Πρακτικά	4ου Συνέδριου	Μάϊος 1988	
Δελτ. Ελλην. Γεωλ. Εταιρ.	Τομ. XXIII/3	σελ. 189-196	Αθήνα 1989
Bull. Geol. Soc. Greece	Vol.	pag.	Athens

SIMPLIFIED ESTIMATION OF SEISMIC MOMENT FROM SEISMOGRAMS: AN APPLICATION FOR GREECE AND ADJACENT AREAS.

J. LATOUSSAKIS*, K. MAKROPOULOS**

ABSTRACT

The estimation of the seismic moment of regional and local earthquakes from the readings of Wood-Anderson type seismograph is attempted by deriving an empirical formula connecting the seismic moment with quantities used in routine magnitude calculations. This technique proposed by B.BOLT and M. HERRAIZ (1983), simplified the usually laborious work involved in such estimation and can be used in daily routine observatory work. The proposed relation is of the type:

$$\log Mo = a + b\log(CxDx\Delta^{p})$$

where C is the maximum peak-to-peak amplitude read on a Wood-Anderson seismogram, D is the duration between the S arrival and the onset with amplitude C/d, Δ is epicentral distance, and a,b,p and d constants.

Least square fits were made to data from 66 Wood-Anderson records of 33 local and regional earthquakes from Greece and adjacent areas. The seismic moments of these events was already evaluated independently from spectal analysis. The values p=1.8, d=3 proved appropriate and subsequent regression yielded.

$$\log Mo = (16.82\pm0.41)+(1.04\pm0.05)\log(CxDx\Delta^{1.8})$$

where Mo is dyne-cm, C in millimeters, D in seconds and Δ in kilometers. The correlation coefficient is r=0.93. The high correlation coefficient found (0.93) coupled with significantly less scatter of the data indicate that this relation is preferable compared with similar one connected the same parameters with the M_L magnitude.

ΣΥΝΟΨΗ

Επιδιώκεται η εξαγωγή ενός εμπειρικού τύπου που συνδέει τον υπολογισμό της σεισμικής ροπής με στοιχεία που χρησιμοποιούνται στον υπολογισμό του μεγέθους γειτονικών και τοπικών σεισμών από εγγραφές του σεισμογράφου Wood-Anderson

---

Ι. ΛΑΤΟΥΣΑΚΗΣ και Κ. ΜΑΚΡΟΠΟΥΛΟΣ - ΑΠΛΟΠΟΙΗΜΕΝΟΣ ΥΠΟΛΟΓΙΣΜΟΣ ΣΕΙΣΜΙΚΗΣ ΡΟΠΗΣ ΑΠΟ ΣΕΙΣΜΟΓΡΑΦΗΜΑΤΑ: ΕΦΑΡΜΟΓΗ ΣΤΟΝ ΕΛΛΗΝΙΚΟ ΧΩΡΟ.

* *National Observatory of Athens. Seismological Institute, 118 10 Athens, Greece.*
** *University of Athens. Department of Geothermy and Geophysics. Panepistimiopolis, Ilissia, 157 84, Athens, Greece.*

στην καθημερινή ανάλυση. Αυτή η τεχνική που προτάθηκε από τους BOLT και HERRAIZ (1983) απλοποιεί την πολύπλοκη διαδικασία που απαιτείται για τέτοιους υπολογισμούς και μπορεί να χρησιμοποιηθεί στην καθημερινή πρακτική. Η προτεινόμενη σχέση είναι του τύπου:

$$\log Mo = a + b\log(C x D x \Delta^{p})$$

όπου C είναι το μέγιστο πλάτος της αναγραφής του σεισμογράφου Wood-Anderson, D είναι η διάρκεια μεταξύ της εισόδου των S κυμάτων και του σημείου όπου το πλάτος γίνεται C/d, Δ είναι η επικεντρική απόσταση, και a,b,p και d σταθερές.

