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Short note
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On the digitizing of historical seismograms

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The pens of early mechanical seismographs record a curved rather than the straight line when the pendulum is shifted from the equilibrium position. Consequently, the abscissa of the seismogram is generally not a linear function of time. This can be avoided by simple corrections. The first one changes the digitizer coordinates into those of the zero line of the seismogram, and the second one transforms the zero line coordinates to the nonlinear time scale. This process will preserve both amplitudes of displacement and the time history of the seismogram.

O digitaliziranju povijesnih seizmograma

U mehaničkih se seizmografa pisaljka za vrijeme registracije osciliranja tla ne giba okomito na vremensku os seizmograma, nego kružno oko osi zakretanja. To unosi dodatnu promjenljivu komponentu gibanja pisaljke paralelnu s gibanjem registracijskog papira, dakle i s vremenskom osi, pa seizmogram postaje nelinearna vremenska funkcija. Taj efekt dolazi posebno do izražaja ukoliko se takav seizmogram digitalizira, a može ga se izbjeći primjenom određenih korekcija. Prvo valja transformirati koordinate iz sustava digitalizatora u sustav nul linije seizmograma, a zatim prijeći u sustav nelinearne vremenske osi.

Ustanovljeno je da prvu transformaciju valja izvoditi kad god su amplitude veće od 5 mm, a odstupanje smjera nul linije od apscise digitalizatora veće od 0.57°. Za seizmograme registrirane na Wiechertovom seizmografu mase 1000 kg, drugu korekciju valja provesti za elongacije veće od 7 mm, dok za one kod Wiechertovog horizontalnog seizmografa mase 80 kg i Vicentinijevog seizmografa tu korekciju valja provesti za elongacije veće od 4 mm.

Introduction

Most of the rare and thereby very appreciated historical seismograms from the beginning of this century, were obtained by the seismographs with mechanical recording systems. There is a great number of such seismograms in the archives of the Andrija Mohorovičić Geophysical Institute in Zagreb.

The instrumental seismology started in Zagreb in 1906 when Dr. A. Mohorovičić set the Vicentini type seismograph (Pacher 1987) into operation. Immediately after that, the Wiechert type horizontal seismographs (first the one with the 80 kg and later the one with 1000 kg pendulum mass) were installed in 1908, and 1909, respectively. The recorders of these instruments were constructed, so that the pen rotated about the pen pivot causing curvature of the recorded trace. When using digitizers with rectangular coordinates for historical seismograms, the appropriate corrections must be introduced.

Restoring the zero line coordinates

Seismogram is an empirical curve representing the ground motion, generally with abscissa on the zero line and ordinate Y measuring the ground displacement. The distances X on the abscissa are measured in millimeters, and knowing the paper velocity can be transformed into the time units.

By setting the seismogram in the digitizer rectangular coordinate system (x', y'), the intercept l and the slope $k = \mathrm{tg}\ \alpha$ of the zero line, can be defined by the least squares method (Skoko et al., 1965). To preserve the time scale as well as the amplitudes of the seismogram, a two steps transformation must be applied. The first step consist of a simple translation of the digitizer abscissa x' by distance l to the point where the zero line intersects the ordinate (the new coordinates x, y in Fig.1). The second step is a rotation of new coordinates (x, y) into the zero line coordinate system (X, Y) (Fig. 1) defined by relations:

$$X_0 = x_0 \cos\alpha + y_0 \sin\alpha$$
$$Y_0 = y_0 \cos\alpha - x_0 \sin\alpha$$

where the coordinates of the particular point Q of the seismogram are assigned index 0.

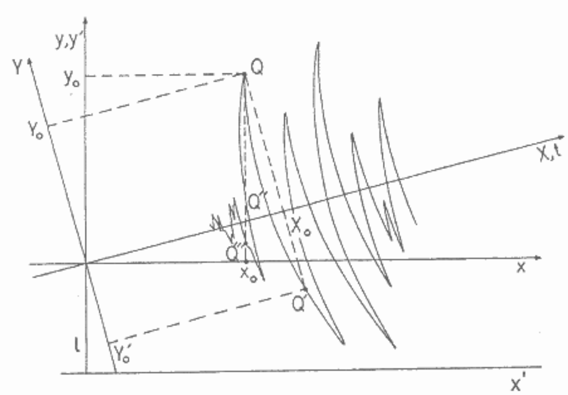

Figure 1. Transformation of digitizer coordinates (x', y') back to the zero line coordinates and ambiguity of ordinate for abscissa x_0.

The absolute values of differences between the zero line abscissa (X_0) and the digitized (x_0) one may be expressed as:

$$|X_0 - x_0| = \frac{1}{(k^2+1)^{1/2}} \left[1 - (k^2+1)^{1/2}\right] x_0 + k\, y_0 \; .$$

Table 1 gives the values of this difference for several assumed k (or α). The values exceeding the assumed digitizing accuracy (±0.05 mm) are set in italics. It is seen that even for very small α, the correction is significant for amplitudes larger than 5 mm.

