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Estimates of the Inaccuracy of Surface-Wave Magnitude due to Errors of Seismogram Evaluation

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Summary

Errors of the standard surface-wave magnitude determination were analysed taking into account errors of the seismogram reading of amplitudes and periods and errors of the seismograph magnification including calibration procedure and the potential drift of some parameters during operation. Limits of the maximum uncertainty of the magnitude for the surface waves in the period range from 10 to 20 seconds were estimated for given conditions as follows: 0.15 of the magnitude unit for the digital seismograph and up to 0.20 of the magnitude unit for the previous model of seismograph with galvanometer and analog record.

1. *Introduction*

In the observatory practice concept of earthquake magnitude introduced by Richter and Gutenberg is still yet applied. Its value is equal to $\log(A/T)_{max}$, where A is the displacement amplitude of ground motion, T is the corresponding period and several additional terms for corrections of epicentral distance, focal depth, station conditions, earthquake mechanism and wave propagation. Nevertheless, magnitudes of particular earthquakes obtained at different seismological stations show sometimes a great scatter up to 0.3 of the magnitude unit was mentioned by *Willmore* (1979). Part of this discrepancy may be assigned with the inaccuracy of seismogram evaluation and part with application of mean empirical magnitude calibrating functions. In the present paper attention is paid to the inaccuracy of the first term determination for surface waves.

We shall analyse in more detail both errors of the seismograph calibration and the potential contribution of parameters fluctuation during long-term observations for estimating the limits of the actual magnification of two types of seismographs: one with the analog galvanometric recording used previously in the WWSSN and one recent seismograph with the digital recording. Seismographs with the Press-Ewing vertical seismometer model 201 operated at the stations Nurmijärvi (NUR) and Kangasniemi (KAF) in Finland. Magnification of both seismographs were derived experimentally by the standard method when the seismometer mass was excited by the equivalent harmonic current flowing through the calibration coil. The influence of the drift of individual parameters on the magnification was calculated changing the instrumental parameters one by one in the assumed limits. In the first case the magnification formula was defined by 12 independent parameters, in the second case only by 7 parameters, taking the electronic part as a "black box" with no drift of its nominal response. The actual value of magnification is assumed to lie around the mean value of magnification received in time of calibration within the limits given by 3 standard deviations of the average plus constant error of the sensitivity level plus maximum estimated deviations caused by the nonstability of parameters. These limits make it possible to find more reliable estimates of error of the ground displacement amplitude. Altogether with the error of measurement of the period of motion the magnitude inaccuracy was estimated.

2. *Errors of the calibration procedure*

For derivation of magnification we have to use one of general methods of calibration which is applicable to arbitrary seismograph model to keep the systematic errors the same. Minimum number of necessary parameters is preferred to decrease cumulation of errors.

One suitable calibration procedure is based on simulation of the effect of the ground motion by the harmonic current flowing through the calibration coil and recording the response of the whole system, i.e. in case of seismograph with galvanometric recording the analog amplitude on the seismogram and with the digital seismograph the number of digital counts between successive extremes. Magnification M at period T seconds is given in the Operation and maintenance manual (1962) by the relation.

$$M = M_p X_s 4\pi 2/T^2 \ 1/(G_c{}^* i_s) \ , \qquad (1)$$

where M is dimensionless in the first case and in the second case it has the dimension of the digital count per metre, M_p is the effective mass of the seismometer pendulum (in kilogrammes), X_s is the peak-to-peak recorded amplitude (in metres or digital counts), i_s is the peak-to-peak amplitude of current (in amperes) which is fed in the calibration coil at period T (seconds), $G_c{}^*$ is the modified electromechanical constant of the calibration coil (in newtons per ampere).

This method has the advantage that the system is checked all at once at operational conditions. One must pay only attention not to introduce any systematic error when calibration is carried out due to the seismic noise with the decreased sensitivity. The linearity of pendulum should be satisfied and in the first case the influence of changes of the coupling coefficient on the magnification should be negligible.

