UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STRONG-MOTION DATA FROM THE WESTMORLAND, CALIFORNIA EARTHQUAKE OF APRIL 26, 1981

R. P. Maley and E. C. Etheredge

OPEN FILE REPORT
No. 81-1149

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards.

Prepared on behalf of the
National Science Foundation
Grant CA-114

Menlo Park, California
September 1981

CONTENTS

FIGURES

TABLES

INTRODUCTION

A moderate earthquake occurred 8 km northwest of Westmorland, California on April 26, 1981, triggering U.S. Geological Survey (USGS) strong-motion accelerographs at 22 of the 29 stations located in the Imperial Valley region. Details of the event, provided by the California Institute of Technology Seismological Laboratory, are as follows:

Origin time:	12 hr 09 min 28.4 sec (UTC)
Epicenter:	33.13 N
	115.65 W
Magnitude:	$M_L = 5.6$
Depth:	8 km

The earthquake triggered all instruments less than 28 km from the epicenter with the nearest record from Salton Sea, 9 km north of the epicenter (Figure 1). In addition to the network operated by the USGS, the State of California Division of Mines and Geology (CDMG) obtained records from stations located at Westmorland, Niland, and in El Centro adjacent to the former site of the Imperial County Services Building (Mc Junkin and Kaliakin, 1981). Data were recorded by both the USGS and CDMG networks from ground level accelerographs (ground stations, not necessarily free-field stations) located in one story buildings or in small fiberglass instrument shelters. Most recorders were equipped with WWVB radio recivers, but due to either poor signal or receiver-timer problems, real time was impressed on only half of the records.

STRONG-MOTION DATA

Table 1 provides a summary of the instrumental data for the 22 USGS stations and includes the following information: calculated epicentral distances using the Caltech epicenter, S-wave minus trigger (S-t) time intervals when the S-wave onset can be determined, trigger times obtained from the WWVB radio code, peak accelerations for each component, and pertinent comments about the various records. Maximum accelerations exceeded 0.10 g at four stations; Salton Sea 0.22 g (9 km), Brawley 0.18 g (17 km), Parachute Test 0.23 g (20 km), and Superstition Mountain 0.11 g (24 km). The first three stations are located on alluvium while the Superstition Mountain station is on granite. Although maximum accelerations are essentially equivalent at Salton Sea, Brawley, and Parachute Test, the level of motion is significantly larger and of longer duration at Salton Sea, with pulses exceeding 0.10 g for over 6 seconds (Figure 2). The maximum accelerations in El Centro and along the El Centro array were generally 0.02 to 0.06 g. This earthquake was the second time the entire El Centro array was triggered by a single event, the first being the October 15, 1979 Imperial Valley Earthquake (Porcella and Matthiesen, 1979).

Mc Junkin and Kaliakin (1981) reported the following accelerations for the CDMG instrumentation located in Imperial Valley: Westmorland, 7 km, 0.49 g horizontal and 0.80 g (spike) vertical; Niland, 19 km, 0.19 g horizontal and 0.13 g vertical, and El Centro, 35 km, less than 0.05 g. All CDMG instruments are located on alluvium.

Upon reviewing the stations and records from this and other Imperial Valley earthquakes, one may question the effect of structures upon the response of ground recordings. Some years ago the USGS abandoned the use of the words free-field as a designation of ground station in lieu of insufficient definition of what is a free-field station. Perhaps the sites that most closely approach free-field conditions* are those where the accelerographs are housed in relatively light weight fiberglass housings generally anchored to a concrete pad 4 feet square by 6 inches thick. These housings are located at El Centro array stations 2, 4, 5, 6, 8 and 12, although it should be pointed out that the station 2 housing is on a large concrete pad integrally tied to a well head and associated piping while station 8 is less than 10 feet from a large oak tree. Among the other array sites, station 1 is in a small filter building with large pipes passing through the concrete pad into the ground and laterally through the side of the building. Stations 3, 11, and Meadows Union are moderate sized school buildings, station 7 is a large steel frame maintenance building at Imperial Valley College, station 9 is the massive Imperial Valley Substation, station 10 a large hospital building, and station 13 a "garage-type" building adjacent to a levee. Other instrument housings consist of moderate size concrete block buildings at Holtville and Calexico, moderate size metal frame buildings at Bonds Corner and Salton Sea, and a large complex structure with multiple appurtenances at Parachute Test. The

*Does not include elements of the differential array where triaxial transducers are buried at shallow depth in a pea gravel.

