated at the Institute of Physics of the Earth permit the galvanometers with natural periods up to 0.2 sec to be balanced for the utilise of them under registration of the earthquakes with intensity VII-IX [5].

While registering strong earthquakes light-beam oscillographs, particularly, ISO-2M are packed with mirror frame galvanometers GB-IV type with natural frequency 10 or 120 Hz.

As Table 1 testifies, galvanometric registration unlike direct registration with set parameters, allows the records of different kinematic elements of ground motions to be obtained, provides two times larger dynamic range and makes it possible to vary frequency characteristics. To obtain precise data a channel calibration is carried out. Total relative errors while determining frequency characteristics of channels with galvanometric registration do not exceed 10 %.

Registration possibilities of oscillograph ISO-2M with galvanometers GB-IV type and with different seismometers are shown in Fig.2. As well Fig.2 given a scheme of horizontal parts of curves of minimal realized sensitivity of different galvanometric channels. Registration possibilities of a chosen channel are determined by parameters of a seismometer and galvanometer (providing enough vibrostrength of registering part). Data about maximal registered amplitudes of ground motions for various seismometers are presented in Table 2. Corresponding values of

limiting earthquake intensities (scale MSK-64) for seismometers VBP-3, OSP and APT-1 are shown by dotted lines in Fig.2. Vibrostrength and possibility of balancing of used galvanometers do not allow earthquakes with such limiting intensities to be recorded while registering displacements and velocities with seismometer S5S, maximal intensity VI-VII is determined by permissible amplitude of displacement of the pendulum swinging centre.

Period range for analyzed in Fig.2 channels is determined by well-known theses of the theory of galvanometric registration, this range is limited by the values presented in Table 1 and on Fig.2 and by resolution of record accounted for about 30 Hz (0.03 sec) for oscillograph ISO-2M.

Zones of amplitudes and those of periods which are not registered by mentioned galvanometric channels, are shown by fine sectioning in Fig.2. These channels do not record only the most intensive earthquakes (with intensity X and more). As well Fig.2 shows that it is necessary to seek the ways of expansion of registered motion range to longer periods, particularly, when recording velocities and displacements. This fact will permit the obtained data to be used while solving the problems of source physics and, probably, those of prediction of strong earthquakes.

To expand a total dynamic range of devices with galvanometric registration, in the USSR the record at two levels of sensitivity with connecting seismometer coil through decoupling shunts with two galvanometers.

Now in the USSR some tens of devices with oscillographs ISO-2M record near earthquakes. Seismometers S5S ($T_s = 5$ sec) are used in these oscillographs. Velocities (natural frequency of galvanometer $f_g = 120$ Hz) and displacements ($f_g = 5 - 15$ Hz) of ground motions at two levels of sensitivity are registered. Ranges of sensitivity of channels allow earthquakes with intensity from II-III to VIII-IX to be recorded in case of satisfactory balancing of galvanometers.

During last years some hundred strong earthquake records and their aftershocks have been obtained with devices with oscillographs ISO-2M at the stations and in the fields.

2. SEISMOGRAPH SSRZ FOR REGISTRATION OF STRONG AND DESTRUCTIVE EARTHQUAKES

To record the most strong earthquakes seismographs SSRZ with direct optical registration are used in the USSR. Stability of characteristics is an important quality of

these instruments.

Fig. 3 shows a schematic diagram of SSRZ. Inert mass 5 of accelerometer is suspended by two thin steel plates to the device's body. Damping of the system is realized by means of polimetisiloksan liquid. Mass motions is optically registered on a film in cassette 2. The cassette is protected with hermetic case 3. The record is carried out with an optical system consisting of lamp 4, a mirror strengthened on inert mass and lens. Electric driver 7 moves 35-mm film. Film speed is 6 mm/sec. Besides the record of the three components of study object acceleration, registration of one-half second time marks from electromagnetic marker and registration of temperature with bimetallic thermograph are carried out. The device is engaged automatically by a starter. A sensitive element of the starter is a vertical electrodynamic seismometer. When motion velocity of the object is 0.3-0.5 cm/sec, the starter switches on electric power supply of a lamp, motor of film-guide and generator of time marks. The registration on a film begins in 0.05-0.1 sec after starter's switching. Through 50 sec after beginning of registration electric power supply is switched off automatically and the device is ready to record a following earthquake. Number of record cycles of SSRZ is 10.

Accelerometers intended for registration of earthquakes with intensity from V-VI to IX-X have the parameters: free motion frequency is 35 Hz, sensitivity is 12 mm/g or 50 mm/g, damping value is 0.6.

The time of reliable autonomous work of seismograph SSRZ is not less than 6 months and is determined by the life of batteries (12 v DC).