Εφαρμόστηκε η μέθοδος των ελαχίστων τετραγώνων σε ένα δείγμα 66 εγγραφών του σεισμογράφου Wood-Anderson του σταθμού Αθηνών που αφορούν 33 τοπικούς και γειτονικούς σεισμούς του Ελληνικού χώρου. Οι σεισμικές ροπές αυτών των γεγονότων είχαν υπολογιστεί ανεξάρτητα με φασματική ανάλυση. Οι τιμές p=1,8, d=3 αποδείχθηκαν οι πλέον κατάλληλες και η τελική σχέση διαμορφώθηκε σε

$$\log Mo = (16.82 \pm 0.41) + (1.04 \pm 0.05)\log(C x D x \Delta^{1.8})$$

όπου Mo σε dyn-cm, C σε χιλιοστά του μέτρου, D σε δευτερόλεπτα και Δ σε χιλιόμετρα. Ο συντελεστής συσχέτισης είναι 0.93. Ο υψηλός συντελεστής συσχέτισης που βρέθηκε, συνδυασμένος με τη σημαντική λιγώτερη διασπορά των δεδομένων δείχνει ότι αυτή η σχέση είναι προτιμέτερη από τις παρόμοιες που συνδέουν τη σεισμική ροπή με το τοπικό μέγεθος M_L.

INTRODUCTION

In modern seismology there is a need for routine estimation of seismic moments Mo among the other source parameters of earthquakes. One way to fulfil this need is the Seismographic Station to provide such information by computing moments directly from local magnitudes. There are, however, objections based on theoretical reasons, for the efficiency of the correlation between seismic moment and maximum Wodd-Anderson amplitude alone. In many cases, for example, there is a need to consider the duration of the largest seismic wave pulses.

Although the number of the observatories which have digital computing facilities is increasing, the estimation of the seismic moment for regional seismicity based on spectral characteristics is not a daily practice. There is still a need for a procedure that allows the estimation of the seismic moment Mo directly and quickly from traditional records. BOLT and HERRAIZ (1983) demonstrated that, in the process of calculating Richter magnitudes, the addition to the usual maximum amplitude determination from Wood-Anderson seismograms of a further simple measurement that is a measure of wave duration, provieds a generally reliable estimation of the seismic moment.

THE ESTIMATION PROCEDURE

KELLIS-BOROK (1960) derived the following analytical expression for seismic moment Mo

$$Mo = 4\pi\mu\beta \frac{\Delta\Omega o}{2R\vartheta\varphi} \qquad (1)$$

where μ is rigidity, β the shear wave velocity, $R\vartheta\varphi$ depends on the source radiation pattern, Δ is the distance from the source, and Ωo is affected by the particular selection criterion used and routine measurement procedures. Also $R\vartheta\varphi$ is often assumed to be unity, because it is not usual or even possible to determine focal mechanisms for every local earthquake.

As an approximation to the $\Delta\Omega o$ term, BOLT and HERRAIZ (1983) proposed the theoretical quantity

$$\Psi = CxDx\Delta^{p} \qquad (2)$$

where C is the maximum peak-to-peak amplitude, D is the duration of the phase and Δ^{p} is epicentral distance raised to a power p.

There is an inherent subjectivity in the measurement of the duration D of seismic events. In order to avoid this problem BOLT and HERRAIZ, suggested that suitable duration D could be defined as the time between the S onset and the point having an amplitude c such that c/C = 1/3. Also, they tested the exponent p by least-squares fitting of various data for p=0.8 and p=1.5 without finding any statistical improvement. So, they proposed the value p=1.

