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Station Corrections for Canadian Magnitudes of Earthquakes and Underground Explosions in North America and Asia

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INTRODUCTION

Seismologists generally recognize that magnitude calculations are in an unsatisfactory state. This results from two factors: (1) differences in magnitude formulae and methods of computation used by different observatories and national agencies, and (2) large variations in phase amplitudes among observatories because of geological effects of the path, near both the observatory and the source region. Attempts to eliminate the first factor have been made through suggestions for world-wide adoption of standard formulae. The second factor can only be eliminated by a systematic calibration of each observatory for each source region and the application of corrections to the computed magnitudes.

The standard teleseismic magnitude formulae suggested by Båth (1966) and adopted for use by the Dominion Observatory are

$$m = \log (A/T) + Q(\Delta, h) + S_m \qquad (1)$$

for P waves from vertical short-period seismograms, and

$$M = \log (A/T) + 1.66 \log \Delta + 3.3 + S_M \qquad (2)$$

for Rayleigh waves from vertical long-period seismograms. A is the maximum trace phase amplitude converted to ground displacement in microns; T is the corresponding period in seconds; $Q(\Delta, h)$ is the Gutenberg and Richter (1956) distance (Δ) and focal depth (h) calibrating function; S_m is the station correction for P waves; and S_M is the station correction for Rayleigh waves. Equation (1) is widely accepted, with some variations on Q, particularly at near distance. Equation (2) has recently come into common use but variations exist in the component of the Rayleigh wave measured and in the range of periods permitted (Basham, 1969a). The use of M should be restricted to seismic events of shallow depth, say $h < 50$ km.

During a study of the relative excitation of Rayleigh waves and P waves of earthquakes and underground explosions in North America and Asia (Basham, 1969a and 1969b) station corrections for 20 stations of the Canadian network were computed for each source type in each region. To bring together all available corrections under one cover, tables of S_m and S_M are presented here. It is hoped that this will encourage the use of available corrections in conjunction with the accepted formulae and promote the eventual determination of Canadian station corrections for all major seismic regions of the world.

Lists of events used in the Asian study were, for purposes of brevity, omitted from the 1969b paper and are included here. Events used to determine the North American corrections are given in the 1969a paper.

STATION CORRECTIONS

The earthquakes and explosions used in the Asian M versus m study are listed in Tables I and II, respectively. The information was taken from the USCGS "Preliminary Determination of Epicenters" cards. Station corrections were determined from events recorded at 14 or more stations and are mean values of $\bar{\bar{m}}$-m (station) for the P wave correction (S_m), and $\bar{\bar{M}}$-M (station) for the Rayleigh wave correction (S_M). In these determinations $\bar{\bar{m}}$ and $\bar{\bar{M}}$ are averages of all available raw (uncorrected) magnitudes for the particular events, and m (station) and M (station) are the individual raw values. To compute the Canadian m and M magnitudes with their rms scatter given in Tables I and II, the station corrections are added to the individual station raw magnitudes to determine corrected station magnitudes, which are in turn averaged. The values of n in Tables I and II indicate the number of stations contributing to the final m and M magnitudes. The procedure for determining the North American corrections was the same except that events recorded at 17 or more stations (rather than 14) were used.

P wave corrections and Rayleigh wave corrections, with their rms scatter, determined in these studies are listed in Tables III and IV, respectively. In two cases - P waves from southwestern North American earthquakes and Rayleigh waves from Asian explosions - the phases were not recorded by enough stations to allow the computation of station corrections.

USE AND LIMITATIONS OF STATION CORRECTIONS

A station correction given in Table III or IV, when applied to a raw station magnitude, will yield an equivalent Canadian mean value to within an accuracy roughly equivalent to the rms scatter on the station correction. Averaging of corrected station magnitudes to determine a Canadian mean will yield a value whose accuracy does not depend significantly on the number of stations used; see, for example, the rms scatter on Canadian magnitudes in Tables I and II.

No systematic attempt is made to adjust Canadian magnitudes to agree with those of any other agency, although checks should always be made to identify any consistent bias in Canadian values, for example, the effect of intracontinental Rayleigh wave propagation discussed in the 1969a and 1969b papers. A comparison of some Canadian and United States magnitudes is given in Table V. For each suite of events the Canadian magnitudes are slightly smaller than the United States values but in each case the rms scatter is as large as the mean difference.