3. SOME PROMISES OF DEVELOPMENT OF INSTRUMENTS FOR REGISTRATION OF STRONG EARTHQUAKES

Important investigations and constructive works are carried out in the USSR to improve and elaborate instruments to record strong and destructive earthquakes.

A new vibrograph has been elaborated and tested. In this instrument a special unbalanced systems like suspended systems of magnetolectric galvanometers [6] are used as a sensitive element. Advantage of these systems is a possibility of adjustment of electromagnetic damping in wide ranges and unification of accelerometers, velocimeters and displacement meters.

Possibilities of frequency range expansion of instruments are studied as well. Speaking about frequency range of seismographs and, in particular, of accelerographs with direct registration, one is to remember about possibility to operate at a long-period part of frequency characteristic of a channel. Integration and double integration of

records give a possibility to separate ground motions with periods an order higher than natural period of a seismometer when stability and precision of a channel are sufficient. But in this case errors up to 100 % and more can appear, if the interval of integration is comparable with the period of a separated wave. Just the same situation arises when we separate out periods of 30-60 sec in records, real duration of which is close to this value.

A low dynamic range of accelerographs prevents from separating of long-period waves in records of the accelerographs. For example, according to data [2], a maximal ground displacement can come up to 30-40 cm within period of 30 sec. It corresponds to acceleration of the order of 1 cm/sec^2 . Such accelerations are absent in the records of accelerographs with maximal registered acceleration 1-2 g. Registration of accelerations within rather a wide interval of amplitudes demands a dynamical range of a channel not less than 80 db to be.

These difficulties, evidently, can be overcome at the cost of utilisation of wide broad-band electronic seismographs with a large dynamic range.

Accelerometers with electric output can be recommended to register strong and destructive earthquakes in a near zone. Satisfactory dynamic and frequency range are provided for by piezoelectric devices. Elaborated three-component piezoelectric accelerometer APT-1 [7] (Institute of Physics of the Earth, Academy of Sciences of the USSR) has the following fundamental parameters: natural frequency about 2 kHz, sensitivity, 0.3-0.5 v/g, maximal registered acceleration - 2 g, dynamic range - 80 db, maximal period of motions, registered with constant sensitivity - 5-7 sec.

Restrictions of principle imposed on maximal period of registered motions can be overcome at the cost of use of a new piezoelectric sensor with resonance excitation [8]. This sensor is distinguished from well-known ones by amplitude modulation of resonance vibrations of piezoelement. The amplitude is varied under measured effect. In this case the sensor turned out to be sensitive to motions of the lowest frequencies up to constant pressures.

Registering possibilities of seismographs for strong motions essentially depend on the way of record. In the USSR the works on utilisation of magnetic record in strong motion seismographs are carried out. The use of digital magnetic record provided a large dynamic range is preferable here.

CONCLUSION

1. Soviet accelerographs SSRZ with direct optical registra-

tion and devices with galvanometric registration on the base of oscillograph ISO-2M allow strong earthquakes in intensity range II-X and in the frequency range 0-30 Hz to be recorded.

2. Devices operate in a triggering regime automatically not less than 6 months.
3. Analysis of actual data concerning ground motions and construction of devices' parameters point to preferable use of accelerograph for registration of ground motions as within engineering and within seismological ranges of periods with a possible future integration of accelerograms.
4. Utilisation of accelerometers with electric output and magnetic record is promising. The magnetic record permits frequency and dynamic ranges to be widened and data treatment to be automatized.

REFERENCES

1. G.Berg, G.Housner. Integrated velocity and displacement of strong earthquake ground motion. Bull.Seism.Soc.Am.V.51, № 2, 1961.
2. N.Ambraseys. Maximum intensity of ground movements caused by faulting. Proc.IV World Conf.Earth.Eng. Chile, 1969.
3. Information reference book on seismic instruments, vyp.II, Izd. IFZ AN SSSR, M., 1970.
4. V.M.Fremd. On the possibility of utilisation of galvanometers for registration of strong earthquakes. V sb. "Seismicheskie pribory", vyp.6, M. "Nauka", 1972.
5. E.S.Borisevich. About balancing of galvanometers intended for registration of strong earthquakes. V sb. "Seismicheskie pribory", vyp.6. M. "Nauka", 1972.
6. E.S.Borisevich, D.P.Kirnos, V.M.Fremd. Mirror frame torsional vibrometers. V sb. "Seismicheskie pribory", vyp.6. M. "Nauka", 1972.
7. V.M.Fremd, G.E.Galstyan, M.V.Zabelin. Three-component piezoelectric accelerometer APT-1. V sb. "Seismicheskie pribory", vyp.6, M. "Nauka", 1972.
8. V.M.Fremd. Piezoelectric transducer of motions. Avt. svid. SSSR, № 338868. Byull. "Otkrytiya, izobreteniya, promyshl. obraztsy, tov.znaki", № 16, 1972.

