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Waterways Experiment Station

U.S. Army Corps of Engineers Seismic Strong-Motion Instrumentation Program

by Robert F. Ballard, Jr., Tina H. Grau

Prepared for Headquarters, U.S. Army Corps of Engineers

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Preface

The Strong-Motion Instrumentation Program (SMIP) described herein is operated by the U. S. Army Engineer Waterways Experiment Station (WES) by authorization of Headquarters, U. S. Army Corps of Engineers (HQUSACE). This report was written by Mr. Robert F. Ballard, Jr. (Program Manager) and Mrs. Tina H. Grau, Earthquake Engineering and Geosciences Division (EEGD), Geotechnical Laboratory (GL), WES, to document the evolution of the SMIP. This report is intended to furnish background, insight, and past experience in the program to various USACE Districts and Divisions involved in instrumenting facilities across the United States and in the Commonwealth of Puerto Rico. Further, it is an attempt to consolidate pertinent reference materials associated with the SMIP into a single document.

Mr. Ballard and Mrs. Grau were under the GL administrative supervision of Dr. Arley G. Franklin (retired), Chief, EEGD; Dr. Lillian D. Wakeley, Acting Chief, EEGD; and Dr. W. F. Marcuson III, Director. Messrs. Monroe B. "Joe" Savage and Lewis B. Smithhart, Data Acquisition Section, Operations Branch (OB), Instrumentation Systems Development Division (ISDD), Information Technology Laboratory, WES, were authors of Appendices B and C and assisted in providing descriptions of instrumentation systems and installation and maintenance procedures. Messrs. Savage and Smithhart were under the supervision of Mr. Bruce C. Barker, Chief, OB, ISDD, and Dr. C. Robert Welch, Chief, ISDD, ITL.

Dr. Robert W. Whalin was Director and COL Robin R. Cababa, EN, was Commander of WES during preparation of this report.

1 Evolution of SMIP

Purpose

During the 1970s, the U.S. Army Corps of Engineers (USACE) embarked upon an undertaking which has since been termed the Strong-Motion Instrumentation Program (SMIP). The SMIP was designed to allow observation and analysis of seismic waves produced by earthquakes and explosions to examine the effect of these motions on USACE projects. Objectives of SMIP are threefold:

a. To provide insight into the safety of and to act as an inspection guide for existing USACE projects.

b. To provide a measure of project performance.

c. To act as a database for performance predictions and earthquake research.

The existence of performance data in the engineering profession is unequivocally beneficial. For instance, D'Appolonia (1990) describes the value of field performance data for geotechnical engineering. He summarizes:

> "Data from long-term monitoring should be integrated into the design process [to] provide a basis for future decisions and maintain a facility in a functional state consistent with its intended purpose. A planned approach to decision making over time that draws on long-term field measurements for input, with planned analysis of the measurements and appropriate contingent actions, is sought. A monitored-decision process provides a means to gain knowledge, be innovative, and mitigate adverse relationships between parties involved in the ownership, construction, and operation of a facility."

Seismic Threat Evaluation

As owners of critical structures, the USACE is obligated to ensure their safety to the public. The threat of earthquake induced damage is as valid and important today (as exemplified in the Northridge, CA quake of 17 January 1994) as it was with the wake-up call of the near catastrophic failure of the Lower San Fernando Dam (Los Angeles, CA) in 1971. The SMIP program was instituted to provide seismic safety monitoring of Corps structures and provide strong motion data to help advance the state-of-the-art of earthquake engineering to ensure no more surprises happen.

After a felt event, when the public asks: Is the dam safe? How will the USACE answer? How will we quantify the earthquake load and verify if it is within the expected design loads? Answers to these questions require a well conceived program of long-term strong motion monitoring.

Importance

The collection of strong motion records is important for characterizing seismicity, "the occurrence of earthquakes in space and time." Determination of seismicity is a necessary step in determining an area's seismic hazard. Seismic safety analyses of critical structures depend on the use of earthquake motion time histories or parameters derived from them (earthquake records) as input to the analysis. The needed time histories are usually scaled versions or derived from actual recorded strong motions. To accurately characterize seismicity, we therefore need to sample in both "time and space." This results in the need for SMIP networks intelligently dispersed and continually monitoring throughout the country.

Additionally, factors such as inherent geologic variability, dynamic processes of plate tectonics, and the short time frame through which strong motion data have been collected (~100 years) compared to the recurrence time scale of some major earthquakes (~1,000 years), make it imperative that strong motion data collection continue. This is necessary if we are to gain a thorough understanding of earthquake related phenomena and enable accurate seismic hazard determinations.

The U. S. Army Engineer Waterways Experiment Station (WES) has been performing seismic safety analysis studies of critical structures for more than 25 years. An important step in these studies was a seismological investigation for seismic hazard determination which relies heavily on catalogued strong motion records. Examples of the use of strong motion records and their part in these studies can be obtained from many WES reports.

Background

As described by Ballard et al. (1990), the SMIP was formalized in 1973 by Engineer Regulation (ER) 1110-2-103, Strong-Motion Instruments for Recording Earthquake Motions on Dams, (Department of the Army) which essentially required instrumentation of all USACE dams within seismic risk zones 2, 3, and 4 (after Algermissen 1969). After careful planning and deliberation with experts in the field of earthquake measurements and analysis, a revised Engineering Manual

(EM) 1110-2-1908, Instrumentation of Earth and Rock Fill Dams, (Department of the Army 1976) was published for use by USACE district offices. This EM provides guidance and information concerning the selection of instruments for measuring dynamic response of earth and rock-fill dams and describes techniques for collecting and analyzing data.

In 1973, the USACE also entered into agreements with the U.S. Geological Survey (USGS) to assist in the SMIP. Specifically, the USGS was to:

a. Provide guidance in the selection of instruments.

b. Review installations for conformance with network specifications and provide suggestions for proper protection from weather and other elements.

c. Act as recipient (thus assuring adherence to specifications) for new instruments and calibrate them for installation.

d. Install and maintain those instruments at regular intervals throughout the federal fiscal year.

The USGS receives funding under the Earthquake Hazards Reduction Act to run a strong motion program. This program collects, archives, and disseminates data and performs research for the reasons listed above. ***It is an important distinction that they do not perform monitoring to ensure safety of particular structures and that <u>their emphasis is geologic</u> not structural based.*** The agreement and these important distinctions establish that the USGS SMIP and WES SMIP do not have duplicating but complementary missions.

In 1973 estimates of less than 200 installed instruments were provided to the USGS as the number that would ultimately make up the USACE strong-motion network. Since a large number of these installations would be east of the Rocky Mountains, the USGS viewed them as a necessary and desirable extension of an envisioned national network, which at that time had most recording stations located in the state of California.

In 1977, however, the USGS was assigned additional missions and funding without commensurate increase in personnel allotments. The WES subsequently proposed alternative plans for programs which would enable the USACE to absorb much of the work previously performed by USGS. After a very thorough investigation of alternatives which included consideration of contractual services, it was decided that the USGS would continue to provide installation, service and data collection for instruments in the western U.S. The WES was to phase itself into installation and maintenance of approximately one-half of the USACE instruments located in the central and eastern part of the U.S. Additionally, in a reciprocal arrangement, WES was to service certain USGS and Veterans Administration (VA) instruments. Transition occurred over a two-year period. This continuing arrangement has proven highly cost and quality effective—an exemplary demonstration of 'partnering'.

Since 1978 WES Instrumentation Services Development Division (ISDD) has assumed responsibility for in-house maintenance of more than sixty percent of the USACE instruments with USGS providing service for the remainder. Personnel of WES Earthquake Engineering and Geosciences Division (EEGD), Geotechnical Laboratory (GL), provide overall project management of SMIP and analyze recorded data.

Functionally, the SMIP has been structured so that a USACE agency can design its own program for strong-motion instrumentation with guidance from the Engineering Manual (and WES if they so desire). Upon completion of a plan for instrumenting a specific structure, the individual agency then forwards its plan to WES for approval. Once it is determined that all criteria have been taken into consideration for that particular project, WES then approves the installation.

By directive, WES is also responsible for:

a. Maintaining records of instrument servicing and location.

b. Reviewing instrument locations and type to assure conformance with USACE policy.

c. Processing and analyzing records obtained.

d. Furnishing copies of obtained records to the USACE district offices concerned.

e. Coordinating with USGS and the USACE district offices to establish schedules for inspection visits.

f. Billing USACE district offices for services provided.

g. Reimbursing USGS for expenses incurred.

h. Providing personnel for installation and maintenance of USACE instruments not serviced by USGS.

In addition to its heavy involvement with the USGS, the USACE has established a working arrangement whereby data are exchanged and coordination established with the state of California Division of Mines and Geology strong-motion network and with the U.S. Department of the Interior, Bureau of Reclamation (USBR). In actuality, the state of California operates the largest network of strong-motion instrumentation in the U.S., commonly referred to as CSMIP. The strong-motion instrumentation program instituted by the USBR is in its infancy but will ultimately include about 150 instruments. It is intended that close ties remain in effect between all of these agencies and the profession at large.

USACE Mandate for Strong-Motion Instrumentation

ER 1110-2-1156 (Department of Army 1992) describes dam safety policy, organization, responsibilities, and procedures. Guidance and direction for seismic design and evaluation for all civil works projects is given in ER 1110-2-1806 (Department of Army 1995). ER 1110-2-1802 (Department of Army 1979) discusses policy, objectives, and establishes procedures regarding reporting earthquake effects. Several regulations pertinent to the CE SMIP are included at Appendix A to consolidate their availability. **(NOTE: To order printed copies of these and other documents, write to the USACE Publications Depot, ATTN: CEIM-IM-PD, 2803 52nd Ave., Hyattsville, MD 20781-1102. Most official USACE engineering regulations, circulars, and manuals are provided in portable document format (PDF) from the USACE internet site at *http://www.usace.army.mil/inet/usace-docs/*).**

According to an updated ER 1110-2-103, (Department of the Army 1981) issued by USACE, all dams in zones 2, 3 and 4 of the seismic risk maps should be instrumented for strong-motion earthquake measurement. As previously mentioned, guidance on details concerning instrumentation, location, and selection is currently given in EM 1110-2-1908 (Department of Army 1995). These documents are adequate for most situations; however, numerous questions have arisen regarding instrumentation of dams in seismic risk zone 2. A popular viewpoint suggested that the low probability of obtaining meaningful data does not justify the cost of installing and maintaining instruments. In an effort to supplement the above documents (particularly for zone 2) so that sound decisions can be made regarding dams with uncertainties about the need for instrumentation, additional guidance was developed to aid in the judgment process. Considerations below are listed in order of relative importance.

a. *Nature of Foundation*. If foundation materials underlying the dam are composed of sands or silty sands that might be subject to liquefaction, the dam should be instrumented. If the foundation materials are rock or other materials that are not subject to liquefaction, the remaining factors below should be taken into account.

b. *Type of Construction*. Regardless of seismic risk zone, all hydraulic fill dams should be instrumented. Rolled earth fill or rock fill dams (being less susceptible to liquefaction) should be considered for instrumentation as indicated by other influencing factors.

c. *Height of Dam*. Most dams more than 33 m high should be instrumented.

d. *Presence of Known Capable Faults*. If the dam is located nearer than 40 km to a known capable fault, it should be instrumented.

e. *History of Seismic Activity at the Site*. If acceleration levels greater than 0.2 g have been recorded in the vicinity of the dam, it should be instrumented.

f. *Distance from Higher Risk Zone Boundaries.* If the dam is located less than 160 km from a higher risk zone boundary, it should be instrumented.

2 Locations of Strong-Motion Instruments

As of March 1998, the USACE SMIP consisted of the following: 123 instrumented projects located in 32 states and 1 commonwealth. The locations of these projects and the seismic risk zones in which they are situated are shown in Figure 1. Descriptions of instrument locations and number of instruments as of March 1998 are shown in Table 1.

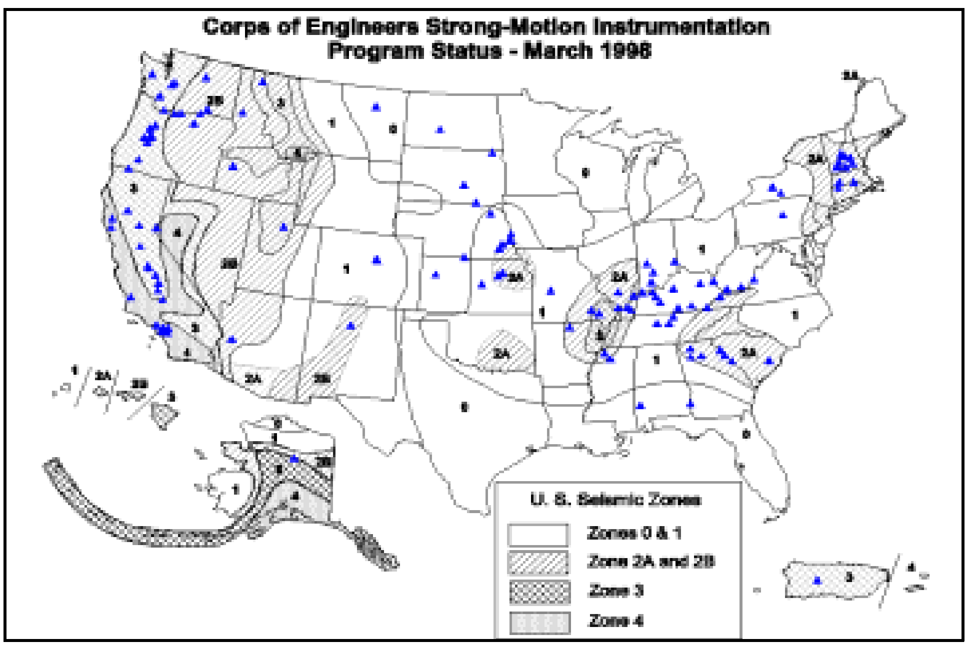

Figure 1. Seismic zone map of strong-motion instrumentation project locations

Table 1
Corps of Engineers Strong-Motion Instrumentation Program Status - March 1998

District (Division) Station No.	Project	Type	H (m)	State	Accelerographs Installed	Accelerographs Planned	PAR[1] Installed	Seismic Alarm Devices Installed	Seismic Alarm Devices Planned	Serviced By USGS[2]	Serviced By WES	Coordinates Lat. N	Coordinates Long. W
St. Louis (MVD)													
2422 RLD	Rend Lake	earth & gravity	16	IL	3 SSA-1	--	1	--	--	--	X	38-02.3	88-58.2
2415 WPD	Wappapello	earth & rock	33	MO	3 SMA-1	--	1	--	--	--	X	36-55.8	90-16.7
	Wappapello				3 SSA-1								
Vicksburg (MVD)													
2444 AKD)	Arkabutla	earth	29	MS	3 SMA-1	--	3	--	--	--	X	34-45.4	90-07.4
2445 SRD	Sardis Lake	earth	36	MS	3 SMA-1	--	3	--	--	--	X	34-24.0	89-47.5
	Sardis Lake				1 SSA-1								
Kansas City (MRD)													
2474 HND	Harlan County	earth	32	NE	2 SMA-1	--	--	--	--	--	--	40-04.0	99-12.7
2470 KND	Kanopolis	earth	40	KS	2 SMA-1	--	--	--	--	--	--	38-37.3	97-58.2
2442 MDD	Milford	earth & rock	45	KS	5 SMA-1	--	--	--	--	--	--	39-05.2	96-53.9
2473 HTD	Harry S. Truman	earth & rock	40	MO	2 SMA-1	--	--	--	--	--	--	38-16.0	93-24.1
2439 TCD	Tuttle Creek	earth & rock	47	KS	5 SMA-1	--	--	--	--	--	--	39-15.4	96-35.4
Omaha (MRD)													
2253 BCD	Bear Creek Lake	earth	55	CO	3 SMA-1	--	--	--	--	--	--	39-39.0	105-08.4
2243 BBD	Big Bend	earth	29	SD	3 SMA-1	--	--	--	--	--	--	44-02.3	99-26.7
2239 CCD	Cherry Creek Lake	earth	43	CO	3 SMA-1	--	--	--	--	--	--	39-38.9	101-51.5
2238 CDD	Chatfield Lake	earth	45	CO	5 SMA-1	--	--	--	--	--	--	39-33.5	105-03.5
2230 FPD	Ft. Peck Lake	earth	77	MT	3 SMA-1	--	--	--	--	--	--	48-00.1	106-25.0
2233 FRD	Ft. Randall	earth	50	SD	3 SMA-1	--	--	--	--	--	--	43-03.9	98-33.3
2235 GRD	Garrison	earth	62	ND	1 SMA-1	--	--	--	--	--	--	47-30.1	101-25.9
2237 GPD	Gavins Point	earth	23	SD	2 SMA-1	--	--	--	--	--	--	42-50.9	97-28.9
2231 OHD	Oahe	earth	75	SD	3 SMA-1	--	--	--	--	--	--	42-50.9	97-28.9
2484 OMA	Old Mill Area, Omaha	rock	--	NE	1 SMA-1	--	--	--	--	--	--	---	---
	Papilo Creek:												
2485	Site 11, Cunningham	earth	20	NE	2 SMA-1	--	--	--	--	--	--	41-20.3	96-03.3
2486	Site 20, Wehr Span	earth	18	NE	2 SMA-1	--	--	--	--	--	--	41-10.3	96-09.0
	Salt Creek:												
2481	Site 2, Olive Creek	earth	14	NE	2 SMA-1	--	--	--	--	--	--	40-35.1	96-50.8
2482	Site 17, Holmes Lake	earth	21	NE	2 SMA-1	--	--	--	--	--	--	40-47.0	96-38.2
2483	Site 18, Branched Oak	earth	17	NE	2 SMA-1	--	--	--	--	--	--	40-58.2	96-51.2
2480 LFB	Federal Bldg., Lincoln	--	--	NE	1 SMA-1	--	--	--	--	--	--	---	---

[1] PAR = Peak Acceleration Recorders
[2] USGS = US Geological Survey

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Table 1 (Contined)