Many of the corrections given in Tables III and IV are not statistically different from zero because of rms scatter larger than the corrections themselves; this is true of many of the earthquake corrections but few of the explosion corrections. The cause of the earthquake correction scatter is associated with the critical dependence of P wave corrections on fine-scale geographic source region differences and of Rayleigh wave corrections on differences in propagation path. The earthquakes are distributed over wide regions compared with the explosions at nearly identical epicentres. Much of the P wave amplitude variation at a single station as a function of small changes in the epicentre location can be attributed to geological conditions near the station which vary markedly with the angle and azimuth of the emerging ray. A station which exhibits a strong effect of this type is MBC for Asian P waves. In Table III MBC has large negative P wave corrections for both central Asian and Novaya Zemlya explosions, but a zero correction with large scatter for Asian earthquakes. The latter result is a combination of large positive and large negative values for different earthquake locations, and is an obvious example of the requirement for finer-scale regionalization of the magnitude corrections.

The Q (Δ, h) function (see Equation (1)) of Gutenberg and Richter (1956) is not reliable for distances less than 20°. This effect contributed to large P wave corrections for the five stations nearer than 20° to the Nevada test site (see Table III), and on the basis of these five station corrections a modification was made to the Q function (Basham, 1969a). It is suggested that, until this effect is better defined, P wave magnitudes of western North American events at distances less than 20° from these five stations be based on the modified Q function with the station corrections omitted from the calculation.

Bearing in mind the possibility of errors because slight changes in epicentre can have a strong effect on a required station correction, the station corrections in Tables III and IV can be applied a little more broadly than indicated by the column headings. On the assumption that explosion test site corrections are representative of a larger region surrounding the site, and vice versa, Nevada explosion P wave corrections have been applied to southwestern North American earthquakes (in the 1969a paper) and Asian earthquake Rayleigh wave corrections have been applied to Asian explosions (in the 1969b paper). In general the Rayleigh wave corrections, because they depend on the total transit path rather than local conditions, are less sensitive to small changes in epicentre. The Rayleigh wave corrections for Nevada explosions and southwestern North American earthquakes (Table IV) for most stations agree within the rms scatter.

The data presented here provides accurate calibration of Canadian P and Rayleigh wave magnitudes of explosions at both the Nevada and Asian test sites, and useful, but less accurate, calibration for magnitudes of earthquakes from natural seismic regions surrounding the test sites. Calibration of the numerous and more active seismic regions of the world awaits further study.

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Table I

EARTHQUAKES USED IN ASIAN M VS. m STUDY

Date	Time	Lat. °N	Lon. °E	h (km)	m_{CGS}	Canadian Magnitudes			
						m	n	M	n
10 Jun 66	22:41:48.5	45.1	99.7	33	5.1	4.99±.27	12	4.57±.12	13
30 Aug	06:10:33.4	51.7	104.4	33	5.0	5.01±.24	10	4.22±.13	14
18 Jan 67	05:34:32.6	56.6	120.8	11	6.1	5.72±.29	19	5.94±.16	18
20	01:57:23.1	48.0	102.9	33	6.1	6.40±.25	19	6.43±.15	18
22	12:01:49.0	48.1	102.9	33	5.1	5.19±.25	15	4.39±.14	4
11 Feb	09:27:29.6	52.0	106.2	5	5.4	5.07±.24	15	4.49±.18	16
20	15:18:39.9	33.7	75.3	24	5.7	5.42±.29	14	4.86±.16	9
24 Apr	08:51:10.9	37.4	72.7	31	5.6	4.97±.30	12	4.56±.18	13
25	10:30:37.8	43.3	87.0	34	5.2	5.05±.18	14	4.44±.15	15
27	23:15:19.7	41.7	82.3	33	5.0	4.98±.25	12	4.21±.19	7
20 Aug	02:02:05.2	45.3	80.1	33	5.1	5.35±.30	13	4.99±.14	15
13 Mar 68	22:38:38.9	42.4	66.5	33	5.2	5.18±.25	11	4.31±.19	3
14	02:08:36.6	42.3	66.5	33	5.4	5.37±.22	14	4.64±.14	7
4 Jun	05:10:52.0	35.7	82.1	33	4.8	4.66±.23	3		0
8 Jul	13:14:29.9	38.0	67.6	28	5.2	5.13±.20	10	4.26±.15	10
21	01:41:19.5	55.2	113.3	33	5.1	4.77±.39	8	4.54±.11	15
31 Aug	10:47:37.4	34.0	59.0	13	6.0	6.48±.22	16	(7.12)	16
1 Sep	05:39:46.7	39.1	46.0	38	5.1	5.02±.29	6	4.57±.11	9
	07:27:30.2	34.0	58.2	15	5.9	6.20±.34	17	6.29±.16	15
	19:16:37.2	34.2	58.3	23	5.0	4.92±.19	7		0
4	08:08:44.3	33.9	59.2	24	5.0	4.87±.20	9	4.50±.12	13
	11:19:35.6	33.9	59.1	25	5.1	4.92±.23	8	4.11±.13	11
	23:24:47.2	34.0	58.2	15	5.4	5.51±.22	13	4.95±.15	19
5	08:57:45.3	46.7	82.2	33	4.7	4.92±.34	7	4.32±.23	6
9	02:20:57.9	66.1	142.1	33	5.1	4.95±.40	13	4.13±.20	13
11	19:17:12.9	33.9	59.4	33	5.2	5.10±.19	10	5.54±.12	19