Brawley instrument is installed in a steel transformer-type housing with a tall light pole located a few feet away. The single self-contained accelerograph at the El Centro differential array is located in the central recording house, a small concrete block structure. Unfortunately, rock sites are at a premium in the Imperial Valley with the lone exception being the Superstition Mountain station where the instrument building is situated on granite.

In summary, most accelerograph stations in the Imperial Valley do not approach those that could be called free-field ground motion recording sites. Since instruments are usually located on private property, through the courtesy of individual owners, there are necessarily many siting compromises related to access, environment, safety from vandalism, and above all cooperation of the owner. At present, there is no thought of relocating the existing instrumentation, although some future additions may be contemplated, including the use of downhole transducers and possibly second instruments in small shelters near some of larger structures in the network.

S-wave minus trigger times (S-t) such as those shown in Table 1, have been reported for numerous earthquakes over the past several years with the assumption that the instruments are triggered during one of the first P-wave arrivals. Clearly, this is not always true, particularly when P-waves are small and lack a strong impulsive character. For example, during the Westmorland earthquake, El Centro 6 had an S-t interval of 0.8 to 1.1 seconds larger (triggered earlier) than El Centro 1, 2, and 3 at nearly equivalent distances. In other instances, no S-t exists when instruments were triggered during later arrivals. For instance, trigger times, obtained from the WWVB code at El Centro 7 and 8, are respectively 4 and 3 seconds later than station 6 although at essentially equal distances. The instrument at station 6 is housed in a small fiberglass shelter located 1.2 km east of the Imperial Fault while station 7 is a large corrugated steel frame building with concrete slab floor 0.7 km west of the fault. The April 26 records from station 6 show lower frequency ($\sim$8 Hz) higher amplitude vertical motion while station 7 has higher frequency ($\sim$20 Hz) lower amplitude vertical motion. These same characteristics were noted on aftershock recordings of the October 15, 1979 earthquake. Later triggerings could be attributed to a number of variables: site response including effects of transmission path and source mechanism, structural modification of base shaking, and response characteristic of vertical starters which have a peak sensitivity at 4 Hz falling off rapidly above 10 Hz. Thus, depending upon the frequency and the level of ground motion, at least for smaller events, strong-motion instruments may or may not trigger within a few tenths of a second of first P-wave arrivals. The relatively long triggering delays observed at stations 7 and 8 (3 and 4 plus seconds) would exceed the standard 2.5 second pre-event memory (PEM) used by the USGS in digital strong-motion systems. Similar delays were observed at station 9 where three accelerographs are installed: a Kinemetrics* SMA-1, a Kinemetrics* DSA-1 digital recorder with PEM, and a standard USC & GS strong-motion accelerograph, each triggered independently by Kinemetrics* VS-1 vertical starters. An analog playback of the DSA-1 vertical component reveals there was ground motion occurring at the site at the beginning of the 2.5 seconds of recorded pre-event data. Acceleration levels were below the nominal 0.01 g triggering level for the first 1.6 seconds while the following 0.9 second shows acceleration pulses that reach and just slightly exceed 0.01 g. Two percent of g is not attained until 3.2 seconds into the recording. Although the instruments are not interconnected, relative triggering times can be determined by comparing the same phase arrivals on identical components. This comparison indicates the SMA-1 and the USC & GS accelerograph triggered approximately 2.8 to 3.0 seconds after the PEM data was being recorded. The trigger delay after ground accelerations nominally reached 0.01 g was a little more than 1 second in each instance. If smaller earthquake recordings are of sufficient seismological and/or engineering interest an additional 2.5 second PEM could be incorporated in the existing digital systems.