As follows from (1) it is not necessary to know more details about the calibrated seismograph. Therefore, results of *Tobyás et al.* (1977) about errors of calibration of seismograph with the galvanometric recording can be applied for the digital seismograph with small modifications. Standard deviations of the average magnification are only about 3 %, i.e. the maximum error should be about 9 %. We have to add to this value a constant by which the absolute accuracy of particular parameters used in (1) are estimated.

The effective mass of seismometer pendulum M_p is given by the manufacturer. In case of some changes of the mechanical part, for instance when the high impedance coils have been reinstalled in the seismometer, its error makes a constant shift of the whole magnification level independent of the period as it was the case described by *Tobyás* (1981). Also the value of G_c* is given by the manufacturer. It is regularly checked and the repeated measurements yield the error of the electromechanical constant of 1.5 % with the vertical seismometer. The influence on the magnification course is the same as with the previous parameter. The errors of the current amplitude and the period of sine wave depend on the quality of measuring instruments: in our case it was bellow 0.3 % for the current and negligible for the period because the precise low-frequency generator was used.

Estimates of errors of the above mentioned parameters are common for both seismograph models. The only differences of errors are connected with the amplitude X_s determination. With the analog record in the first case the amplitude X_s can be adjusted to be greater than 50 mm so that the relative error is less than 1 %. This is possible in case that the record is not disturbed by another signal (e.g., by the meteorological microseisms). Including some uncertainty, due to the arc error which reaches 0.3 % at amplitude of 100 mm and the shrinkage of the seismogram photopaper up to 0.5 %, we arrived at the maximum total errors of magnification about 12 - 13 %. With the digital recording the error of amplitude determination is smaller or can be under favourable circumstances even neglected if the digitized course of the seismograph response is successfully fitted by least-squares to the theoretical sine-wave course to avoid the microseismic and electronic noise when seeking the real amplitude X_s. Therefore, the maximum total error of magnification of the digital seismograph will be slightly smaller - up to 10 %. These numbers are valid for the given calibration method and correspond to careful and accurate measurements with the high quality instruments and cannot be substantially decreased.

3. *Magnification changes between calibrations*

The successive calibrations display some differences which are not only due to the obtainable accuracy of the procedure but also due to drifts of some parameters of seismograph. It is evident in cases when some "constant" should be adjusted to the prescribed limits to obtain a defined standard response of seismograph. For mathematical modelling of magnification deviations independent parameters should be taken into account. With the aid of estimated parameters deviations from their nominal values we shall calculate their influence on the magnification. Different analytical relations describe the ideal linear behaviour of the measuring system of both models of seismograph.

3.1 *Seismograph with the galvanometric recording*

The basic scheme of seismograph with specification of individual independent parameters is shown in Fig. 1. The dynamic behaviour of the seismometer pendulum is described by the free period T_s, the critical resistance a_s and the open circuit damping constant D_{s0} (both reduced to the free period $T_s = 1$ s) and the resistance of the signal coil R_s. Corresponding parameters of galvanometer are denoted by T_g, a_g, D_{g0}, R_g, where the critical resistance and open circuit damping constant are again reduced to the free period of galvanometer equal to 1 s. This is done to introduce simple dependence of damping constants on the actual free periods. The step and continuous attenuators are inserted by a simple attenuator with resistors *X, Y, Z* (*Tobyás et al.*, 1976).