District (Division)					Accelerographs		PAR[1]	Seismic Alarm Devices		Serviced By		Coordinates	
& Station No.	Project	Type	H (m)	State	Installed	Planned	Installed	Installed	Planned	USGS[2]	WES	Lat. N	Long. W
Baltimore (NAD)													
2642	Almond Lake	earth	27	NY	3 SMA-1	--	4	--	--	--	X	42-20.5	77-42.1
2643/2644	Tioga-Hammond L.	earth & rock	43/37	PA	2 SMA-1	--	5	--	--	--	X	41-54.1	77-07.7
Norfolk (NAD)													
2528 GAD	Gathright	earth & rock	78	VA	4 SMA-1	--	2	--	--	--	X	37-57.3	79-57.1
New England (NAD)													
2617 BMD	Ball Mt. Lake	earth & rock	81	VT	3 SMA-1	--	1	--	--	--	X	43-06.3	72-46.5
2636	Colebrook River	earth & rock	68	CT	2 SMA-1	--	--	--	--	--	X	42-00.3	73-02.2
2626 EVD	Everett	earth & rock	35	NH	3 SMA-1	--	--	--	--	--	X	43-05.6	71-39.6
2627 FFD	Franklin Falls	earth	43	NH	3 SMA-1	--	--	--	--	--	X	43-27.2	71-39.6
2623 HVD	Hodges Village	earth	17	MA	3 SMA-1	--	--	--	--	--	X	42-07.2	71-52.8
2624 KVD	Knightville	earth	48	MA	3 SMA-1	--	--	--	--	--	X	42-17.4	72-51.7
2625 LFD	Littleville Lake	earth & rock	50	MA	3 SMA-1	--	--	--	--	--	X	42-15.9	72-52.9
2629 NHD	N. Hartland	earth	37	VT	2 SMA-1	--	--	--	--	--	X	43-36.3	72-21.6
2630 NSD	N. Springfield	earth gravity	57	VT	3 SMA-1	--	--	--	--	--	X	43-20.5	72-30.8
2628 SYD	Surry Mtn. Lake	earth	26	NH	3 SMA-1	--	--	--	--	--	X	42-59.8	72-18.5
2631 TWD	Townsend Lake	earth	41	VT	3 SMA-1	--	--	--	--	--	X	43-03.0	72-42.1
2632 UVD	Union Village	earth gravity	52	VT	3 SMA-1	--	--	--	--	--	X	43-46.3	72-15.4
Portland (NWD)													
2198	Applegate	earth	74	OR	4 SMA-1	--	--	--	--	X	--	42-03.3	123-06.8
2198	Applegate				1 SSA-1	--	--	--	--	X	--	42-03.3	123-06.8
2146 BRD	Blue River	earth	95	OR	5 SMA-1	1 SSA	--	--	--	X	--	44-10.2	122-19.7
2190 BED	Bonneville L&D	gravity	60	OR	6 SMA-1	--	--	--	--	X	--	45-38.5	121-56.0
2137 CGD	Cougar Lake	rock	158	OR	6 SMA-1	--	--	--	--	X	--	44-07.4	122-14.5
2133 DTD	Detroit Lake	gravity	141	OR	3 SMA-1	--	--	--	--	X	--	44-43.0	122-15.0
2108 GND	Green Peter	gravity	115	OR	3 SMA-1	--	--	--	--	X	--	44-27.5	122-31.5
2143 HCD	Hills Creek Lake	earth	103	OR	3 SMA-1	--	--	--	--	X	--	43-42.7	122-26.0
7006	John Day L&D	gravity	70	OR	4 SMA-1	--	--	--	--	X	--	45-43.0	120-41.1
2151 LPD	Lookout Point Lake	earth	84	OR	6 SMA-1	--	--	--	--	X	--	43-54.8	122-45.0
2182 LCD	Lost Creek Lake	earth & rock	105	OR	6 SMA-1	1 SSA	--	--	--	X	--	42-40.1	122-40.2
7005	The Dalles L&D	gravity	61	OR	4 SMA-1	--	--	--	--	X	--	45-36.9	121-08.3
7007	Toutle River	earth & rock	55	WA	5 SMA-1	--	--	--	--	X	--	46-21.3	122-33.6
7004	Willow Creek Lake	gravity	47	OR	3 SMA-1	--	--	--	--	X	--	45-21.1	119-32.7

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Table 1 (Contined)

District (Division) & Station No.	Project	Type	H (m)	State	Accelerographs Installed	Accelerographs Planned	PAR[1] Installed	Seismic Alarm Devices Installed	Seismic Alarm Devices Planned	Serviced By USGS[2]	Serviced By WES	Coordinates Lat. N	Coordinates Long. W
Seattle (NWD)													
2161 CJD	Chief Joseph	gravity	70	WA	3 SMA-1	--	--	1	--	X	--	47-59.8	119-37.6
2189 HSD	Howard A. Hanson	earth & rock	72	WA	3 SMA-1	--	--	1	--	X	--	47-16.6	121-47.1
2242 LBD	Libby	gravity	128	MT	4 SMA-1	--	--	1	--	X	--	48-24.7	115-18.5
2164 MUD	Mud Mountain	earth	130	WA	3 SMA-1	--	--	1	--	X	--	47-08.4	121-55.9
2158 WYD	Wynoochee Lake	gravity	55	WA	3 SMA-1	--	--	--	--	X	--	47-23.1	123-36.3
Walla Walla (NWD)													
2222 DWD	Dworshak	gravity	219	ID	4 SSA-2	--	--	--	--	X	--	46-31.1	116-17.1
7009	Ice Harbor	gravity	65	WA	2 SMA-1	--	--	--	--	X	--	46-15.0	118-52.7
2213	Lucky Peak	earth	104	ID	1 K-2	--	--	--	--	X	--	43-31.8	116-03.3
7011	McNary	gravity	67	OR	3 SMA-1	2 K-2	--	--	--	X	--	45-55.8	119-17.7
Alaska (POD)													
2767 MCD	Moose Cr., Chena R.	rock	40	AK	1 SMA-1	--	--	--	--	X	--	64-47.4	147-11.0
Buffalo (GL&ORD)													
2621 MMD	Mt. Morris	gravity	75	NY	3 SMA-1	--	2	--	--	--	X	42-44.0	77-54.5
Huntington (GL&ORD)													
2547	Bluestone Lake	gravity	50	WV	2 SSA-1	--	--	--	--	--	X	37-38.4	80-53.2
2546	J. W. Flannagan	earth & rock	76	VA	3 SSA-1	--	--	--	--	--	X	37-14.0	82-20.7
2548	R. D. Bailey Lake	rock	94	WV	4 SSA-1	--	--	--	--	--	X	37-35.5	81-49.3
	Yatesville			KY	2 SSA-2							38-6.0	82-36.0
Louisville (GL&ORD)													
2463 BVD	Brookville Lake	earth & rock	55	IN	3 SMA-1	--	1	--	--	--	X	39-26.4	85-00.0
2464 CMD	Cagles Mill Lake	earth	45	IN	3 SMA-1	--	1	--	--	--	X	39-29.2	86-55.0
2465 CLD	Cannelton L&D	gravity	47	IN	2 SMA-1	--	1	--	--	--	X	37-53.8	86-42.3
2488	Cave Run Lake	earth & rock	45	KY	3 SMA-1	--	1	--	--	--	X	38-07.1	83-32.0
2466 MLD	Monroe Lake	earth & rock	28	IN	3 SMA-1	--	1	--	--	--	X	39-00.4	86-30.7
2467 NBD	Newburgh L&D	gravity	33	IN	2 SMA-1	--	1	--	--	--	X	37-55.7	87-22.5
2471 NLD	Nolin Lake	earth & rock	50	KY	3 SMA-1	--	1	--	--	--	X	37-16.7	86-14.7
2489	Olmsted L&D	gravity	43	IL	1 SSA-2	3 SSA-2	--	--	--	--	X	37-11.0	89-03.0
2468 PAD	Patoka Lake	earth & rock	26	IN	2 SMA-1	--	1	--	--	--	X	38-26.1	86-42.5
2472 RHD	Rough River Lake	earth & rock	45	KY	3 SMA-1	--	1	--	--	--	X	37-37.2	86-30.0
2462 SML	Smithland L&D	gravity	24	IL	5 SMA-1	--	2	--	--	--	X	37-10.0	88-26.0
2478 TVD	Taylorsville Lake	earth & rock	44	KY	3 SMA-1	--	1	--	--	--	X	38-00.5	85-19.0
2469 UND	Uniontown L&D	gravity	16	KY	2 SMA-1	--	1	--	--	--	X	37-46.2	87-57.5

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Table 1 (Contined)

District (Division) & Station No.	Project	Type	H (m)	State	Accelerographs Installed	Accelerographs Planned	PAR[1] Installed	Seismic Alarm Devices Installed	Seismic Alarm Devices Planned	Serviced By USGS[2]	Serviced By WES	Coordinates Lat. N	Coordinates Long. W
Nashville (GL&ORD)													
2427 BYD	Barkley	earth & gravity	48	KY	6 SMA-1	--	1	--	--	--	X	37-01.3	88-13.2
2434 CHD	Center Hill Lake	earth & gravity	76	TN	5 SMA-1	--	1	--	--	--	X	36-06.1	85-49.2
2436 DHD	Dale Hollow Lake	gravity	61	TN	4 SMA-1	--	1	--	--	--	X	36-27.1	85-32.4
2430 PPD	J. Percy Priest	earth & gravity	40	TN	5 SMA-1	--	1	--	--	--	X	36-09.5	86-36.8
2437 LRD	Laurel River Lake	rock	86	KY	3 SMA-1	--	1	--	--	--	X	36-57.4	84-16.4
2475 MFD	Martins Fork Lake	gravity	30	KY	4 SMA-1	--	2	--	--	--	X	36-45.1	83-15.5
2432 WCD	Wolf Creek	earth & gravity	79	KY	5 SMA-1	--	1	--	--	--	X	36-52.3	85-08.7
Charleston (SAD)													
2545	St. Stephens	earth & gravity	39	SC	4 SMA-1	--	1	--	--	--	X	33-25.4	79-55.5
Jacksonville (SAD)													
2519 BKL	Cerrillos	rock	100	PR	7 SMA-1	--	--	1	--	--	X	18-04.7	66-34.6
Mobile (SAD)													
2533 ALD	Allatoona Lake	arch	66	GA	3 SMA-1	--	--	--	--	--	X	34-09.8	84-43.7
2534 BUD	Buford	earth	70	GA	2 SMA-1	--	--	--	--	--	X	34-09.6	84-04.4
2535 CRD	Carters Lake	earth & rock	136	GA	3 SMA-1	--	--	--	--	--	X	34-36.8	84-41.1
2540 CVD	Coffeeville L&D	earth & gravity	27	AL	1 SMA-1	--	--	--	--	--	X	31-45.4	88-07.7
2537 GLD	Walter F. George	earth & gravity	45	GA/AL	1 SMA-1	--	--	--	--	--	X	31-37.6	85-03.8
Savannah (SAD)													
2526 HWD	Hartwell Lake	earth & gravity	73	GA	5 SMA-1	--	2	--	--	--	X	34-21.4	82-49.3
2536 RRD	R.B. Russell	earth & gravity	73	GA	4 SMA-1	--	1	1	--	--	X	34-01.5	82-35.5
2524 CKD	Strom Thurmond	earth & gravity	61	SC	6 SMA-1	--	2	--	--	--	X	33-39.7	82-11.9
Los Angeles (SPD)													
2301 AOD	Alamo	earth	86	AZ	2 SMA-1	--	--	1	--	X	--	34-13.9	113-36.1
951 BAD	Brea	earth	27	CA	3 SMA-1	--	--	1	--	X	--	33-53.3	117-55.5
108 CND	Carbon Canyon	earth	30	CA	3 SMA-1	--	--	1	--	X	--	33-54.9	117-50.5
969 PRD	Prado	earth	37	CA	3 SMA-1	--	--	1	--	X	--	33-53.4	117-38.6
1064 SSD	Salinas	arch	41	CA	1 SMA-1	--	--	--	--	X	--	35-20.0	120-30.0
287 SOD	San Antonio	earth	49	CA	3 SMA-1	--	--	1	--	X	--	34-09.4	117-40.8
5400	Santa Fe	earth	28	CA	--	--	--	1	--	X	--	33-06.0	117-57.7
949 SPD	Sepulveda	earth	17	CA	--	2	--	1	--	X	--	34-10.0	118-28.4
289 WND	Whittier Narrows	earth	17	CA	2 SSA-2	--	--	1	--	X	--	34-01.2	118-03.2

(Sheet 4 of 5)

Table 1 (Concluded)

District (Division) Station No.	Project	Type	H (m)	State	Accelerographs Installed	Accelerographs Planned	PAR[1] Installed	Seismic Alarm Devices Installed	Seismic Alarm Devices Planned	Serviced By USGS[2]	Serviced By WES	Coordinates Lat. N	Coordinates Long. W
Sacramento (SPD)													
1010 BKD	Black Butte	earth	43	CA	5 SMA-1	--	--	2	--	X	--	39-49.1	122-20.2
1450 BND	Buchanan	rock	62	CA	7 SMA-1	--	--	2	--	X	--	37-13.0	119-59.0
1017 CYD	Coyote	earth	50	CA	4 SMA-1	--	--	2	--	X	--	39-12.0	123-08.0
1692	Englebright	arch		CA	2 SMA-1	--	--	1	--	X	--	39-14.3	121-16.0
	Englebright				1 SSA					X	--		
1442 HID	Hidden	earth	50	CA	7 SMA-1	--	--	2	--	X	--	37-06.6	119-53.0
1035 ISD	Isabella	earth	56	CA	11 SMA-1	--	--	2	--	X	--	35-36.3	118-28.4
1484 LSD	Lake Success	earth	43	CA	6 SMA-1	--	--	2	--	X	--	36-03.5	118-55.1
1724	Little Dell	earth	68	UT	5 SSA-2	--	--	1	--	X	--	40-46.2	111-42.2
1133 MKD	Martis Creek	earth	35	CA	7 SMA-1	--	--	2	--	X	--	39-19.6	120-06.7
1047 NGD	New Hogan	earth & rock	64	CA	4 SMA-1	--	--	2	--	X	--	38-09.1	120-48.7
1054 PFD	Pine Flat	gravity	131	CA	4 SMA-1	--	--	2	--	X	--	36-49.9	119-19.5
1098 TMD	Terminus	earth	76	CA	7 SMA-1	--	--	2	--	X	--	36-25.0	119-00.2
1216 WSD	Warm Springs	earth	97	CA	5 SMA-1	--	4	2	--	X	--	38-43.0	123-00.5
	Warm Springs				2 SSA-1	--	--	--	--	X	--	38-43.0	123-00.5
Albuquerque (SWD)													
2312	Abiquiu	earth	97	NM	--	2 SSA-2	--	--	--	X	--	36-14.4	106-25.8
2311 COD	Cochiti	earth	77	NM	7 SMA-1	--	3	--	--	X	--	35-37.5	106-20.0
Little Rock (SWD)													
2479	Clearwater	earth	46	MO	3 SMA-1	--	--	--	--	--	X	37-08.2	90-46.3
2401 NRD	Norfolk	gravity	71	AR	1 SMA-1	--	--	--	--	--	X	36-15.0	92-14.4
	Norfolk				1 SSA-2								
				TOTAL	**432**	**11**	**54**	**38**					

(Sheet 5 of 5)

3 Descriptions of Strong-Motion Instruments

The instruments used for SMIP range from seismic alarm devices to digital accelerographs. In all, 432 accelerographs, 54 peak acceleration recorders, and 38 seismic alarm devices are presently (1998) used in the SMIP. Seismoscopes were eliminated from the network during Fiscal Year 92 because of questionable reliability in documenting motions at sites subjected to earthquakes.

Accelerographs

Accelerographs are the most versatile and widely used instruments by SMIP for recording strong motions. Accelerographs may be analog or digital devices which incorporate an accurate time-base receiver tuned to the National Institute of Standards and Technology (NIST) radio station WWV. Until recently, many agencies selected analog instruments because of their proven reliability. Cost is no longer a major factor since digital instruments can now compete with analog equipment and reliability equals or surpasses that of analog instruments. For new SMIP installations and upgrades of existing sites, WES strongly recommends approved digital instruments. Currently, WES uses accelerographs of the type manufactured by Kinemetrics Inc., of Pasadena, California (the analog Model SMA-1, digital Models SSA-1, SSA-2, or Etna). Figures 2, 3, 4 and 5, respectively, are photographs of these instruments. It should be noted that the SMA-1 is no longer manufactured, but working units can be traded on upgrades to digital units.

Even though outdated, the Kinemetrics Model SMA-1 (Fig. 2) is a tried and proven analog triaxial strong-motion accelerograph that photographically (optically) records strong motions on 70 mm film. It employs three flexure-type accelerometers (longitudinal, vertical and transverse) in a orthogonal arrangement and has a maximum recordable peak acceleration of 1.0 g. A vertical acceleration-sensitive starter (preset at a level of 0.01 g for all instruments) senses the initial ground motion P-wave, and actuates the SMA-1 in less than 50 msec (0.05 sec). As a general rule of thumb, a trigger level of 0.01g will activate an accelerograph if an earthquake of magnitude 4.0 or larger occurs

Figure 2. Model SMA-1 analog accelerograph

within approximately 80 km of the instrument's location. The device continues to operate for a duration of 10 seconds after the vertical starter no longer senses motion above the preset trigger level. Film is recovered during semi-annual service trips or shortly after a known strong-motion event. An attached event counter provides the number of times the instrument was activated. This count is very important to service personnel, particularly when an excessive number may be an indicator of malfunctioning. Although it is possible to develop film in the field, photographic laboratory developing is preferred. In the past, the Kinemetrics SMA-1 was the most frequently installed accelerograph for the SMIP, but is ultimately being replaced by digital models as analog instruments fail or updating is desired.

The Kinemetrics Model SSA-1 (Fig. 3) is a solid-state, digital strong-motion accelerograph that records seismic events at 200 samples per second per channel with 12-bit resolution. The SSA-1 can be configured to record up to four external channels of data from Kinemetrics FBA-11 and FBA-13 force-balance accelerometers. The typical instrument uses internally mounted triaxial force balance accelerometers with 2g range. SSA-1 trigger thresholds are determined by a software-based algorithm with a bandwidth of 0.1 to 12 Hz, preset for each of the three data channels. When signal amplitude exceeds a preset trigger threshold (normally 0.01g), the SSA-1 records and stores acceleration data in CMOS RAM. On-site data retrieval involves downloading data files to an IBM-compatible laptop personal computer. The Kinemetrics SSA-1 can be interrogated remotely via telephone modem and in 1990 was considered one of the most technically advanced accelerographs available.

