~~Enclosure (3)~~ 3

Northwest U.S. Subduction Zone

Seismic Risk Assessment

Proposal to U.S.G.S. research

program for the U.S.N.R.C.

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Commercial 213-356-6822

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1) Statement of Problem

Despite the fact that there is good evidence of present day convergence of the Juan de Fuca and North American plates, there has been remarkably little historic seismic activity along the shallow part of the Juan de Fuca subduction zone. Although it is impossible to rule out the possibility of aseismic creep, we find that the Juan de Fuca subduction zone shares many features with other subduction zones which both have been locked and have experienced great earthquakes (Heaton and Kanamori, 1983; included as an appendix). We propose to study the possible source characteristics and ensuing strong ground motions and Tsunami hazards for hypothetical great shallow subduction zone earthquakes off the coast of Washington and Oregon.

The first phase of the study will define the geometry and dimensions of potential rupture areas. We will also attempt to characterize the nature of rupture heterogeneity which can be expected. In the second phase, we will estimate the natue of ground motions which may result by comparing the northwestern U.S. with other subduction zones for which strong motion records are available. In the third phase, we will synthesize ground motions for hypothetical great earthquakes by summing the responses of individual segments of the proposed rupture surface. The responses of individual segments will be approximated both by actual recordings of moderate-sized earthquakes and also by numerical calculation of the theoretical response of layered crustal structure to point dislocations.

2) Importance of the Problem to Program Goals

This research is directly motivated by the licensing procedure for the Washington Public Power Supply System System Nuclear Project No. 3 located at Satsop, Washington. The possibility of large shallow subduction zone earthquakes was excluded in the design phase of this facility. However, new study of the nature of the Juan de Fuca subduction zone indicates that such events may be possible. EStimates of ground shaking from large subduction zones earthquakes are of central importance in the licensing review of this plant. Furthermore, due to the nature of this problem, this research is relevant to earthquake hazard estimation throughout the entire western parts of Washington and Oregon. This includes the currently operating Trojan nuclear plant in Oregon.

Work to be undertaken

Work on this project falls naturally into three catagories.

Characterization of the source In this phase of the work we will construct models of the feasible rupture parameters of shallow thrust earthquakes on the Juan de Fuca subduction zone. We will include parameters such as fault length, fault dip, fault width, average stress drop, and rupture heterogeneity. Constraints on these parameters will be investigated by studying other subduction zones. That is we will assume that rupture characteristics of Juan de Fuca subduction zone events will be similar to rupture characteristics seen for other subduction zones with similar physical characteristics. Physical characteristics which will be compared are; are of subducted lithosphere, rate of convergence, fault dip, topography of the subducted plate, geometry of the accretionary wedge, nature of marine terraces, and temporal and spatial patterns of seismicity. There are good reasons to suspect that these physical characteristics are closely related to the rupture parameters of shallow subduction earthquakes (see accompaning paper by Heaton and Kanamori). If subduction zones with similar physical characteristics can be found, then the nature of rupture heterogeneity for events on these zones will be characterized by studying the teleseismic body wave radiation from these events.

Earthquake recurrence rates will be estimated using estimates of the plate convergence rate together with estimates of rupture dimensions.

Estimation of strong ground motions We will use several procedures to estimate strong ground motion. The first procedure is described by Heaton et al. (1983). In this procedure a suite of strong motion records is constructed by collecting and scaling records taken at sites with similar tectonic conditions. Records are scaled with respect to site distance, earthquake size, and site conditions. However, it is desirable to collect records which require as little scaling as possible. Once a scaled suite of records has been constructed, we can calculate the statistical mean, median, standard deviation, etc. of various strong motion parameters. An example of this procedure is given in Table 1. In this example, records from strike-slip earthquakes have been scaled to a distance of 50 km and earthquake magnitude of 6½. Records were chosen so that little scaling was necessary. The suite of scaled response spectra is shown in Figure 1. The average spectrum, average plus one standard deviation spectrum, spectrum of the largest single record, and the spectrum which envelops all others are shown in Figure 2. Although the scatter may seem large, it is an accurate representation of the range of motions that have been observed at 50 km from magnitude 6½ strike-slip earthquakes.

This same procedure will be applied to construct suites of strong motion records from subduction zones. These records are principally from Japan. In Figure 3 we show a comparison of peak acceleration plotted as a function of distance and magnitude for ground motions recorded in Japan and the western U. S. We see that magnitude and distance scaling relationships seem to be similar in Japan and the western U.S. We also see that there is sufficient data to simulate subduction zone earthquakes with magnitudes up to about 7½, provided that the distance is greater than 50 km. However for larger earthquakes and smaller source distances, the procedure described above is not appropriate.

Although no records are available for earthquakes of $M > 8$, we can make synthetic ground motions by summing records from smaller earthquakes. This type of summation has been used with reasonable success by Hartzell (1978) and Kanamori (1979) on large strike-slip earthquakes. The technique has also been used by Heaton and also Kanamori to simulate ground motions for subduction zone earthquakes for use by Exxon Production Research Co.

The basic assumption in the synthesis procedure is that the motions from a large earthquake are a linear sum of the motions from smaller earthquakes. Enough smaller earthquakes are summed so that the sum of the seismic moments of the smaller events equals the moment of the large event. Timing delays due to rupture and travel time dealys are included in the summation process. The details of the timing assumptions in this summation process can, however, affect the nature of the final product. In order to discover appropriate timing assumptions, we will also construct synthetic teleseismic body waves for great earthquakes by summing body waves from smaller events. We will require that our models which produce strong motions also provide an adequate characterization of observed teleseismic body waves.

We will also investigate the feasibility of using the theoretical responses of point dislocation sources as Green's functions for three-dimensional finite fault simulations of very large earthquakes. This technique may be useful if observed records are not available at desired source-station geometries. Such Green's functions would be calculated assuming a horizontally-layered earth structure. The Green's functions would then be integrated over the fault surface in order to produce motions due to a finite rupture surface. These techniques have been used with considerable success to model records from moderate-sized earthquakes (Heaton, 1982; Hartzell and Helmberger, 1982; Hartzell and Heaton, 1983).

Evaluation of Tsunami hazard In order to obtain a rough estimate of the hazard due to local Tsunamis which may be generated by a great shallow subduction zone event, we will search for subduction zones with ocean bottom profiles and source geometries similar to that found in the Juan de Fuca subduction zone. Local Tsunamis generated by historic earthquakes in these other regions will be catalogued. These Tsunamis will then be scaled to account for differences in seismic moment to come up with estimates of the potential heights of Tsunamis that might be expected along the coast of Washington, Oregon, and British Columbia.

