BMR Journal of Australian Geology & Geophysics, 9, 313-316

The response and calibration of seismographs at Riverview College Observatory, New South Wales, 1909–1962

L.A. Drake[1]

Seismograms from Riverview College Observatory for 1909 to 1962 are a valuable record of seismic ground motion in the Sydney region during that time, because the constants of the seismographs at Riverview were carefully and regularly determined. So that the seismograms can be effectively used, this paper sets out where the constants of the seismographs for this period can be found, how the response of the seismographs can be calculated from the values of the constants, and how the constants themselves were determined. The constants from the Wiechert and Mainka seismographs are static magnification, period, damping ratio, and solid friction. The constants for the Galitzin seismographs are galvanometer period, seismometer or pendulum period, damping constant of the seismometer, and synchronous magnification. Simple formulae give the magnification and phase lead of the respective seismographs in terms of the constants.

Introduction

The response characteristics of pre-World-Wide Standard Seismographs are important when studying earthquakes that took place before 1960. Recent work (Kanamori, 1982) indicates that these old seismograms are often of sufficient quality to enable focal mechanisms to be determined and are vital for earthquake risk studies. Thus it is important for the calibration parameters of old seismographs to be readily accessible.

As part of a project to film historical seismograms (Glover & Meyers, 1981), seismograms from Riverview College Observatory (at Lane Cove, NSW) covering the period 17 March 1909 to December 1962 were moved to the Australian Archives in Canberra, where they are now under the care of the Earthquake Seismology Group of the Bureau of Mineral Resources. Anyone wishing to use these needs to know the instrumental constants at the time of recording and how to determine the magnification and phase lead of the seismograph from these constants. This paper sets out: (i) where to find the instrumental constants of the Riverview seismographs; (ii) how to find the magnification and phase lead from these constants; and (iii) how the constants were determined. Because of its importance in the study of earthquake magnitudes, the determination of the static magnification of a Wood-Anderson seismograph is also considered.

A Wiechert seismograph with N–S and E–W components was operated at Riverview from 17 March 1909 until June 1955. A Weichert vertical seismograph was operated from 19 May 1909 until January 1944. Mainka N–S and E–W seismographs were operated from August 1910 until December 1962. Galitzin vertical, N–S, and E–W seismographs were operated from 19 January 1941 until December 1962. The World-Wide Standardized Seismograph Net (WWSSN) Benioff and Sprengnether seismographs have been operated at Riverview since December 1962. The Mainka seismographs were also operational on 9 March 1973, when the Burragorang Valley earthquake of magnitude 5.5 sent the WWSSN seismographs off-scale (Drake, 1974). The Mainka seismograms for this date are still at Riverview.

Seismograph constants

The constants for the Wiechert and Mainka seismographs are static magnification V, period T, damping ratio e, and solid friction r/T^2. Those for the N–S and E–W Wiechert seismograph were published in the *Seismological Bulletin* of Riverview College Observatory each year from 1909 until 1955, except for 1910 and 1931–33. The constants for these years, together with those for 1927 (before the magnification was increased on 2 November 1927) are set out in Table 1. Similarly, the constants of the vertical Wiechert seismograph were published in the Riverview *Seismological Bulletin* from 1909 to 1944, except for 1910 and 1931–33. These constants, together with those for 1927, are also given in Table 1.

Table 1. Wiechert constants

		V	T	e	r/T^2
26 Mar 1910	Z	61	3.6	2.8	0.040
5 Nov 1910	N	203	8.1	10.6	0.020
	E	198	6.6	6.3	0.021
17 Oct 1927	Z	80	5.1	3.3	0.100
	N	158	7.7	4.0	0.030
	E	170	7.6	4.6	0.033
15 Jun 1931	Z	61	5.2	3.7	0.047
	N	199	8.6	3.8	0.019
	E	206	9.5	3.9	0.017
15 Jun 1932	Z	58	5.3	3.2	0.053
	N	202	8.4	3.5	0.020
	E	213	9.2	3.3	0.015
20 Jun 1933	Z	60	5.1	3.0	0.092
	N	209	8.1	3.7	0.021
	E	215	9.2	3.7	0.014

The constants of the N–S and E–W Mainka seismographs were published in the Riverview *Seismological Bulletin* each year from 1911 to 1956, except for 1931 to 1933. For 1910, 1931–33, 1956, 1959, and 1960, they are set out in Table 2.