Table 1. Differences of abscissas (mm) in two coordinate systems when one is rotated by the angle α with respect to the other.

x/mm	y/mm	$\alpha = 0.57°$	$\alpha = 5.7°$	$\alpha = 30°$
0.1	0.1	0.001	0.01	*0.37*
5.0	5.0	*0.05*	0.47	1.83
200.0	200.0	2.00	18.90	73.20

Restoring the time axis from the distances along the zero line

In the case of small recording paper velocity and large pen deflections at short period ground vibrations, the different points of the seismogram could be transferred into the same time coordinate if no correction for arm deflection is applied (points Q, Q'', Q''' or Q and Q' in Fig. 1).

The geometry of the pen arm motion is illustrated in Fig. 2. If the recording paper is at rest, the pen arm $Q_0P_0 = R$ can rotate about pivot P_0 drawing an arc S_0 and the motion of the pen can be presented by two components, the normal one and the one which is parallel to the zero line. The last one will simply be added to the motion of the recording paper, moving with the constant velocity c.

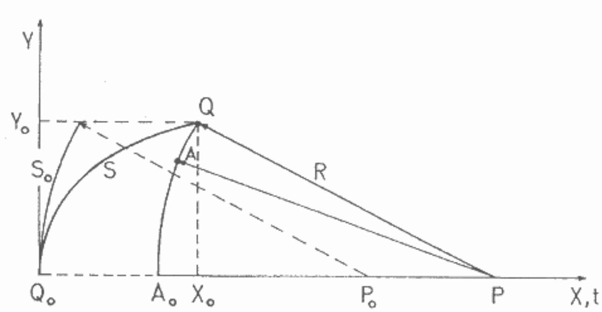

Figure 2. Transformation of the zero line coordinate to the time coordinate axis.

Because of this additional component, the record trace will be neither an arc, as when the paper is at rest, nor the sine line as it is expected for harmonic motion of the indicator. The curve S drawn on the smoked paper is therefore always positively shifted in the time for any deflection of the pen from the zero position (Crouse and Matuschka 1983).

To deal with the problem, let Q be a point of the seismogram S, for which the time correction should be applied. If the origin of the zero line coordinate system is set in Q_0, the time coordinate t of Q is calculated on the basis of the abscissa X_0 of point Q. It should be taken into consideration here that the geometric position of points A, having the same time as the point Q, forms an arc A_0AQ of radius R with the center in P, which is a curve of a constant time. The zero ordinate point A_0 on the arc will have the same time as the point Q on the seismogram. The point A_0 has advances the point Q in time because the velocity of A_0 is the same as the velocity c of the recording paper, which means that from the known abscissa of A_0 the time coordinate of Q can simply be calculated by division with c. As the point A_0 is not marked on the seismogram (except when $A_0Q = 0$), its position can be determined either graphically or analytically. For the later case, one can easily obtain the expression

$$Q_0A_0 = Q_0X_0 - A_0X_0 = Q_0X_0 - [R - (R^2 - Y_0^2)^{1/2}]$$

The time coordinate t of Q is

$$t = \frac{Q_0X_0 - [R - (R^2 - Y_0^2)^{1/2}]}{c}.$$

Even if the paper velocity c of the mechanical seismograph is practically constant, the time coordinate (e.g. Q_0X_0/c) is a function of the elongation Y of the pen. Introducing the time correction

$$\Delta t = -\frac{R - (R^2 - Y_0^2)^{1/2}}{c}$$

the uniqueness of ground displacement as function of time is preserved.

The correction estimate for Vicentini and Wiechert seismographs

The effect of the rotating pen on the correction Dt depends on the recorder construction. The amount of the correction for selected values of pen elongation for the Vicentini and both of the Wiechert horizontal seismographs (80 kg and 1000 kg) is calculated and the results are presented in Table 2. As the length R of the pen arms of the two horizontal components of the Vicentini seismograph that was installed in Zagreb were not equal (140 and 160 mm) we took their mean to estimate the time correction for both.

Table 2. Values of time correction Δt (in seconds) for digitized seismograms recorded by the Vicentini, Wiechert 80 kg and Wiechert 1000 kg seismographs. The length R of the pen arm is measured in millimeters and the velocity c of the paper in millimeters per minute.

Elongations Y/mm:			1	4	7	10	70
Instrument	R	c	Corrections Δt				
Vicentini	150	10	0.02	*0.32*	0.98	2.00	104.0
Wiechert 80	170	20	0.009	*0.14*	0.43	0.88	45.2
Wiechert 1000	445	30	0.002	0.04	*0.11*	0.23	11.1

The values of the time corrections larger than the accuracy of digitizing (±0.05 mm) are set in italics in the table. Elongations corresponding to these values are boundaries beyond which the corrections must be applied. For Vicentini and Wiechert 80 kg the boundary elongation value is 4 mm and for the Wiechert of 1000 kg mass the value is 7 mm.

Conclusion

The note presents two corrections which should be applied to the digitized data of historical seismograms. Rotational movement of the recording pen of the early seismographs causes additional curvature of the trace, causing the ambiguity of the ordinate. To avoid this it is more suitable to apply the expressions for transformation of the digitized coordinates into the rotated zero line coordinate system, rather then using the classical trend removing procedure. Thereafter, for each digitized point the value of the ordinate dependent time coordinate is calculated. Both corrections are significant if the amplitude exceeds few millimeters. Because of simplicity of the procedure, it is desirable to include them in the computer program for digitizing historical seismograms regardless of the amplitude of the record.

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