REGULATORY INFORMATION DISTRIBUTION SYSTEM (RIDS)

ACCESSION NBR:8206210584 DOC.DATE: 82/06/14 NOTARIZED: NO DOCKET #
FACIL:50-397 WPPSS Nuclear Project, Unit 2, Washington Public Powe 05000397
AUTH.NAME AUTHOR AFFILIATION
BOUCHEY,G.D. Washington Public Power Supply System
RECIP.NAME RECIPIENT AFFILIATION
SCHWENCER,A. Licensing Branch 2

SUBJECT: Forwards response to request for addl info re area vs magnitude relationship.Info prepared by Woodward-Clyde consultants.

DISTRIBUTION CODE: B001S COPIES RECEIVED:LTR 1 ENCL 1 SIZE: 13
TITLE: PSAR/FSAR AMDTS and Related Correspondence

NOTES:

	RECIPIENT ID CODE/NAME		COPIES LTTR	COPIES ENCL	RECIPIENT ID CODE/NAME		COPIES LTTR	COPIES ENCL
	A/D LICENSNG		1	0	LIC BR #2 BC		1	0
	LIC BR #2 LA		1	0	AULUCK,R.	01	1	1
INTERNAL:	ELD/HDS2		1	0	IE FILE		1	1
	IE/DEP EPDS	35	1	1	IE/DEP/EPLB	36	3	3
	MPA		1	0	NRR/DE/CEB	11	1	1
	NRR/DE/EQB	13	3	3	NRR/DE/GB	28	2	2
	NRR/DE/HGEB	30	2	2	NRR/DE/MEB	18	1	1
	NRR/DE/MTEB	17	1	1	NRR/DE/QAB	21	1	1
	NRR/DE/SAB	24	1	1	NRR/DE/SEB	25	1	1
	NRR/DHFS/HFEB	40	1	1	NRR/DHFS/LQB	32	1	1
	NRR/DHFS/OLB	34	1	1	NRR/DHFS/PTRB	20	1	1
	NRR/DSI/AEB	26	1	1	NRR/DSI/ASB	27	1	1
	NRR/DSI/CPB	10	1	1	NRR/DSI/CSB	09	1	1
	NRR/DSI/ETSB	12	1	1	NRR/DSI/ICSB	16	1	1
	NRR/DSI/PSB	19	1	1	NRR/DSI/RAB	22	1	1
	NRR/DSI/RSB	23	1	1	NRR/DST/LGB	33	1	1
	REG FILE	04	1	1	RGN5		2	2
EXTERNAL:	ACRS	41	16	16	BNL(AMDTS ONLY)		1	1
	FEMA-REP DIV	39	1	1	LPDR	03	1	1
	NRC PDR	02	1	1	NSIC	05	1	1
	NTIS		1	1				

TOTAL NUMBER OF COPIES REQUIRED: LTTR 63 ENCL 58

Washington Public Power Supply System

P.O. Box 968 3000 George Washington Way Richland, Washington 99352 (509) 372-5000

June 14, 1982
G02-82-539
SS-L-02-CDT-82-076

Docket No. 50-397

Mr. A. Schwencer, Chief
Licensing Branch No. 2
Division of Licensing
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Schwencer:

Subject: NUCLEAR PROJECT NO. 2
AREA VERSUS MAGNITUDE RELATIONSHIP

Enclosed are sixty (60) copies of the information requested by the NRC concerning Area Versus Magnitude Relationship.

Very truly yours,

GD Bouchey

G. D. Bouchey
Deputy Director, Safety and Security

CDT/jca
Enclosure

cc: R Auluck - NRC
WS Chin - BPA
R Feil - NRC Site

B001

TASK 7b AREA VERSUS MAGNITUDE RELATIONSHIP

Introduction

The purpose of this task is to develop an empirical relationship between earthquake magnitude and fault area that can be used to estimate earthquake magnitudes in the range $4 \leq M_S \leq 6$ for faults having limited dimensions. The existing empirical relationships are based primarily on data for large magnitude earthquakes ($M \geq 6$) and associated fault parameters (e.g., rupture length, displacement, and rupture area). The data sets for these relationships do not include sufficient information to allow meaningful estimates of earthquake magnitude for faults having relatively limited dimensions. Therefore, the worldwide historical seismicity record was examined to obtain fault parameter data in this lower magnitude range.