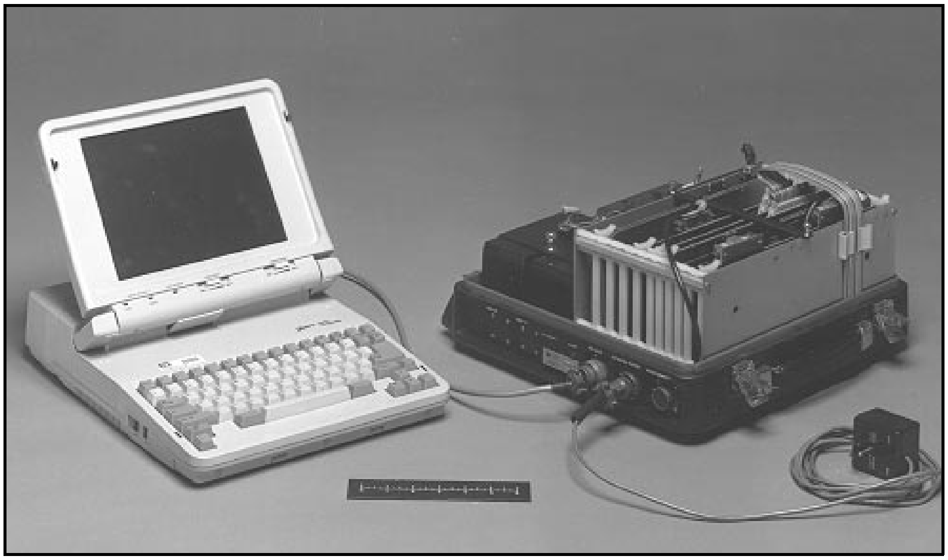


Figure 3. Model SSA-1 digital accelerograph

Addressing the market need for a more economical digital accelerograph, specifically one that could cost compete head-to-head with the analog SMA-1, Kinemetrics introduced the model SSA-2 (Fig. 4) which borrows heavily from the SSA-1. This unit retains all of the "necessary" features of the SSA-1 minus a few convenience items to appreciably reduce cost. The SSA-2 has been thoroughly evaluated by WES (and USGS) and was accepted for inclusion in the SMIP.

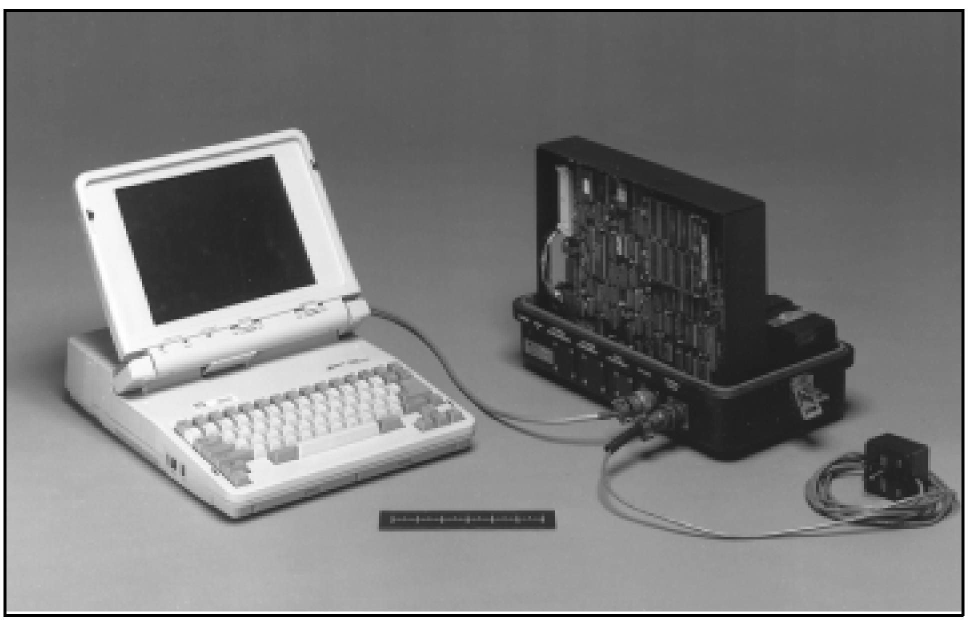


Figure 4. Model SSA-2 digital accelerograph

With the passage of time, digital technology has evolved in such an upward spiral that both the SSA-1 and SSA-2 have been replaced by Kinemetrics with its current (1998) ETNA model (Figure 5). However, both SSA-1's and -2's are still an active part of the SMIP program. Several ETNA units have recently been purchased for installation at Corps projects.

Figure 5. Etna digital strong-motion accelerograph

Factors Influencing Conversion of Analog to Digital

Of the 432 accelerographs now installed, only 47 are digital recording instruments, but as older instruments are replaced and new installations are added to the network, conversion will be made to digital. At the program’s inception, only analog devices were available. Upon introduction of digital instrumentation, lack of reliability became an overriding issue. During the decade of the 1980s, manufacturers overcame this obstacle and ultimately produced highly reliable instruments satisfactory for use in the SMIP network.

The following discussion will address the economic, scientific, and reliability factors concerning both types of instruments. One immediate advantage of digital accelerographs is having the earthquake raw data already in digital form. The analog to digital conversion is inherent in the instrument’s design. There is tremendous savings in time and cost going from raw data to a finished report. The instrument's record file is retrieved directly from solid-state memory to a portable computer's memory. Then, "quick look" software resident on the computer can provide a time history plot in a few minutes. Total digital signal processing can be performed on a personal computer, and report quality plots of acceleration, velocity, and displacement (plus spectrum analysis) can be ready within 24 hours or less.

When information is recorded on analog recorders, one must carefully recover the film and chemically process it in darkroom conditions. At this point, a contact print can be made for a "quick look", but to fully analyze the record, one must optically digitize raw data and generate a digital record for future computer analysis. Since the optical digitizer WES uses is in California, film must be shipped or hand carried there to make a digital record. This involves several weeks' delay to prepare a complete report for the Corps Division and District.

This procedure is both time-consuming and costly. Digital accelerographs are superior in virtually all respects.

Other advantages of digital accelerographs are:

a. **More data are obtained** because the bandwidth is DC to 50 hertz on a digital recorder instead of DC to 25 hertz on an analog recorder.

b. **Higher dynamic range** exists from about 40 dB to 66 dB using a 12-bit analog-to-digital converter. This means that a 2g full-scale accelerometer can be used to recover data down to 0.001g, the advantage being that 2g accelerometers are less expensive to build than 1/8g or 1/4g and are more durable.

c. **Triggering of the instrument is more versatile**. Using a digital unit, all three axes of recorded acceleration, vertical and two horizontal can be sensed. With an analog recorder, a single vertical trigger is used. The three-trigger accelerometers can be "weighted" to make the instrument equally sensitive to each axis, or it can be set to two or three times as sensitive in any one axis. Consequently, triggering can be tailored to site conditions.

d. **Remote interrogation** of the accelerograph is possible by use of a telephone line and modem. Complete status of the unit can be determined, i.e., number of triggers, solid-state memory used and remaining battery voltage of the main power supply and memory battery. In addition, function tests of all accelerometers may be performed and data record files of earthquake events or function tests may be transferred via modem. This is an important advantage in that it will eventually allow fewer service visits, thus appreciably reducing cost while increasing reliability.

e. **Pre-event data** for the earthquake event can be obtained. The digital recorder is continuously digitizing and storing data from the accelerometers. Data continuously "rolls through" the solid-state memory until the instrument is triggered. At that time, up to 15 seconds of pre-event data and the complete earthquake event is stored in a data file.

f. **Post-event data** can be obtained up to 60 seconds after the earthquake's acceleration is less than the trigger acceleration threshold (typically 0.01g). A typical application might be intake structures swaying at a low frequency and low acceleration level long after the main event has ceased.

g. **Remote location of accelerometers** from the recording instruments is easily accomplished. If an accelerometer location is too small or has limited space for the entire instrument, cabling can be installed to a remotely located tri-axial accelerometer package. Under certain circumstances, accelerometer packages can be placed at optimum depths in boreholes.

h. **Better documentation** is available through automatic storage of key data on the record header. Typically, information such as time and date of each event, peak acceleration of each axis, duration of the event, sensor orientation, instrumentation location (latitude, longitude, elevation), battery voltage, VAC power present, serial number, and user comments can be stored in memory.

In summary, a valid case can be made for ultimate conversion to a fully digital network. The use of digital instruments provides more reliable networks which are easier to service and produces higher quality information-rich earthquake records in a far more economical fashion.

Peak Acceleration Recorders

Peak Acceleration Recorders (PAR) provide a low-cost method for detecting a strong-motion event and often serve as a backup for accelerographs. Terra Technology of Redmond, Washington, and Engdahl Enterprises of Costa Mesa, California, both manufacture peak acceleration devices installed and maintained by the SMIP. The devices operate on different principles. The Terra Technology PRA-103 employs a spring-mass magnetic stylus on a magnetic tape and records peak acceleration of up to 2.0g. The tape is returned to the laboratory where it is dusted with ferric powder and analyzed. The PAR-650L from Engdahl (shown in Figure 6) records a peak acceleration level of up to 2.5g. A diamond stylus rests on a soft metal plate that is etched when strong motions are detected. The metal plates are returned to the manufacturer for resurfacing after the recorded event is analyzed. The PAR-650L has a local annunciator for preset

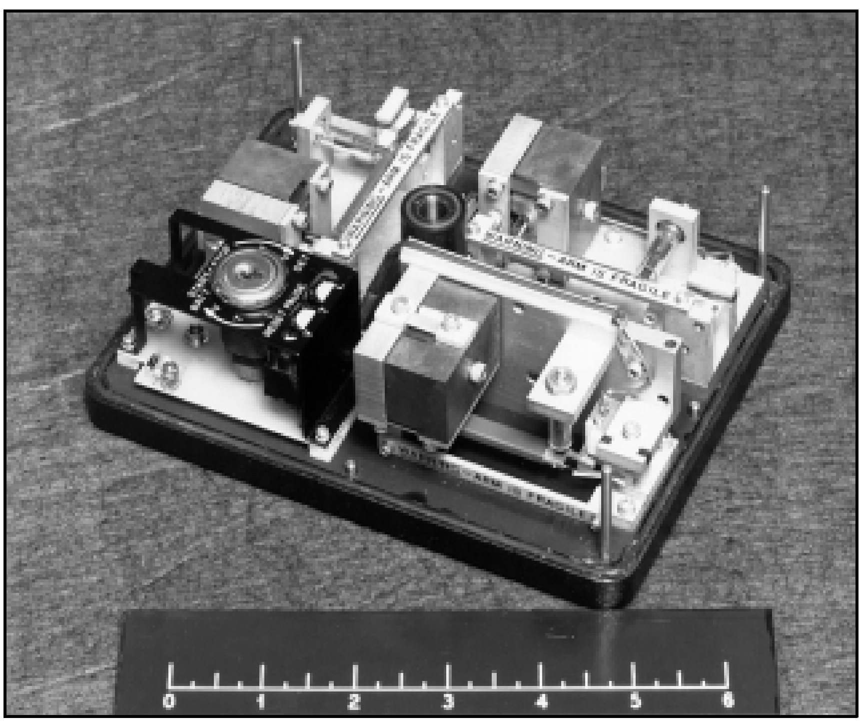


Figure 6. Engdahl model PAR 650L peak acceleration recorder (case removed)

accelerations (normally 0.1g). Approximately 75 percent of peak acceleration devices serviced by WES are the model PRA-103 produced by Terra Technology.

Seismic Alarm Device

WES designed and fabricates the Seismic Alarm Device (SAD) since it is not commercially available. Its intended purpose is to provide the responsible agency with immediate cost effective information in the aftermath of an earthquake. The device is ideal for use on unmanned facilities. The SMIP network currently incorporates 38 Seismic Alarm Devices. This alarm package (shown in Figure 7) contains a vertical accelerometer with ten individual threshold level relays. The latching relay bank stores accelerations greater than the preset threshold. A light-emitting diode (LED) indicates peak acceleration on the main control board. The standard SAD is calibrated to display peak accelerations in steps of 0.05g from 0.05 to 0.50g. Accelerations at or greater than the threshold cause the appropriate LED to illuminate and sound an alarm indicating the instrument has triggered and should be inspected. This device has also been adapted to activate an automatic telephone dialer and remote annunciator.

Although some material is redundant, it was concluded that two documents describing the SAD should be provided to the reader in their entirety. (Each document stands alone, intended for different audiences.) Appendix B: WES Seismic Acceleration Alarm Device Technical Specification provides a detailed description of the device. The Seismic Alarm Device Operation Manual is also provided at Appendix C.

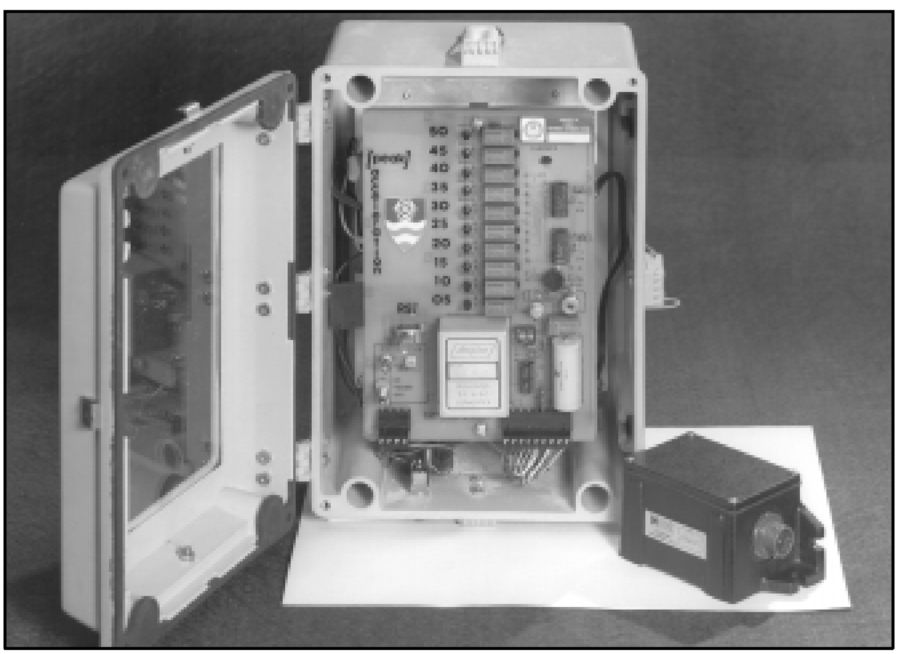


Figure 7. Seismic Alarm Device (SAD) (WES design)

4 Instrument Installation

Every USACE strong-motion installation must be carefully planned in accordance with regulations so that instruments are strategically located to ensure that recorded seismic data capture all important structure responses and provide a good characterization of seismic loads. (See ER 1110-2-103, Strong-Motion Instruments for Recording Earthquake Motions on Dams; ER 1110-2-1806, Earthquake Design and Analysis for Corps of Engineers Projects; and EM 1110-2-1908, Instrumentation of Earth and Rock-Fill Dams, Part 2, Earth Movement and Pressure Measuring Devices.) Such considerations as power, protection from weather and vandalism, and service access must also be addressed on a site-by-site basis. Generally, instruments located within existing facilities such as control structures or power houses are installed in low-trafficked rooms such as storage areas. Those installed in open areas use a widely accepted lightweight, economical, protective structure. Plans for these structures are shown in Figures 8 and 9. Typical installations are shown in Figures 10-12. Use of the commercially available Western Power Products, Inc. Model 41-2 fiberglass shelter provides both an economical and a seismically acceptable installation.

In an effort to address questions concerning modification of earthquake records due to soil-structure interaction, an intensive study jointly sponsored by the National Science Foundation (NSF) and WES was conducted under contract and reported (Crouse and Hushmand, 1989 and Crouse et al., 1990). Forced harmonic and impulse-response vibration tests were conducted at several California accelerograph stations operated by the California Division of Mines and Geology and USGS. Results of tests on relatively short, lightweight structures showed presence of highly damped fundamental frequencies of 20 and 40 Hz (beyond earthquake range of interest). However, at tall (> 6 ft) shelters fundamental frequencies in the 12 Hz region were observed (within the range of interest). While foundation impedance functions could be theoretically calculated within acceptable limits, it was readily recognized that the shorter, lighter, higher-frequency shelters were much more desirable. Hence, the current design shelter used by the USACE presents a minimally complex strong motion instrument housing.

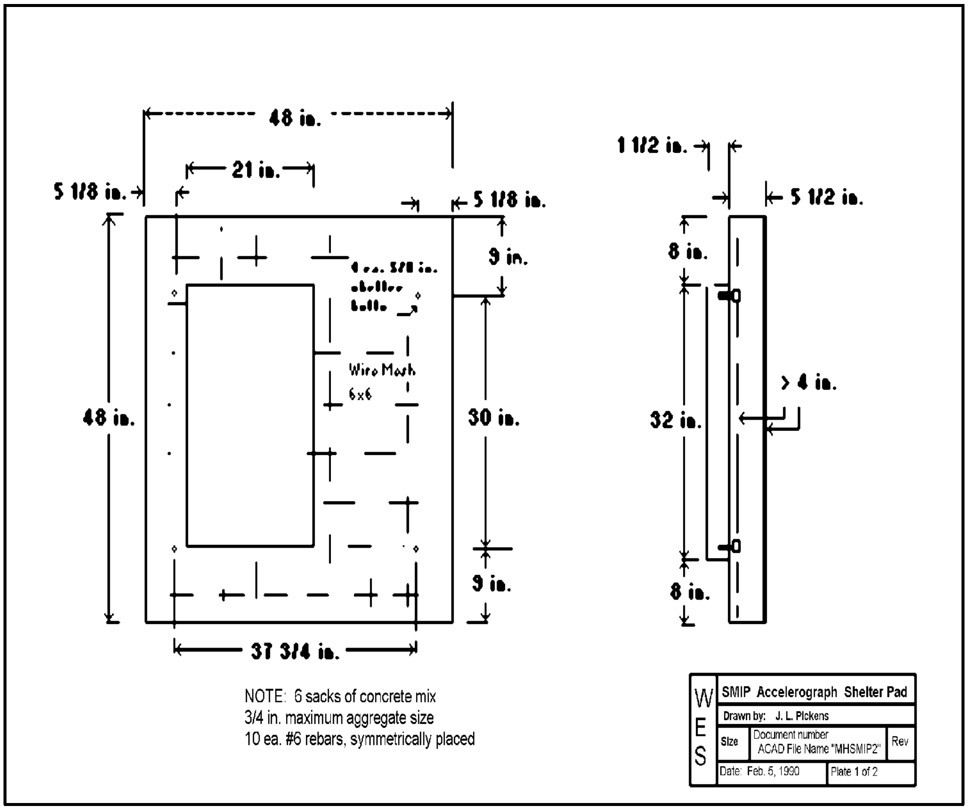


Figure 8. SMIP instrument shelter pad foundation plan

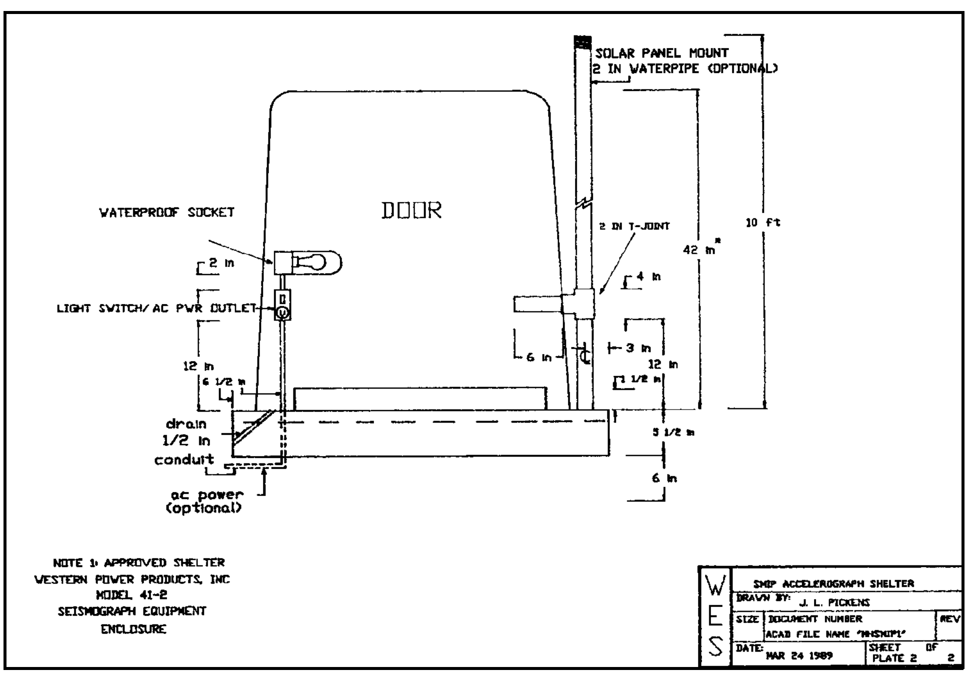


Figure 9. Plans of Western Power Products, Inc. model 41-2 equipment protective enclosure