Table 2. Mainka constants

		V	T	e	r/T^2
18 Nov 1910	N	166	6.3	1.5	0.031
	E	143	6.0	2.2	0.021
15 Jun 1931	N	90	11.9	4.4	0.006
	E	90	6.9	3.3	0.014
15 Jun 1932	N	84	14.3	5.8	0.010
	E	69	10.1	4.8	0.026
20 Jun 1933	N	80	12.2	4.4	0.011
	E	82	13.0	3.8	0.010
11 Dec 1956	N	143	8.5	6.2	0.023
	E	138	9.1	6.8	0.014
8 Aug 1959	N	176	7.8	9.2	0.015
	E	143	8.3	4.2	0.009
15 Jun 1960	N	152	7.1	4.2	0.018
	E	137	8.6	4.3	0.012

The constants for the vertical, N–S and E–W Galitzin seismographs were published in the Riverview *Seismological Bulletin* from 1941 to 1956. They are the period of the galvanometer T_1, the period of the seismometer T, the damping constant of the seismometer μ^2, and the synchronous magnification of the seismograph V. The constants for 1954 (re-calculated with a programmable calculator), 1957, 1959, and 1960 are given in Table 3.

[1] School of Earth Sciences, Macquarie University, North Ryde, NSW 2113

Table 3. Galitzin constants

		T_1	T	$\mu 2$	V
28 Jan 1954	Z	10.9	9.7	0.12	408
	N	11.7	12.3	0.19	582
	E	12.3	12.2	0.03	501
15 May 1957	Z	10.8	10.1	−0.01	510
	N	11.8	12.6	0.19	591
	E	12.5	11.7	−0.02	493
17 Jul 1959	Z	11.1	11.2	0.21	478
	N	11.2	11.0	−0.38	486
	E	12.7	12.5	−0.38	551
7 Jul 1960	Z	11.1	11.2	0.21	478
	N	11.4	11.4	0.95	740
	E	12.7	12.0	−0.74	514

Constants were carefully determined at Riverview, usually every month, from 1909 to 1956, and at longer intervals for the final six years, 1956 to 1962, when the response of the seismographs was fairly stable. Use of the Riverview seismograms in conjunction with the values of the instrumental constants at the time the seismograms were recorded provides a valuable record of seismic ground motion in the Sydney region from 1909 to 1962.

Magnification and phase lead

It can be shown for oscillatory ground motion sin pt, where p is the angular frequency of the motion and t is time, that the displacement of a seismograph is given by:

$$y = \frac{V\sin(pt + \phi)}{[(1 - u^2)^2 + 4\zeta^2u^2]^{1/2}} \quad \text{with } \tan\phi = \frac{2\zeta u}{1-u^2}$$

where ϕ is phase lead, $u = n/p$, $T = 2\pi/n$, ζ is the fraction of critical damping, $\mu^2 = 1 - \zeta^2$ and lge $= \pi\zeta/\mu$ (Sohon, 1932, p.62; Byerly, 1933; Bullen, 1963, p.144; Garland, 1979, p.71). These expressions give the magnification and phase lead of the Riverview Wiechert and Mainka seismographs in terms of their constants, static magnification V, period T, and damping ratio e. The solid (or pen) friction r/T^2 is used to find the damping ratio e, but is not further needed to find the magnification and phase lead. The phase lead is zero at short periods, $\pi/2$ when the ground period is that of the seismograph (T), and π at long periods. At periods longer than T, it is necessary to add π to the principal value of the inverse tangent (that a calculator gives). Causality is not a problem with the phase lead, because we are considering steady oscillatory ground motion and ignoring the transient solutions of the seismograph equation.

For oscillating ground motion sin pt, the displacement of the light spot of a Galitzin seismograph is given by:

$$y = \frac{4uV}{(1 + u^2)^2} \sin(pt + 2\phi - \pi/2),$$

where u and ϕ are as above and V is now the synchronous magnification of the seismograph (Sohon, 1932, p.92). The period of the galvanometer T_1 is assumed to be close to that of the seismometer T. For the routine calculation of ground amplitudes at Riverview, the mean of T_1 and T was used in the value of u. The seismometer and galvanometer of a Galitzin seismograph should be critically damped ($\zeta = 1$); the constant μ^2 ($= 1 - \zeta^2$) indicates to what extent the seismometer was not critically damped, a negative value indicating overdamping. The phase lead of the Galitzin seismograph ($2\phi - \pi/2$) can easily be verified to be a lag up to a ground motion period of 0.414T, and, at a ground motion period of 2T, a lead-in time of 0.91T (i.e. a little less than π radians). The phase lead-in time of the Sprengnether (WWSSN) seismographs is approximately 0.42T for ground motion of twice the period of the seismometer (cf. Drake, 1973). This is consistent with the phase lead of the Galitzin seismographs, because the Sprengnether seismometers are connected to galvanometers of long period (100 s).