4) Strategy and timetable

Although the following work plan may evolve as we proceed into this project, we propose the following tasks and accompanying timetable.

Task I Characterization of source geometry. In this task, we compile physical characteristics of the Juan de Fuca subduction zone. Much of this background work has been done in the Final Safety Analysis Report of the WPPSS Nuclear Project Number 3 (October 1983)

Task II Comparison with other subduction zones. This will be primarily a literature search combined with interviews of knowledgeable colleagues. Cataloguing of physical features should allow us to select those zones with similar characteristics (October-November, 1983).

Task III Estimate source dimensions and geometry of shallow Juan de Fuca subduction zone event. Models of source geometry and size will be constructed (November 1983).

Task IV Characterize rupture heterogeneity. This task ventures into an area not yet ___ studied. We intend to collect teleseismic time functions for large subduction zone events and to characterize the roughness of the time functions (December 1983 - Spring 1984).

Task V Construct suites of scaled strong ground motions. Catalogues of strong motion records will be searched to find records which may be similar to those expected from a Juan de Fuca subduction zone event. (January - March, 1984).

Task VI Construct synthetic strong motion records by summing records from smaller events. Models will be checked for consistancy with teleseismic recordings of other great subduction zone events (Spring 1984).

Task VII Estimate local Tsunami hazard. A catalogue of local Tsunamis with source geometrics and ocean bottom profiles similar to the Juan de Fuca subduction zone will be constructed. Tsunami heights will then be scaled using the results of Task III (Summer 1984).

5) <u>Location of proposed work</u>

This project will be conducted at the Pasadena, California, field office of the Office of Earthquakes, Volcanoes, and Engineering USGS. This office is located on the campus of the California Institute of Technology.

6) <u>Other commitments or anticipated difficulties that will affect progress or completion of the project</u>

Most computer codes to manipulate data and compute synthetic ground motions are written and working. However, these codes must be updated. Furthermore, we expect to transfer our work from the Caltech Prime 750 computer to a new USGS VAX 11-750 computer in the Fall of 1983. Although we hope that this transition goes smoothly, there may be unanticipated delays caused by this. Digital recordings of ground motions from subduction zones are presently available, but if a larger catalogue becomes necessary, then collection of other records may delay our schedule.

Both principal investigators in this project are also 1/2 time committed to work in the Seismology Branch project entitled, Southern California Cooperative Seismic Network Project. Their research in this project covers several areas, with the main emphasis in FY1984 being research into possible new directions for seismic networks. Since the Pasadena Field Office is a small office having many responsibilities, the occurrence of local emergency situations, such as earthquakes, may affect work schedules on research projects.

7) <u>Products</u>

04/84 Preliminary report on nature of shaking from Juan de Fuca subduction zone earthquakes to the U.S.N.R.C.

10/84 Final report

10/84 Scientific paper on the nature of seismic hazards associated with the Juan de Fuca subduction zone.

Major facilities and equipment needed

The major requirement of this project is computer time. We presently purchase computer time from Caltech on a Prime 750 computer. However, it appears that a new USGS Vax 11-750 computer will become available for our use in Fall 1983. Thus our projected computer costs cover expenses for the Caltech computer which we feel will be necessary during the process of converting computers.

9) Expected interaction with other projects and workers

There will be strong interation with Hiroo Kanamori at Caltech who maintains strong interest in the nature of subduction zone earthquakes. He is presently working on similar studies under a research grant from Exxon Production Research Company. We also expect interaction from Doug Coats of Exxon Production Research Company and C.B. Crouse of Earth Technology Corporation. Caltech graudate students, in particular, Anne Mori, will be encouraged to participate in the research. Due to the far-ranging implications of this research, we expect to interact frequently about the nature of our preliminary conclusions with researchers at USGS-Menlo Park, Univ. of Washington, USGS-Denver, and the U.S. N.R.C.

10) Qualifications of principal investigators

The principal investigators in this project, Heaton and Hartzell, have considerable experience in the field of synthesizing both strong motions and teleseismic ground motions from complex realistic earthquake sources. They both also have experience in the problem of summing records of smaller earthquakes to simulate large ones. Both have experience in the commercial consulting field and Heaton has considerable experience in the field of estimating ground motions at subduction zones. A full summary of the qualifications of the principal investigators is contained in the resumes included with this proposal