TABLE 1

SOVIET AUTONOMOUS DEVICES FOR REGISTRATION OF STRONG
EARTHQUAKES IN A TRIGGERING REGIME

Device Parameters	Accelerograph SSRZ with optical registration	Galvanometric device with oscillograph ISO-2M
Number of registering channels	3	6
Registered parameter	acceleration	acceleration, ve- locity, displace- ment
Range of registered frequencies, Hz	up to 30	0.2-30; 0.25-30; 1-30
Range of registered degree of intensity	III-VII or VI-X ^x	III-VIII or IV-IX ^{xx}
Film width, mm	35	35
Film speed, mm/sec	6	5 or 10
Duration of record cycle, sec	50	60 or 30
Number of record cycles	10	5
Time of autonomous work, mth	6	6
Sources of power supply: dry batteries or accumulators, v	12	6

^x at different accelerometers
^{xx} at two levels of sensitivity

TABLE 2

PARAMETERS OF SEISMOGRAPHS FOR GALVANOMETRIC REGISTRATION
OF NEAR EARTHQUAKES

Type of instrument	Natural period, sec	Reduced length, cm	Working damping	Maximal registered ground amplitude	Sensitivity of transducer, $\frac{v \text{ sec}}{m}$
S5S	5	42	0.6	1.5 cm	13
VBP-3	2	100	0.7	20 cm	0.1
OSP	0.2	-	7	140 cm/sec	15
APT-1	$5 \cdot 10^{-4}$	-	-	2 g	0.5 v/g

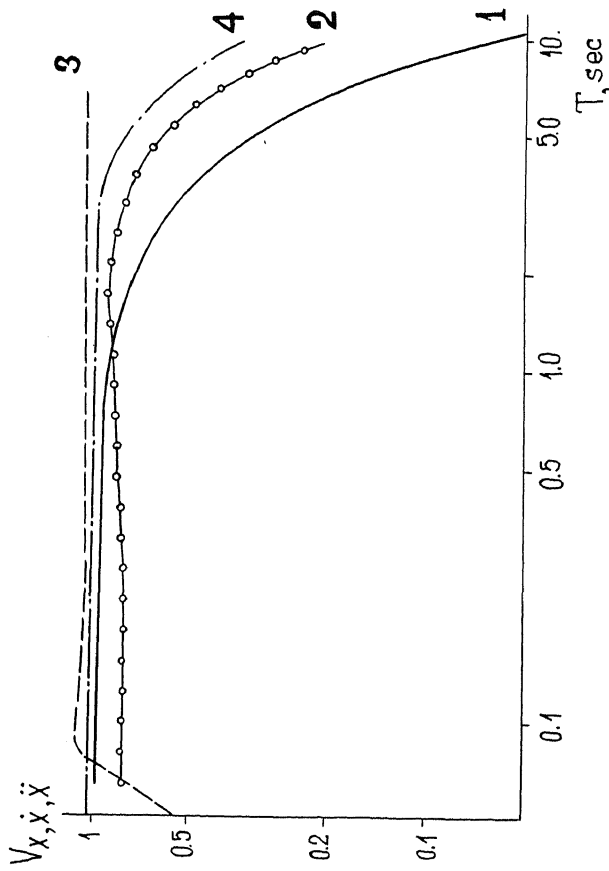


Fig. 1. Amplitude-frequency characteristics of instruments for registration of strong earthquakes. 1, 2 - galvanometric channels for record of displacements and motion velocities; 3 - accelerographs with direct optical registration; 4 - accelerographs with galvanometric registration.