APPLICATION TO GREECE AND ADJACENT AREAS

In order to apply the above method in Greece, seismic moment data for earthquakes in the region already published are collected from various sources. They are tabulated in Table 1 along with other parameters and the corresponding reference. As it can be seen from this Table, the preponderance comes NORTH (1977). They have been determined using Rayleigh-wave spectral amplitudes. In cases where for the same earthquake the investigator gives moment values deduced from different type of waves, like PROCHAZKOVA (1980), the solution resulted from the surface-wave amplitudes is tabulated and used in the present regression analysis. When a particular event, like Thessaloniki, 1978, has been studied in several papers, the latest solution is adopted and included in data set. Since July 1981, the National Earthquake Information Service, NEIS, started to compute a centroid, moment tensor solution for certain events (NEIS, monthly listing, July 1981). Thus, after July 1981, the scalar seismic moment reported by NEIS for earthquakes in the area complete the data in Table 1.

The other parameters of the events listed in the Table 1, except magnitudes, are taken from the Bulletins of the International Seismological Center, ISC, and NEIS. The surface-wave magnitude M_s, for the events before 1979 are from MAKROPOU[...] M_s are from

MAKROPOULOS et al. (1986). The maximum amplitudes and duration were measured from the standard Wood-Anderson seismograph records of the National Observatory of Athens.

The evaluation of $\log\Psi_i$ for the events used in this paper was tested by least-squares fitting of various data for p=0.10 and p=3.0. The value p=1.8 was chosen because it had the best fitting.

Table 2 gives the measurements of C, D and Δ obtained. The units of C, D and Δ are millimeters, seconds and km correspondingly, which are normally used in observatory readings. The values of $\log\Psi_i$ have been plotted against the adopted seismic moment logMo in Figure 1.

The least square fit is

$$\log Mo = (16.82 \pm 0.41) + (1.04 \pm 0.05) \log\Psi \qquad (3)$$

with a coefficient of regression, 0.93.

Since the initial work of WYSS and BRUNE (1968), log-linear relations between Mo and magnitude M have been constructed for various magnitude ranges (JOHNSON and MCEVILY, 1974; BAKUM and LINDH, 1977; PEARSON, 1982) and for the area of Greece TSELENTIS et al. (1988). In order to test the procedure, comparison was made between the seismic moments calculated from equation (3) and the $Mo = f(M_s)$ relation of TSELENTIS et al. (1988). Relation (3) gives evaluations of seismic moment closer to the observed ones.

TABLE 1
Parameters of Earthquakes Used

No	Date (y.m.d.)	Coord. (°N)	(°E)	M_s	Mo 10^{24} dyn.cm	FT	Reference
1	1966.05.09	34.43	26.44	5.9	13.0	T	North (1971)
2	1966.10.29	38.90	21.10	5.8	7.8	D	North (1977)
3	1967.03.04	39.60	21.29	6.8	91.0	N	North (1977)
4	1967.11.30	41.41	20.44	6.5	150.0	N	North (1977)
5	1968.05.30	35.45	27.88	5.9	12.0	T	North (1977)
6	1969.01.14	36.11	29.19	5.9	53.0	T	North (1977)
7	1969.03.03	40.09	27.50	5.9	7.3	S	North (1977)
8	1969.03.23	39.14	28.48	5.9	9.1	N	North (1977)
9	1969.03.25	39.25	28.44	5.8	18.0	N	North (1977)
10	1969.03.28	38.55	28.46	6.4	120.0	N	North (1977)
11	1969.07.08	37.50	20.31	5.8	4.1	D	North (1977)
12	1969.10.13	39.78	20.59	5.7	3.4	D	North (1977)
13	1970.03.28	36.21	29.51	7.0	300.0	N	North (1977)
14	1970.04.08	38.34	22.56	6.2	31.0	N	North (1977)
15	1970.04.23	39.13	28.65	5.4	3.8	N	North (1977)
16	1970.08.19	41.08	19.77	5.3	7.2	T	North (1977)
17	1971.05.12	37.64	29.72	5.8	40.0	T	North (1977)
18	1975.01.08	38.24	22.65	5.7	3.2	T	Prochazkova (1980)
19	1975.09.12	36.27	21.90	5.0	2.5	-	Prochazkova (1980)
20	1975.09.22	35.20	26.26	5.7	0.7	N	Prochazkova (1980)
21	1978.05.23	40.73	23.26	5.8	3.1	N	Prochazkova (1980)
22	1978.06.20	40.82	23.15	6.4	57.0	N	Bar.& Lan. (1981)