M.Y. Effort	Funding Requested
0.4	40K

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Figure Captions

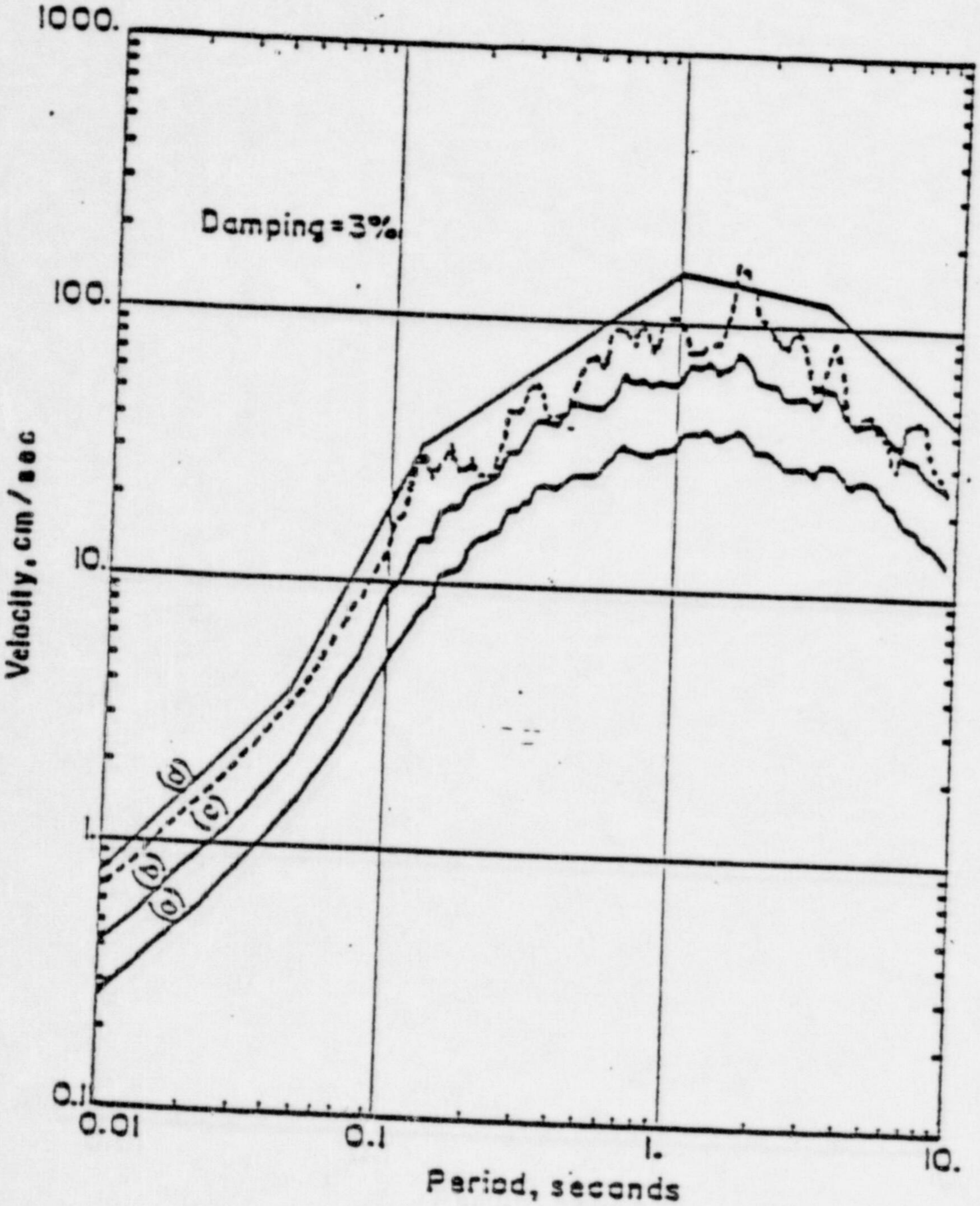
Figure 1. Response spectra (3% damped) for horizontal components of 15 records from strike-slip earthquakes which are scaled to a distance of 50 km and a magnitude of 6½. Records description and scaling parameters are given in Table 1. Figure is from Heaton et al. (1983).

Figure 2. a) average spectrum, b) average plus one standard deviation specturm, c) specturm of the largest single record, d) spectrum which envelopes all others; based on spectra shown in Figure 1 (taken from Heaton et al. 1983).

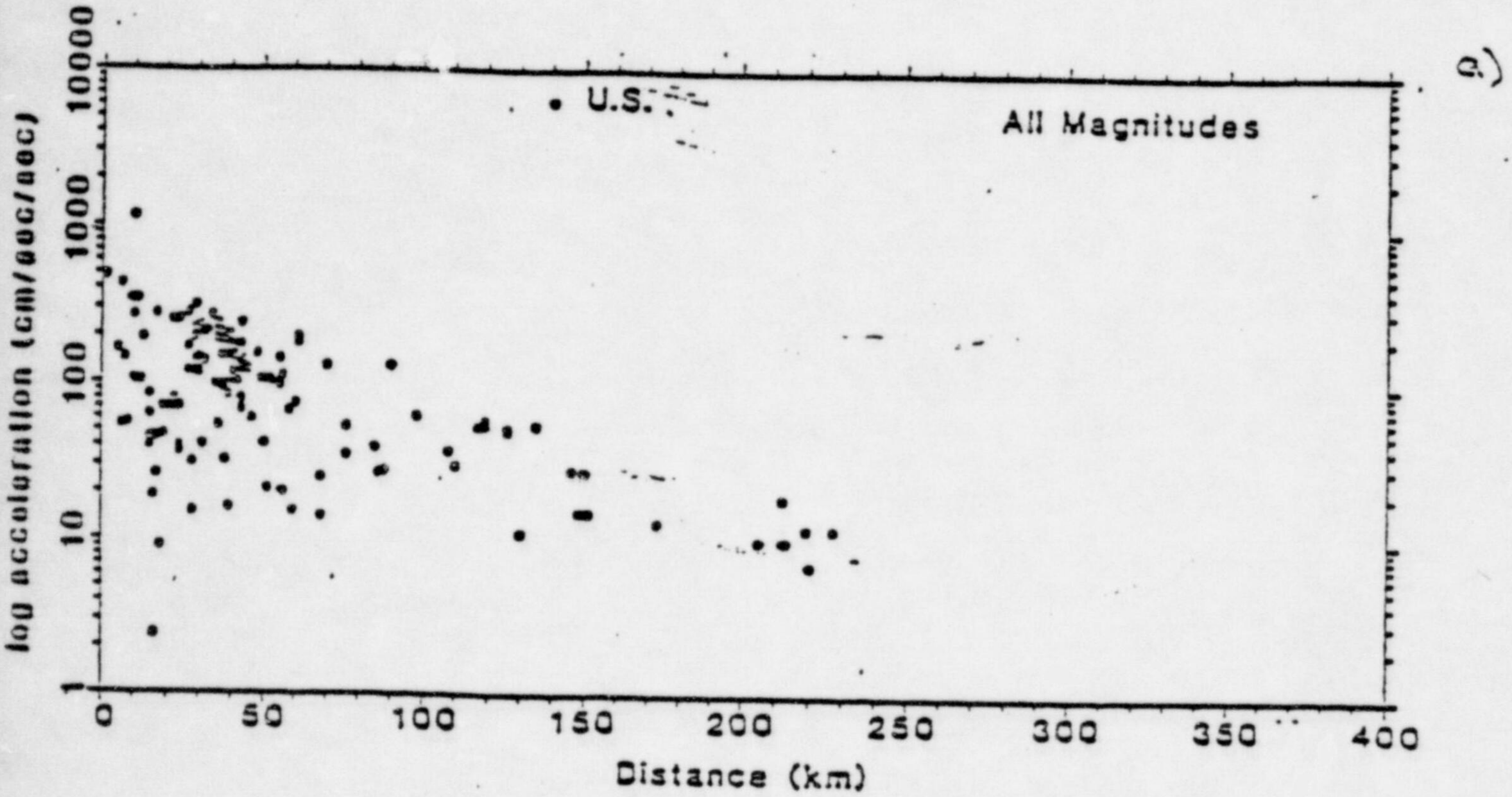
Figure 3. Comparison of peak ground accelerations recorded in the western U.S. and Japan. Distance is approximately the closest horizontal distance to the rupture. Dashed line is the modified local magnitude distance attenuation law of Jennings and Kanamori (1983). Figure is from Heaton et al. (1983).