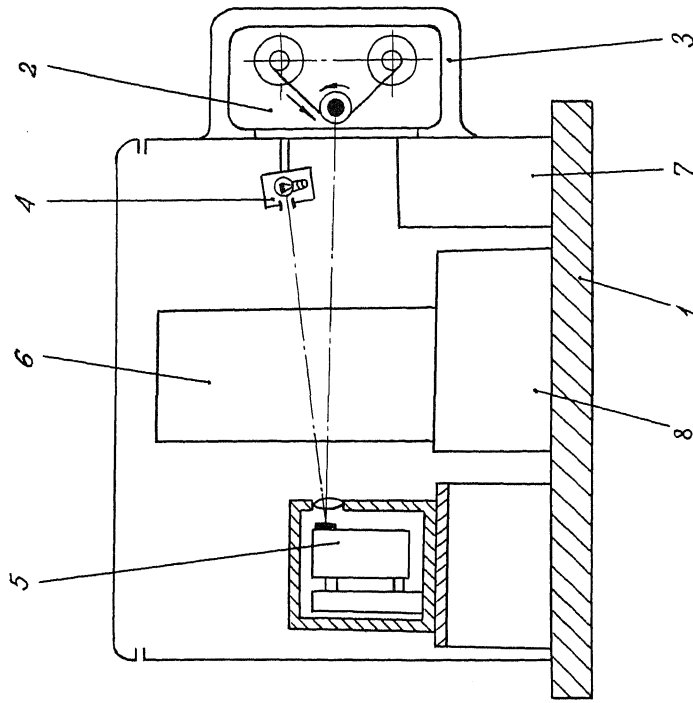


Fig. 3. Schematic circuit of seismograph SSRZ. (See in the text).

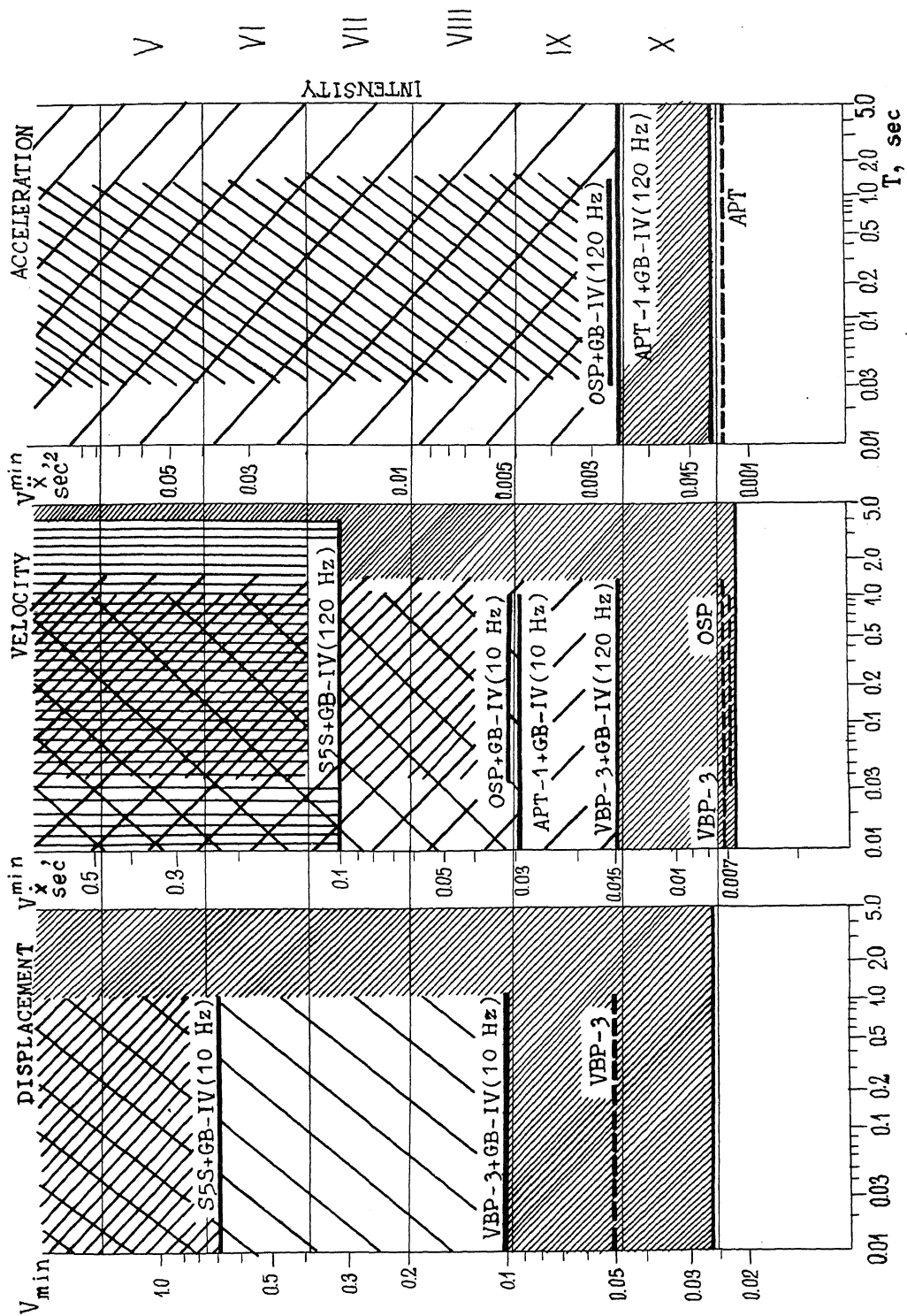


Fig.2. Registering possibilities of channels of oscillograph ISO-2M.