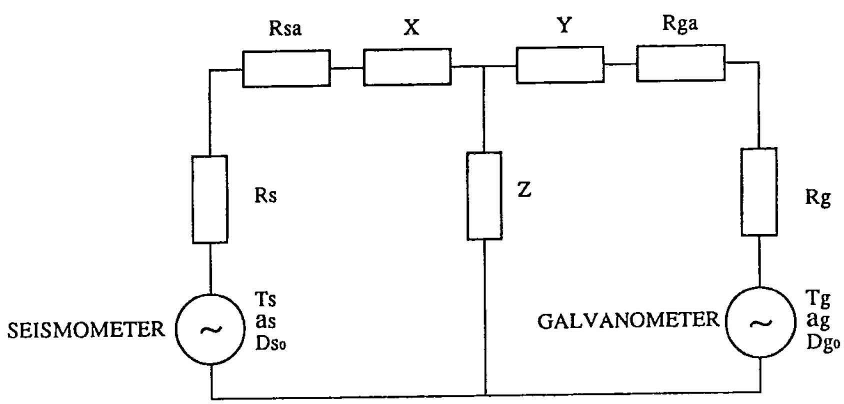


Fig. 1. Scheme of the seismograph with the galvanometric analog recording and specification of independent parameters.

The additional resistors connected in series with the seismometer and galvanometer coils R_{sa}, R_{ga} are for calculation convenience added to X and Y, respectively and $X_1 = X + R_{sa}$, $Y_1 = Y + R_{ga}$.

The general analytical formula for magnification M of pendulum seismograph with the galvanometric recording is defined by *Kirnos* (1962) with seismograph constants

$$M = M_1\,[(4D_sD_g\sigma^2)/(T_sT_g)]^{1/2}\,U, \tag{2a}$$

$$M_1 = 2L/l(K_s/K_g)^{1/2}, \tag{2b}$$

$$U = 1/(T^{-2} + a + bT^2 + cT^4 + dT^6)^{1/2}. \tag{2c}$$

The scaling factor M_1 is defined by the following constants: the recording distance of the galvanometer L, the reduced length of seismometer pendulum l, the moment of inertia of the seismometer K_s and the moment of inertia of galvanometer K_g. The amplitude response function U depends on the period of ground motion T and the following basic constants of the seismograph: the free period of seismometer T_s and galvanometer T_g, their damping constants D_s and D_g, respectively and the coupling coefficient σ^2. They define the parameters $a = m^2 - 2p$, $b = p^2 - 2mq + 2s$, $c = q^2 - 2ps$, $d = s^2$, $m = 2(D_sT_s^{-1} + D_gT_g^{-1})$, $p = T_s^{-2} + T_g^{-2} + 4D_sD_gT_s^{-1}T_g^{-1}(1 - \sigma^2)$, $q = 2(D_sT_s^{-1}T_g^{-2} + D_gT_g^{-1}T_s^{-2})$, $s = T_s^{-2}T_g^{-2}$. The scaling factor M_1 and both free periods are the only three independent parameters. The other basic constants are defined by independent quantities as follows: $D_s = D_{s0}T_s + a_sT_s/(R_s + R_{se})$, $D_g = D_{g0}T_g + a_gT_g/(R_g + R_{ge})$, where R_{se} and R_{ge} are the external resistances of the signal and galvanometer coil, respectively, and the coupling coefficient $\sigma^2 = Z^2/[R_s + X_1 + Z)(R_g + Y_1 + Z)](D_s - D_{s0}T_s)(D_g - D_{g0}T_g)/D_sD_g$. It means that the magnification is defined by 12 independent parameters which can be changed during operation. The deviation of scaling factor shifts the level of the magnification by the constant factor in the whole range of periods of motion.

The influence of the other parameters should be calculated for the nominal values of parameters of the seismograph at NUR: $T_s = 14.9$ s, $T_g = 98.0$ s, $a_s = 58.52\ \Omega$, $a_g = 7.71\ \Omega$, $D_{s0} = 0.0004$, $D_{g0} = 0.0019$, $R_s = 476\ \Omega$, $X_1 = 340\ \Omega$, $Z = 212.2\ \Omega$, $Y_1 = 331.6\ \Omega$, $R_g = 492\ \Omega$. These parameters enable to adjust damping constants $D_s = 0.89$ and $D_g = 0.95$ close to the standardized values and the coupling coefficient in (2a) to obtain the maximum magnification of 1,500 at the period of 15 s.