TABLE 1

No.	Earthquake		Station	Magnitude M_w (if available)	Center of Energy Distance (km)	Soil Type	Calculated M_L	$-\log A_o$	C_s	A_l (m)	Scale Factor	Avg. Peak Horizontal Velocity (cm/sec)	Avg. Scaled Peak Velocity (cm/sec)
1	3/11/33	Long Beach	Vernon CMD Bldg.	6.3	36	0	6.23	2.28	+.15	12.59	.87	23.	20.
2	3/11/33	Long Beach	L.A. Subway Term.	6.3	42	0	6.23	2.38	+.15	10.0	1.10	20.5	22.6
3	12/30/34	L. California	El Centro	6.5	61	0	6.38	2.61	+.15	8.32	1.32	16.0	21.1
4	10/21/42	Borrego Valley	El Centro	6.5	46	0	6.38	2.44	+.15	12.3	.89	6.2	5.5
5	12/21/54	Eureka	Ferndale City Hall	6.5	40	1	6.38	2.35	0	10.72	1.02	31.	31.6
6	4/20/65	Japan	Site #CB002	6.1	50	0	6.08	2.43	+.15	6.31	1.74	7.8	7.8
7	4/20/65	Japan	Site #CB057	6.1	45	0	6.08	2.49	+.15	8.91	1.23	20.2	24.8
8	4/9/68	Borrego Mtn.	El Centro	6.6	65	0	6.45	2.65	+.15	8.91	1.23	20.2	24.8
9	10/15/79	Imperial Valley	Cerro Prieto	6.4	39	2	6.3	2.33	-.15	6.61	1.66	15.	24.9
10	10/15/79	Imperial Valley	Delta	6.4	50	0	6.3	2.49	+.15	9.12	1.2	29.2	35.1
11	10/15/79	Imperial Valley	Victoria	6.4	60	0	6.3	2.6	+.15	7.08	1.55	10.2	15.8
12	10/15/79	Imperial Valley	Calipatria	6.4	41	0	6.3	2.37	+.15	12.02	.91	13.7	12.4
13	10/15/79	Imperial Valley	Superstition	6.4	42	0	6.3	2.39	+.15	11.48	.95	6.9	6.6
14	10/15/79	Imperial Valley	Plaster City	6.4	38	0	6.3	2.32	+.15	13.49	.81	4.5	3.6
15	10/15/79	Imperial Valley	Niland	6.4	51	0	6.3	2.5	+.15	8.91	1.23	10.1	12.4
	Test Case			6.5	50	0	6.38	2.49	+.15	10.96		14.26 ± 8.5	17.87 ± 9.



1000.
100.
10.
1.
0.1
0.01
0.1
1.
10.
Damping=3%
Velocity, cm/sec
Period, seconds
(d)
(c)
(b)
(a)


a)
U.S.
All Magnitudes
log acceleration (cm/sec/sec)
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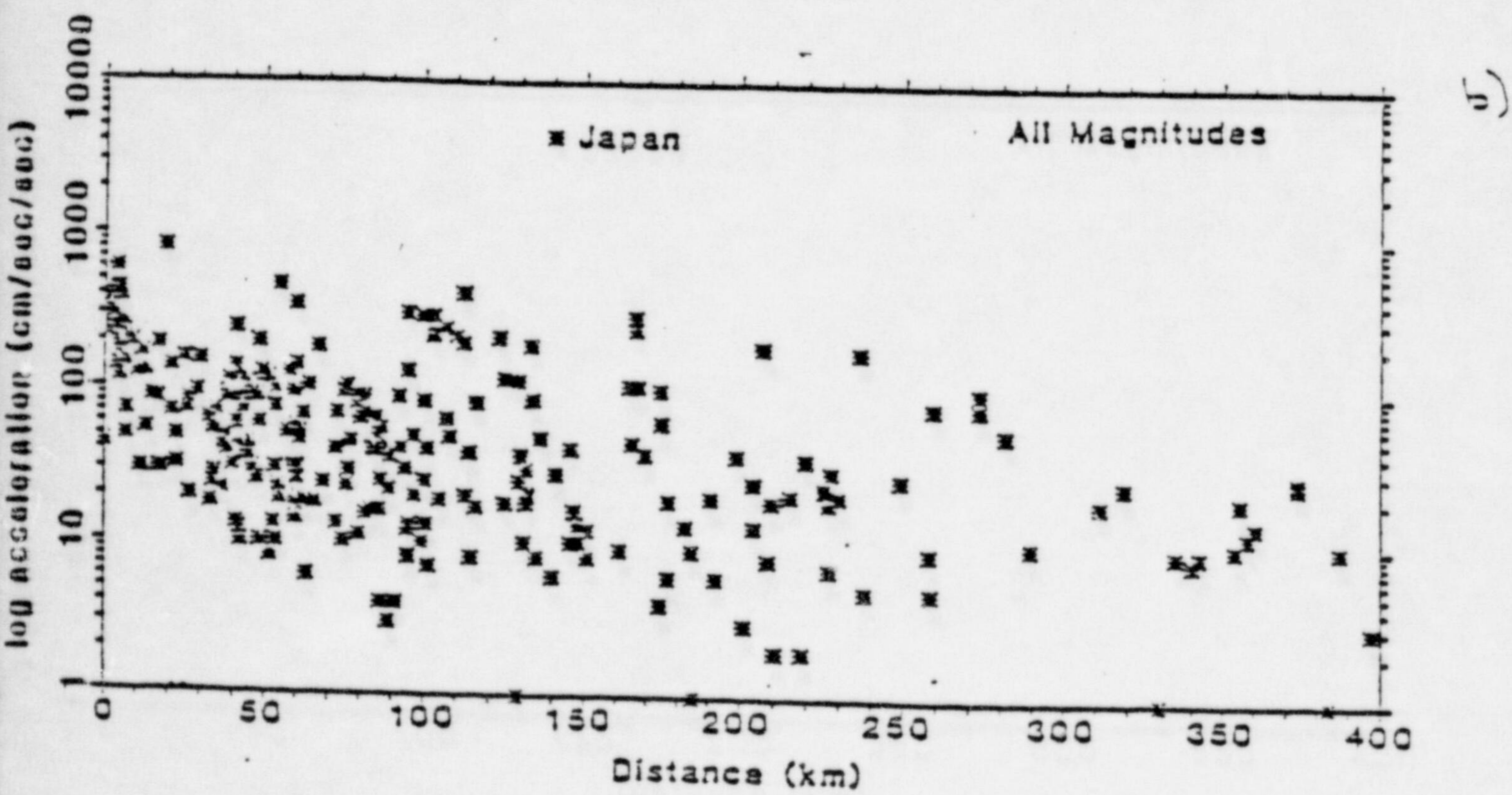
Distance (km)