Because the magnitude threshold at which surface rupture occurs is about M 5 to 6, fault parameters that are developed from observations of surface rupture, such as rupture length and maximum displacement per event, are often not reliable indicators of energy release for earthquakes of $M \leq 6$. Observations of earthquakes of $M \leq 6$ do not show a consistent relationship between magnitude and the occurrence, length, or amount of surface displacement associated with these earthquakes. This suggests that the surface faulting associated with these earthquakes may be more a function of local conditions (e.g., fault type, material properties, depth of focus) than of the magnitude of the event. For these reasons, magnitude-related fault parameters that depend on geologic evidence of surface rupture were not used in developing an empirical relationship in this study.

Recent studies (Wyss, 1979) have shown that for earthquakes of $M_S \geq 5.7$ earthquake magnitude is related to the rupture area on the fault surface. Rupture areas have been assessed for

historical earthquakes from the dimensions of aftershock sequences, seismic wave analysis, and geodetic modelling. Based on a worldwide data set of about 90 historical earthquakes of all fault types, Wyss (1979) presents a well-defined relationship of the form:

$$M_s = \text{Log } A + 4.15$$

where A is the rupture area in square kilometers. Wyss (1979) notes that both the length of the rupture area and the rupture area itself are more reliable indicators of the size of an earthquake than is surface rupture length.

Rupture area is closely related to seismic moment (Purcaro and Berckhemer, 1982) and, therefore, to the amount of energy released during an earthquake. Rupture area versus seismic moment relationships have been established for seismic moments from 10^{30} dyne-cm to as small as 10^{13} dyne-cm (Pearson, 1982). On this basis, it is apparent that the rupture area versus magnitude relationship can be extended below M 6. In addition, rupture area may be assessed for historical earthquakes without relying on evidence of surface rupture. For these reasons, the rupture area versus magnitude relationship was judged to be an appropriate empirical approach magnitude for faults having limited dimensions.

The estimation of future rupture areas on a particular fault can be made based on assessments of rupture length and downdip fault width. Fault rupture length is usually estimated from geologic evidence for segmentation of the fault zone or from assumptions regarding the fraction of the total fault length that may rupture during a single event. Downdip fault width is assessed from: 1) the maximum depths of historical seismicity; 2) geophysical data that constrain the local crustal model; 3) geodetic data regarding the maximum depths of fault slippage; or 4) the

regional tectonic model. In addition, if the fault rupture length can be estimated, compilations of data relating rupture length to downdip fault width for worldwide historical earthquakes (e.g., Purcaro and Berckhemer, 1982) may be used to assess downdip fault width.

Analysis and Results

In order to compile a sufficiently large number of data points, the seismologic literature was reviewed for all earthquakes having magnitudes of 4 to 6 for which fault rupture areas had been, or could be, assessed. From these, earthquakes were selected that had well-constrained magnitudes and aftershock locations. Aftershock sequences are defined by the seismicity occurring during the first few days after the main shock. In most cases, the rupture area was estimated from the distribution of aftershocks. In some cases, the rupture area was constrained by seismic wave analysis and/or geodetic data. In the present analysis, the rupture area associated with the main shock is assumed to be defined by a rectangular region on the fault surface that encloses the aftershock sequence, unless more rigorous estimates have been made for a specific earthquake in the literature to define an irregularly shaped rupture area. It is assumed that the distribution of slip is uniform over the rupture surface defined by the aftershocks, although it is recognized that the rupture may actually be complex (Aki, 1979).