The course of relative deviations of magnification $\delta M(\%)$ in the period range 1 - 100 s are shown in Fig. 2 for 1 % drift of particular parameter. Only values of $\delta M \geq 0.02$ % are given. This level is not reached at all with the D_{s0} and with D_{g0} for periods up to 15 s. The graphs show a great variety of magnification changes for individual parameters drift from their nominal values. Deviations $\delta M > 0.4$ % are reached for the following parameters: T_s (2), a_s (4), a_g(5), R_s(9), Z(11), R_g (13).

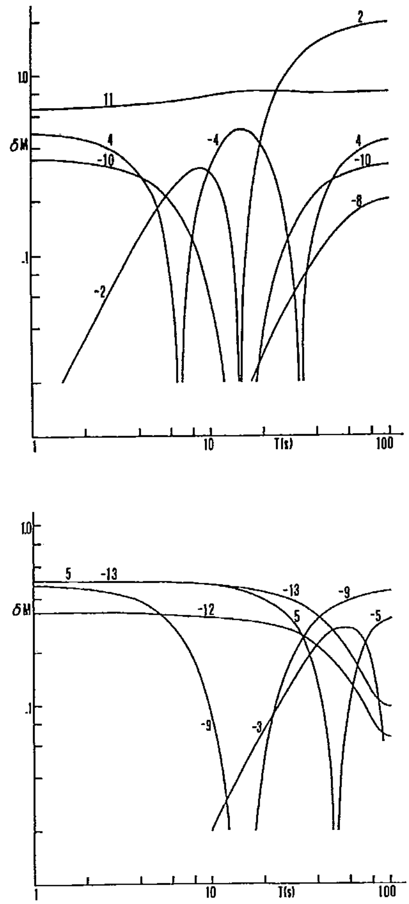


Fig. 2. Relative deviations of magnification δM (%) for 1 % deviation of the following particular parameters from their nominal values: T_s (2), T_g (3), a_s (4), a_g (5), D_{s0} (7), D_{g0} (8), R_s (9), X_1 (10), Z (11), Y_1 (12), R_g (13). Minus sign before the number corresponds to the negative deviation of δM.

For further derivation of possible maximum magnification changes we can use values in Table 1. Here the relative deviations δM are listed for some discrete periods of surface waves (10 - 40 s). The period of 100 s is added as a limiting period for some special records. If we take the usual range of surface waves periods within 10 and 20 seconds and 5 % random deviations of seismograph periods we arrive at δM of 1.5 - 2.3 % for the seismometer period and 0.1 - 0.4 % for the galvanometer period drift. There is no reason to suppose any changes of critical resistances when the zero positions are not changed. The resistances in the circuit can be changed only by variations of the temperature in the seismograph vault. The seismic vault at NUR station is heated and the temperature is kept at 20 ± 1 °C. These variations cause deviation of the copper coils resistances by 0.4 %, i.e. this can be neglected for both R_s and R_g. The standard resistors of the circuit (X_1, Z, Y_1) have the sensitivity to temperature by one order lower and they need not to be taken into account. The estimated changes of magnification are under the above mentioned conditions 1.6 - 2.7 %. Much larger changes of temperature in the range 2 - 5 °C are reached when visiting the seismometer vault. Then for the upper limit changes of both coils resistances yield the magnification deviation 1.1 - 1.0 % at maximum. The same influence is awaited when the power supply is interrupted. Therefore, we suppose that the magnification can be changed in the period range 10 - 20 s during the long-term operation by about 2.7 - 3.7 %.

Table 1. Relative deviations $\delta M(\%)$ for positive 1(%) drift of particular parameters at given periods T.