b)
Japan
All Magnitudes
log acceleration (cm/sec/sec)
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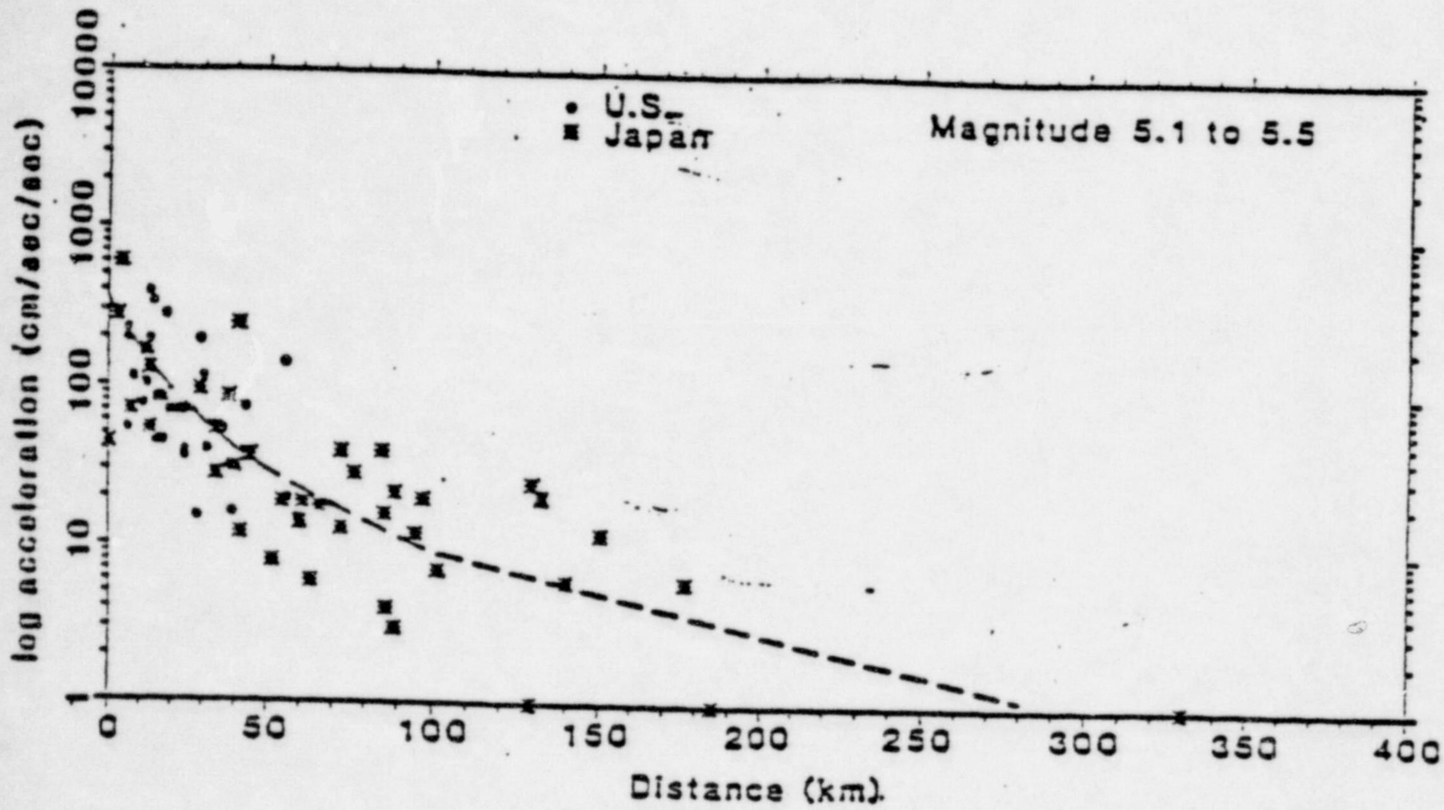
Distance (km)



• U.S.
■ Japan
Magnitude 5.1 to 5.5
log acceleration (cm/sec/sec)
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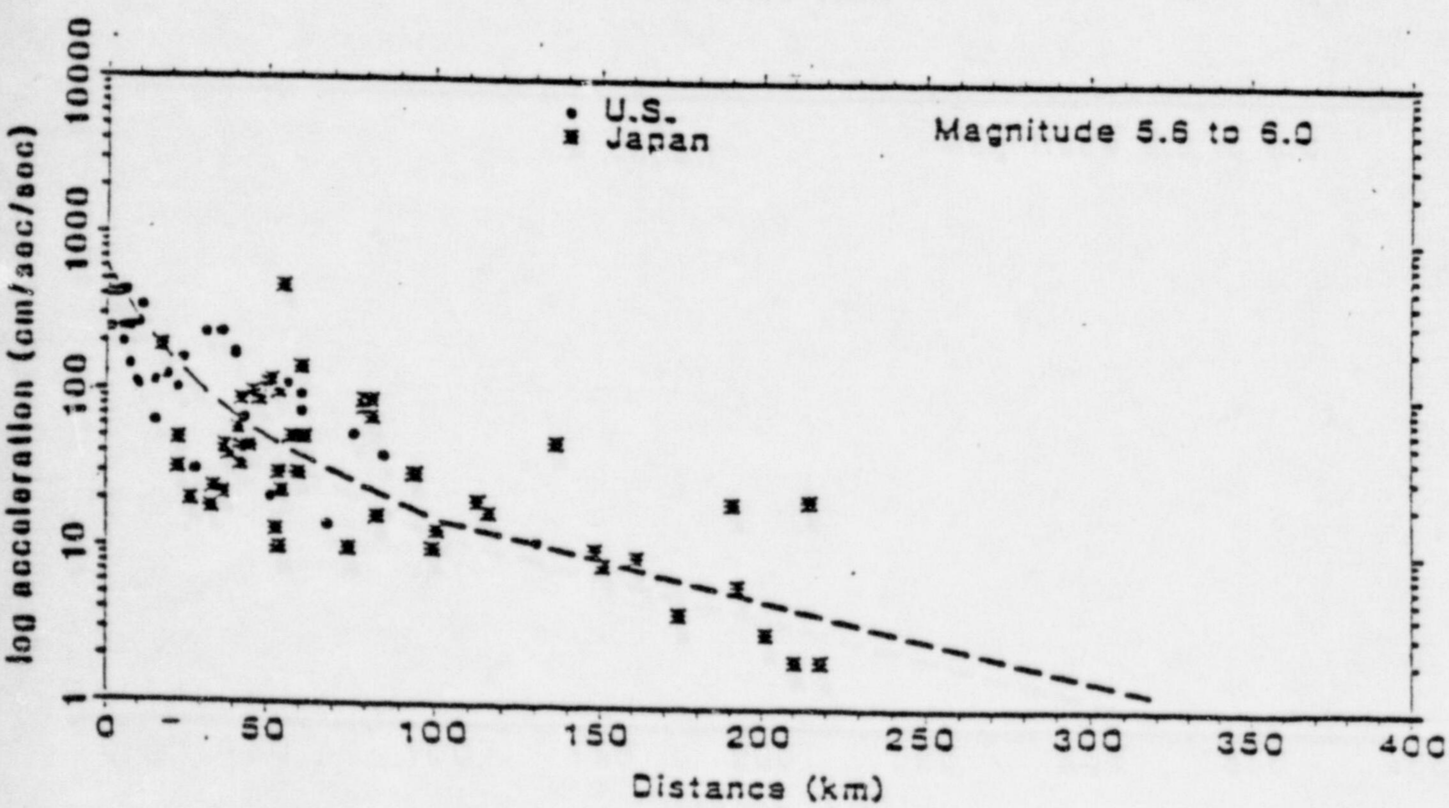
Distance (km)