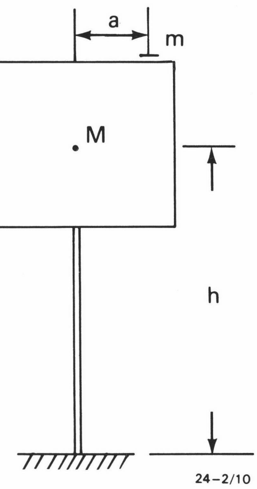

Figure 1. Horizontal Wiechert seismograph with test mass m.

Determination of N—S Wiechert constants

The inverted Wiechert 'astatic' (unstable) pendulum is shown in Figure 1. Its mass is M (1 tonne at Riverview) and its centre of mass is at a height h (940 mm at Riverview) above its point of support. When a small mass m is placed a distance a (346 mm at Riverview) north of the centre of the mass, a torque mga deflects the mass a small angle θ to the north (g is the acceleration of gravity). A torque Mgh sin θ tends to deflect the mass more, but a restoring torque $\beta\theta$ from the spring connections of the seismograph's magnifying levers keeps the mass deflected at angle θ. We have,

$$(\beta - Mgh)\,\theta = mga$$

(Wiechert, 1903a; Sohon, 1932, p. 24). If I is the moment of inertia of the mass about its point of support and T is the period of the seismograph, we also have,

$$(\beta - Mgh)\,\theta = 4\pi^2 I\theta/T^2$$

If ℓ (=I/Mh) is the reduced pendulum length and y is the pen deflection for the mass deflection θ, the static magnification

$$V = \frac{y}{\ell\theta} = \frac{4\pi^2 yMh}{mga\,T^2}$$

Basically, in any static magnification determination, the unknown moment of inertia of the seismometer and its restoring force are replaced by its period of oscillation by means of the pendulum equation. In the determination of static magnification of Wiechert seismographs, the unknown small deflection of the mass (θ) is replaced by the known value of the small deflecting mass m. Static magnification is the magnification of the seismograph at very short periods (u is small in the seismograph displacement equation).

It is worth noticing that in the determination of the static magnification of a Wood-Anderson seismograph (Fig. 2), the small angle of deflection, θ, of the seismometer (Fig. 3) is found by tilting the seismometer sideways a known angle ψ; OZ is the direction of the vertical, i is the inclination of the seismometer (mass M), S is its upper point of support, and

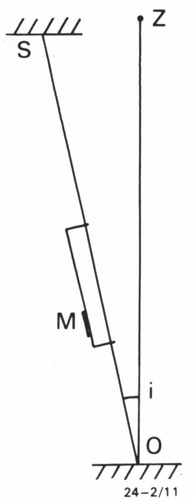

Figure 2. Wood-Anderson seismograph suspension.

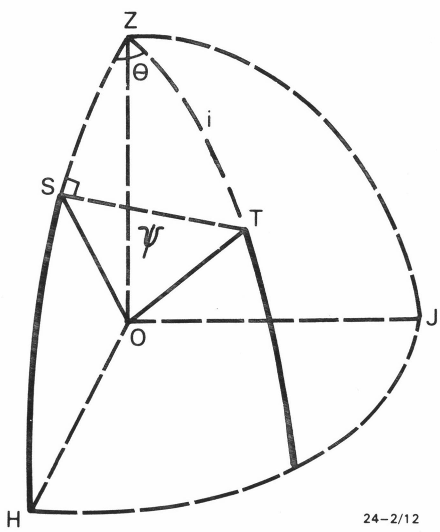

Figure 3. Tilt of Wood-Anderson seismograph $\psi = i\,\theta$.

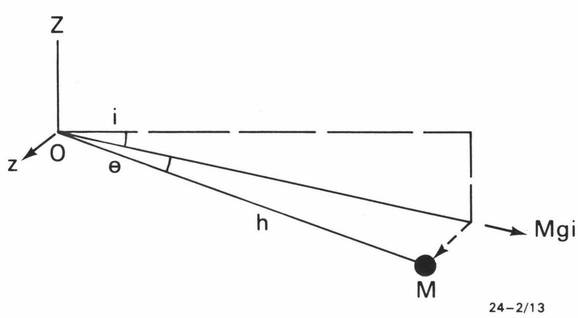

Figure 4. Horizontal seismograph displaced an angle θ.