The 24 earthquakes that were selected for the analysis are summarized in Table 1 and are plotted in Figure 1. The empirical relationship between rupture area and earthquake magnitude is of the form:

$$M_S = 0.656 \text{ Log } A + 4.257$$

The correlation coefficient is 0.834. Local magnitudes, M_L, have not been converted to surface wave magnitudes, M_S, because there is little difference between the two scales in this magnitude range. The rupture area versus magnitude relationship is well-defined by the data, particularly in the magnitude range of 5 to 6. The slope of the regression of magnitude on the logarithm of rupture area is about 0.7, whereas it is about 1.0 for $M \geq 6$ (Wyss, 1979). This difference may reflect differences in the stress drops of earthquakes in the magnitude ranges $M \geq 6$ and $M \leq 6$.

The relationship presented in Figure 1 can be used to estimate earthquake magnitude for rupture areas as small as about 5 km^2. For example, the Central fault on Gable Mountain is estimated to have a maximum inferred area of 9 km^2 (Response to 360.20). Assuming that this entire area ruptures during an earthquake, the estimated magnitude from Figure 1 is about M_S 4.9.

TABLE 1

Event	Date	Location	M_s	Area (km^2)	Reference
1	12/21/56	Mizakejima, JP	6.0	550	Utsu (1969)
2	3/22/57	San Francisco, CA	5.3 (M_L)	45	Tocher (1959)
3	5/7/61	Hyogo Prefecture, JP	5.9	570	Utsu (1969)
4	9/14/63	Watsonville, CA	5.4 (M_L)	210	McEvilly (1966)
5	11/16/64	Corralitos, CA	5.0	18	McEvilly (1966)
6	9/10/65	Antioch, CA	4.9 (M_L)	18	McEvilly and Casaday (1967)
7	6/27/66	Parkfield-Cholame, CA	5.5 (M_L)	520	Eaton et al (1970)
8	9/12/66	Truckee, CA	5.9	100	Kanamori and Anderson (1975)
9	11/12/66	South of Hokkaido, JP	5.9	210	Utsu (1969)
10	7/1/68	Saitama, JP	5.6	60	Abe (1975); Kanamori and Anderson (1975)
11	5/28/69	Coyote Mountain, CA	5.9 (M_L)	30	Thatcher and Hamilton (1973)
12	10/16/70	SE Akita, JP	6.0	165	Mikumo (1974); Hasegawa et al (1975)
13	9/4/72	Stone Canyon, CA	4.7 (M_L)	12	Wesson and Ellsworth (1972)
14	2/21/73	Pt. Mugu, CA	5.2	15	Ellsworth et al (1973); Boore & Stierman (1976); Stierman & Ellsworth (1976); Castle et al (1977)
15	3/25/73	Gulf of California	5.5	40	Reichle et al (1976)

Table 1 - continued

Event	Date	Location	M_S	Area (km^2)	Reference
16	3/28/75	Pocatello Valley, ID	6.0 (M_L)	144	Arabasz et al (1981)
17	7/12/75	Maniwaki, Quebec	4.2 (M_L)	1	Horner et al (1978)
18	8/1/75	Oroville, CA	5.6	150	Lahr et al (1976); Clark et al (1976); Langston & Butler (1976); Hart et al (1977)
19	8/17/76	Kawazu, JP	5.4	31.5	Abe (1978)
20	1/8/77	Briones Hill, CA	4.3 (M_L)	8(9)	Johnston et al (1978); Savage & Prescott (1978)
21	8/13/78	Santa Barbara, CA	5.6	50	Lee et al (1978); Wallace et al (1981)
22	8/6/79	Coyote Lake, CA	5.7	200	Lee et al (1979)
23	1/24/80	Livermore, CA	5.9 (M_L)	264	Scheimer et al (1982)
24	2/29/80	Arudy, France	5.0	35	Souriau et al (1982)

REFERENCES

Abe, K., 1975, Static and dynamic fault parameters of the Saitama earthquake of July 1, 1968: Tectonophysics, v. 27, pp. 223-238.