c)



• U.S.
■ Japan
Magnitude 5.6 to 6.0
log acceleration (cm/sec/sec)
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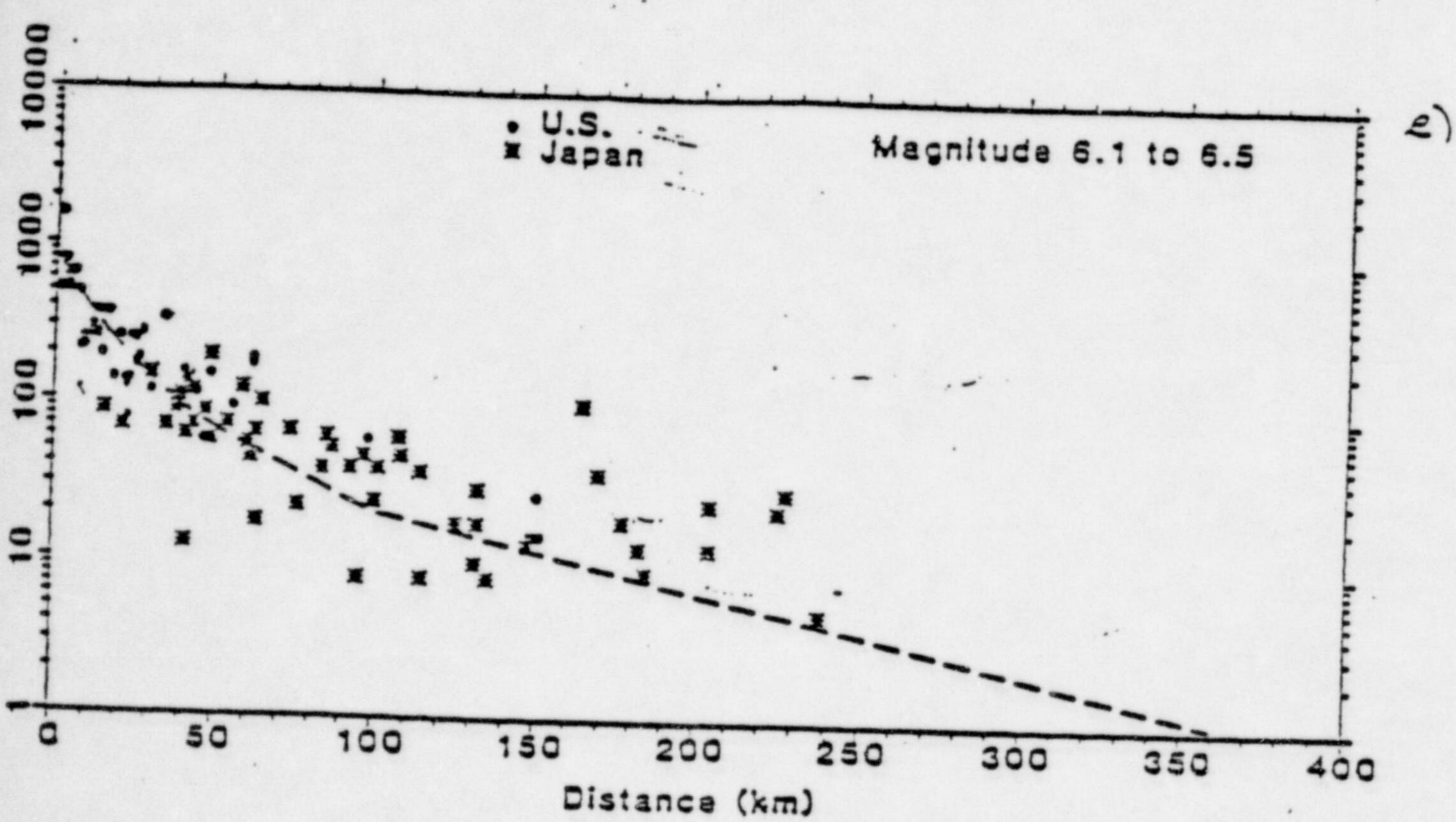
Distance (km)

d)