Numerous foreshocks and aftershocks of magnitude 3 to 4 events (Caltech Seismological Laboratory) recorded at Salton Sea on April 26 and 27 are listed in Table 2 (also reported by Mc Junkin and Kaliakin for CDMG's Westmorland

*Use of product names or trademarks is for descriptive purposes only and does imply endorsement by the US Geological Survey.

station). Maximum accelerations equalled or exceeded 0.05g during four of those earthquakes, the largest 0.11 g five and one-half hours after the main shock. Fourteen of the aftershocks and one foreshock occurred during the instruments normal run time thus allowing the determination of S-wave minus P-wave times (S-P) and comparisons with S-t times. The foreshock S-P was 2.3 seconds compared to S-t's of 1.9 to 2.2 seconds. The aftershock S-P's within the first 30 minutes of the main shock ranged from 2.2 to 2.8 seconds compared to S-t's of 2.3 to 2.5 seconds. This suggests the trigger delay was a few tenths of a second at Salton Sea, perhaps no larger than 0.4 second. Five hours after the main earthquake, S-P's suddenly decreased to 1.3 to 1.5 seconds for all nine measurable shocks while S-t's ranged from 1.1 to 1.3 seconds, again indicating a few tenths of second trigger delay. The later aftershocks, at least those recorded by strong-motion instruments, had migrated nearer to the recording station compared to the main event and the closely following aftershocks. Relatively local seismicity has been observed during previous earthquake sequences. For instance, seven shocks recorded at Salton Sea within two weeks after the magnitude 6.4 October 15, 1979 earthquake had small S-t times of 0.9 to 1.6 seconds, and in one instance a S-P of 1.2 seconds, (Porcella & Matthiesen, 1980), indicating a relatively near source area. The epicenter of the 1979 earthquake was 66 km from the Salton Sea station.

COMMENTS

Peak accelerations during the Westmorland earthquake were approximately 0.2 g at five nearby strong-motion stations between 9 and 20 km of the epicenter.

In contrast relatively high accelerations were recorded at Westmorland at 8 km, ranging from 0.49 g horizontal to 0.80 vertical. Since Westmorland and Salton Sea are at nearly equivalent epicentral distances, one may conjecture that although the earthquake originated between the two cities, faulting at depth may have progressed southward towards Westmorland resulting in relatively high amplitude ground motions at that site. The general level of shaking was significantly larger at Westmorland throughout the earthquake with accelerations exceeding 0.25 g for more than three seconds.

Estimates of trigger delays, that is, the time it takes for the initiation of strong-motion recording after the first P-wave onset, varies from a few tenths of a second to well over 2.5 seconds. These delays can be calculated by correlating records of one earthquake from different instruments or by comparison of records of several events from a single instrument. For the Westmorland earthquake and related shocks, comparisons included; trigger times at stations equidistant from the epicenter (El Centro array), records obtained from instruments installed next to a digital accelerograph with a 2.5 second pre-event memory (El Centro 9), and S-t versus S-P times from shocks closely spaced in time (Salton Sea). Although there are several factors that influence triggering efficiency including trigger characteristic, earthquake mechanism and travel path, and site response, the ultimate triggering is directly related to the amplitude and impulsiveness of early P-wave arrivals. When P-waves are small but impulsive, even from minor earthqaukes (M = 2.0 to 3.5), the triggering efficiency in very high with at most a 0.2 to 0.4 second delay. On the other hand, when the P-waves are attenuated and have a less impulsive nature, trigger delays of several seconds may not be unusual. This is demonstrated by the 3 to 4 second delays observed at the El Centro array stations west of the Imperial Fault during the Westmorland event. These delays substantially exceeded the 2.5 second memory capability of the digital accelerograph at El Centro 9. Delays of this order of magnitude would not be anticipated at near-field stations during larger earthquakes and perhaps can be expected only at more distant sites when the induced ground response is low.

For the second time all 13 instruments in the El Centro array were triggered by a single event, thus allowing comparison of site responses for different events. The historic collection of strong-motion data from the Imperial Valley exceeds 500 records, over 300 of these from earthquakes in the past two years. More than 70 records from separate earthquakes have been obtained at El Centro 9, formerly known as the El Centro Imperial Valley Irrigation District Station since its installation in 1933. Although most records are from earthquakes less than magnitude 6 (except for the 1940 and 1979 shocks), the collection of data is the most comprehensive for a single region except for the Los Angeles area where a dense network of accelerographs provided in excess of 200 records from the 1971 San Fernando earthquake and aftershocks (Maley and Cloud, 1971). This frequent recurrent seismicity in the Imperial Valley has provided a fertile ground for the evaluation of various strong-motion recorders in a range of environmental conditions, mild to severe, with full knowledge that the system would be tested frequently by real earthquakes. The instrumentation is subject in some instances to extremely high temperatures, a considerable amount of dust in strong winds, occasional flash flooding, and the usual amount of vandalism especially where antennae and solar panels are installed. More important results pertinent to network reliability include, the adaptability of photographs recording accelerographs to high tenperature environments (exceeding 130 F), the use of modified transformer housings for ground sites, the non-adaptability of existing digital recording systems to high temperatures and to remote ground station siting because of relatively high power requirements, and the poor to failing response of downhole transducers presently due to chemical corrosion and subsequent water intrusion.