(continued)

TABLE 1 (continued)
Parameters of Earthquakes Used

No	Date (y.m.d.)	Coord. (°N)	Coord. (°E)	M_s	Mo 10^{24} dyn.cm	FT	Reference
23	1982.01.18	39.96	24.39	6.8	94.0	S	NEIS
24	1982.08.17	33.71	22.94	6.6	40.0	T	NEIS
25	1982.11.16	40.82	19.58	5.7	3.2	-	NEIS
26	1983.01.17	38.01	20.23	7.0	240.0	T	NEIS
27	1983.03.19	35.08	25.35	6.0	3.3	-	NEIS
28	1983.03.23	38.29	20.26	6.2	22.0	S	NEIS
29	1983.08.06	40.14	24.77	6.7	120.0	S	NEIS
30	1983.09.27	36.69	26.91	5.8	1.4	-	NEIS
31	1984.02.11	38.40	22.09	5.4	3.3	-	NEIS
32	1984.05.06	38.84	25.63	5.3	1.6	-	NEIS
33	1984.05.22	35.91	22.52	4.0	0.6	-	NEIS

FT=Fault Type; N=Normal; S=Strike-slip; D=Dip-slip; T=Thrust

TABLE 2
MEASUREMENTS TAKEN FROM SEISMOGRAMS AND Ψ VALUES

Event No	Comp.	Δ(km)	C(mm)	c(mm)	D(sec)	LOGΨ(mm.sec.km)
1	N-S	470	11.0	4.0	139.3	8.00
	E-W		11.0	4.0	127.0	7.95
2	N-S	245	87.5	28.0	41.2	7.86
	E-W		115.5	40.0	36.8	7.93
3	N-S	165	315.0	104.0	104.5	8.51
	E-W		288.0	88.5	97.0	8.44
4	N-S	445	57.4	18.0	116.5	8.59
	E-W		79.2	25.5	87.0	8.61
5	N-S	470	13.0	4.3	105.7	7.95
	E-W		18.0	6.2	78.5	7.96
6	N-S	535	46.0	13.2	84.0	8.50
	E-W		35.0	10.8	105.0	8.48
7	N-S	410	23.3	8.0	67.0	7.90
	E-W		17.0	6.0	84.0	7.86
8	N-S	445	36.0	12.2	67.2	8.15
	E-W		30.0	8.5	81.0	8.15
9	N-S	445	34.5	11.8	93.0	8.27
	E-W		28.0	8.0	118.5	8.29
10	N-S	430	94.5	31.5	75.0	8.59
	E-W		52.0	16.8	111.0	8.50
11	N-S	300	97.5	30.8	51.5	8.16
	E-W		84.5	35.0	54.5	8.12
12	N-S	335	66.8	18.5	21.7	7.71
	E-W		47.3	17.5	21.0	7.61
13	N-S	575	204.5	64.0	177.0	9.53
	E-W		233.2	69.2	160.5	9.54
14	N-S	105	240.5	77.5	130.2	8.13
	E-W		240.9	75.0	109.0	8.06

(continued)