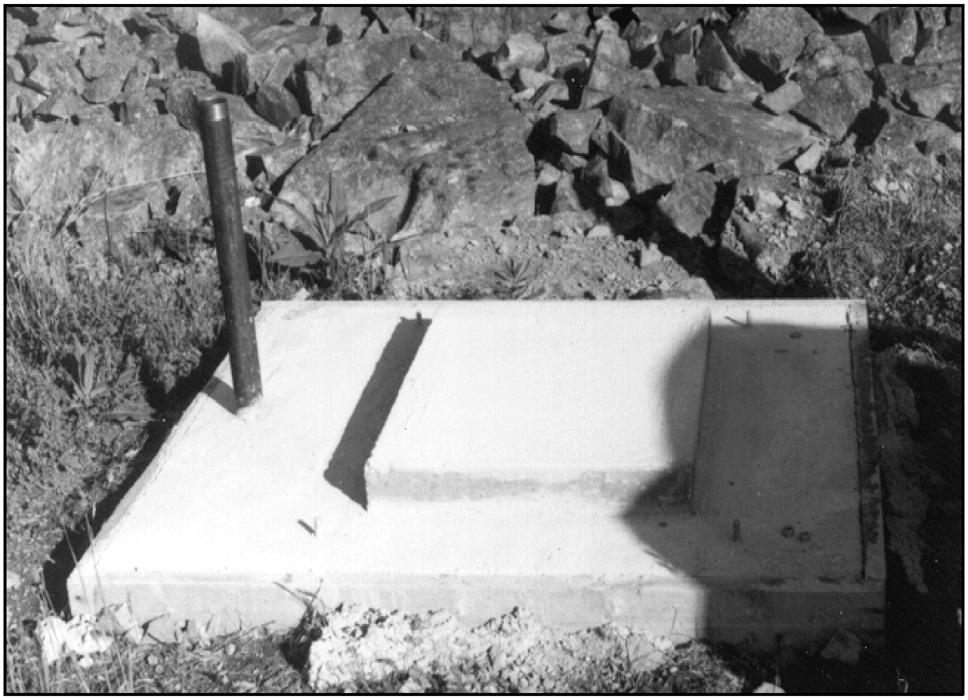


Figure 10. Typical instrument shelter pad foundation

Figure 11. Typical strong-motion instrument installation at crest of Almond Dam, NY. Note solar cell power source

Figure 12. Typical strong-motion instrument installations (Almond Dam, NY, toe and free field stations)

5 Operation and Maintenance

ISDD personnel (an electronics engineer and two electronics technicians) prepare and service SMIP instruments under the jurisdiction of WES. Laboratory functions are shown in Figures 13-15. Typically one electronics technician is involved in servicing that includes four routes looping through all project sites twice a year. Plenty of spare parts are at hand to make the service teams autonomous. A detailed inspection record for each device is completed on location and accompanies recorded data to WES for interpretation and cataloguing in a computer database. Figure 17 is an example inspection record form.

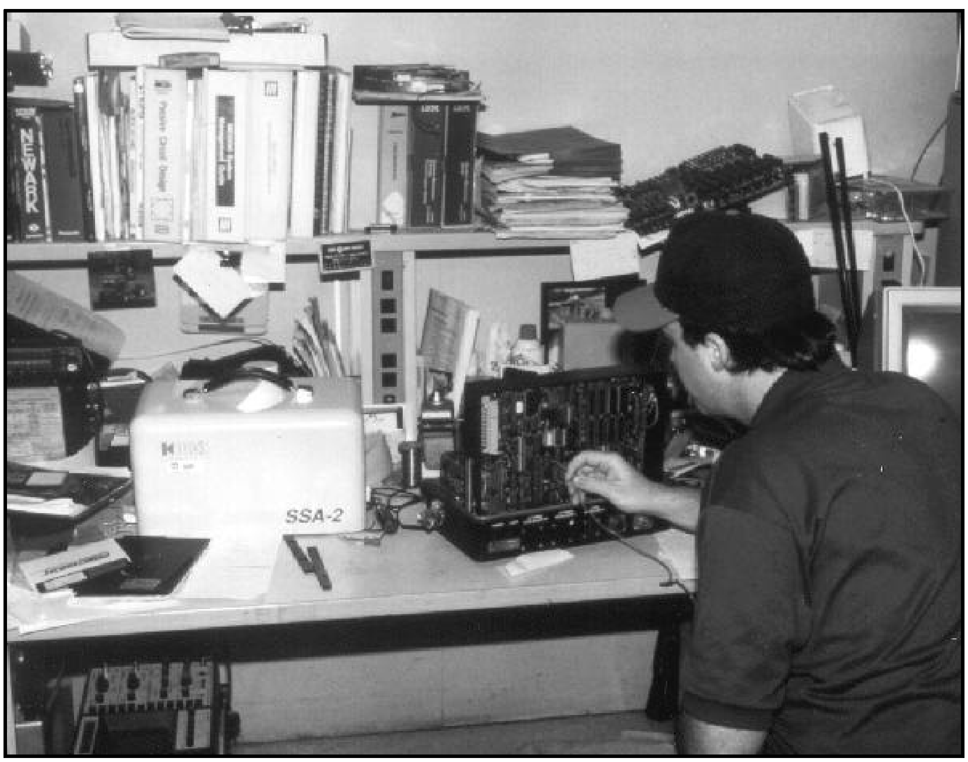


Figure 13. WES Instrumentation Services Division personnel checkout/repair of strong-motion instruments

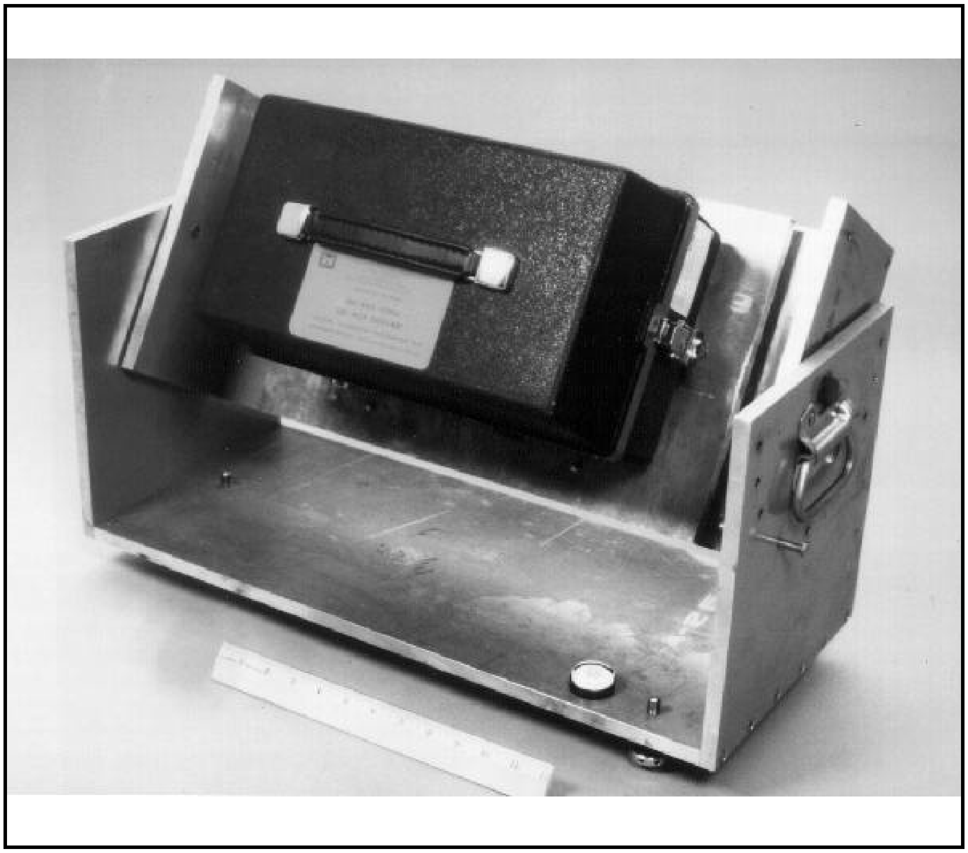
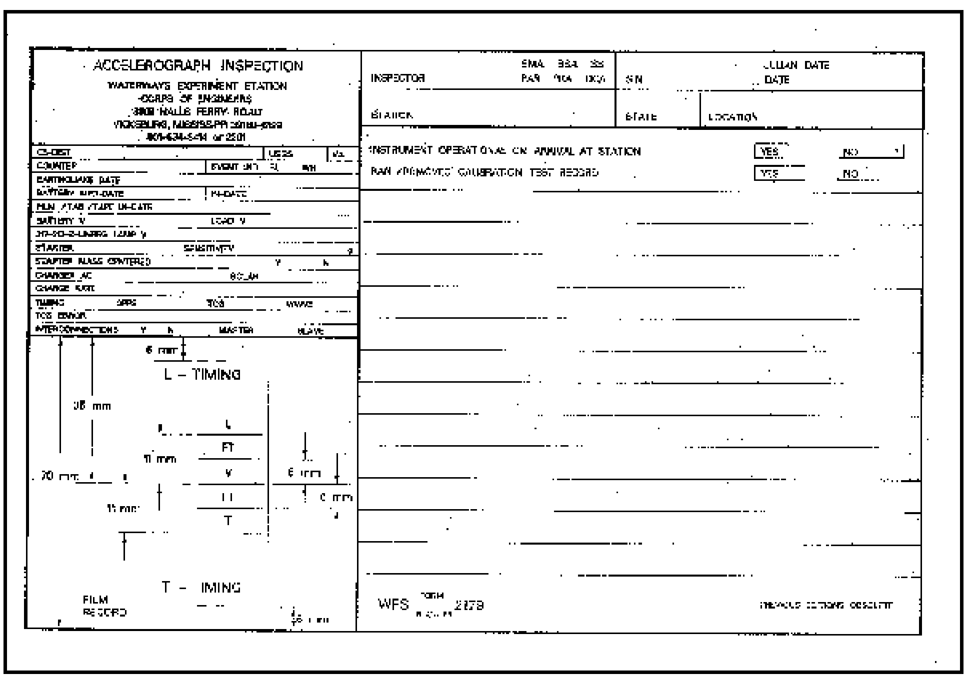


Figure 15. Laboratory tilt table calibration test. All accelerographs are sub-jected to periodic calibration. The tilt table is portable enough to be used in field servicing

Figure 14. WES Instrumentation Services Division preinstallation Laboratory checkout of strong-motion accelerograph

Figure 17. WES SMIP dedicated van servicing crest instrument at J.W. Flannagan Dam, VA (Huntington District)



ACCELEROGRAPH INSPECTION
WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI

INSPECTOR
SMA BSA SS
S/N
JULIAN DATE
DATE
STATION
STATE
LOCATION
INSTRUMENT OPERATIONAL ON ARRIVAL AT STATION YES NO
RAN (REMOVED) CALIBRATION TEST RECORD YES NO

CS-DEST
COUNTER
EVENT NO
EARTHQUAKE DATE
BATTERY
FILM
BATTERY V
LOAD V
STARTER
SENSITIVITY
STARTER MASS CENTERED
CHARGER AC
SOLAR
CHARGE RATE
TIMING
TCG ERROR
INTERCONNECTIONS Y N
MASTER
SLAVE

6 mm
L – TIMING
38 mm
L
FT
V
T
11 mm
70 mm
6 mm
T – TIMING
FILM RECORD

WES FORM 2279
PREVIOUS EDITIONS OBSOLETE

Figure 16. WES example inspection record form

Once accelerometer recordings of an earthquake are delivered to WES, they are processed and baseline and instrument corrections are made. Kinematrics developed (PC-compatible) software is used to process data received at WES. For analog records, the traces are first optically digitized at a rate of 600 points per second of record. Computer algorithms written by USGS are used to integrate the variation of acceleration with time to obtain velocity and displacement records. Further processing includes plots of response spectra. Once all data reduction is completed, a WES seismologist analyzes results to determine natural periods and various amplification factors. Reports are published for larger events under sponsorship of the respective USACE district office (e.g., Chang 1985).

To minimize operating costs while increasing reliability and overall effectiveness of the SMIP, it is necessary to modify and/or upgrade various instruments as maintenance records and technological advances dictate. Charges for services are adjusted annually on the basis of actual cost. Currently, individual letters including costs and newsworthy items are submitted to participating Corps agencies on an annual basis. This action essentially has served to replace a biannual Engineering Circular thus saving appreciable cost.

6 Earthquake Data Retrieval

Earthquake data can be event parameters such as location, time, magnitude, or more detailed data such as accelerograms and parameters derived from these records for individual recording stations.

Earthquake Information

The National Earthquake Information Center (NEIC), located in Golden, Colorado, dispenses factual information about an earthquake within minutes of its occurrence. Such factors as location, magnitude, damage, casualties, and history of previous seismic events are sent to interested parties throughout the world. Access to the NEIC database is available to anyone via computer and telephone modem. The system is called "Quick Epicenter Determinations" (QED) and there is no charge for logging onto the NEIC system. More detailed information and examples of data available from NEIC are shown at Appendix E.

Earthquake Accelerogram Data

WES is linked to NEIC via electronic-mail. Several WES personnel monitor earthquake information on a daily basis. If an earthquake exceeds magnitude 4.5 and its epicenter is located within 80 km of an instrumented USACE structure, WES contacts the responsible USACE district office to determine whether or not instruments have triggered. If personnel on the site confirm instrument activation, special arrangements are made to service the instrument(s) and retrieve records.

Digitized raw (uncorrected) earthquake records are processed using USGS AGRAM/BAP accelerogram computer processing software and output in USGS Strong Motion CD-ROM (SMC) format. This processing includes filtering (noise removal), baseline correction, removal of instrument response, data formatting, and calculation of response spectrum. Records are then logged into the USGS NSMIP database catalog and archived. The WES strong motion database provides on-line Internet access to unprocessed data from the 1994

Northridge, CA earthquake (http://geoscience.wes.army.mil/smip.html), and can be reached by anonymous ftp. Other internet sources for this type data are the USGS NSMIP strong motion digital data series database (http://agram.wr.usgs.gov), NOAA National Geophysical Data Center earthquake database, Boulder, CO (http://julius.ngdc.noaa.gov), National Center for Earthquake Engineering Research's (NCEER) strong motion database located at Lamont-Doherty Earth Observatory (http://www.ldgo.columbia.edu/nceer/nceer.html), and the California Department of Conservation, Department of Mines and Geology's strong motion data center (http://www.consrv.ca.gov/dmg/csmip/index.htm).

7 Significant Earthquakes Recorded to Date

Since inception of the SMIP, a number of significant earthquake records have been acquired. Appendix E is a tabulation of USACE strong-motion data archived between 1971 and 1997.

One of the most important recent events was an earthquake that occurred near Franklin Falls, New Hampshire, on 18 January 1982. This event was rated at 4.8 on the Richter Scale and triggered some 13 instruments in the New England area. These data (see Figure 18 for a typical record) are the most significant strong motions recorded in the New England area in over 40 years. Detailed analyses indicated that preconceived notions about attenuation factors, frequencies, and amplitudes should be revised for the New England area. (Chang, 1982, 1987)

Other high quality records have been obtained at Coyote Dam, California, in March 1978, Mt. Borah, Idaho, in October 1983 (Chang 1985), and Whittier Narrows, California, in October 1987 and in February 1988. The Mt. Borah earthquake (M_S = 7.3; USGS, 1983) was recorded at Dworshak Dam (330 km from epicenter), Lucky Peak Dam (179 km from epicenter), and at Ririe Dam (180 km from epicenter) which was constructed and instrumented by USACE but is presently owned and operated by the USBR. The 1987 Whittier Narrows earthquake was recorded at Brea, Carbon Canyon, Prado, San Antonio, Sepulveda, and Whittier Narrows Dams. No SMIP instruments were triggered during the October 1989 Loma Prieta, California, earthquake (M_S = 7.1). The nearest USACE project (New Hogan Dam, California) was located more than 130 km from the epicenter. More recently, the magnitude 5.8 M_L "Sierra Madre" earthquake of 28 June 1991 in the Los Angeles area was recorded by USACE instruments at seven sites. On 22 April 1992, the magnitude 6.1 M_W Joshua Tree earthquake epicentered near Desert Hot Springs, CA, was recorded by six USACE instruments. Most noteworthy, however, were numerous records obtained as a result of the 17 January 1994 Northridge, California M_s = 6.6 earthquake. Example records are shown in Figures 19-21. Numerous other less significant earthquakes were also recorded.

It is interesting to note that the data displayed in Figures 19 and 20 were digitally recorded, whereas Figures 21 and 22 show analog recordings. It is readily apparent that the digital records, which can be scaled upon retrieval, show greater clarity and detail for "quick look" analysis. Analog records must be digitized or optically magnified for more than a cursory analysis.