ACKNOWLEDGEMENTS

The Geological Survey thanks the numerous property owners that have allowed long term operation of seismic equipment on their land in Imperial Valley. The authors are indebted to Frank Risavich and John Nielsen who operate the Southern California strong-motion network and assisted in record recovery and processing following the Westmorland earthquake.

REFERENCES

Maley, R.P. and Cloud, W.K., 1971,
Strong-motion accelerograph records, Strong-Motion Instrumental Data on the San Fernando Earthquake of February 9, 1971, Earthquake Engineering Research Laboratory, California Institute of Technology and Seismological Field Survey, NOAA, D.E. Hudson, Editor, p. 1-53.

Mc Junkin, R.D. and Kaliakin, N.A., 1981,
Strong-motion records recovered from the Westmorland, California earthquake of 26 April 1981, California Division of Mines and Geology, 11 p.

Porcella, R.L. and Matthiesen, R.B., 1979,
Preliminary summary of the U.S. Geological Survey strong-motion records from the October 15, 1979 Imperial Valley earthquake, U.S. Geological Survey, Open File Report 79-1654, 41 p.

Porcella, R.L. and Matthiesen, R.B., 1980,
Strong-motion data summary, Imperial Valley earthquake of October 15, 1979 and aftershocks, Seismic Engineering Program Report September-December 1979, U.S. Geological Survey Circular 818-C, p. 3-60.