TABLE 2 (continued)
MEASUREMENTS TAKEN FROM SEISMOGRAMS AND Ψ VALUES

Event No	Comp.	Δ(km)	C(mm)	c(mm)	D(sec)	LOGΨ(mm.sec.km)
15	N-S	455	18.0	6.0	45.7	7.70
	E-W		9.2	3.2	53.2	7.47
16	N-S	480	8.0	2.6	62.5	7.53
	E-W		8.0	2.5	56.0	7.48
17	N-S	535	18.0	6.6	135.5	8.30
	E-W		13.5	4.2	140.0	8.19
18	N-S	100	110.5	39.5	50.2	7.34
	E-W		86.5	25.2	45.8	7.20
19	N-S	250	26.3	7.2	26.2	7.15
	E-W		15.7	6.0	29.2	6.98
20	N-S	375	17.0	5.5	8.0	6.77
	E-W		12.5	4.2	14.5	6.89
21	N-S	300	55.8	17.5	36.7	7.77
	E-W		39.8	13.0	57.2	7.82
22	N-S	310	173.0	53.6	83.2	8.64
	E-W		152.0	47.4	91.0	8.63
23	N-S	230	252.6	82.5	115.0	8.71
24	N-S	480	23.6	8.8	59.0	7.97
	E-W		21.5	7.2	61.7	7.95
25	N-S	410	8.5	3.0	51.5	7.34
	E-W		12.0	4.2	51.0	7.49
26	N-S	300	282.6	88.5	90.8	8.87
	E-W		225.0	75.2	124.5	8.91
27	N-S	355	20.0	6.8	39.2	7.48
	E-W		14.8	5.5	38.6	7.35
28	N-S	300	91.0	28.3	84.0	8.34
	E-W		86.7	28.0	98.0	8.39
29	N-S	260	311.2	104.5	140.0	8.99
30	N-S	320	18.0	6.0	11.0	6.81
	E-W		12.5	4.6	15.0	6.78
31	N-S	150	78.0	22.0	56.2	7.56
	E-W		92.2	31.2	62.5	7.68
32	N-S	230	46.5	16.5	28.5	7.37
	E-W		40.0	13.0	21.8	7.19
33	N-S	260	13.0	4.0	18.8	6.74
	E-W		10.6	3.7	15.0	6.55

DISCUSSION

The application of the method confirms generally the conclusions of BOLT and HERRAIZ (1983). Thus the goodness-of-fit of a linear relation between logMo and log(CxDxΔ) found for Wood-Anderson readings provides some confidence in the estimation of the seismic moment routinely by this method. Further the comparison test indicates that the term Ψ = CxDxΔ is a more consistent measure of seismic moment than the peak amplitude without regard to the duration of the largest wave motion, i.e. M_L.

The main nonrandom errors in the estimated moments comes, as with magnitude determination, from the neglect of the wave radiation pattern. Nevertheless there is a need of improvement of the relation (3) using a larger number of calibration seismic moments.