Parameter		**Period** T**(s)**				
No		**10**	**20**	**30**	**40**	**100**
T_s	(2)	-0.29	0.46	1.12	1.46	1.91
T_g	(3)	-0.02	-0.08	-0.15	-0.22	0.05
a_s	(4)	-0.32	-0.39	-0.07	0.14	0.44
a_g	(5)	0.47	0.40	0.28	0.14	-0.30
D_{s0}	(7)	0.00	-0.01	-0.04	-0.02	0.00
D_{g0}	(8)	-0.01	-0.03	-0.06	-0.09	-0.20
R_s	(9)	-0.09	-0.05	-0.21	-0.31	-0.44
X_1	(10)	-0.06	-0.04	-0.15	-0.22	-0.31
Z	(11)	0.77	0.81	0.79	0.78	0.78
Y_1	(12)	-0.31	-0.30	-0.26	-0.21	-0.07
R_g	(13)	-0.46	-0.43	-0.38	-0.31	-0.10

As it is evident from Table 1 the cumulative influence of the seismometer and galvanometer period drift is increasing at longer periods and reaches nearly 10 % at period of 100 s. The influence of deviations of resistances R_s, R_g, X, Y, Z remains stable near 1 %; under these conditions the potential uncertainty of magnification reaches 11 %.

3.2 Seismograph with the digital recording

According to the scheme in Fig. 3 used in KAF (*Teikari and Suvilinna*, 1991), parameters of the seismometer are again as in the preceding case T_s, a_s, D_{s0}, R_s. The resistor in series with the seismometer signal coil is R_1 and the input resistance of the preamplifier of the electronic circuit is denoted by R_{in}. The voltage across this resistor is amplified in the broad range and filtered by 2 Butterworth 2nd order low-pass filters. The analog signal is digitized with the sampling rate of 20 Hz in a dynamic range of 66 dB by the analog to digital converter with 11 bit + sign, i.e. in the range of $\approx \pm 2^{11}$.

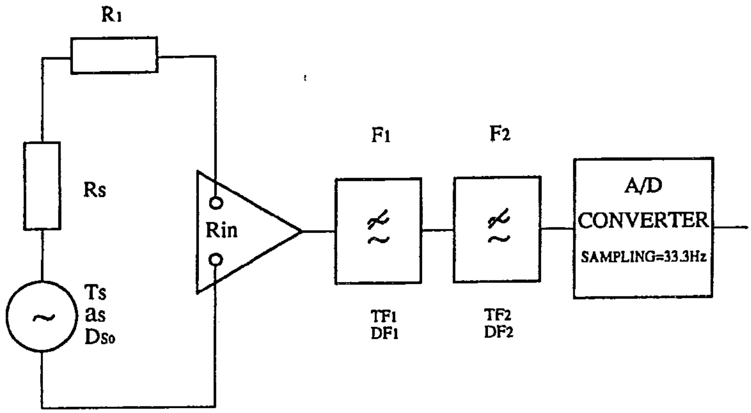


Fig. 3. Scheme of the digital seismograph with the specification of independent parameters of the seismometer circuit.

We suppose that the electronic part of this seismograph has only two states: it operates with the prescribed nominal response, as it was at the moment of calibration, or it is totally out of operation. Therefore, we shall further pay attention only to the voltage across the input resistor R_{in} and its variations will be taken as the variations of magnification of the whole seismograph. Relation for amplitude of voltage E reads

$$E = 2\pi/T\ U_s\ G_s/l\ R_{in}/\Sigma R\ A, \qquad (3)$$

where G_s is the electromechanical constant of the signal coil with the physical dimension Volt x second, $\Sigma R = R_s + R_1 + R_{in}$ and A is the displacement amplitude of the vertical harmonic ground motion with the period T. The amplitude response U_s is defined by the relation

$$U_s = [(1 - T^2/T_s^2)^2 + 4T^2(D_{s0} + a_s/\Sigma R)^2]^{-1/2}. \qquad (4)$$

Specification of parameters is the same as in the preceding seismograph with the galvanometric recording, i.e. D_{s0} and a_s are the normalized values for the free period of seismometer equal to 1 second.