Table I (Cont'd)

EARTHQUAKES USED IN ASIAN M VS. m STUDY

Date	Time	Lat. °N	Lon. °E	h (km)	m_{CGS}	Canadian Magnitudes m	n	M	n
12 Sep 68	15:36:48.8	39.8	77.8	8	4.9	4.78±.27	6	4.31±.32	7
14	13:48:31.2	28.4	53.1	33	5.8	5.80±.23	14	5.86±.09	17
19	04:57:40.3	49.4	140.2	33	4.9	4.94±.38	7	4.32±.17	15
26	00:46:13.8	33.7	69.9	45	5.2	5.42±.30	10	4.82±.19	19
19 Oct	07:01:33.4	37.3	73.2	51	5.2	5.40±.38	13	4.65±.23	10
	09:52:03.4	37.5	73.3	33	5.4	5.44±.35	13	4.91±.22	14
30	04:07:20.7	37.4	73.2	12	5.5	5.41±.36	11		0

Table II

EXPLOSIONS USED IN ASIAN M VS. m STUDY

Date	Time	m_{CGS}	Canadian Magnitudes			
			m	n	M	n
Central Asia*						
15 Mar 64	07:59:58.0	5.6	5.45±.08	9		
19 Jul	05:59:58.9	5.5	5.37±.22	10		
16 Nov	05:59:57.4	6.0	5.59±.20	10		
15 Jan 65	05:59:58.5	6.3	6.29±.23	10		
3 Mar	06:14:57.0	5.6	5.34±.09	8		
11 May	06:39:57.8	5.2	4.73±.10	6		
17 Jun	03:44:58.5	5.4	5.16±.09	11		
29 Jul	03:05:02	4.5	4.28±.13	3		
17 Sép	03:59:57.4	5.6	5.12±.08	7		
8 Oct	05:59:59.2	5.7	5.33±.09	12		
21 Nov	04:57:58.0	5.8	5.52±.09	12		
24 Dec	04:59:58.1	5.2	4.74±.07	9		
13 Feb 66	04:57:57.9	6.2	6.23±.11	17	4.32±.16	8
20 Mar	05:49:57.7	6.2	6.01±.09	16	4.28±.15	7
21 Apr	03:57:57.9	5.4	5.29±.07	13		
29 Jun	06:57:58.0	5.6	5.42±.07	16		
21 Jul	03:57:57.8	5.6	5.28±.10	14		
5 Aug	03:57:58.1	5.7	5.36±.10	15		
19 Oct	03:57:57.7	5.6	5.69±.11	17		
18 Dec	04:57:57.8	5.9	6.01±.27	15		
26 Feb 67	03:57:57.7	6.0	6.02±.11	19	4.31±.37	2
20 Apr	04:07:57.6	5.7	5.49±.09	14		
17 Oct	05:03:58.0	5.7	5.57±.06	14		
30	06:03:57.9	5.5	5.36±.10	15		
24 Apr 68	10:35:57.1	5.0	4.75±.09	13		
11 Jun	03:05:57.8	5.3	5.13±.09	14		
19	05:05:57.3	5.5	5.47±.23	18		
12 Jul	12:07:57.2	5.4	5.22±.15	13		
20 Aug	04:05:58.1	4.8	4.63±.14	10		
5 Sep	04:05:57.4	5.5	5.40±.11	18		
29	03:42:57.5	5.8	5.81±.11	20		

Table II (Cont'd)

EXPLOSIONS USED IN ASIAN M VS. m STUDY

Date	Time	m_{CGS}	Canadian Magnitudes m	n	M	n
Novaya Zemlya**						
18 Sep 64	07:59:54.8	4.3	3.97±.03	2		
25 Oct	07:59:58.8	4.9	4.69±.17	7		
27 Oct 66	05:57:58.0	6.3	6.39±.14	18	4.74±.20	17
21 Oct 67	04:59:58.1	5.9	5.82±.08	18	4.13±.02	2
7 Nov 68	10:02:05.3	6.0	5.97±.10	18	4.37±.23	13

*Epicentres within about one degree of 50°N 78°E. **Epicentres within about one degree of 73°N 55°E.