Abe, K., 1978, Dislocations, source dimensions, and stresses associated with earthquakes in the Izu peninsula, Japan, Journal Physics Earth, v. 26, pp. 253-274.

Aki, K., 1979, Characterization of barriers on an earthquake fault: Journal of Geophysical Research, v. 84, no. B11, pp. 6140-6148.

Arabasz, W.J., Richins, W.D., and Langer, C.J., 1981, The Pocatello Valley (Idaho-Utah border) earthquake sequence of March to April, 1975, Bulletin of the Seismological Society of America, v. 71, no. 3, pp. 803-826.

Boore, D.M., and Stierman, D.J., 1976, Calculation of ground motion in a three-dimensional model of the 1966 Parkfield earthquake, Bulletin of the Seismological Society of America, v. 66, no. 2, pp. 385-404.

Castle, R.O., Church, J.P., Elliott, M.R., and Savage, J.C., 1977, Preseismic and coseismic elevation changes in the epicentral region of the Point Mugu earthquake of February 21, 1973: Bulletin of the Seismological Society of America, v. 67, no. 1, pp. 219-231.

Clark, M.M., Sharp, R.V., Castle, R.O., and Harsh, P.W., 1976, Surface faulting near Lake Oroville, California in August 1975: Bulletin of Seismological Society of America, v. 66, no. 4, pp. 1101-1110.

Eaton, J.P., O'Neill, M., and Murdock, J.N., 1971, Aftershocks of the 1966 Parkfield-Cholame, California, earthquake: Bulletin of the Seismological Society of America, v. 60, pp. 1151-1197.

Ellsworth, W.L., Campbell, R.H., Hill, D.P., Page, R.A., Alewine, P.W., III, Hanks, T.C., Heaton, J.A., Hileman, J.A., Kanamori, H., Minster, B., and Whitcomb, J.H., 1973, Point Mugu, California earthquake of 21 February 1973 and its aftershocks, Science, v. 182, pp. 1127-1129.

Hart, R.S., Butler, R., and Kanamori, H., 1977, Surface-wave constraints on the August 1, 1975, Oroville earthquake: Bulletin of the Seismological Society of America, v. 67, no. 1, pp. 1-7.

Hasegawa, A., and Kasakara, K., 1975, On the focal mechanism of the southeastern Akita earthquake of 1970: Journal of the Seismological Society of Japan, v. 28, pp. 141-151.

Horner, R.B., Stevens, A.E., Hasegawa, H.S., and LeBlanc, G., 1978, Focal parameters on the July 12, 1975, Maniwaki, Quebec, earthquake; an example of intraplate seismicity in eastern Canada: Bulletin of the Seismological Society of America, v. 68, no. 3, pp. 619-640.

Johnston, M.J.S., Jones, A.C., Daul, W., and Mortensen, C.E., 1978, Tilt near an earthquake ($M_L = 4.3$) Briones Hills, California: Bulletin of the Seismological Society of America, v. 68, no. 1, pp. 169-173.

Kanamori, H., and Anderson, D.L., 1975, Theoretical basis of some empirical relations in seismology: Bulletin of the Seismological Society of America , v. 65, pp. 1073-1095.

Lahr, K.M., Lahr, J.C., Lindh, A.G., Bufe, C.G., and Lester, F.W., 1976, The August 1975 Oroville earthquakes: Bulletin of the Seismological Society of America, v. 66, no. 4, pp. 1085-1099.

Langston, C.A., and Butler, R., 1976, Focal mechanism of the August 1, 1975, Oroville earthquake: Bulletin of the Seismological Society of America, v. 66, no. 4, pp. 111-1120.