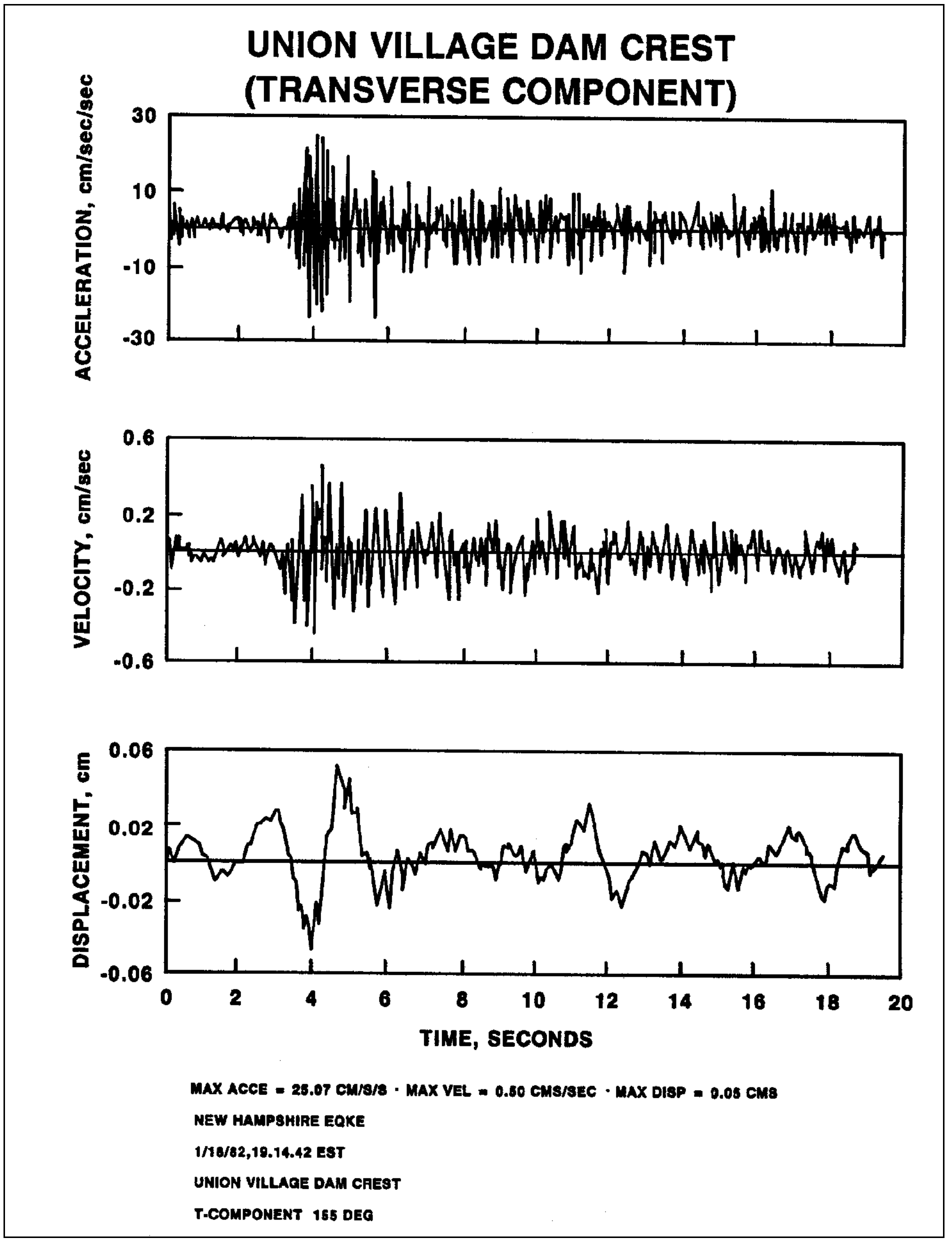


Figure 18. New Hampshire earthquake of 1982. Transverse component, Union Village Dam crest

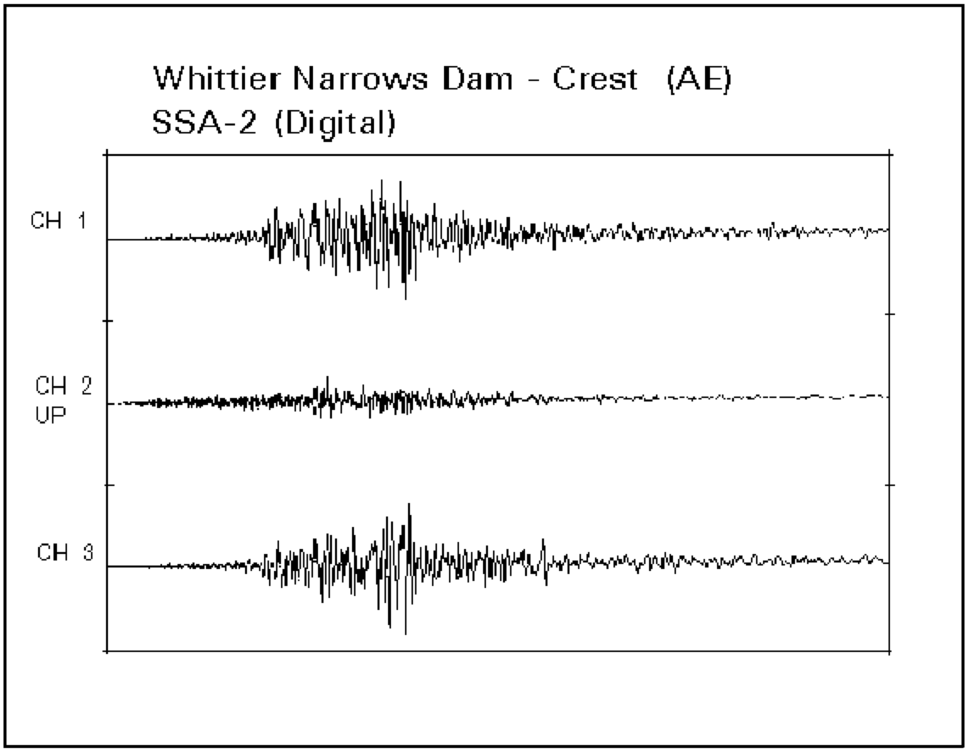


Figure 19. Example record of 17 January 1994 Northridge, CA M_s = 6.6 earthquake (No. 1) (Porcella, et al, 1994)

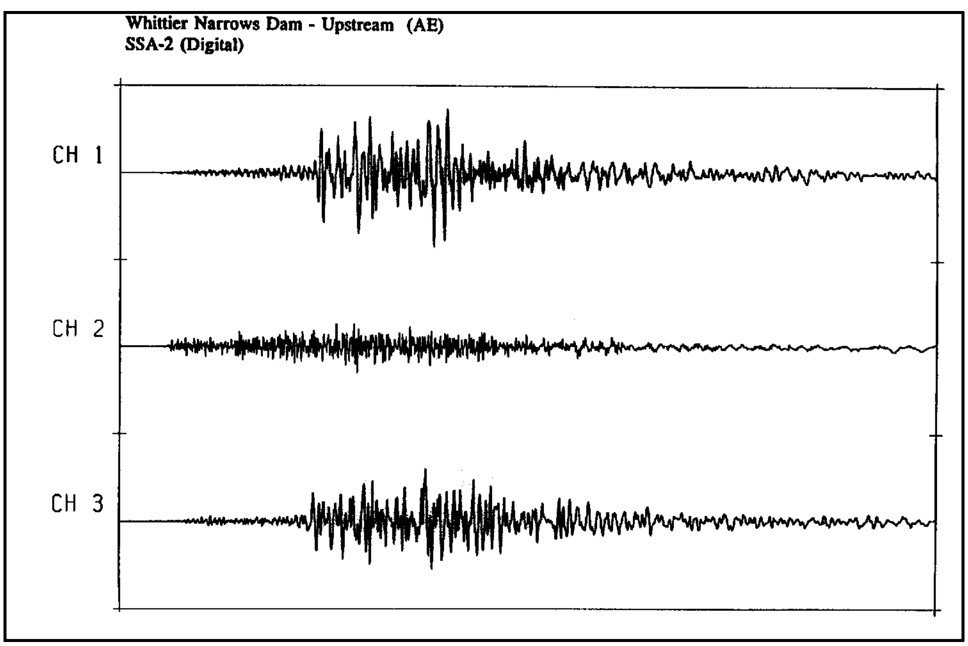


Figure 20. Example record of 17 January 1994 Northridge, CA M_s = 6.6 earthquake (No. 2)

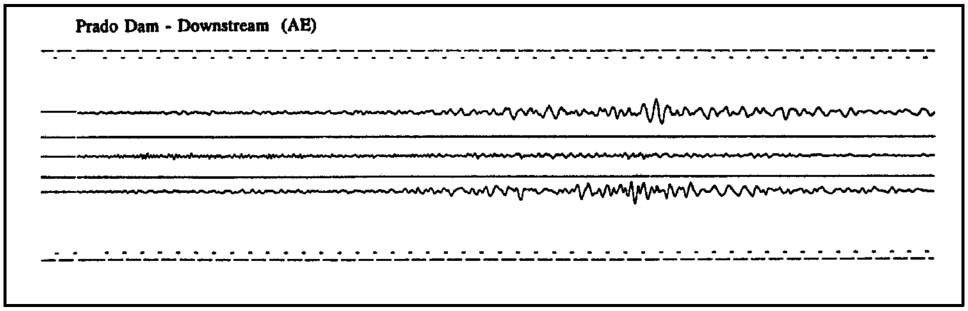


Figure 21. Example record of 17 January 1994 Northridge, CA M_s = 6.6 earthquake (No. 3)

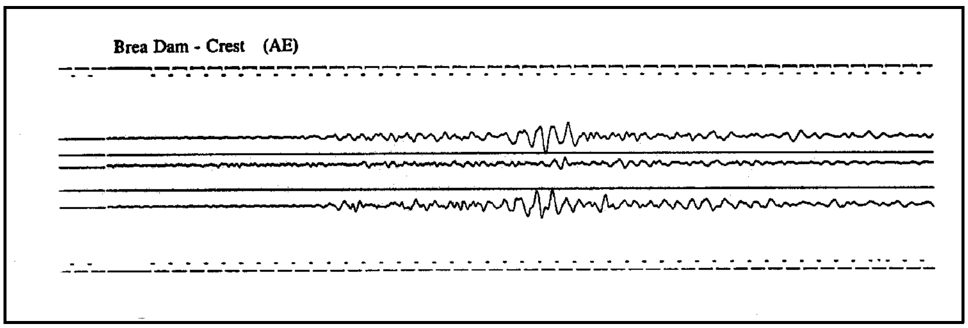


Figure 22. Example record of 17 January 1994 Northridge, CA M_s = 6.6 earthquake (No. 4)

8 Current Status and Future Goals

In the beginning, the SMIP was designed to provide insight into the safety of, and to act as an inspection guide for existing and future structures. It was devised to provide a measure of project performance and design performance comparisons, and to act as a database for performance predictions and earthquake research. These goals are being achieved. Because of the relatively short recorded history of seismic events in the United States, seismic risk maps are continually updated but still can only give an approximation of the long-term hazard.

As additional information is gained and technological advances made, both in terms of instrumentation and analytical seismic analysis techniques, more reliable assessments of USACE projects will be made. As confidence is gained, many of the very conservative assumptions now being used to assess structure stability will undoubtedly be revised to more realistically address the problem. Thus, many structures considered borderline by today's standards can be conclusively assessed as safe by future standards thereby eliminating or drastically modifying expensive remedial actions. These measures will invariably result in reduced costs.

A second goal, minimizing on-site inspections after earthquakes, has already proven feasible in areas of high earthquake activity through the development and installation of seismic alarm devices on USACE projects. Following an event, site personnel can readily determine if any of the preset threshold levels were reached. After enough data are obtained through the SMIP, an acceptable threshold level of acceleration can be safely established for individual structures. Inspections would be required only if that threshold level is exceeded— thereby saving numerous operational man-hours. An automatic telephone dialer, highly desirable for unmanned structures, can be incorporated to relay information to district or division offices.

In the normal course of technological improvements in instrumentation, it is expected that digital accelerographs will ultimately replace analog instruments and could even be used as “seismic alarm” devices. Performance and reliability evaluation of digital devices is an ongoing goal of the SMIP. As performance evaluations show continued positive signs of reliability, recommendations will be made to incorporate specific models which meet SMIP criteria. A prime objective of the strong-motion instrumentation program is to automate data acquisition and instrument status, via computer modem or FM radio telemetry remote capability, for better response and control of the network. The first working example of this concept was installation of a stand-alone digital accelerograph at Olmsted Dam (Louisville District). This instrument was installed during January 1995 and can be queried by modem. Additional instruments have since been installed at Yatesville Dam (Huntington District). These remotely located accelerographs are pioneering the use of solar-powered cellular telephones for modem operation.

As the transition to digital instruments continues, incentives are being offered to Corps agencies to promote the upgrade. WES and USGS have agreed to reduce digital service visits to a biennial mode. Digital instruments utilizing modems and telephone lines will be queried from WES on a monthly basis. If a malfunction is noted, on-site personnel will be informed and guided through checkout procedures. If a “fix” cannot be achieved, that instrument will be repaired by WES or USGS personnel during the next scheduled service visit. A dramatic service cost reduction (by as much as a factor or three) is anticipated using this procedure. The biennial on-site visit will be necessary for normal maintenance and battery replacement.

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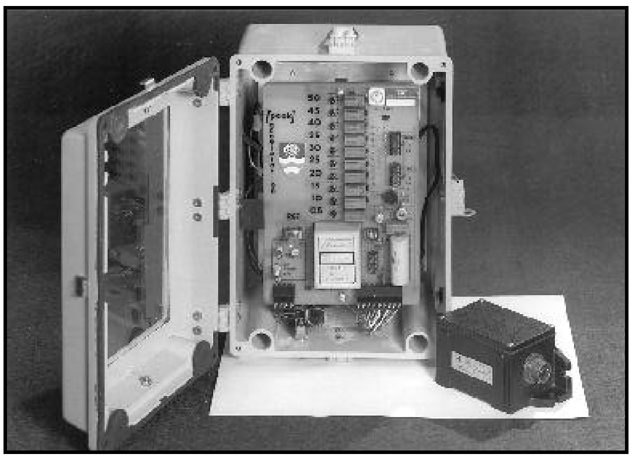
Appendix A
Pertinent Strong-Motion Instrumentation Program Regulations

Appendix B WES Seismic Acceleration Alarm Device, Model SAD Technical Specifications



Introduction

The Seismic Acceleration Alarm Device, Model SAD, is designed and fabricated by personnel of the Instrumentation Services Division (ISD), US Army Corps of Engineers Waterways Experiment Station (WES). The purpose of the device is to provide project personnel with an immediate readout of the peak vertical acceleration level experienced on a structure following an earthquake.

General Description

The Model SAD is an electronic peak acceleration recorder comprised of a vertical accelerometer unit and a control/display unit. The accelerometer unit senses and amplifies the acceleration level which is routed to the display unit by means of a 10-ft shielded cable. The control/display unit supplies the DC power and calibration commands to the accelerometer and processes the incoming acceleration signal. Acceleration that exceeds a preset level is stored in a latching relay bank and the peak level is retained and displayed by an array of light emitting diodes (LEDs) located on the control/display board. If a preset alarm threshold is exceeded, an audible alarm or a optional relay contact closure is activated. The optional relay contact can activate a telephone dialer, GOES satellite transmission, control circuit, computer interface, etc.

The glass windowed door of the control/display unit is locked to prevent unauthorized access to critical controls and calibration switches. Acceleration level LEDs, DC power indicator, battery charger light, as well as alarm level and calibration switches, can clearly be seen through the door window. The audible alarm reset button is the only external control.

The device is typically calibrated to display ten (10) peak acceleration levels from 0.05 to 0.50 g. Acceleration of or greater than 0.50 g will cause the 0.50 g LED to remain illuminated. The output alarm level is switch selective to trigger from any one of ten levels, 0.05g to 0.50g.

The power system consisting of a 12-volt, 6.5 amp-hour battery, an 8 amp-hour battery charger and a DC/DC converter provides an uninterruptible power supply. Battery charger power is normally drawn from the conventional 120-volt commercial AC line. This arrangement provides a 48-hour continuous back up capability.

Operation

The device is designed to operate unattended for long periods. Routine periodic inspections consist of viewing the display board through the observation window to ensure that the DC power LED light is on and the battery charger light and data LEDs are off.

When an acceleration level greater than 0.05 g occurs, the device will indicate the peak level by latching "on" the appropriate 0.05 g resolution LED. An alarm is sounded indicating the instrument has triggered and should be read. The alarm is silenced by pushing the ALARM RESET button located on the outside of the control/display unit. The acceleration level from the display, the approximate time and date of the event are normally recorded in the project log book.

Special Operational Features

a . After the device has been triggered, it remains active ready to record levels which exceed previously recorded peaks.

b. Only the maximum peak vertical level is stored.

c. The alarm is sounded each time the alarm threshold is exceeded.

d. Data stored in the latching relays is recoverable, even if the power is lost. Simply reapply power.

e. The only way to clear the level display LED is to reset the storage relays with the SYSTEM RESET push button on the main control/display board. Typically, the panel door is locked.

f. The 0.50 g LED indicates that the device has experienced acceleration at or above the 0.50 g level.

g. It is designed to operate in a bipolar fashion. Either positive or negative acceleration peaks will drive the data display. The system can be made to operate in unipolar manner by removing the appropriate operational amplifier and/or dot bar driver.

h. The ALARM RESET push button is the only external operator control. Operating this switch will reset the audible alarm; it will not reset the data display.

Example

A hypothetical example will help illustrate SAD operation. Consider the device operating with no LED illuminated when a 0.22 g acceleration occurs. Data is latched into the storage relays, the 0.20 g LED data array is updated to display the acceleration level, and the audible alarm is turned "on" to alert the project operators that the 0.10 g alarm threshold has been exceeded. Project personnel should then reset the alarm and record the 0.20 g reading, time, date, etc.

The device is now operating with the 0.20 g LED illuminated when another earthquake occurs. This second earthquake has a peak acceleration amplitude of 0.36 g. The 0.20 g LED light will be turned "off" and the 0.35 g LED turned "on" since the new acceleration is greater. The alarm will again be sounded to alert the operators that an earthquake has occurred. They should then reset the alarm and record the new reading, time, date, etc.

Another aftershock occurs later with a peak acceleration of only 0.16 g. The alarm will be sounded indicating the alarm threshold has been exceeded. However, the 0.35 g LED light will remain "on" since it represents the largest of the two acceleration levels.

The data LEDs could be reset after each alarm if a qualified person unlocks the control/display panel and depresses the display reset button. A policy should be established as to when, why and by whom the device is reset.

Cost

The 1998 cost of a Model SAD in quantities of 5 or more is $3250 each. Installation cost (1998) is the same as an electronic accelerograph and is $700 each.

Options

The Model SAD can be modified to accept a horizontal accelerometer if that mode is desired. The distance between the accelerometer and control/display panel can be increased up to 100 ft at a cost for cable of $1.50 per ft. It is recommended that the panel and accelerometer be located inside a weatherproof building; however, at additional cost the system can be made weatherproof. Contact WES about other needs or options not listed.