OHJ is the horizontal plane. By the sine formula for the spherical triangle STZ, sin i = sin ψ /sin θ , or, since the angles are small, $\theta = \psi / i$.

Figure 4 shows the pendulum, mass M, of a horizontal seismograph; OZ is the vertical, and the distance of the centre of mass from the point of support of the pendulum is h; i is the inclination of the pendulum down from the horizontal in its equilibrium position; Mgi is the gravity component in this direction and θ is the angular displacement of the pendulum caused by, say, a ground displacement z. We have, from the pendulum equation,

$$Mgih\,\theta = 4\pi^2 I\,\theta / T^2$$

If ℓ is the reduced pendulum length of the Wood-Anderson seismometer and y is the light spot displacement for the tilt ψ, we have for the static magnification,

$$V = \frac{y}{\ell\theta} = \frac{4\pi^2 y}{g\psi T^2}, \qquad \text{since } \ell = \frac{I}{Mh}$$

The period T of the N–S Wiechert seismograph is easily observed (with the damping removed). While the damping is removed, an estimate of solid or pen friction is made by measuring successive amplitudes of oscillation y_1 and y_2 (Fig. 5). Without damping, y_1 should be equal to y_2, and the effect of friction has been to increase y_1 by an amount r, where $r = (y_1 - y_2)/2$, and to decrease y_2 by an amount r (Sohon, p. 74). Hence, when the damping is replaced, the estimate of the damping ratio e $(=y_1/y_2)$ is taken to be $(y_1 - r)/(y_2 + r)$.

The determination of the E–W Wiechert seismograph constants is similar to the determination of the N–S constants, and the determinations of the vertical Wiechert and N–S and E–W Mainka seismograph periods and damping ratios are similar to the determinations of the N–S Wiechert period and damping ratio.

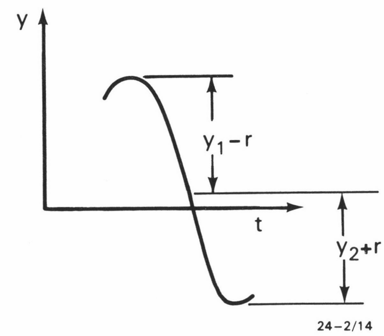

Figure 5. Undamped oscillation decreased by solid (pen) friction.

Determination of the vertical Wiechert static magnification

Figure 6 is a sketch of the pendulum of the Riverview vertical Wiechert seismograph. The pendulum of mass M (80 kg) has a radius of gyration and a reduced pendulum length h about its axis of rotation; it is supported by a spring of stiffness k (insulated from varying temperature). If I is the moment of inertia of the pendulum about its axis of rotation, we have, from the pendulum equation,

$$kh\,\theta/2 = 4\pi^2 I\,\theta/T^2$$

A small mass m (10 g at Riverview) is placed at a distance h/2 from the axis of rotation of the pendulum (Wiechert, 1903b, p.111); the pendulum rotates an angle θ and the pen of the seismograph deflects a distance y. We have $k\theta = mg$ and, since $I = Mh^2$, the static magnification

$$V = \frac{y}{h\theta} = \frac{8\pi^2 My}{mgT^2}$$

Determination of the Mainka static magnification

The N–S and E–W Mainka seismographs can be represented by Figure 4 (M at Riverview is 450 kg). A small mass m (5 g at Riverview) is attached to M by a horizontal thread over a pulley and deflects the pendulum an angle θ and the pen of the seismograph a distance y (Sohon, 1932, p.21). We have

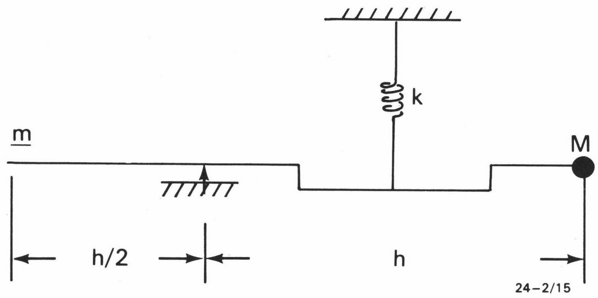

Figure 6. Wiechert vertical seismograph with test mass m.