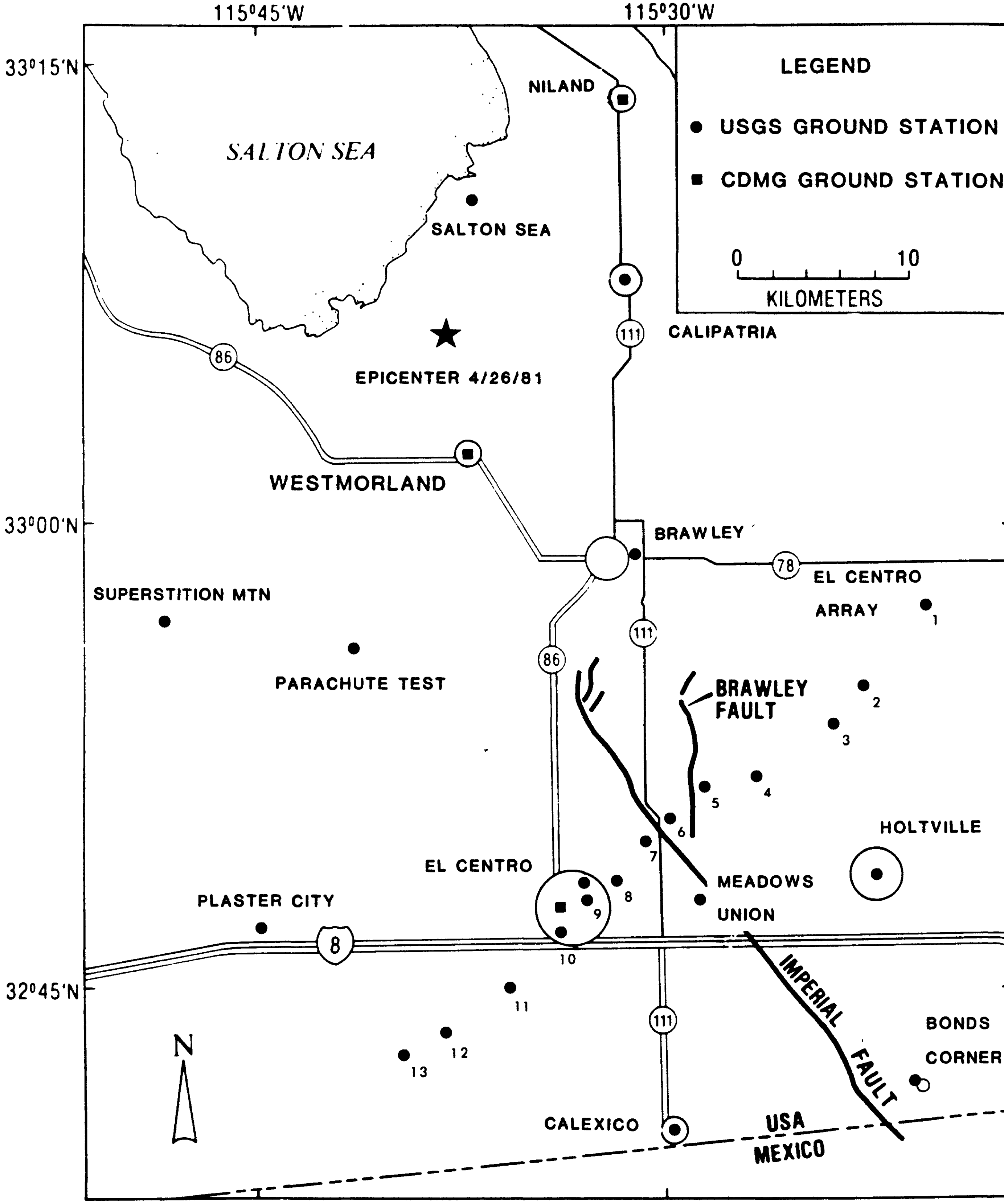

Figure 1. Strong-motion stations in Imperial Valley.