WES Points of Contact

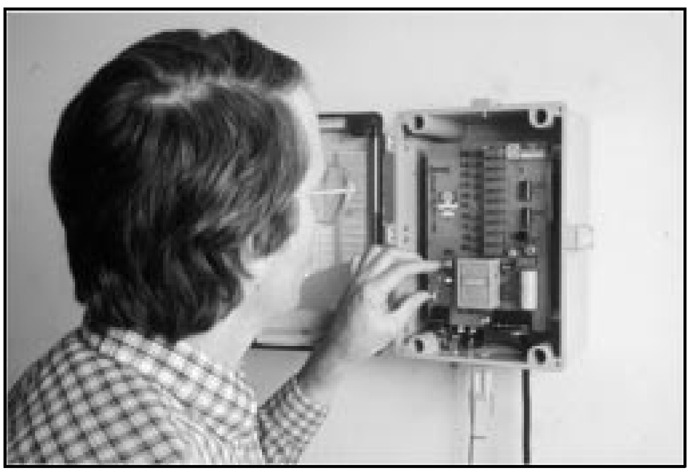
Lewis Smithhart, Electronics Technician
601-634-2578 or 601-634-3300
EMAIL: smithhl3@ex1.wes.army.mil

Joe Savage, Electronics Engineer
601-634-3414
FAX: 601-634-2747
EMAIL: savagem@ex1.wes.army.mil

USAE Waterways Experiment Station
ATTN: CEWES-IJ-O
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Appendix C
Seismic Alarm Device, Model SAD Operation Manual

Mod 3: 15 June 1992



USACE WATERWAYS EXPERIMENT STATION

CEWES-IJ-O 601-634-2578

1.0 INTRODUCTION

This manual describes the Seismic Acceleration alarm Device, SAD mod 3. The following upgrades were incorporated into the standard SAD design to produce the mod 3:

1. An eleven position rotary switch has been added to the alarm set point circuit. This switch allows any one ten acceleration levels to trigger the alarm.

2. PC board plug P2 has been increased from 9 to 10 pins to accommodate an easy interface for a remote alarm switch closure connection.

3. An external battery charger has been added to replace the internal charger.

4. Minor changes have been made to the PC board layout.

2.0 GENERAL DESCRIPTION

The SAD consist of a low frequency accelerometer and a signal processor unit. The processor contains the electronics necessary to process and display the acceleration input. It also contains the power supply, alarm and control circuits of the SAD.

The SAD monitors and displays the maximum peak acceleration output from its Kinemetric's model FBA-11 accelerometer. Ten LEDs on the display panel are used to indicate the peak acceleration level recorded.

Any one of ten acceleration levels can be selected to generate both a local audible alarm and a relay switch closure for a remote alarm indication.

3.0 INITIAL SYSTEM CHECK

The steps for the pre-installation check out are as follows:

1. Inspect the SAD for any damage that may have occurred in shipping. Make sure that all of the electrical terminal connections are tight.

2. Verify that the SAD controls are set as follows:
   a. **Power** switch is **OFF**
   b. **Cal** rotary switch is in position **0**
   c. **Dip** switches are all **ON**
   d. **Alarm Set Point** rotary switch is set to position **1**
   e. **AC/DC** jumper is in **DC**

3. Install the 12 volt battery in the space provided behind the plexiglass back plate. Connect the positive terminal to the red wire; the negative terminal to the black wire.

4. Replace the plexiglass back plate and PC board. Plug the charger into a 120 AC volt outlet. Measure + 12 VDC between pin 1 (HI) and pin 3 (LOW) of P1 on the PC board. Verify that the charger is operational.

5. Turn the **Power** switch to **ON**. Momentarily depress the **Data Reset** and **Alarm Reset** push buttons and verify that the audio alarm and the red **Data** LEDs are off. The green **Power On** LED should be illuminated.

6. Check the converter power output at connector P2:

Pin 1	+ 12 VDC
Pin 2	COMMON
Pin 3	- 12 VDC

7. The SAD processor converts the voltage output from the FBA-11 into an acceleration display. In order to insure that this conversion is accurate, the SAD comparator reference voltage must be set to match the FBA-11's calibration. This procedure must be repeated any time an accelerometer or processor board is replaced.

   Monitor the voltage between the **Range Test Point** (HI) and common (pin 2 of P2). Adjust the **Range Adjust** potentiometer for a DC voltage that is equal (+/- 10mv) to the absolute value (disregard sign) of the 0.50 g calibrated voltage output as indicated on the FBA Acceleration Calibration Data sheet. This voltage is approximately equal to 1.25 volts for a 1 g full scale FBA. The accelerometer output is now calibrated to the SAD display. A copy of the calibration should be left on site for further reference.

8. The following instructions explain how setup the FBA accelerometer:

   a. Turn the **Power** switch to **OFF**.

   b. Turn the **Alarm** (dip switch no.4) to **OFF**.

   c. Place the FBA on a level surface. Its input arrow must be aligned to the axis of installation. For the normal VERTICAL measurement installation the arrow will point UP. Connect the FBA to the Processor input cable.

   d. Connect a meter to monitor the DC voltage input to the comparator circuit (R4 to COMMON).

   e. Turn the **Power** switch to **ON**.

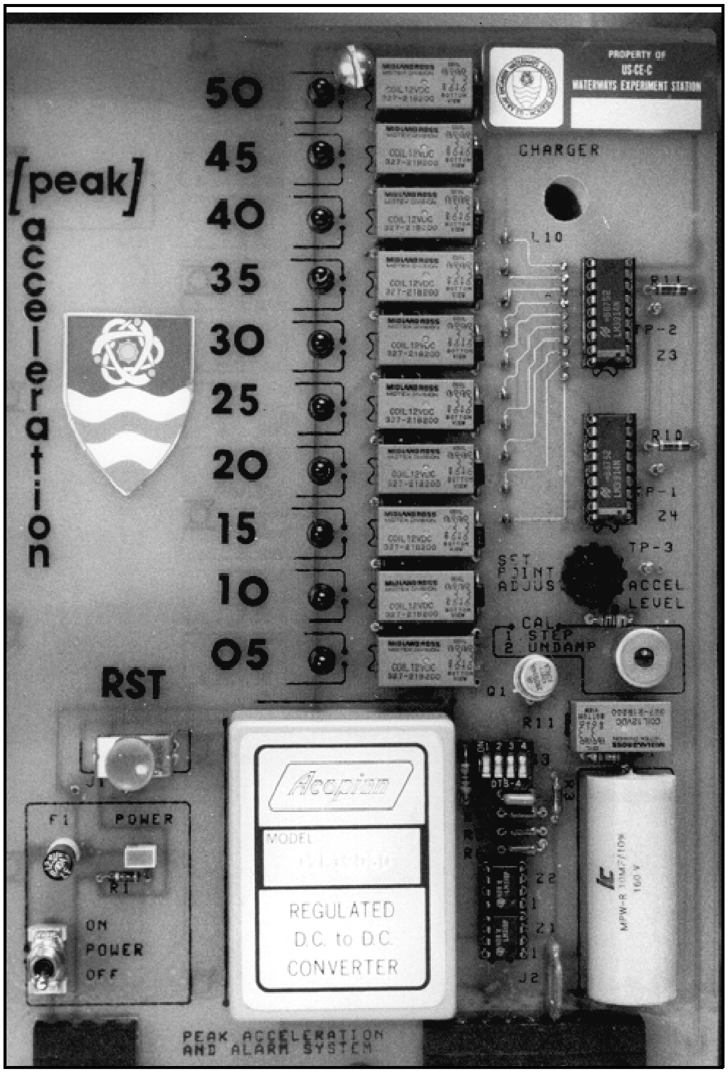


Figure C-1. SAD control panel

f. Follow the accelerometer adjustment instructions as outlined in paragraph 5.0 of the FBA-11 operations manual to balance the meter reading to less than +/- 10 mv DC.

g. Momentarily depress the **Data Reset** push button to clear the data display.

h. Tilt the accelerometer and note that the data display LEDs update properly.

9. Check the alarm circuit operation. Turn the **Alarm** (dip switch no.4) to **ON** and select a minimum alarm set point with the **Alarm Set Point** rotary switch. Tilt the FBA and note that the alarm is sounded when the set point is reached. A switch closure will appear between pins 9 and 10 of P2 when the SAD is in an alarm condition.

4.0 INSTALLATION GUIDE

Use the following steps as a guide for permanent installation of the SAD.

1. Select a permanent location for the SAD on the structure that is free from high background vibrations and strong RF fields that might effect the instrument.

2. Readjust the balance after the FBA has been secured in place. *A large offset will cause the display to be in error by the amount of the offset!*

3. Check the Cal Step voltage.

   a. Record the offset voltage at R4.(note sign +/-)

   b. Turn the **CAL** rotary switch to position **1**.

   c. Record the FBA output voltage at R4.

   d. Subtract the voltage measured in step 1 from the reading taken in step 3. Record this calculated value in the local file as the **Cal Step Voltage**.

   e. Return the **Cal** switch to the **0** position and reset the display.

4. Make the following checks before securing the instrument:

   Select desired alarm threshold with the **Alarm Set Point** switch.
   Make sure that dip switches are all **ON**.
   Push the **Data Reset** and **Alarm Reset** push buttons and verify that the data display and alarm are off.
   Verify that battery and charger are connected and working properly.

5.0 ELECTRICAL CONNECTIONS

P1 is the 3 pin PC board connector.

Pin	Function
1	+ 12 Volt Battery
2	Audio Alarm Trigger
3	Common Battery

P2 is the 10 pin PC board connector.

Pin	Function
1	+ 12 Volt Converter Output
2	Common
3	- 12 Volt Converter Output
4	Signal Common
5	Undamp Command to the FBA
6	Step Command to the FBA
7	Accelerometer Signal Output
8	Alarm Reset
9/10	Switch Closure For Remote Alarm

6.0 CONTROLS

CONTROL	FUNCTION
Power Switch	Applies battery and charger power to SAD
Dip Switch	1. + Accelerometer signal to comparator 2. - Accelerometer signal to comparator 3. Not used 4. Audio alarm on/off
Data Reset PB	Resets the red data display LEDS
Alarm Reset PB	Resets the audio and remote alarm
Alarm Set Point	Used to select acceleration level that will activate the alarm circuit

CONTROL	FUNCTION
Cal	Used to test FBA accelerometer 0. Normal operation position 1. Cal step command to FBA 2. Undamp command to FBA Caution: Never set Cal switch to any position other than 0, 1, OR 2.
Jumper	Selects AC or DC input coupling
Range Adjust	Single turn potentiometer that is used to calibrate the SAD output

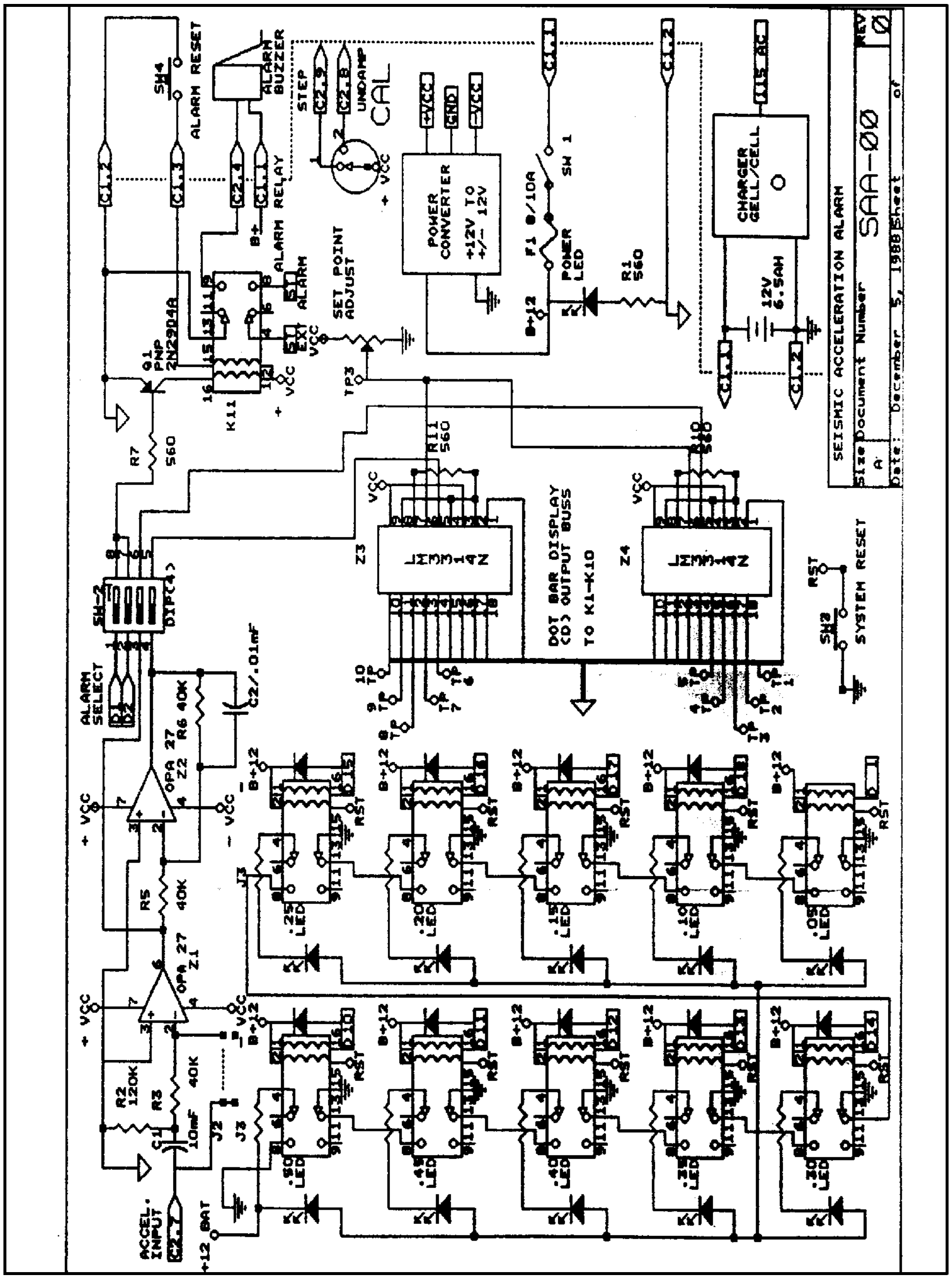


Figure C-2. Diagram of SAD circuitry.

7.0 INDICATORS

INDICATOR	FUNCTION
Data Display	10 Red LEDS that indicate peak acceleration
Power LED	Green LED that indicates that power is applied

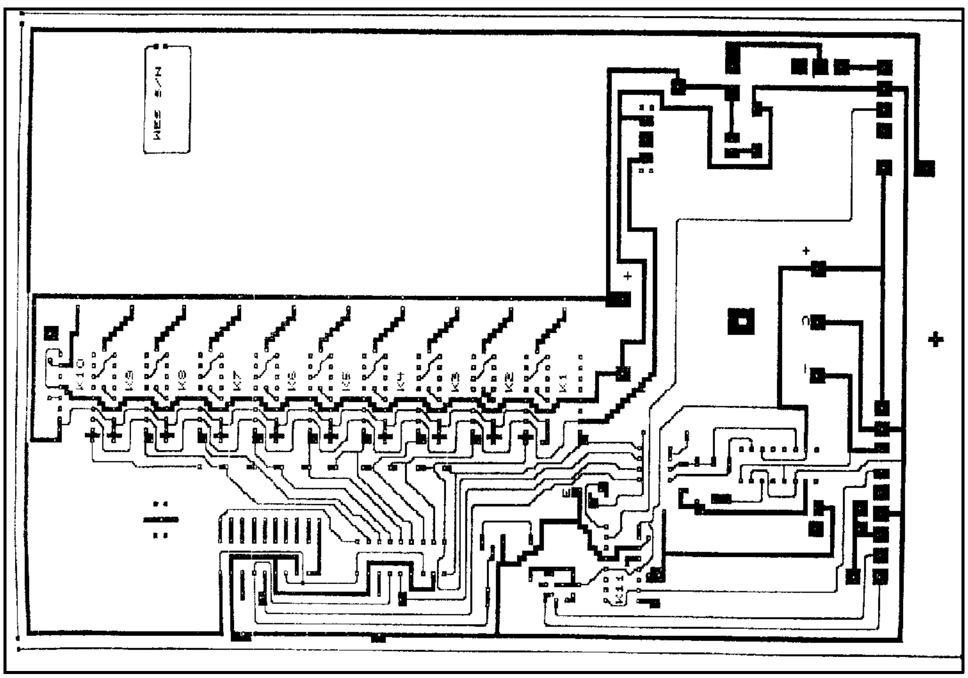


Figure C-3. SAD circuitry diagram (solder side)

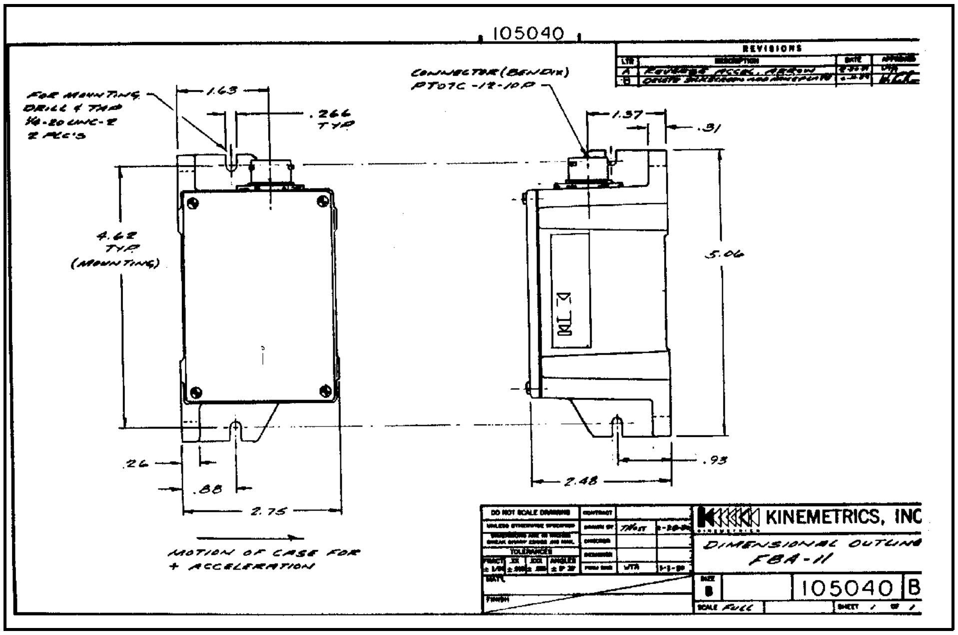


Figure C-4. Dimensional outline of accelerometer case

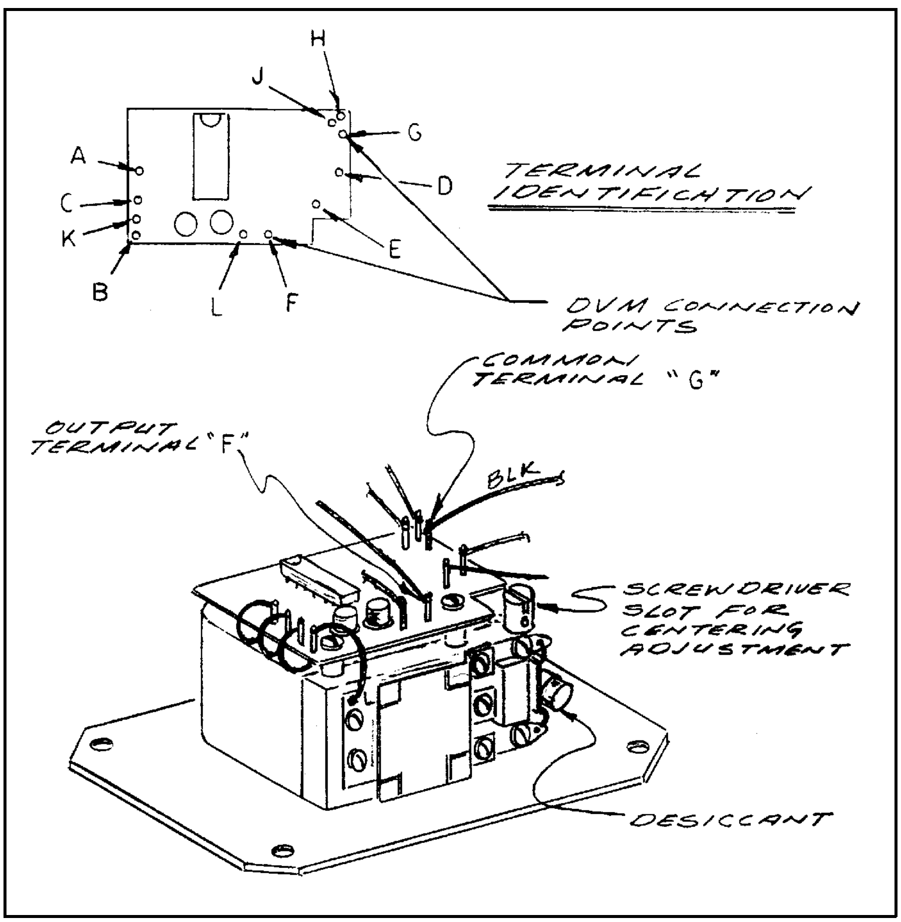


Figure C-5. Balancing accelerometer output

INSTRUCTIONS FOR HOFFMAN FIBERGLASS ENCLOSURES

BULLETINS A-17, A-41, A-42, A-43, A-45, AND A-50

CONDUIT INSTALLATION – EQUIPMENT AND CONDUIT GROUNDING

1. INSTALLATION OF CONDUIT AND ALLEN-BRADLEY BULLETIN 1490 HUBS

NOTE: HUBS MUST BE ATTACHED TO THE CONDUIT BEFORE THE HUBS ARE ATTACHED TO THE ENCLOSURE.