According to (3,4) there are only 6 parameters on which the course of voltage amplitude response depends and another two parameters define the whole level of δE. For the relative changes E due to the relative deviation of the free period of seismometer δT_s we get using (3) and (4)

$$\delta E = [-2U_s^2(1 - T^2/T_s^2)T^2/T_s^2]\ \delta T_s\ , \tag{5}$$

with $\delta E \to 0$ for $T \to 0$ and $\delta E \to 2\ \delta T_s$ for $T \to$ oo. The relations for the other parameters are as follows:

$$\delta E = [4T^2U_s^2a_s/\Sigma R\ (D_{s0} + a_s/\Sigma R) - 1]\ R_s/\Sigma R\ \delta R_s = P_1R_s/\Sigma R\ \delta R_s, \tag{6}$$

$$\delta E = P_1R_1/\Sigma R\ \delta R_1, \tag{7}$$

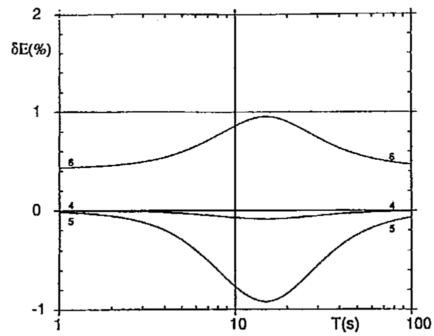
$$\delta E = [-4U_s^2T^2(D_{s0} + a_s/\Sigma R)]D_{s0}\ \delta D_{s0} = P_2D_{s0}\ \delta D_{s0}, \tag{8}$$

$$\delta E = P_2a_s/\Sigma R\ \delta a_s, \tag{9}$$

$$\delta E = (-P_2a_sR_{in}/\Sigma R^2 + 1 - R_{in}/\Sigma R)\ \delta R_{in}\ , \tag{10}$$

where P_1 and P_2 are the terms in brackets of (6) and (8), respectively. For the limiting periods $T = 0$ and $T =$ oo $\delta E = -\ R_s/\Sigma R\ \delta R_s$ for (6) and $\delta E = -\ R_1/\Sigma R\ \delta R_1$ for (7). Relative deviations of voltage are for both limits zero with (8) and (9) and $\delta E = (R_1 + R_s)/\Sigma R\ \delta R_{in}$ at both limits of (10).

Values of δE were calculated for the nominal parameters of the digital seismograph which operates at the seismological station at Kangasniemi: Ts = 15 s, $D_{s0} = 0.00033$, a_s = 2005 Ω, R_s = 9.72 kΩ, R_1 = 5.5 kΩ, R_{in} = 20.4 kΩ (i.e. the damping constant of seismometer $D_s = 0.75$). The graphs are shown in Fig. 4. The largest deviations of the voltage are due to changes of the free period of seismometer (curve 1), critical resistance of the signal coil (curve 5) and the input resistance R_{in} (curve 6). The last parameter is as a part of the electronics without changes and a_s is supposed to be constant as in the preceding case. For estimates of the magnification changes during operation only two parameters are remaining in comparison to the four parameters of the seismograph with the galvanometric recording



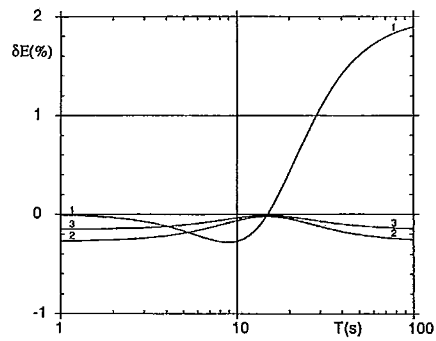


Fig. 4. Relative deviations of voltage δE (%) for 1 % deviations of individual parameters from their nominal values: T_s (1), R_s (2), R_1 (3), D_{s0} (4), a_s (5), R_{in} (6).

The environmental conditions at KAF are similar as in NUR (temperature in the vault is kept at 17 ± 1 °C) and therefore, we shall calculate the maximum deviations for 5 % of the free period of seismometer drift and 0.4 % of resistance drift in case of good operation of heating and 2 % drift of resistance in case of interruption of heating system. The necessary data for surface waves periods are listed in Table 2.

