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Comparison of Montreal P-Wave Magnitudes from Short Period and Intermediate Period Seismograms

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INTRODUCTION

During recent international seismological discussions (Davies, 1968), it was noted that different body-wave magnitudes can result if determinations are made from records written by seismographs with different pass bands. The case in point relates to different P-wave magnitudes reported by U.S.S.R. seismologists using broad band Kirnos-type seismographs SGK-M ($T_s = 12.5$ s, $T_g = 1.2$ s) and Western seismologists using narrow band Benioff-type seismographs ($T_s = 1.0$ s, $T_g = 0.75$ s).

For simplicity of the determinations, the P-wave magnitude has been defined in terms of a single maximum amplitude A/T measurement. If, for measurements made directly from the records, A is proportional to T, then magnitudes determined at different periods will be equivalent. P-wave spectra can show the variation of amplitude with period, but, because of the non-stationary properties of a P-wave signal, the spectral amplitude at period T and the amplitude measured from the record may not be equal. Ideally, it would be of interest to calculate A/T characteristics from synthetic P-wave signals as they would be written by seismographs with different pass bands, but this is not theoretically possible for earthquakes with complex source functions and is only approximately possible for the first few signal cycles for explosions with a less complex source function. Hence, a direct measure of maximum amplitudes at different periods (i.e., from different pass band instruments) provides the best empirical measure of the effect on magnitude.

The operation at the Montreal station (latitude 43°30'09" N, longitude 73°37'23" W) of both short-period and intermediate-period seismographs provides an opportunity to make a comparison of P-wave magnitudes determined from different pass band instruments at the same recording site. The calibration curves for the short-period vertical (SPZ) and intermediate-period vertical (IPZ) seismographs are shown in Figure 1. The velocity sensitivity of the SPZ is sharply peaked near 0.6 second. that of the IPZ is essentially flat from about 1.0 to 6.0 seconds. The seismometer periods (T_s) and galvanometer periods (T_g) are indicated by small arrows in Figure 1.

EVENTS AND MEASUREMENTS

The Montreal seismograms for a period of 35 months between 1964 and 1967 were searched for earthquakes for which both SPZ and IPZ P-wave A/T measurements could be made. The usable events are restricted to those with good signal-to-noise ratio on IPZ, yet with SPZ amplitudes not too large for measurement. A total of 156 events were measured, of which 134 had USCGS epicenters within 100° of Montreal, well distributed over the earth's seismic regions.

The maximum amplitude usually occurs at the same point in time on both the SPZ and IPZ records, generally within 5 seconds of the P onset on SPZ and at the first or second cycle on IPZ. When the maximum occurs at a later time (as is often the case for very large earthquakes), the amplitude was measured at approximately the same time on both records.