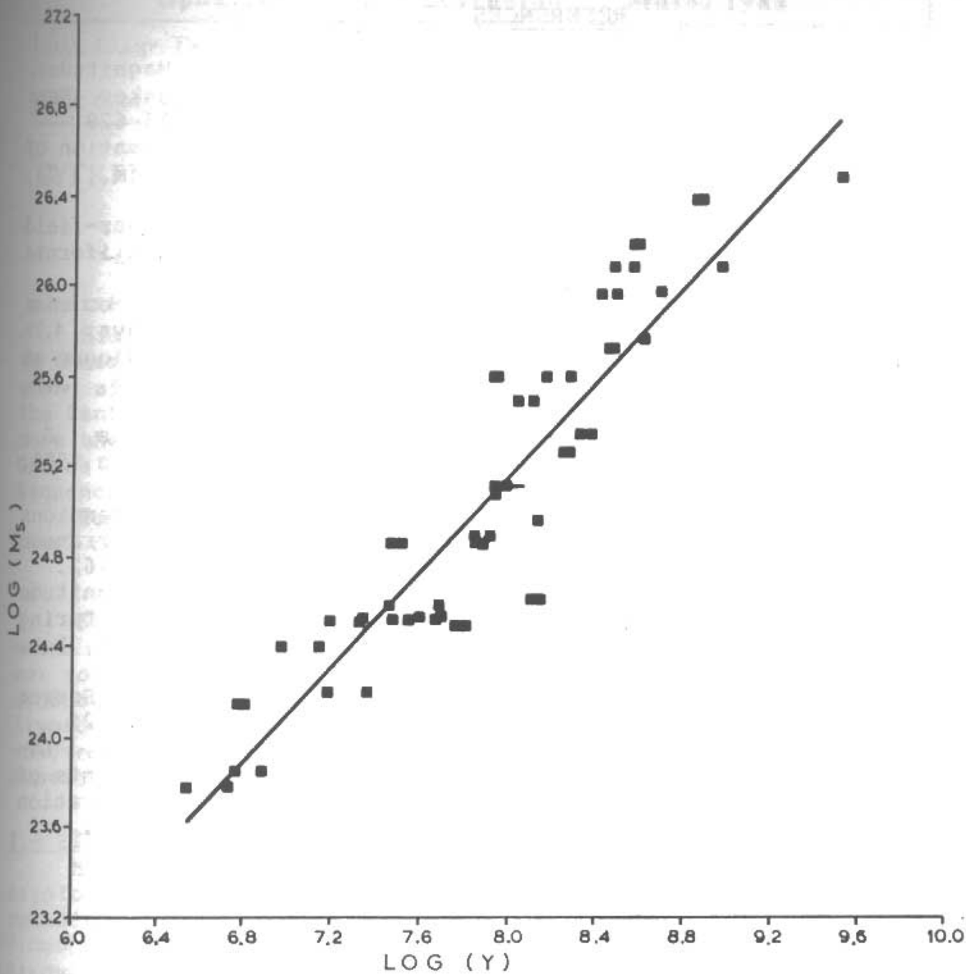

Fig. 1. Correlation between independently estimated seismic moments M_O and the quantity $\psi = C \times D \times \Delta$ (see text) measured from Wood-Anderson seismographs.

REFERENCES

Bakum, W.H. and Lindh, C.Q., 1977. Local Magnitudes, Seismic Moments and Coda Durations For Earthquakes Near Orovile, California. Bull. Seism. Soc. Am., 67, 615-629.

Bolt, B. and Herraiz, M., 1983. Simplified Estimation of Seismic Moment from Seismograms. Bull. Seism. Soc. Am., 73, No 3, pp. 735-748.

Johnson, L.R. and Mc Evily, T.V., 1974. Near-field Ovservations and Source Parameters of Central California Earthquakes. Bull. Seism. Soc. Am., 64, 1855-1886.

Keilis-Borok, V.I., 1960. Investigation of the Mechanism of Earthquakes (English Translation). Soc. Res. Geophys., 4.29.

Makropoulos, K.C. and Burton, P.W., 1981. A Catalogue of Seismicity in Greece and the Adjacent Areas. Geophys. J.R. Astron. Soc., 65, 741-762.

Makropoulos, K.C., Drakopoulos, J. and Latoussakis, J., 1986. A revised Earthquake Catalogue for Greece Since 1900. Univ. of Athens, Seism. Lab., Publ. No 2, 132 pp.

North, R.G., 1977. Seismic Moment, Source Dimensions and Stresses Associated With Earthquakes In the Mediterranean and Middle East. Geophys. J.R. Astron. Soc., 48, 137-162.

Pearson D., 1982. Source Parameters and A Magnitude Moment Relationship From Small Earthquakes Observed During Hydraulic Fracturing Experiments In Crystalline Rocks, L.A. UR 81-2923, Los Alamos Scientific Laboratory.

Prochazkova D., 1980. Determination of Source Parameters. Proc. 17th Assoc. ESC, Budapest, pp. 217-221.

Tselentis, G.A., Stavrakakis, G. Makropoulos, K., Latoussakis, J. and Drakopoulos J., 1988. Seismic Moments of Earthquakes At the Western Hellenic Arc and Their Application To the Seismic Hazard of the Area. Tectonophysics, 148.