Lee, W.H.K., Johnson, C.E., Henyey, T.L., and Yerkes, R.L., 1978, A preliminary study of the Santa Barbara, California, earthquake of August 13, 1978, and its major aftershocks, U.S.G.S. Circular 797, 14 p.

Lee, W.H.K., Herd, D.G., Cagnetti, V., Bakun, W.H., and Rapport, A., 1979, A preliminary study of the Coyote Lake earthquake of August 6, 1979 and its major aftershocks: U.S.G.S. Open-File Report 79-1621, 43 p.

McEvilly, T.V., 1966, The earthquake sequence of November 1969 near Corralitos, California: Bulletin of the Seismological Society of America, v. 56, pp. 755-773.

McEvilly, T.V., and Casaday, K.B., 1967, The earthquake sequence of September, 1965, near Antioch, California: Bulletin of the Seismological Society of America, v. 57, no. 1, pp. 113-124.

Mikumo, T., 1974, Some considerations on the faulting mechanism of the southern Akita earthquake of October 16, 1974, Journal Physics Earth, Tokyo, v. 22, pp. 87-108.

Pearson, C., 1982, Parameters and a magnitude moment relationship from small earthquakes observed during hydraulic fracturing experiments in crystalline rocks: Geophysical Research Letters, v. 9, no. 4, pp. 404-407.

Purcaru, G., and Berckhemer, H., 1982, Quantitative relations of seismic source parameters and a classification of earthquakes: Tectonophysics, v. 84, pp. 57-128.

Reichle, M.S., Sharman, G.F., and Brune, J.N., 1976, Sonobuoy and teleseismic study of Gulf of California transform fault earthquake sequence: Bulletin of the Seismological Society of America, v. 66, no. 5, pp. 1623-1641.

Savage, J.C., and Prescott, W.H., 1978, Geodolite measurements near the Briones Hills, California, earthquake swarm of January 8, 1977, Bulletin of the Seismological Society of America, v. 68, no. 1, pp. 175-180.

Scheimer, J.F., Taylor, S.R., and Sharp, M., 1982, Seismicity of the Livermore Valley region: Proceedings of the Conference on Earthquake Hazards in teh Eastern San Francisco Bay Area, California Division of Mines and Geology Special Report (in press).

Souriau, M., Souriau, A., and Gagnepain, J., 1982, Modelling and detecting interactions between earth tides and earthquakes with application to an aftershock sequence in the Pyrenees, BSSR, v. 72, no. 1, pp. 165-180.

Stierman, D.J., and Ellsworth, W.L., 1976, Aftershocks of the February 21, 1973, Point Mugu, California earthquake: Bulletin of the Seismological Society of America, v. 66, no. 6, pp. 1931-1952.

Thatcher, W., and Hamilton, R.M., 1973, Aftershocks and source characteristics of the 1969 Coyote Mountain earthquake, San Jacinto fault zone, California: Bulletin of the Seismological Society of America , v. 63, pp. 647-661.