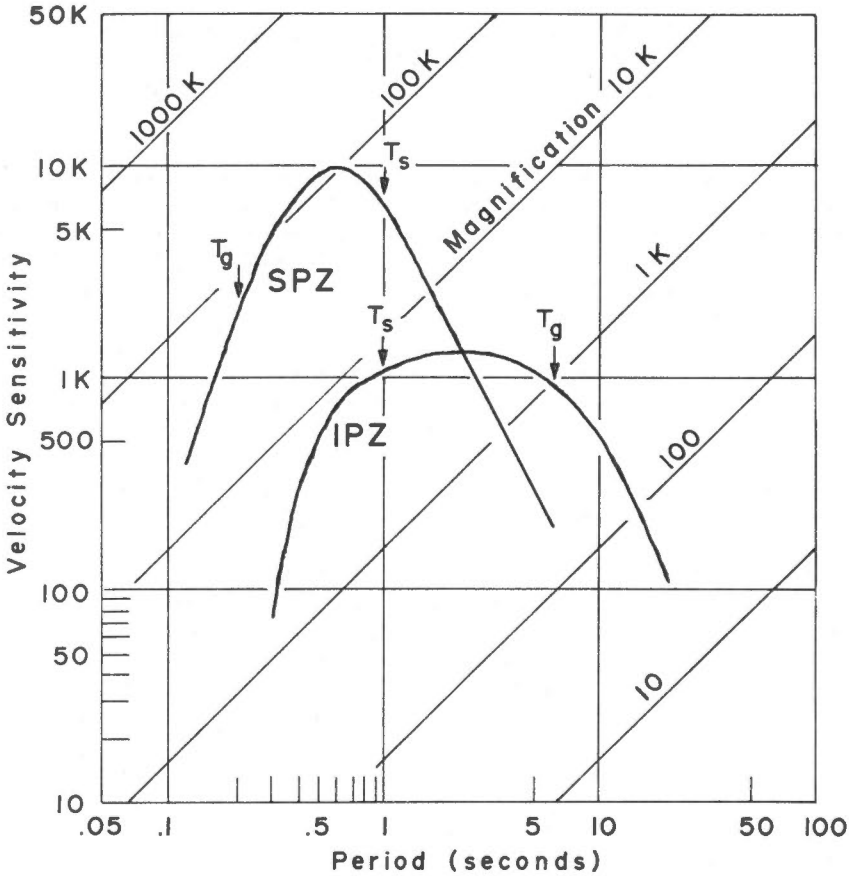

Figure 1. Calibration curves for Montreal intermediate-period vertical (IPZ) and short-period vertical (SPZ) seismographs.

Seventy per cent of the SPZ periods fall within the range 0.8 to 1.2 seconds; 24 per cent are larger (up to 2.5 seconds) and 6 per cent are smaller (down to 0.6 second). The IPZ periods are well distributed in the range 0.6 to 6.0 seconds; 44 per cent fall within the range 1.5 to 2.5 seconds; 40 per cent are larger and 16 per cent are smaller. The difference between the SPZ and IPZ periods of maximum amplitude motion is highly variable; i.e., the relative proportion of longer period energy varies strongly from event to event. Some source regions show characteristic effects; for example, South American events are strongly impulsive at Montreal with little difference in dominant periods on SPZ and IPZ.

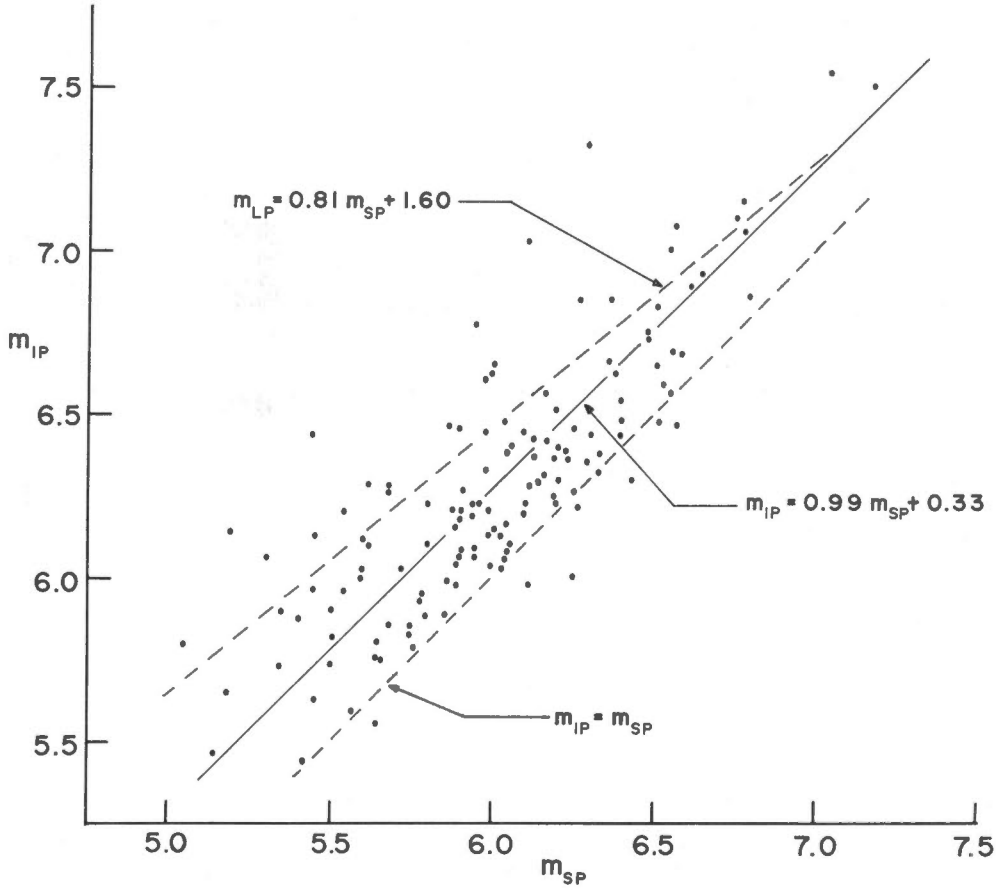

Figure 2. A plot of intermediate-period magnitude (m_{IP}) versus short-period magnitude (m_{SP}) for 134 earthquakes.