e)
U.S.
Japan
Magnitude 6.1 to 6.5
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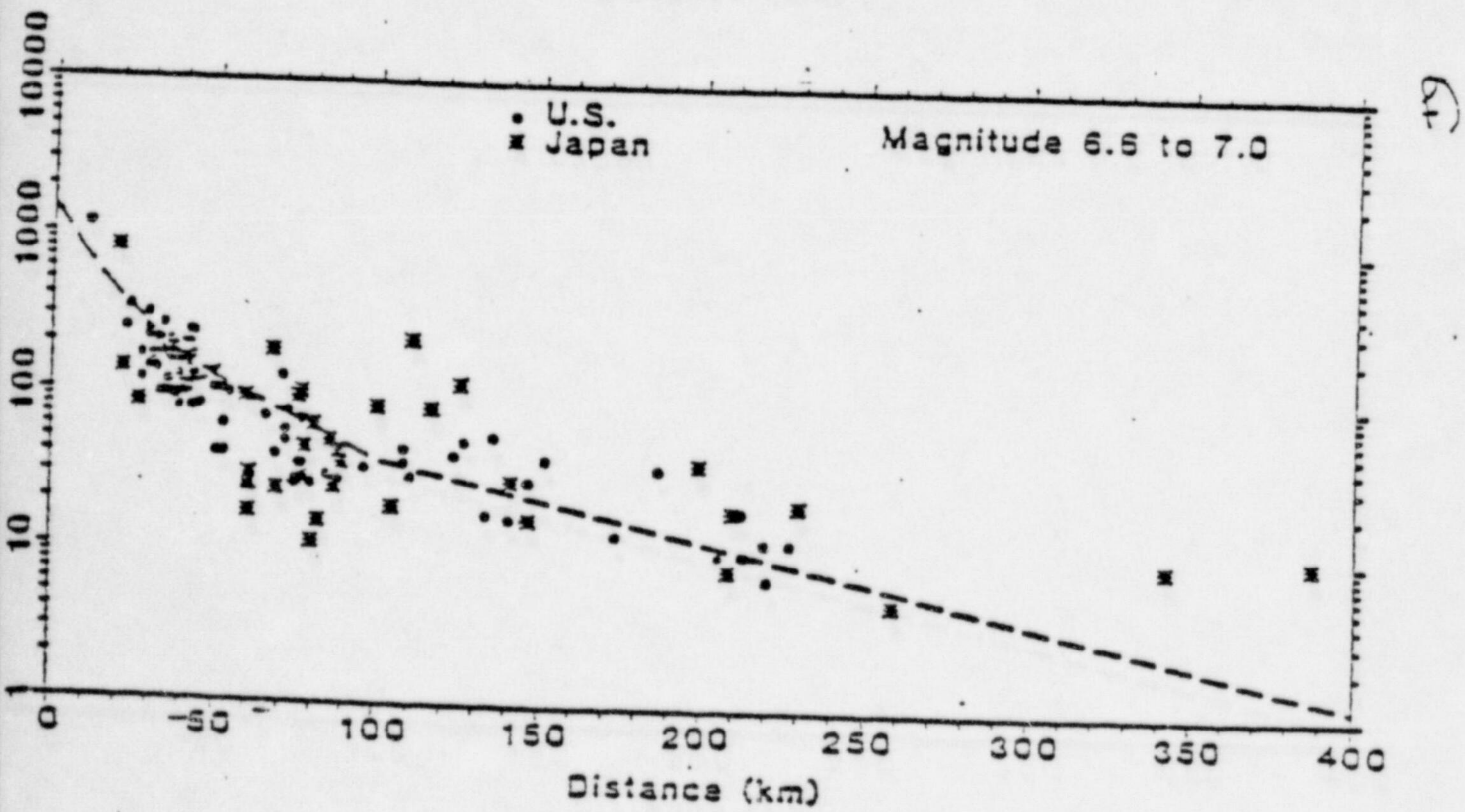
Distance (km)



f)
U.S.
Japan
Magnitude 6.6 to 7.0
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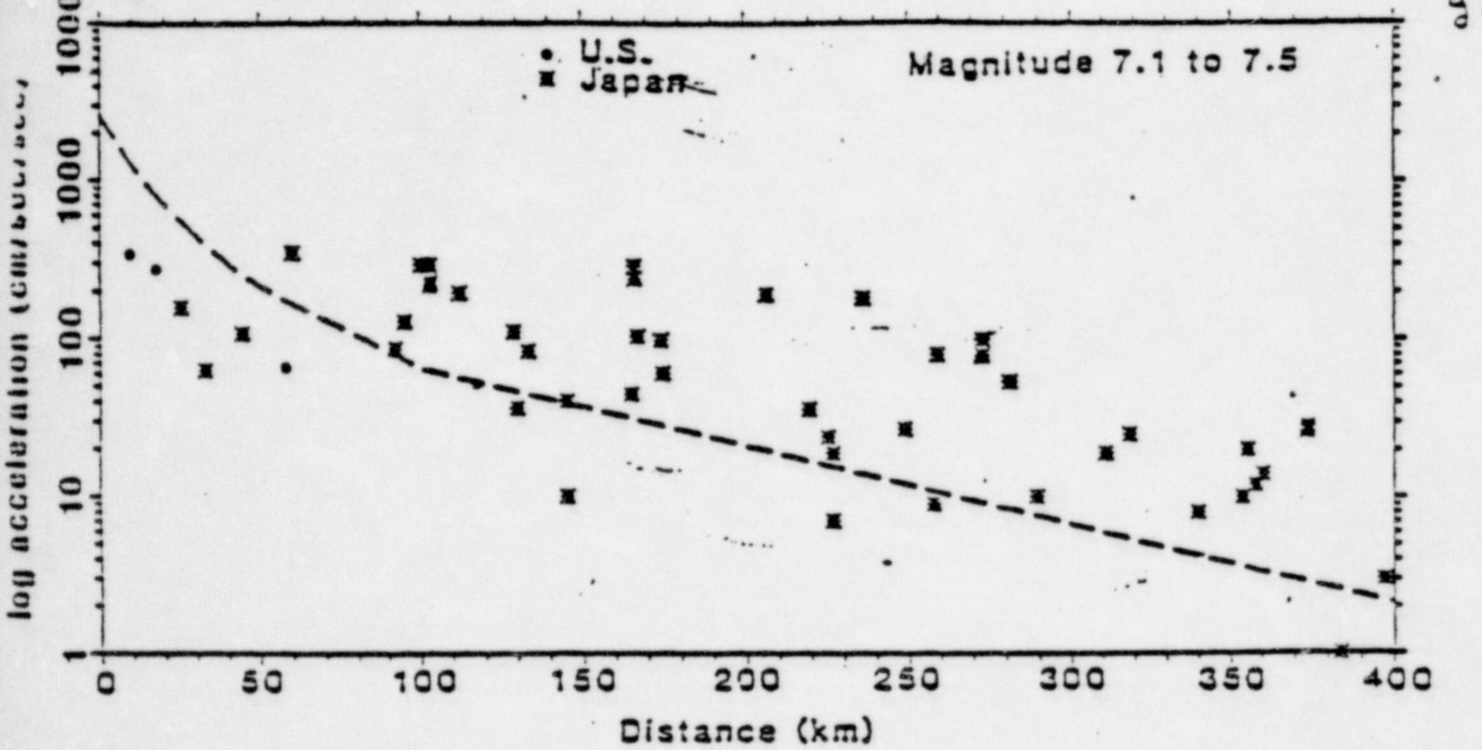
400
Distance (km)