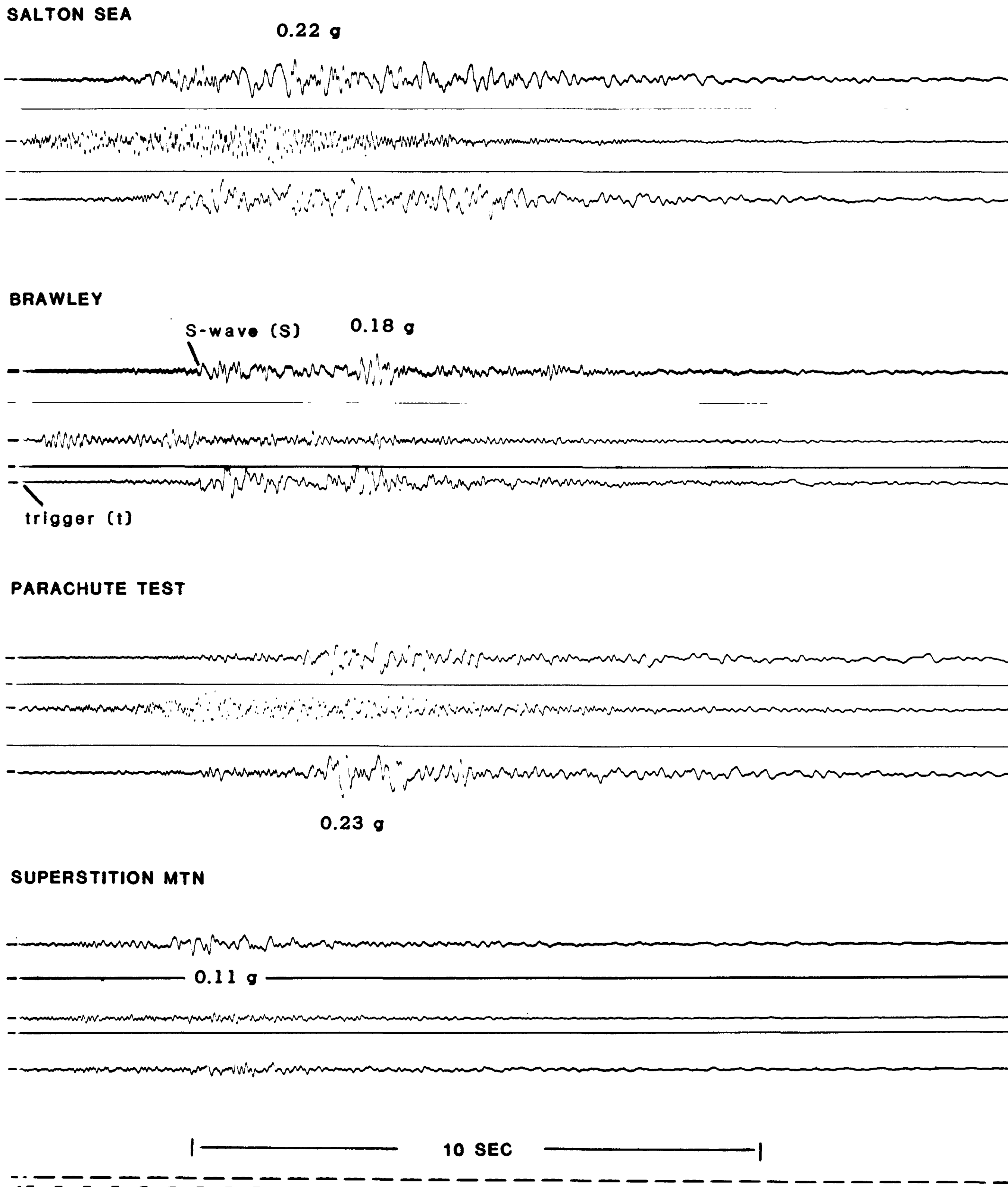

Figure 2. Strong-motion records from the Westmorland earthquake exceeding 0.10 g

Table 1 - GROUND MOTION DATA

INCLUDES ALL STATIONS LESS THAN 70 KILOMETERS FROM THE EPICENTER

Station Number	Coord	Epicentral Distance (km)	S-t[1] (sec)	Trigger[2] Time	Acceleration[3] Azimuth (degree)	Maximum (g)	Comments
Bonds Corner 5054	32.69 N 115.34 W	53					Not triggered
Brawley 5060	32.99 N 115.51 W	17	3.1	32.1	315 up 225	0.18 0.11 0.16	Pulses 0.01g were recorded for 2.8 sec.
Calexico 5053	32.67 N 115.49 W	49	5.2	41.3	315 up 225	0.02 0.01 0.02	
Calipatria 5061	33.13 N 115.52 W	12					Inoperative
Coachella Canal 1 1479	33.64 N 116.08 W	70		45.3	315 up 225	0.04 0.01 0.04	
Coachella Canal 2 5064	33.56 N 115.95 W	57					Not triggered
Coachella Canal 3 5065	33.51 N 115.77 W	46					Not triggered
Coachella Canal 4 5066	33.36 N 115.59 W	28					Not triggered
E C Diff Array 5165	32.80 N 115.54 W	34		39.2	360 up 270	0.05 0.02 0.08	
E C Meadows Un 464	32.80 N 115.47 W	37					Not triggered
El Centro 1 5056	32.96 N 115.32 W	34	2.2	37.8	230 up 140	0.05 0.03 0.06	

Table 1 - GROUND MOTION DATA

INCLUDES ALL STATIONS LESS THAN 70 KILOMETERS FROM THE EPICENTER

Station Number	Coord	Epicentral Distance (km)	S-t[1] (sec)	Trigger[2] Time	Acceleration[3] Azimuth (degree)	Acceleration[3] Maximum (g)	Comments
El Centro 2	32.92 N	32	2.3	38	230	0.05	
5115	115.37 W				up	0.02	
					140	0.03	
El Centro 3	32.89 N	33	2.5		230	0.03	
5057	115.38 W				up	0.02	
					140	0.02	
El Centro 4	32.86 N	33			230	0.02	
955	115.43 W				up	0.01	
					140	0.02	
El Centro 5	32.86 N	31			230	0.06	
952	115.47 W				up	0.01	
					140	0.05	
El Centro 6	32.84 N	32	3.3	37.9	230	0.05	
942	115.49 W				up	0.03	
					140	0.06	
El Centro 7	32.83 N	32		41.0	230	0.05	
5028	115.50 W				up	0.01	
					140	0.03	
El Centro 8	32.81 N	33		40.0	230	0.05	
958	115.53 W				up	0.03	
					140	0.05	
El Centro 9	32.79 N	34			360	0.03	
117	115.55 W				up	0.04	
					270	0.04	
El Centro 10	32.78 N	36			230	0.03	
412	115.57 W				up	0.02	
					140	0.04	
El Centro 11	32.75 N	38			230	0.06	
5058	115.59 W				up	0.04	
					140	0.05	