SHORT-PERIOD VERSUS INTERMEDIATE-PERIOD MAGNITUDES

Short-period magnitudes (m_{SP}) and intermediate-period magnitudes (m_{IP}) are calculated from $\log(A/T)_{SP}$ and $\log(A/T)_{IP}$, respectively, for each of the 134 events at a distance less than 100° from Montreal. The mean magnitude difference $\delta m = m_{IP} - m_{SP}$ is 0.28. This means that on the average $(A/T)_{IP}$ is approximately twice as large as $(A/T)_{SP}$.

A plot of m_{IP} versus m_{SP} for the 134 events is shown in Figure 2. The solid line is a least squares fit to the plotted points and is given by the equation

$$m_{IP} = (0.99 \pm .01)m_{SP} + (0.33 \pm .01)$$

where the errors are probable errors in the mean. Although the scatter is large, the least squares line is nearly parallel to $m_{IP} = m_{SP}$, the lower broken line in Figure 2. There is some dependence of δm on m, which is not suggested by the slope of the least squares line and which is not easily seen in the scatter plot. The mean magnitude difference δm is $0.34 \pm .03$ for $m_{SP} < 6.0$ and $0.21 \pm .03$ for $m_{SP} > 6.0$ (standard deviations in the mean). The data points in Figure 2 tend to be denser below the least squares line, but restrained by the $m_{IP} = m_{SP}$ line, and dispersed over a wider range above the least squares line.

The upper broken line in Figure 2, which lies above the m_{IP} versus m_{SP} line, is a least squares relationship, given by Romney (1964), between m_{LP} and m_{SP}, P-wave magnitudes calculated at the same station from long-period and short-period seismographs, respectively. Romney does not give data on the measured periods from the long-period instruments, but P-waves recorded on Canadian 15-90 and 30-90 (T_s - T_g) seismographs commonly have periods near 10 seconds. The implication is, then, for P-wave periods larger than the intermediate periods measured in this study, that the magnitude difference will increase further.

OBSERVED DEPENDENCE OF A ON T

From the definition of the P-wave magnitude, the $m_{IP} - m_{SP}$ magnitude difference is given by

$$\delta m = \log(A/T)_{IP} - \log(A/T)_{SP}$$

or

$$\delta m = \log(A_{IP}/A_{SP}) - \log(T_{IP}/T_{SP}) \qquad (1)$$

An empirical relationship between δm and one of the terms on the right of Equation (1) will yield the effective dependence of A on T. Consider the case of P-wave amplitudes which vary in the manner: $A \alpha T^n$ where n is a positive number. Then $\log(A_{IP}/A_{SP}) = n \log(T_{IP}/T_{SP})$ and Equation (1) gives

$$\delta m = (n-1) \log(T_{IP}/T_{SP}) \qquad (2)$$

The data are presented in this way in Figure 3. The plotted points are observed values of δm versus $\log(T_{IP}/T_{SP})$. The three straight lines are Equation (2) for integer values of n = 1, 2, and 3. The plotted points, although widely scattered, conform nearest to the case $A \alpha T^2$; however, Equation (2) with n = 2 is not a fit to the plotted points in the least squares sense. This result suggests that P-wave magnitudes would be roughly independent of the period of measured motion if the magnitude were defined in terms of $\log(A/T^2)$ rather than $\log(A/T)$. In fact, because T_{SP} is near 1.0, application of Equation (2) with n = 2 as an adjustment to the magnitude yields the formula

$$m = \log(A/T^2) + Q(\Delta, h)$$

for P-waves of any period T between, say, 0.6 and 10 seconds; no additional additive constant is required.