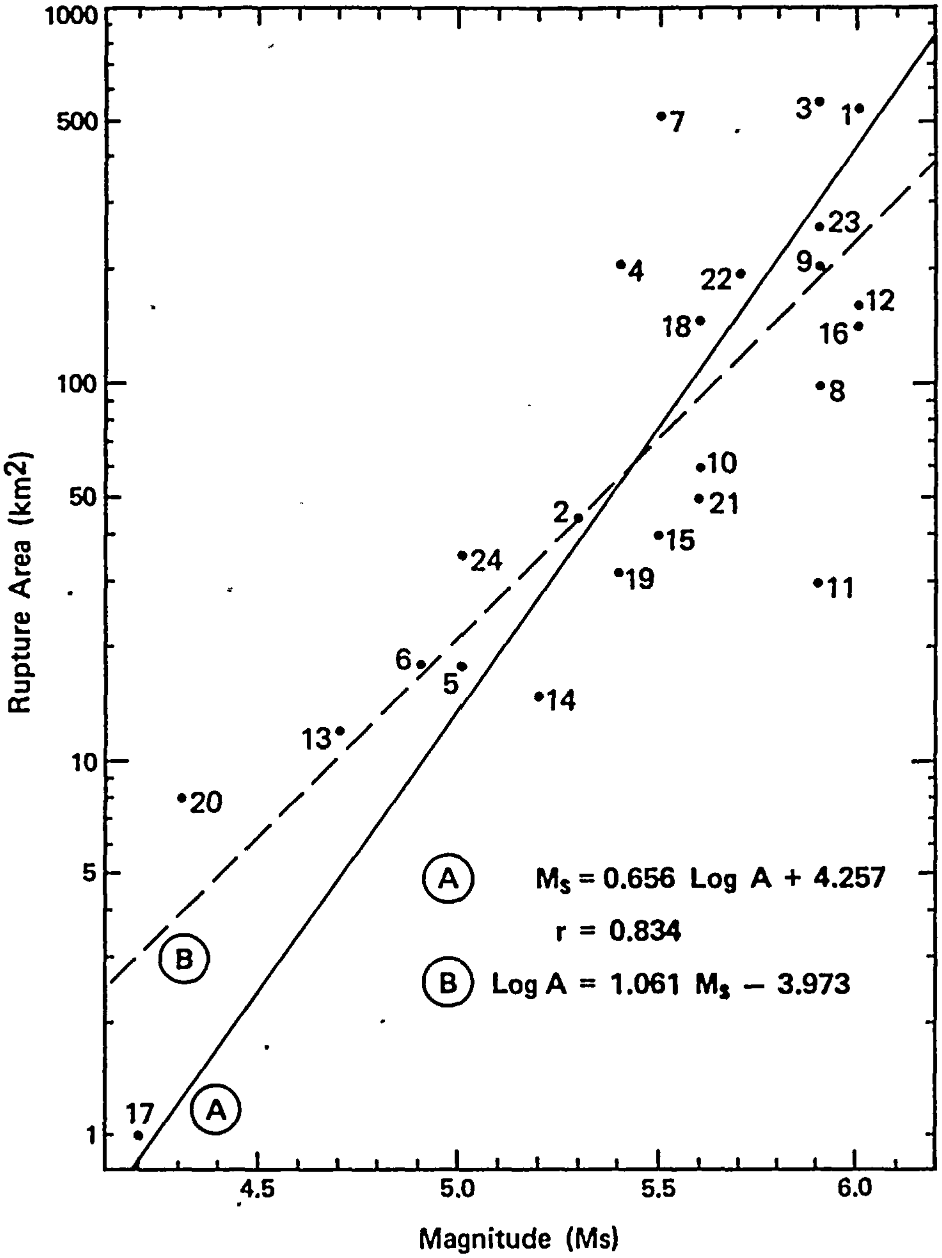
Tocher, D., 1959, San Francisco Earthquakes of March 1957: California Division of Mines Special Report 57, pp. 61-71.

Utsu, T., 1969, Aftershocks and earthquake statistics (1): Hokkaido University Journal of the Faculty of Science, v. VII, 3, pp. 129-195.

Wallace, T.C., Helmberger, D.V., and Ebel, J.E., 1981, A broad band study of the 13 August 1978 Santa Barbara earthquake: Bulletin of the Seismological Society of America, v. 71, no. 6, pp. 1701-1718.

Wesson, R.L., and Ellsworth, W.L., 1972, Preliminary hypocentral data for the Stone Canyon earthquake of September 4, 1972: Earthquake Notes, Eastern Section Seismological Society of America, v. XLIII, no. 3, pp. 13-15.

Wyss, M., 1979, Estimating maximum expectable magnitude of earthquakes from fault dimensions: Geology, v. 7, pp. 336-340.



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	PLOT OF RUPTURE AREA VERSUS MAGNITUDE	Figure 1

[illegible]