a)
U.S.
Japan
Magnitude 7.1 to 7.5
log acceleration (cm/sec/sec)
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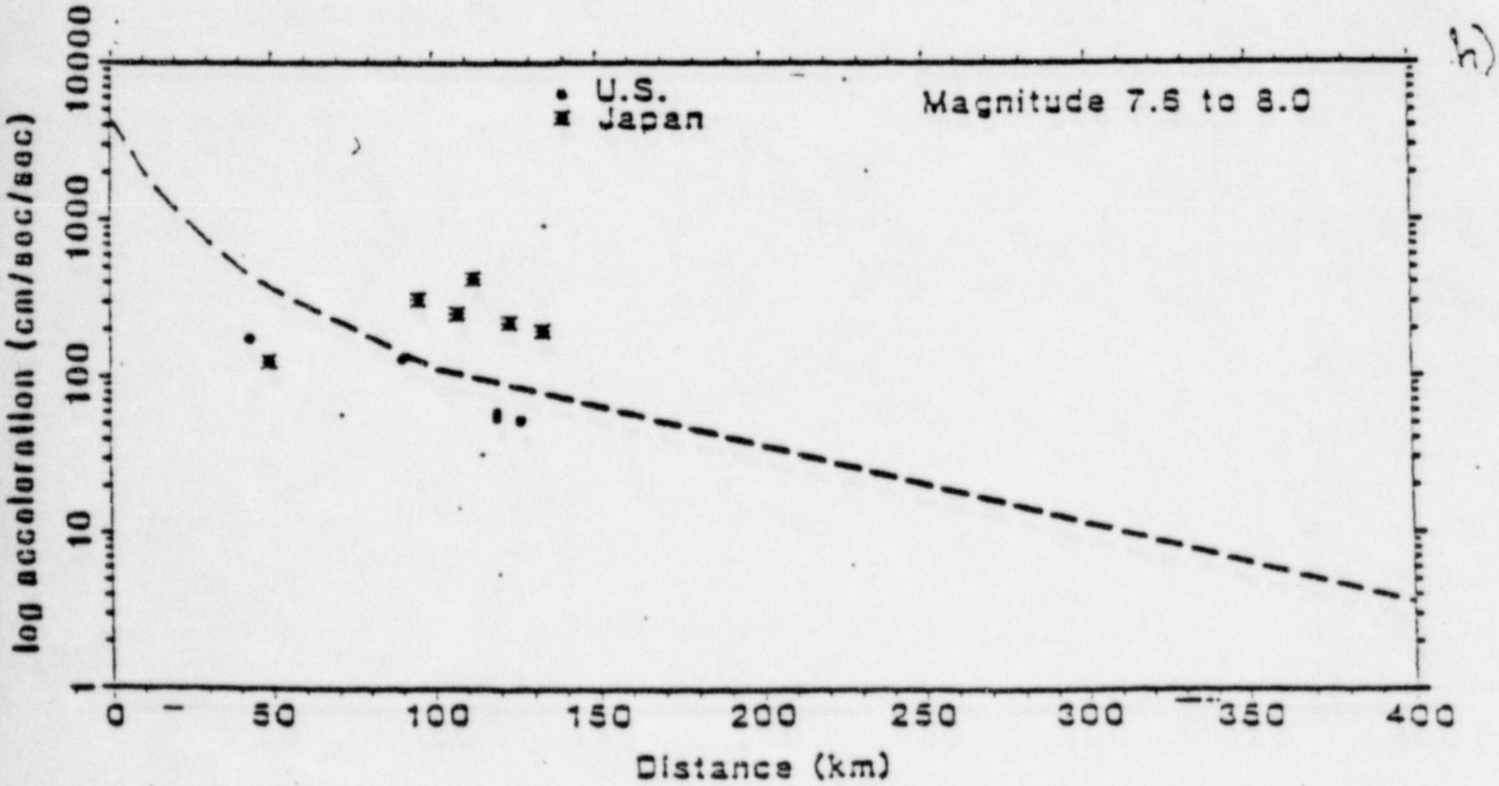
Distance (km)



h)
U.S.
Japan
Magnitude 7.6 to 8.0
log acceleration (cm/sec/sec)
10000
1000
100
10
1
0
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250
300
350
400
Distance (km)

Resume: Thomas H. Heaton

Title: Geophysicist - U. S. Geological Survey

Expertise: Seismology / Earthquake Engineering

Past Experience:

- 1979-1982 - Geophysicist with U.S. Geological Survey at Caltech office. Strong ground motion studies and earthquake prediction studies
- 1978-1979 - Senior Seismologist with Dames and Moore. Estimation of earthquake hazards for major energy facilities. Half-time visiting associate at the Seismological Laboratory at Caltech with emphasis on strong ground motion modeling.
- 1977-1978 - Consultant to Dames & Moore--Seismic hazard studies
- 1974-1978 - Consultant to Converse, Davis, Dixon & Associates--Fault hazard studies
- 1974- Converse, Davis, Dixon & Associates--Engineering geology with emphasis on fault hazard studies

PROFESSIONAL AFFILIATIONS

Seismological Society of American
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ACADEMIC BACKGROUND

Chemistry and physics major, Bates College, 1968-1970
B.S. in physics with special interests in mathematics and geology, Indiana University, 1972
Ph.D. in Geophysics, minor in Applied Mechanics, California Institute of Technology, 1978

PUBLICATIONS

Alewine, R.W., and T.H. Heaton, Tilts associated with the Pt. Mugu earthquake, Proceedings, Conference on Tectonic Problems of the San Andreas Fault System, Geological Sciences, XIII, Stanford University, 94-103, 1973.

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	FILE LOCATION		

DESCRIPTION ☐ LETTER ☒ MEMO ☐ REPORT ☐ OTHER

Bonneville Power Administration V. WPPSS

SPECIAL INSTRUCTIONS OR REMARKS

Coordinate with ELD.

ASSIGNED TO	DATE	INFORMATION ROUTING
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Eisenhut	6/19/84	GCunningham
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Knighton		PPAS

NRC FORM 232 (6-80)

EXECUTIVE DIRECTOR FOR OPERATIONS

PRINCIPAL CORRESPONDENCE CONTROL