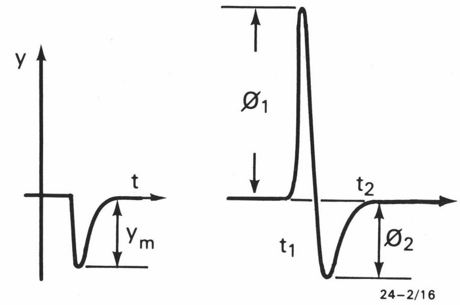

Figure 7. Galitzin pendulum and galvanometer 'tap' deflections.

$mg = Mgi\,\theta$ and, from the pendulum equation for a horizontal seismograph, we have the static magnification

$$V = \frac{y}{\ell\theta} = \frac{4\pi^2 My}{mgT^2}, \qquad \text{since } \ell = \frac{I}{Mh}$$

Determination of the Galitzin constants

It is interesting that Galitzin was able to find the magnification of an electromagnetic seismograph without using either a shaking table or a low- frequency alternating-current source.

The undamped period of the galvanometer T_1 is found with the galvanometer on open circuit. The damping constant of the pendulum μ^2, the undamped period of the pendulum T, and the synchronous magnification V are found by giving the pendulum a small (electrical) tap (Fig. 7). A mirror is attached near the point of support of the pendulum and the angular movement θ_m of the pendulum after the tap can be found by measuring the displacement y_m of a light spot. If the galvanometer is critically damped, the ratio of the galvanometer angular displacements ϕ_1 and ϕ_2 (at times t_1 and t_2) gives the damping constant of the pendulum μ^2 (Sohon, 1932, p. 118),

$$\mu 2 = 2.886 - 1.258\ \phi 1/\phi 2$$

The time of zero crossing of the galvanometer trace t_o ($t_1 < t_o < t_2$) and the undamped period of the galvanometer T_1 give the undamped period of the pendulum T,

$$T = 4.189t_o + T_1\ (0.1\mu^2 - 1)$$

Finally, the synchronous magnification V is estimated from the ratio of ϕ_2 and θ_m

$$V = \frac{(40.6 - 13.8\mu 2)\ A_1 T\phi_2}{4\pi\ell T_1\ \theta_m}$$

where A_1 cm is the distance from the galvanometer mirror to the recording drum and ℓ is the reduced pendulum length (Sohon, 1932, p. 125).

The method of determination of the constants of the vertical, N–S and E–W Galitzin seismographs is as just described.

Acknowledgements

Assistance of Dr David Denham and Mr Ron Smith in transporting the Riverview seismograms to Canberra and in maintaining the collection is most gratefully acknowledged. The figures were drafted by M. Steele.

References

Bullen, K.E., 1963 — An introduction to the theory of seismology, *Cambridge University Press.*

Byerly, P., 1933 — Reduction of trace amplitudes. *Bulletin of the National Research Council,* 90, 198–205.

Drake, L.A., 1973 — Rayleigh and Love waves in the Tasman Basin. *New Zealand Journal of Geology and Geophysics,* 16, 997–1007.

Drake, L.A., 1974 — The seismicity of New South Wales. *Journal and Proceedings of the Royal Society of N.S.W.,* 107, 35–40.

Garland, G.D., 1979 — Introduction to geophysics, *Saunders, Philadelphia.*

Glover, D.P. & Meyers, H., 1981 — Historical seismogram filming project: third progress report. *World Data Center A for Solid Earth Geophysics, Boulder, Colorado.*

Kanamori, H., 1982 — Importance of historical seismograms for geophysical research. *Program and Abstracts of Regional Workshop of the IASPEI/UNESCO Working Group on Historical Seismograms, Earthquake Research Institute, University of Tokyo, Japan.*

Sohon, F.W. 1983 — Seismometry. *Volume 2* of Macelwane, J.B. & Sohon, F.W., Introduction to theoretical seismology. *Wiley, New York.*

Wiechert, E., 1903a — Ein astatisches Pendel hoher Empfindlichkeit zur mechanischen Registrierung von Erdbeben (An unstable pendulum of higher sensitivity for the mechanical recording of earthquakes). *Physikalische Zeitschrift,* 4, 821–829.

Wiechert, E., 1903b — Theorie der automatischen Seismographen (Theory of automatic seismographs). *Abhandlungen der Koeniglichen Gesellschaft der Wissenschaften zu Gottingen. Mathematisch-Physikalische Klasse. Neue Folge* Band 11. Nro. 1.