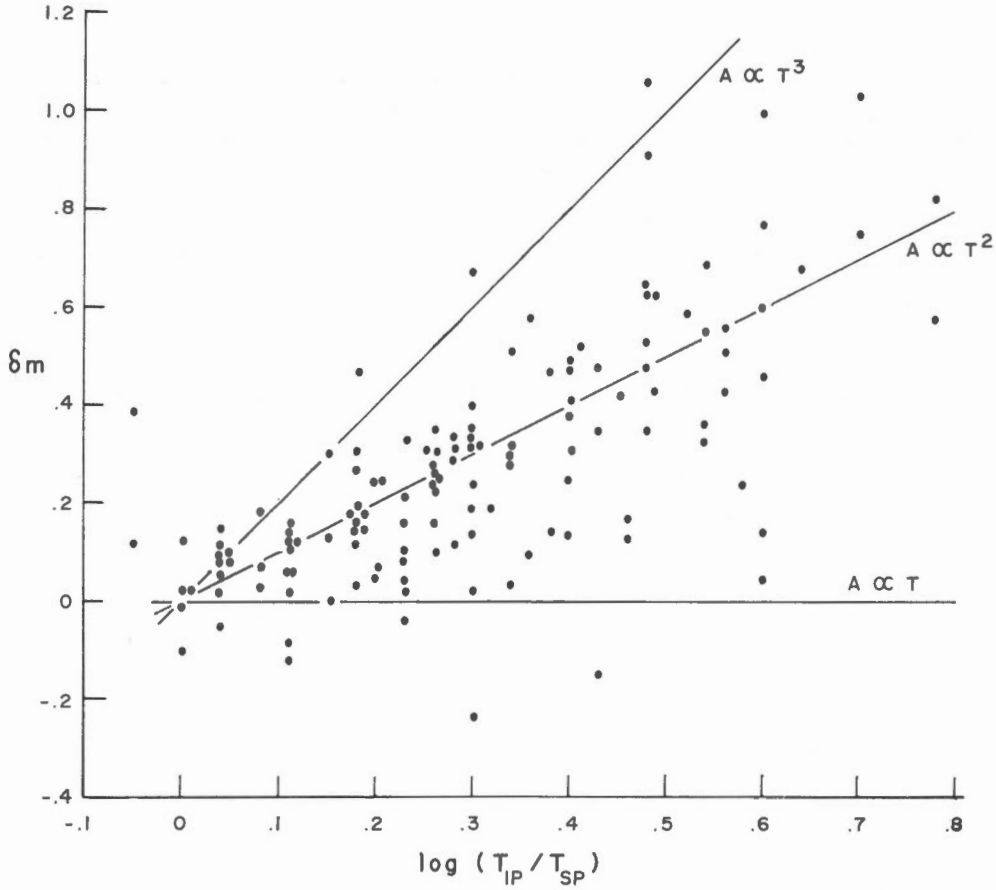

Figure 3. A plot of magnitude difference versus period ratio for 134 earthquakes. The straight lines are Equation (2) for n = 1, 2, and 3.

The results of Figure 3 do not imply that in general the P-wave amplitude spectrum is a smooth function of the form $A \alpha T^2$. If A, the ground displacement, is proportional to T^2, then the ground velocity is proportional to T. A ground velocity spectrum of this type can be represented by the oblique magnification lines in Figure 1. Multiplication of one of the magnification lines by the velocity sensitivity curves shows that the SPZ record would have a maximum amplitude near T = 0.8 second, the IPZ record near T = 7 seconds. The observed SPZ periods are near this value because of the sharply peaked nature of the calibration curve; the IPZ periods cover a broad range (see the distribution of $\log(T_{IP}/T_{SP})$ in Figure 3), many very near the SPZ period but none as large as 7 seconds. Hence, the P-waves contain one or more dominant periods in the band covered by the intermediate-period seismographs; the dominant period of maximum amplitude motion varies considerably among events; and, collectively for this suite of events, the ground displacement at the maximum amplitude trace motion varies roughly in proportion to T^2.

CONCLUSION

A P-wave magnitude can depend on the pass band of the seismogram from which it is determined. The results of this study show that the average difference between intermediate- and short-period magnitudes is about m 0.3, that the difference increases with the period of maximum amplitude motion, and that the effect is highly event-dependent but only slightly magnitude-dependent. The effect of seismograph pass band can be removed (within the accuracy normally attributed to magnitude calculations) by applying - log T as an 'instrument correction' to the magnitude formula.

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