Table 2. Relative deviations δE(%) for positive 1 % drift of particular parameters at given periods T.

Parameter		**Period T(s)**				
No		**10**	**20**	**30**	**40**	**100**
T_s	(1)	-0.273	0.418	1.066	1.416	1.895
R_s	(2)	-0.065	-0.045	-0.122	-0.175	-0.254
R_1	(3)	-0.037	-0.026	-0.069	-0.099	-0.144
D_{s0}	(4)	-0.068	-0.074	-0.049	-0.032	-0.006
a_s	(5)	-0.762	-0.834	-0.551	-0.360	-0.068
R_{in}	(6)	0.864	0.905	0.743	0.633	0.466

For the period range 10 - 20 s we get $\delta E = 1.4 - 2.1$ % for $\delta T_s = 5$ % and negligible influence of 0.4 % deviation of the resistance of the signal coil. For the 5 °C temperature change we receive the total maximum changes of magnification between 1.5 and 2.2 %. For longer periods of ground motion we obtain larger influence of parameters changes on the magnification: 5 - 9.5 % for the seismometer period deviations, 0.05 - 0.12 % and 0.24 - 0.50 %, respectively, for the resistance drifts. For these periods we have 5.2 - 10.0 % estimates for uncertainty of the nominal magnification under the worst conditions of long-term operation of seismograph.

4. *Estimates of the limits of magnitude errors*

Conventional magnitude of particular earthquake is determined by the displacement amplitude A and the corresponding period T of ground motion. The particle motion of surface waves is close to the steady-state harmonic oscillations and the period recorded by the linear system of seismograph is not distorted. The trace amplitude R on seismogram is proportional to the seismograph magnification which is a function of period T. Therefore, for calculation of A simple relation $A = R(T)/M(T)$ may be used. Then the maximum error of surface-wave magnitude due to errors of seismogram evaluation reads

$$\mathrm{d}M_s = (\delta R + \delta M + \delta T)/\ln 10, \tag{11}$$

where $\mathrm{d}P$ means the absolute error and δP the relative error of parameter P, $\delta P = \mathrm{d}P/P$.

The contribution of the magnification inaccuracy to the magnitude error is 0.434 δM of the magnitude unit. For the seismograph with the galvanometric recording we have the maximum error of calibration 13 % and potential drifts of magnification during operation were estimated as 4 % (for periods 10 - 20 s) and 12 % (for periods up to 100 s). It means that the total error of magnification can reach 17 % and 25 %, respectively. The corresponding contributions to the magnitude error in (11) are 0.07 and 0.11 of the magnitude unit. With the digital seismograph we got the maximum calibration error of 10 % and the influence of drift was estimated to 2.2 and 10 %. Therefore, we arrive at the magnitude inaccuracy of 0.06 and 0.09 of the magnitude unit for the same ranges of periods as in the preceding case. The digital seismograph yields only a little smaller errors in comparison to the analog seismograph records.

The second part of the magnitude inaccuracy is due to errors of the trace amplitude and period measurements on the seismogram. With the analog record of the seismograph with galvanometer, when measuring the trace amplitude without any additional optical magnification directly with the millimetre scale rule, then $\mathrm{d}R = 0.5$ mm. For trace amplitudes $R \geq 5$ mm which are not disturbed by seismic noise, the relative error will be $\delta R \leq 0.1$. For the recording speed of 15 mm/min and the minimum period $T = 10$ s we get $\delta T = 0.2$. It means that for the given worst conditions of seismogram evaluation the total contribution of both parameters to the error of magnitude reaches at maximum 0.13. With increasing trace amplitude and/or the wave period the estimated limits are smaller. E.g., for $R \geq 50$ mm and $T = 20$ s this limit is decreased to 0.05 only. When we take in this case maximum errors of magnification, then dM_s is within 0.13 - 0.20 of the magnitude unit.