Table 1 - GROUND MOTION DATA

INCLUDES ALL STATIONS LESS THAN 70 KILOMETERS FROM THE EPICENTER

Station Number	Coord	Epicentral Distance (km)	S-t[1] (sec)	Trigger[2] Time	Acceleration[3] Azimuth (degree)	Acceleration[3] Maximum (g)	Comments
El Centro 12	32.72 N	43		41.9	230	0.05	
931	115.64 W				up	0.02	
					140	0.05	
El Centro 13	32.71 N	43		42.5	230	0.03	
5059	115.68 W				up	0.01	
					140	0.03	
Holtville	32.81 N	40			315	0.03	
5055	115.38 W				up	0.02	
					225	0.03	
Ocotillo Wells	33.14 N	47					Not triggered
5050	116.13 W						
Parachute Test	32.93 N	20	3.1		315	0.16	Pulses 0.10g
5051	115.70 W				up	0.16	were recorded
					225	0.23	for 2.5 sec.
Plaster City	32.79 N	40			135	0.03	
5052	115.86 W				up	0.01	
					45	0.02	
Salton Sea	33.18 N	9	2.3		315	0.19	S-P=2.2 to 2.9
5062	115.62 W				up	0.22	sec for 4 after-
					225	0.20	shocks on main
							event recording.
							Pulses 0.10g
							were recorded
							for 6.1 sec.
Superstition Mtn	32.95 N	24	2.7		135	0.11	Pulses 0.10g
286	115.82 W				up	0.06	were recorded
					45	0.09	for 0.3 sec.

1 S - wave minus trigger time.

2 Time given in seconds and tenths of seconds after 116 days, 12 hours, 9 minutes UTC. Determined from WWVB time code when signal was readable.

3 Azimuth direction of ground acceleration for upward trace motion on the accelerogram.

Table 2

FORESHOCKS AND AFTERSHOCKS RECORDED AT SALTON SEA

Trigger Time[1] Day/hr/min/sec (UTC)	S-t[2] (sec)	Arrival[3] P-Wave[3] Day/hr/min/sec (UTC)	S-P (sec)	Maximum Acceleration (g)
115/02:11:57.3	1.9			0.04
		115/02:13:18.0	2.3	*
115/ ?	2.2			*
115/07:03:16.1	2.0			0.03
The main earthquake triggered the instrument at 116/12:09:31.0				
		116/12:10:11.1	2.4	0.03
		116/12:10:28.9	2.2	0.02
		116/12:10:44.1	2.8	0.06
		116/12:10:51.3	2.8	*
Four small aftershocks with unreadable S-P intervals occurred between 116/12:10:58 and 116/12:11:41				
116/12:40:46.3	2.5			0.03
116/17:13:33.5	1.2			0.05
		116/17:13:37.5	1.5	*
		116/17:13:55.0	?	*
		116/17:14:35.0	1.3	0.02
116/17:42:27.0	1.1			0.11
		116/17:42:47.3	1.4	*
		116/17:42:52.7	1.4	0.03
		116/17:43:02.0	1.3	*

Table 2

FORESHOCKS AND AFTERSHOCKS RECORDED AT SALTON SEA

Trigger Time[1] Day/hr/min/sec (UTC)	S-t[2] (sec)	Arrival[3] P-Wave[3] Day/hr/min/sec (UTC)	S-P (sec)	Maximum Acceleration (g)
116/18:22:18.5				*
116/20-23:42:19.8 [4]	1.3			
		116/20-23:42:33.4	1.4	*
		116/20-23:43:38.7	1.7	0.06
		116/20-23:42:43.7	1.3	*
		116/20-23:43:03.2	1.4	*

1 Start of the recording, usually sometime during P-wave arrivals.

2 S-wave arrival time minus trigger time.

3 First P-wave arrival time when the entire earthquake was recorded during an operating interval.

4 Part of the WWVB hour code was unreadable.

* Maximum acceleration 0.01g.