Conduit holes can be cut in the ends and side walls of this enclosure when required. (See table below for the required hole size.) Use a hole saw or greenlee-type hole cutter to cut the required holes. Conduit connections must be properly aligned to the enclosure wall to prevent unnecessary stress on the enclosure walls.

CONDUIT CONNECTORS (HUBS) TO BE USED FOR INSTALLATION OF CONDUIT			
CONDUIT SIZE	HOLE SIZE	CONDUIT CONNECTOR (HUBS)	GROUNDING BUSHING
		ALLEN-BRADLEY CATALOG NO.	ALLEN-BRADLEY CATALOG NO.
1/2"	7/8"	1490-N1	1490-N19
3/4"	1-1/8"	1490-N9	1490-N20
1"	1-3/8"	1490-N10	1490-N21
1-1/4"	1-3/4"	1490-N11	1490-N22
1-1/2"	2"	1490-N5	1490-N23
2"	2-1/2"	1490-N6	1490-N24
2-1/2"	3"	1490-N7	1490-N25
3"	3-5/8"	1490-N8	1490-N26

2. GROUNDING OF EQUIPMENT AND CONDUIT

CAUTION: THIS NON-METALLIC ENCLOSURE DOES NOT AUTOMATICALLY PROVIDE GROUNDING BETWEEN CONDUIT CONNECTIONS. GROUNDING MUST BE PROVIDED AS PART OF THE INSTALLATION.

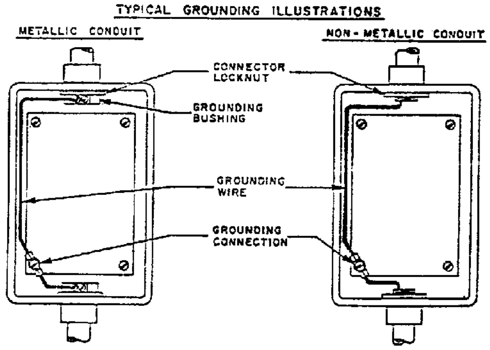
Ground in accordance with the requirements of the National Electrical Code.

Conduit hubs for metallic conduit must have a grounding bushing attached to the hub on the inside of the enclosure. Grounding bushings have provisions for connection of a grounding wire.

Non-metallic conduit and hubs require the use of a grounding wire in the conduit. Grounding bushings are not required.

System grounding is provided by connecting the grounding wires from all conduit entries to the subpanel or to other suitable point which provides continuity. Any device having a metal portion or portions extending out of the enclosure must also be properly grounded.

TYPICAL GROUNDING ILLUSTRATIONS



3. REMOVAL OF HINGED COVER FROM SMALL FIBERGLASS ENCLOSURE.

Cover can be detached from box by spreading each wire hinge loop. The wire hinge loop is open on the end attached to the cover clip. Pull the ends of each hinge loop out of each cover clip. The wire hinge loops can be removed from the box clips if a hinged cover is not required.

HOFFMAN ENGINEERING COMPANY
ANOKA, MINNESOTA 55303 U.S.A.

PART NO. 99401-659 REV. LEVEL G DWG. NO. C1123-A

Figure C-6. Conduit installation - equipment and conduit grounding

Appendix D
USGS NEIC On-Line Information Program

The On-Line Information Program program is available to individuals and groups having access to a 1200- or 2400-baud terminal with dial-up capabilities to a commercial telephone number at the USGS National Earthquake Information Center in Golden, Colorado. Available on a 24-hour basis, 7 days a week, this program has three options: Quick Epicenter Determinations (QED), Earthquake Lists, and Geomagnetic Field Values. More information may be obtained by contacting:

The On-Line Information Program /QED/
USGS/NEIC
Box 25046, Federal Center, MS 967
Denver, CO 80225
Phone: 303-273-8500

Information Via Computer

On-Line Information System
800-358-2663
Within Colorado: 303-273-8672
qed@neis.cr.usgs.gov
Access to earthquake and geomagnetic information within the last 3 weeks. (300 to 1200 baud, 7 data bits, 1 stop bit, zero parity)

Current Seismicity
finger quake@gldfs.cr.usgs.gov

The time period of data available in the QED is approximately 3 weeks -- from about 2 days behind real time to the current *Preliminary Determination of Epicenters* (PDE) in production. Events within 7 days of real time are still being revised and republished for the QED as new data are received from contributing observatories. Events older than 7 days are no longer revised for the QED, but are retained in the database (and are available to QED users) until they are re-worked for publication on the PDE.

The following are printouts of actual data collected via QED.

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U.S. DEPARTMENT OF THE INTERIOR                                   NO. 8-061
GEOLOGICAL SURVEY                                                MAR  2, 1998
NEIC QUICK EPICENTER DETERMINATIONS

UTC TIME    LAT     LONG    DEP GS MAGS  SD STA  REGION AND COMMENTS
HRMNSEC                         MB  Msz     USED

JAN 11
062754.3& 60.230N 140.920W   0              20 SOUTHEASTERN ALASKA. <AEIC>. ML
                                               2.8 (AEIC).
071415.8& 57.830N 156.390W 129              18 ALASKA PENINSULA. <AEIC>.
075804.0* 47.663N   0.291W  10G         1.1   7 FRANCE. ML 2.1 (LDG).
080805.9  30.446N  50.569E  33N 4.7 3.5 0.9  61 NORTHERN IRAN
085505.1& 63.680N 149.820W 141              17 CENTRAL ALASKA. <AEIC>.
090956.7  50.238N 156.342E  70D 5.3     0.8 160 KURIL ISLANDS
103341.4  42.776N 110.937W   5G         0.5  10 WYOMING
135312.5& 53.630N 165.730W  47              12 FOX ISLANDS, ALEUTIAN ISLANDS.
                                               <AEIC>. ML 4.0 (AEIC).
152527.6  43.593N 140.615E 197D 4.7     0.7 115 HOKKAIDO, JAPAN  REGION
161455.2  37.701N 118.880W   5G         0.7  25 CALIFORNIA-NEVADA BORDER REGION.
                                               ML 3.7 (GM), 3.6 (GS).
162143.6  37.699N 118.863W   5G         0.8  10 CALIFORNIA-NEVADA BORDER REGION.
                                               ML 3.2 (GM), 3.2 (GS).
174339.1* 44.155N  10.605E  10G         0.9  11 NORTHERN ITALY. ML 2.4 (LDG).
1808547  37.709N 118.844W   5G         0.6   7 CALIFORNIA-NEVADA BORDER REGION.
181250.8& 59.630N 153.020W 101              13 SOUTHERN ALASKA. <AEIC>.
184359.7  37.711N 118.847W   5G         0.7   9 CALIFORNIA-NEVADA BORDER REGION.
                                               ML 3.2 (GM), 3.1 (GS).
185711.2  52.085N 171.998W  33N 4.5 4.3 1.3  66 FOX ISLANDS, ALEUTIAN ISLANDS
233905.6? 33.51 S 111.55 W  10G 5.3 5.0 1.3  44 SOUTHERN EAST PACIFIC RISE