With the digital data processing the error of the period T measurement may be neglected when a sampling rate as high as 20 Hz is used. The analog/digital converter with the dynamic range of ±2048 counts has an additional constant error of 20 digital counts (i.e. $\delta R = 1$ %); we get for $R \geq 200$ (which corresponds to 0.1 mV on the preamplifier input) $\delta R \leq 0.1$ and the contribution of errors of seismogram measurements to the error of magnitude is 0.043 at maximum. Altogether with the magnification errors $dM_s = 0.10$ - 0.13.

Under the above mentioned conditions of calibration and the overestimated drift of parameters during operation the contribution to the magnitude errors are very close for both seismograph models: 0.07 - 0.11 with the analog seismograph and 0.06 - 0.09 with the digital seismograph. On the other hand the evaluation of seismogram of the digital record is more accurate and the maximum total value of $dM_s \approx 0.13$. It corresponds approximately to the minimum estimate for the analog seismograph with $dM_s \approx 0.12$. Under the worst conditions for the analog record evaluation the total error limit is 0.20 of the magnitude unit. The actual limit can be defined with more precision for the individual seismograms taking into account the real ratio of signal to noise.

5. *Conclusions*

The estimated relative errors of seismograph magnification caused by the inaccuracy of calibration and the potential parameters drift reached about 10 - 15 % with the given seismograph models. These limiting values are not especially small but due to the application of the logarithmic scale in the magnitude relation the uncertainty of the magnitude determination is acceptable. For the mean seismogram reading errors of surface waves in the period range 10 - 20 s the approximate limits of maximum deviations of magnitude were obtained as follows: 0.10 - 0.20 of the magnitude unit for the seismograph with the galvanometric analog recording and 0.05 - 0.15 of the magnitude unit for the digital seismograph.

The advantage of the digital seismograph follows from better possibility of reading seismogram thanks to higher dynamic range as well as better time resolution. This advantage was not pronounced in the calibration procedure and because the dominating part of the seismograph response fluctuation depends on the drift of seismometer parameters, the estimated relative errors of magnification are close to those of the previous seismograph with the galvanometric recording.

In the above estimates the calibration errors and potential parameter variations were overestimated and the seismogram reading errors corresponded to the extreme conditions of seismograph operation. To find more reliable value of influence upon magnitude of particular earthquake, the actual state of magnification can be obtained using the digital seismograph response to the defined excitation of seismometer. The real contribution of the seismogram reading error which depends strongly on the trace amplitude and the level of disturbing seismic noise, can be easy checked with both recording systems. The deviation of magnitude from the mean value of seismic stations network which exceeds the estimated error should be explained by discrepancy of the magnitude calibrating functions with the particular event.

Similar estimates of potential magnitude errors can be carried out for the other models of seismograph, different procedures of seismograph calibration, environmental changes, errors of seismogram evaluation and the other magnitude scales defined by the direct relation to ground motion in the time domain. It is obvious that the mathematical modelling of seismograph response influence on the body waves will be more complicated: the non-harmonic oscillation of ground and the transient motion of seismograph must be taken into account.

Magnitude errors of the recent scales M_w (*Kanamori*, 1977) and M_m (*Okal* and *Talandier*, 1987), based on seismic moment, can be derived if effect of seismograph response on the spectral amplitude is tested for a set of earthquakes records. Only the simplified solution for long-period Rayleigh waves derived for M_m may be analysed as in the present paper. Three formulae (11a-c) valid for different conditions are as follows: (*Okal* and *Talandier*, 1987)

$M_m \approx \log(AT)$, $M_m \approx 1.5 \log A$ and $M_m \approx \log A$. In comparison to formula (11) of the present paper we get: $dM_m = dM_s$ for (11a), $dM_m = (\delta R + \delta M)/\ln 10$ for (11c) and dM_m in (11b) is equal to 1.5 dM_m of (11c). With the above mentioned seismographs which are not optimum for recording long-period seismic waves we get, e.g., at T = 100 s maximum estimates of dM_m for the analog seismogram 0.15 - 0.22 and for the digital data 0.13 - 0.19.

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