Table III

CANADIAN P WAVE MAGNITUDE
STATION CORRECTIONS (S_m)

Station*	Central Asian Explosions	Novaya Zemlya Explosions	Nevada Explosions	Asian Earthquakes
ALE	.41±.13	.27±.09	.30±.13	.11±.27
BLC	-.46±.13	.01±.08	.20±.18	.03±.16
CMC	-.50±.16	-.55±.04	.47±.30	-.10±.13
FBC	-.21±.12	-.10±.01	-.02±.10	.06±.16
FCC**	-.04±.09	.18		-.06±.34
FFC	-.19±.09	-.28±.07	-.01±.25	-.17±.20
FSJ***	-.28±.14	-.03±.01	.47±.23	-.11±.22
GWC	-.26±.18	-.72±.21	.08±.27	-.15±.17
HAL	.57±.19	-.01±.12	.07±.14	.15±.15
MBC	-.69±.11	-.59±.21	.16±.19	.00±.48
OTT	.34±.16	-.37±.06	.00±.27	-.05±.17
PHC***	.51±.24	.25±.03	.38±.22	.16±.20
PNT***	-.27±.13	-.19±.04	-.77±.17	-.36±.25
RES	.46±.12	.50±.11	.30±.20	.40±.25
SCH	.21±.19	-.16±.08	-.13±.17	-.05±.24
SES***	-.25±.13	.19±.09	-.27±.24	-.16±.31
SFA	.59±.14	.00±.09	-.16±.24	.19±.38
STJ	.36±.16	.29±.13	-.61±.24	.28±.38
VIC***	.90±.17	.67±.01	-.24±.32	.45±.28
YKC	-.20±.12	.58±.04	-.08±.21	-.21±.16

*See any recent Canadian Seismological Bulletin for station names, coordinates, and instrumentation. **FCC was not operational early enough to be included in the Nevada study; only one Novaya Zemlya explosion was recorded. ***See text concerning large Nevada corrections and modifications of Q.

Table IV

CANADIAN RAYLEIGH WAVE MAGNITUDE STATION CORRECTIONS (S_M)

Station	Nevada Explosions	SW N. American Earthquakes	Asian Earthquakes
ALE	.02±.13	-.07±.16	.07±.23
BLC	-.13±.13	.02±.17	-.01±.11
CMC	-.06±.15	-.22±.14	.04±.18
FBC	-.01±.11	-.22±.15	.10±.12
FCC			-.11±.11
FFC	.35±.17	.23±.16	-.01±.14
FSJ	-.03±.19	.16±.16	-.05±.17
GWC	-.06±.11	.02±.14	.00±.12
HAL	-.25±.11	-.25±.19	.21±.23
MBC	-.21±.16	-.40±.14	.00±.12
OTT	-.28±.16	-.17±.22	-.06±.16
PHC	.37±.15	.52±.16	.05±.12
PNT	.34±.11	.12±.16	-.17±.17
RES	-.47±.08	-.01±.26	-.03±.14
SCH	-.09±.14	-.12±.22	-.01±.16
SES	.19±.10	.34±.11	-.18±.16
SFA	-.13±.16	-.07±.16	.12±.12
STJ	-.04±.15	-.16±.12	.34±.28
VIC	.28±.10	.32±.06	-.02±.07
YKC	.13±.10	-.04±.15	.01±.14

Table V

COMPARISON OF CANADIAN AND UNITED STATES MAGNITUDES

Events	Mean Magnitude Difference	Data Source
28 Asian earthquakes	$m_{LASA}-m = .02 \pm .41$	LASA bulletins (m_{LASA})
33 Asian earthquakes	$m_{CGS}-m = .04 \pm .22$	See Table I
8 Asian earthquakes	$M^{LASA}-M = .18 \pm .25$	Capon, et al. (1967) (M^{LASA})
36 Asian explosions	$m_{CGS}-m = .17 \pm .16$	See Table II
28 SW N. American earthquakes	$m_{CGS}-m = .25 \pm .38$	Basham (1969a)
18 Nevada explosions	$m_{LRSM}-m = .07 \pm .16$	Basham (1969a)