JAN 12
000432.7* 34.511S 112.086W  10G 4.9 5.3 1.1  40 SOUTHERN EAST PACIFIC RISE
011055.1* 29.492S 179.338W 300G         1.2  15 KERMADEC ISLANDS REGION
041046.2  23.607S 176.113W  33N 5.4 5.2 0.8  36 SOUTH OF FIJI ISLANDS
041205.7  25.007S  70.025W  54D 5.2 4.7 1.2  64 NEAR COAST OF NORTHERN CHILE.
        Felt (V) at Taltal, (IV) at Antofagasta, (III) at Mejillones and (II) at
        Tocopilla.
051108.0*  3.422S 145.812E  33N 4.5     1.4  23 NEAR N COAST OF NEW GUINEA, PNG.
063623.8  34.174N 118.473W  10G         0.5  30 SOUTHERN CALIFORNIA. ML 3.4 (PAS).
075845.1& 54.660N 160.920W   0              14 ALASKA PENINSULA. <AEIC>. ML 2.6
                                               (AEIC).
080549.4   2.658N 128.333E  33N 5.2 4.9 1.4  46 HALMAHERA, INDONESIA
101407.6  30.941S  71.372W  33N 5.8 6.2 0.9 137 NEAR COAST OF CENTRAL CHILE. Mw
        6.6 (GS), 6.5 (HRV). Me 6.2 (GS). Felt (VI) at Combarbala and Ovalle;
        (V) at Coquimbo, Illapel, La Serena, Los Andes and Los Vilos; (IV) at
        Rancagua, San Antonio and Valparaiso; (III) at Santiago. Broadband
        Source Parameters (GS): Dep 28; Radiated energy 3.9*10**13 Nm. Two
        events about 3 seconds apart. Depth based on first event. Moment Tensor
        (GS): Dep 36; Principal axes (scale 10**18 Nm): (T) Val=8.30, Plg=77,
        Azm=150; (N) Val=0.60, Plg=13, Azm=344; (P) Val=-8.90, Plg=3, Azm=254;
        Best double couple: Mo=8.6*10**18 Nm; NP1: Strike=330, Dip=43, Slip=71;
        NP: Strike=176, Dip=50, Slip=107. Centroid, Moment Tensor (HRV):
        Centroid origin time 10:14:16.4; Lat 31.23 S; Lon 72.06 W; Dep 40.9;
        Half- duration 4.5 sec; Principal axes (scale 10**18 Nm): (T) Val=7.40,
        Plg=76, Azm=81; (N) Val=-0.20, Plg=1, Azm=173; (P) Val=-7.19, Plg=14,
        Azm=264; Best double couple: Mo=7.3*10**18 Nm; NP1: Strike=354, Dip=31,
        Slip=91; NP2: Strike=173, Dip=59, Slip=89. Scalar Moment (PPT):
        Mo=1.2*10**19 Nm.
103424.9% 31.164S  71.587W  33N         1.2   7 NEAR COAST OF CENTRAL CHILE
110546.2? 13.43 N  91.40 W  33N 4.1     1.5   7 NEAR COAST OF GUATEMALA
111551.9* 31.135S  71.753W  33N         0.6   8 NEAR COAST OF CENTRAL CHILE
132305.6& 61.430N 150.940W  61  3.0         56 SOUTHERN ALASKA. <AEIC>. ML 3.6
                                               (AEIC), 3.5 (PMR).
135841.7% 47.130N 154.234E  33N         1.3  11 KURIL ISLANDS
141129.2% 46.148N   3.461E  10G         0.6   7 FRANCE. ML 2.3 (LDG).
154152.7% 37.737N  15.013E   5G         0.8   8 SICILY. MD 3.2 (ROM).
155716.7  37.717N 118.867W   5G         0.6   6 CALIFORNIA-NEVADA BORDER REGION.
        ML 2.9 (GS). MD 2.9 (GM). Two events about 30 seconds apart. Hypocenter
        and magnitude are for the first and larger event.
```

Symbols Following Origin Time:

& Indicates that parameters of the hypocenter were supplied or determined by a computational procedure not normally used by NEIS. The source or nature of the determination is indicated by a 2 to 5 letter code enclosed by angle brackets and appearing in the first line of comments. A "-P" appended to the code indicates that the computation is preliminary. These codes are included in the list of abbreviations below.

% Indicates a single network solution. A non-furnished hypocenter has been computed using data reported by a single network of stations for which the date and/or origin time cannot be confirmed from seismograms available to a NEIS analyst. The geometric mean of the semi-major and semi-minor axes of the horizontal 90% confidence ellipse is less than or equal to 16.0 km.

* Indicates a less reliable solution. In general, the geometric mean of the semi-major and semi-minor axes of the horizontal 90% confidence ellipse is greater than 8.5 km and less than or equal to 16.0 km.

? Indiates a poor solution, published for completeness of the catalogue. In general, the geometric mean of the semi-major and semi-minor axes of the horizontal 90% confidence ellipse is greater than 16.0 km. This includes a poor solution computed using data reported by a single network.

Q Indicates a preliminary solution obtained from the NEIC Earthquake Early Alerting Service program "Quick-quake."

The lack of any symbol indicates that the geometric mean of the semi-major and semi-minor axes of the horizontal 90% confidence ellipse is less than or equal to 8.5 km.

Symbols Following Depth:

N Indicates depth was restrained at 33 km for earthquakes whose character on seismograms indicate a shallow focus but whose depth is not satisfactorily determined by the data.

D Indicates depth was restrained by the computer program based on 2 or more compatible pP phases and/or unidentified secondary arrivals used as pP.

G Indicates the depth was restrained by a geophysicist.

* Indicates a less well-constrained free depth. The 90% marginal confidence interval on depth is greater than 8.5 km and less than or equal to 16.0 km.

? Indicates a poorly-constrained free depth. The 90% marginal confidence interval on depth is greater than 16.0 km.

The lack of any symbol indicates that the 90% marginal confidence interval on depth is less than or equal to 8.5 km, or that a contributed hypocenter was computed with a free depth, regardless of the size of the confidence interval.

Symbols and Abbreviations Used in Comments:

BLA Virginia Polytechnic Institute and State University, Blacksburg.
BRK University of California, Berkeley.
CL Coda length magnitude.
DOE U.S. Department of Energy.
ERDA U.S. Energy Research and Development Administration.
EXPLO Some or all parameters of explosion (controlled or accidental)supplied by any group or individual other than ERDA or its successor organizations.
GLD U.S. Geological Survey, Golden, Colorado (other than NEIS).
GS U.S. Geological Survey, Menlo Park, California
HVO Hawaiian Volcano Observatory.
JMA Japan Meteorological Agency (generally used to indicate 7-point Japanese Intensity Scale).
LDG Laboratoire de Detection et de Geophysique, Montrouge, France.
MACRO Hypocenter based upon macroseismic information.
MD Duration magnitude.

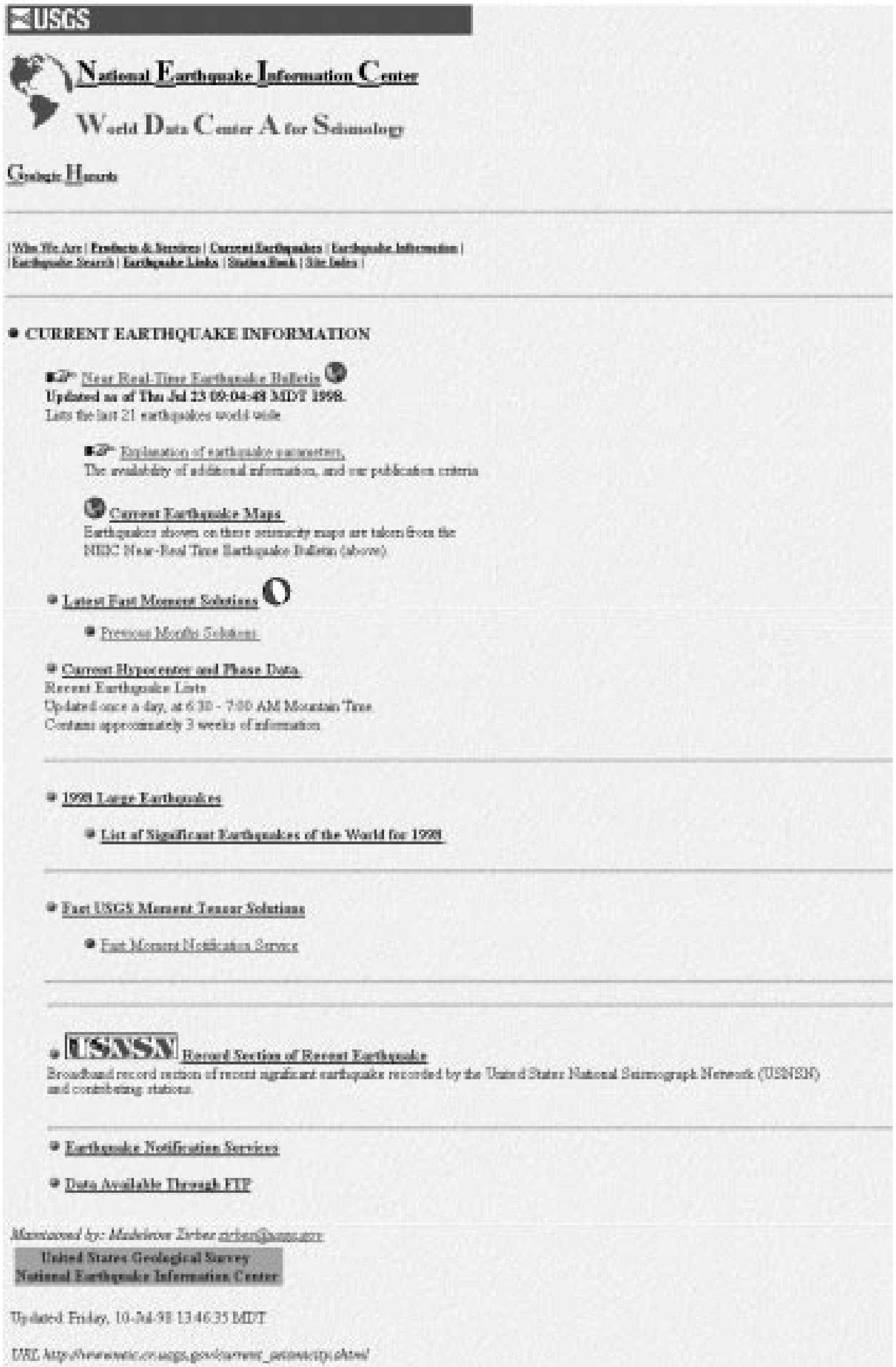
NEIS	U.S. Geological Survey, National Earthquake Information Service, Golden, Colorado
OTT	Earth Physics Branch, Ottawa, Canada.
PAL	Columbia University, Lamont-Doherty Observatory, Palisades, New York.
PAS	California Institute of Technology, Pasadena.
PGC	Pacific Geoscience Centre, Sidney, British Columbia, Canada.
PMR	Alaska Tsunami Warning Center, Palmer, Alaska.
RF	Rossi-Forel Intensity Scale.
SEA	University of Washington, Seattle.
SLC	University of Utah, Salt Lake City.
SLM	St. Louis University, Missouri.
TEIC	Tennessee Earthquake Information Center, Memphis.
TUL	Oklahoma Geological Survey, Leonard.
WES	Weston Observatory, Massachusetts.

Roman Numerals	Used to indicate intensity (when not followed by RF or JMA they refer to the Modified Mercalli Scale or any 12-point intensity scale closely related to it).
-P	Supplied hypocenter is a preliminary computation.

Any additional 3 to 5 letter codes enclosed in parentheses or angle brackets refer to individual station codes. These codes may be found in Geological Survey Open File Report 85-714, "Seismograph Station Codes and Coordinates" (1985).

For an explanation of other topics such as magnitude formulas, travel time tables or intensity scales, please refer to the latest January or July issue of the publication "Preliminary Determination of Epicenters, Monthly Listing."

Near real-time earthquake information bulletins as well as current earthquake maps, and lists of significant earthquakes are available from the USGS NEIC via the internet at http://wwwneic.cr.usgs.gov/current_seismicity.shtml. Examples of information available from this site are shown on the following pages.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National Earthquake Information Center

World Data Center A for Seismology

Geologic Hazards

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| Earthquake Search | Earthquake Links | Station Book | Site Index |

- CURRENT EARTHQUAKE INFORMATION

  Near Real-Time Earthquake Bulletin
  Updated as of Thu Jul 23 09:04:48 MDT 1998.
  Lists the last 21 earthquakes world wide

  Explanation of earthquake parameters,
  The availability of additional information, and our publication criteria

  Current Earthquake Maps
  Earthquakes shown on these seismicity maps are taken from the NEIC Near-Real Time Earthquake Bulletin (above).

- **Latest Fast Moment Solutions**
  - Previous Months Solutions

- **Current Hypocenter and Phase Data.**
  Recent Earthquake Lists
  Updated once a day, at 6:30 - 7:00 AM Mountain Time
  Contains approximately 3 weeks of information

- **1998 Large Earthquakes**
  - **List of Significant Earthquakes of the World for 1998**

- **Fast USGS Moment Tensor Solutions**
  - Fast Moment Notification Service

- USNSN **Record Section of Recent Earthquake**
  Broadband record section of recent significant earthquake recorded by the United States National Seismograph Network (USNSN) and contributing stations.

- **Earthquake Notification Services**
- **Data Available Through FTP**

Maintained by: Madeleine Zirbes zirbes@usgs.gov

United States Geological Survey
National Earthquake Information Center

Updated: Friday, 10-Jul-98 13:46:35 MDT

URL http://wwwneic.cr.usgs.gov/current_seismicity.shtml

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U.S. Geological Survey's National Earthquake Information Center

Guide to Products and Services

Following is a description of the products and services offered by the United States Geological Survey's National Earthquake Infor
Prices are subject to change without notice. Addresses and telephone numbers are listed for the distribution office of each of the pr
the products and services, please contact the USGS/NEIC at the address below

U.S. Geological Survey
National Earthquake Information Center
P.O. Box 25046
Denver Federal Center, MS 967
Denver, CO 80225
(303)273-8500

Contents

(Contact NEIC for current product pricing.)

Maintained by: Madeleine Zirbes zirbes@usgs.gov

United States Geological Survey
National Earthquake Information Center

Updated Thursday, 26-Feb-98 13:29:46 MST

URL http://wwwneic.cr.usgs.gov/neis/pAND/title.html

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science for a changing world

U. S. Geological Survey

NATIONAL STRONG-MOTION PROGRAM

nsmp Since 1932

Seismic Engineering and Ground Response Studies

The National Strong Motion Program (NSMP) comprises three principal sections:

- Network Development and Operations section, responsible for overall management of the National Strong-Motion Network
- Data Management section, responsible for analyses and dissemination of processed data from the National Strong-Motion Network
- Engineering Research section, with specific responsibilities for the investigation of structure response and site effects

Program News | Recent Events | Station List | Station Maps | Recent Studies | Catalogues

Data Sets | People | NOD | BAP | Ask a Geologist

NEW! Surfing the Internet for Strong Motion Data

The USGS Home Page is at http://www.usgs.gov
The USGS Geologic Division Home Page is at http://geology.usgs.gov
The URL of this page is http://agram.wr.usgs.gov

Contacts:
Network Development and Operations: Ron Porcella
Data Analysis and Dissemination: Chris Stephens
Engineering Research: Mehmet Celebi
Webmaster: Kent Fogleman

This site was last updated on May 14, 1998 (KF)

Appendix E
Tabulation of USACE Strong-Motion Data, 1971-1997

Table 2
USACE Strong-Motion Data Archived (1971 - 1997)

Date and Name of Earthquake	Project Site, State	Recorder	Magnitude	Instrument Components			Peak Acceleration (g)			Focal Depth	Epicenter Distance (km)
				L	Z	T	L	Z	T		
02/09/1971	Carbon Canyon Dam, CA	Crest	6.6 M_L	N50W	Down	S40W	0.0686	0.0423	0.0686	13	75.00
	Whittier Narrows Dam, CA	Crest	6.6 M_L	S	Down	S53W	0.0975	0.0597	0.0986	13	54.00
	San Antonio Dam, CA	Crest	6.6 M_L	N75W	Down	N15E	0.0568	-0.028	0.0774	13	72.00
01/01/1976	Carbon Canyon Dam, CA	Crest	4.2 M_L	N50W	Down	S40W	0.06	0.05	0.10	8	7.00
		Right Abutment		N50W	Down	S40W	0.08	0.03	0.13	8	7.00
		Left Abutment		N50W	Down	S40W	0.10	0.04	0.12	8	7.00
	Brea Dam, CA	Crest	4.2 M_L	N50W	Down	S40W	0.08	0.05	0.11	8	9.00
		Downstream		N50W	Down	S40W	0.08	0.04	0.05	8	9.00
03/25/1976 New Madrid	Arkabutla Dam, MS	Left toe	5.0 M_b	S28W	Down	S62E	0.041	0.010	0.022	12	99.00
		Left crest		S28W	Down	S62E	0.021	0.006	0.010	12	99.00
		Right Abutment		S28W	Down	S62E	0.011	0.006	0.011	12	99.00
	Wappapello Dam, MO	Right toe	5.0 M_b	S38W	Down	S52E	0.010	0.005	0.012	12	150.00
		Right crest		S38W	Down	S52E	0.006	0.005	0.006	12	150.00
	Arkabutla Dam, MS	Left toe	4.5 M_b	S28W	Down	S62E	0.010	0.004	0.005	14	99.00
07/27/1980 Sharpsburg, Kentucky Earthquake	Laurel River Dam, KY	Crest	5.1 M_L	195	Up	105	0.05	0.025	0.031	8	141.00
	Nolin River Dam, KY	Crest	5.1 M_L	105	Up	15	0.01	0.01	0.01	8	213.00

Table 2 (Continued)

Date and Name of Earthquake	Project Site, State	Recorder	Magnitude	Instrument Components			Peak Acceleration (g)			Focal Depth	Epicenter Distance (km)
				L	Z	T	L	Z	T		
01/18/1982 Franklin Falls Dam Earthquake	Franklin Falls Dam, NH	Downstream	4.4 M_b	225	Up	135	0.143	0.276	0.385	4-8	8.00
		Right Abutment		45	Up	315	0.293	0.176	0.550	4-8	8.00
		Crest		45	Up	315	0.126	0.116	0.312	4-8	8.00
	Union Village Dam, VT	Crest	4.4 M_b	245	Up	155	0.023	0.024	0.025	4-8	60.00
		Left abutment		245	Up	155	0.009	0.006	0.007	4-8	60.00
		Downstream		245	Up	155	0.038	0.029	0.023	4-8	60.00
	North Hartland Dam, VT	Abutment	4.4 M_b	15	Up	285	0.0113	0.0038	0.0069	4-8	61.00
		Crest		15	Up	285	0.038	0.017	0.039	4-8	61.00
	North Springfield Dam, VT	Crest	4.4 M_b	275	Up	185	0.032	0.014	0.023	4-8	76.00
	Ball Mountain Dam, VT	Crest	4.4 M_b	30	Up	300	0.062	0.128	0.125	5	14.00
03/04/1983 Big Bend Dam Earthquake	Big Bend Dam, SD	Downstream	4.4 M_L	277	Up	187	0.062	0.128	0.125	5	14.00
		Crest		183	Up	93	0.069	0.109	0.043	5	14.00
		Spillway		213	Up	123	0.119	0.034	0.055	5	14.00
10/28/1983 Borah Peak, Idaho Earthquake	Dworshak Dam, ID	Upper gallery	6.9 M_L	141	Up	51	0.012	0.016	0.055	16	330.00
	Lucky Peak Dam, ID	Left abutment	7.3 M_S	229	Up	139	0.013	0.008	0.016	16	179.00
		Upper intake		229	Up	139	0.033	0.012	0.042	16	179.00
		Center crest		229	Up	139	0.071	0.033	0.059	16	179.00
	Ririe Dam, ID	Intake lower tower	6.9 M_L	025	Up	295	0.012	0.008	0.012	16	180.00
		Upper intake tower		025	Up	295	0.052	0.008	0.041	16	180.00
		Abutment		027	Up	295	0.015	0.010	0.017	16	180.00
		Downstream		237	Up	147	0.014	0.010	0.013	16	180.00
		Crest		025	Up	295	0.031	0.025	0.041	16	180.00

Table 2 (Continued)

Date and Name of Earthquake	Project Site, State	Recorder	Magnitude	Instrument Components			Peak Acceleration (g)			Focal Depth	Epicenter Distance (km)
				L	Z	T	L	Z	T		
01/31/1986 Painesville Earthquake	Michael J. Kirwan Dam, OH	Crest	4.9 M_L				0.022		0.028	6	60.00
06/10/1987 Lawrenceville, IL Earthquake	Patoka Dam, IN	Crest	5.0 M_L	47	Up	317	0.025	0.012	0.027	10	88.00
	Monroe Lake Dam, IN	Crest	5.0 M_L	223	Up	133	0.013	0.013	0.013	10	100.08
	Cagles Mill Dam, IN	Crest	5.0 M_L	335	Up	145	0.042	0.019	0.028	10	105.00
	Rough River Lake Dam, KY	Crest	5.0 M_L	41	Up	311	0.039	0.015	0.027	10	155.00
	Nolin River Dam, KY	Crest	5.0 M_L	285	Up	195	0.018	0.005	0.027	10	201.00
10/01/1987 Whittier Narrows Earthquake	Whittier Narrows Dam, CA	Crest	5.9 M_L	033	Up	303	0.30	0.181	0.315	14	4.00
		Upstream		152	Up	062	0.297	0.531	0.229	14	4.00
	Brea Dam, CA	Crest	5.9 M_L	130	Up	040	0.305	0.136	0.233	14	26.50
		L. Abutment		130	Up	040	0.158	0.103	0.102	14	26.50
		Downstream		130	Up	040	0.319	0.087	0.173	14	26.50
	Carbon Canyon Dam, CA	Crest	5.9 M_L	130	Up	040	0.176	0.125	0.203	14	30.00
		L. Abutment		130	Up	040	0.207	0.059	0.154	14	30.00
	Prado Dam, CA	Crest	5.9 M_L	090	Up	360	0.093	0.063	0.083	14	32.00
		L. Abutment		090	Up	360	0.044	0.025	0.080	14	32.00
		Downstream		090	Up	360	0.133	0.054	0.128	14	32.00
	Sepulveda Dam, CA	Crest	5.9 M_L	054	Up	324	0.101	0.080	0.126	14	38.00
	Sepulveda Dam, CA	Downstream		054	Up	324	0.114	0.068	0.141	14	38.00
	San Antonio Dam, CA	Crest	5.9 M_L	090	Up	360	0.099	0.055	0.145	14	38.00
		R. Abutment		090	Up	360	0.031	0.042	0.033	14	38.00
		Downstream		090	Up	360	0.064	0.036	0.051	14	38.00

Table 2 (Continued)

Date and Name of Earthquake	Project Site, State	Recorder	Magnitude	Instrument Components			Peak Acceleration (g)			Focal Depth	Epicenter Distance (km)
				L	Z	T	L	Z	T		
10/04/1987 Whittier Narrows Aftershocks	Whittier Narrows Dam, CA	Crest	5.3 M_L	033	Up	303	0.21	0.09	0.25	8	6.00
	Brea Dam, CA	Crest	5.3 M_L	130	Up	040	0.08	0.07	0.19	8	26.00
		L. Abutment		130	Up	040	0.05	0.05	0.09	8	26.00
		Downstream		130	Up	040	0.07	0.05	0.13	8	26.00
	Carbon Canyon Dam, CA	Crest	5.3 M_L	130	Up	040	0.06	0.04	0.07	8	29.00
		L. Abutment		130	Up	040	0.05	0.03	0.05	8	29.00
		R. Abutment		130	Up	040	0.07	0.03	0.05	8	29.00
	Sepulveda Dam, CA	Crest	5.3 M_L	054	Up	324	0.05	0.04	0.04	8	36.00
		Downstream		054	Up	324	0.04	0.05	0.04	8	36.00
	Prado Dam, CA	Downstream	5.3 M_L	090	Up	360	0.04	0.03	0.07	8	47.00
02/11/1988 Whittier Narrows Aftershocks	Whittier Narrows Dam, CA	Crest	5.0 M_L	033	Up	303	0.16	0.12	0.10	12	5.00
		Upstream		152	Up	062	0.25	0.20	0.25	12	5.00
	Brea Dam, CA	Crest	5.0 M_L	130	Up	040	0.07	0.05	0.18	12	23.00
		L. Abutment		130	Up	040	0.05	0.04	0.07	12	23.00
		Downstream		130	Up	040	0.05	0.04	0.09	12	23.00
	Carbon Canyon Dam, CA	Crest	5.0 M_L	030	Up	040	0.05	0.05	0.05	12	26.00
	San Antonio Dam, CA	Crest	5.0 M_L	090	Up	360	< 0.05	< 0.05	0.06	12	35.00
	Prado Dam, CA	Crest	5.0 M_L	090	Up	360	< 0.05	< 0.05	< 0.05	12	43.00
		Downstream		090	Up	360	0.07	< 0.05	0.08	12	43.00
02/28/1990 San Antonio Dam Earthquake	San Antonio Dam, CA	Crest	5.5 M_L	090	Up	360	0.44	0.35	0.58	10	2.20
		R. Abutment		090	Up	360	0.38	0.78	0.48	10	2.20
		Downstream		090	Up	360	0.48	0.42	0.41	10	2.20

Table 2 (Concluded)

Date and Name of Earthquake	Project Site, State	Recorder	Magnitude	Instrument Components			Peak Acceleration (g)			Focal Depth	Epicenter Distance (km)
				L	Z	T	L	Z	T		
01/17/1994 Northridge, CA Earthquake	Brea	Crest	6.8 M_S	132	Up	042	0.14	0.09	0.23	18	67
		Left Abutment		132	Up	042	0.08	0.08	0.10	18	67
		Downstream		132	Up	042	0.19	0.05	0.12	18	67
	Carbon Canyon	Crest	6.8 M_S	131	Up	041	0.11	0.08	0.19	18	72
		Left Abutment		131	Up	041	0.11	0.03	0.10	18	72
		Right Abutment		131	Up	041	0.14	0.06	0.14	18	72
	Prado	Crest	6.8 M_S	090	Up	360	0.09	0.07	0.10	18	90
		Left Abutment		090	Up	360	0.06	0.04	0.14	18	90
		Downstream		090	Up	360	0.20	0.06	0.18	18	90
	San Antonio	Downstream	6.8 M_S	090	Up	360	0.05	0.03	0.09	18	80
	Santa Fe	Control Room Toe (Seismic Alarm)	6.8 M_S		Up			0.05		18	55
	Sepulveda	Control Room (Seismic Alarm)	6.8 M_S		Up			0.15		18	9
	Whittier Narrows	Crest	6.8 M_S	208	Down	298	0.19	0.07	0.21	18	49
		Upstream (Baseyard)	6.8 M_S	180	Down	270	0.22	0.08	0.15	18	49

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Robert F. Ballard, Jr., Tina H. Grau

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13. ABSTRACT (Maximum 200 words)

This report is an expanded, updated version of a paper presented and published in the proceedings of the 1993 National Earthquake Conference held May 3-5, 1993 in Memphis, TN. The U.S. Army Corps of Engineers (USACE) currently operates a seismic Strong-Motion Instrumentation Program (SMIP) throughout the United States to provide a measure of project performance, provide insight into the safety of USACE projects, and establish a database for earthquake research. Strong-motion instruments used for SMIP consist of digital and analog accelerographs, peak acceleration recorders, and seismic alarm devices. These instruments have been placed at earth, rock, earth and rock, arch, and gravity dams owned and operated by the USACE. At present, 123 projects located in 32 states and Puerto Rico are monitored with more than 500 strong-motion instruments. The USACE network is second in size to that operated by the California Division of Mines and Geology.

The purpose of this report is to present various aspects of the USACE SMIP including criteria for design of installations, recording equipment, operation, maintenance, performance to date, upgrades, future goals, and the importance of interagency cooperation. Particular attention is focused on economics and advantages associated with ultimate conversion to remotely accessed digital instrumentation.

14. SUBJECT TERMS
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