GEOFISICA INTERNACIONAL

STRONG MOTION RECORDS OF THE OAXACA, MEXICO, EARTHQUAKE OF NOVEMBER 29, 1978

J. PRINCE*
L. ALONSO*
C. F. KNUDSON**
I. NAVARRO*
and P. N. MORK**

RESUMEN

l sismo principal del 24 de noviembre de 1978 en el sur del estado de Oaxaca, México, con ıagnitud MS = 7.8, produjo daños ligeros en construcciones modestas, principalmente de adoe, muy similares a las que fueron destruidas en gran proporción por los sismos de Guatemala el 4 de febrero de 1976.

Aunque por falta de instrumentación permanente para movimientos fuertes en la zona epientral no se obtuvo un solo acelerograma en la región más afectada, las aceleraciones máximas).22 g) registradas en la ciudad de Oaxaca, a más de 100 km del epicentro, sugieren aceleracioes máximas considerablemente mayores en Puerto Escondido y Puerto Angel, a 30 y 35 km el epicentro revisado.

Observaciones análogas de daños ligeros asociados a aceleraciones máximas superiores a 0.5 g e han realizado en Acapulco, situado en la misma zona de subducción de la costa del Pacífico.]l nivel reducido de daños en construcciones débiles de adobe todavía queda sin explicación saisfactoria.

* *Instituto de Ingeniería, UNAM.*
** *US Geological Survey, Menlo Park, California, USA.*

1. INTRODUCTION

One remarkable aspect of the Oaxaca, Mexico, earthquake of November 29, 1978 (19:52:53.2 UT, M_S = 7.8) was the relatively light damage produced at various epicentral distances, specially in towns as Puerto Escondido and Puerto Angel, where weak construction and adobe houses are often found. The first data provided by the USGS in their Preliminary Determination of Epicenters ("Preliminary Determination of Epicenters", 1978) gave a 49 km focal depth at coordinates (16,072N, 96,487W) which would give epicentral distances from Puerto Escondido and Puerto Angel of 52 and 76 km. These distances were somehow reassuring in the sense that they could possibly account for the light damage in those places.

The results of more detailed studies soon showed that this was not the best explanation, later studies gave a shallower (18 km) depth of focus and a revised epicentral (15.767N, 96,800W). This new epicenter as shown in Fig. 1 is much closer to Puerto Escondido and Puerto Angel (Singh *et al.*, 1980; Ponce *et al.*, 1979; Ponce, Núñez-Cornú and Sumín de Portilla, 1979). The light damage therefore is difficult to explain.

A single strong-motion record from the epicentral area might have answered many of the questions on the subject but, in contrast to the wealth of local seismological information collected from foreshocks, main event and aftershocks, such a record was unfortunately not obtained. There were no strong-motion instruments in the epicentral area at the time of this Oaxaca earthquake.

Although more than ten accelerographs were installed soon after the mainshock, and were kept there for about one and a half months (5), only a few minor aftershocks were recorded. The nearest strong motion station with an accelerograph located in Oaxaca City, over 100 km away, provided excellent records of the mainshock and also the first two strong aftershocks that occurred within an hour (Espinosa, J. M. *et al.*, 1978).

Since several companion papers provide in great detail the pertinent seismological information about the earthquake, no data of this type other than that already included in the previous paragraphs will be given here.

2. STRONG - MOTION INSTRUMENTATION AND RECORDED EARTHQUAKES

2.1 *Stations operational during the mainshock*

The strong-motion accelerograph located in the city of Oaxaca* (Fig. 1) is of the self-triggered SMA-1 type, which records the ground acceleration from about 0.01 g up to 1 g, in the range 0.08-25 Hz, along two horizontal (at 90°) axes and one vertical axis on 70 mm film. Time marks generated by an internal clock every 0.5 sec are simultaneously recorded. A more complete description of this instrument is found in refs (Halverson, 1973; Mora *et al.*, 1979; Hudson, 1979).

The other SMA-1 accelerograph in the State of Oaxaca, located in Huajuapan de León Fig. 1, at a distance of 250 km from the epicenter, was not triggered by the earthquake sequence. It is possible that it was not in good operational condition at the time of the earthquake. Eleven additional strong motion accelerographs were located at distances between about 340 to 470 km from the epicenter, as shown in Fig 1. The two closest ones were those in PEMEX (the official oil company) installations at Minatitlán (344 km) and Pajaritos (365 km). These are of the older RFT-250 type (Hudson, 1979; Eisenberg and McEvilly, 1971) and were triggered only once by the earthquake sequence, in all likelihood by the main event. All three AR-240 accelerographs (Hudson, 1979; Eisenberg and McEvilly, 1971) located at the crest, toe and right abutment of the Malpaso Dam of the Federal Commission of Electricity (CFE), at an epicentral distance of 375 km were triggered, independently of one another, by their horizontal-motion starter.

The two instruments (SMA-1 's) located in the Laguna Verde Nuclear Power Project of the CFE are of the SMA-1 type. Although they were installed on the same concrete pier, they are not interconnected and are entirely independent. At an epicentral distance of 403 km and founded on solid rock, neither of these instruments was triggered.

*This instrument is owned by the Ministry of Human Settlements and Public Works. (SAHOP)

Two AR-240 accelerographs were triggered by the horizontal motion of the main event at Mexico City, about 470 km distant from the epicenter.

Finally, two more accelerographs are located in Acapulco, at an epicentral distance of nearly 350 km; one is an AR-240, founded on sound rock, which was not triggered by the Oaxaca earthquakes. The other is a SMA-1 on a 7 m thick stratum of compact alluvium overlaying rock. The film in this instrument was removed on December 18, 1978 and three recordings with small amplitudes were found. Since there is no absolute time in this record, the previous maintenance visit to the site had taken place more than three months earlier and as small earthquakes are frequent in Acapulco, it is not certain which, if any, corresponds to the main Oaxaca event. No further reference to these records will be made.

The only other facility operational at the time of the mainshock and capable of accurate recording of ground acceleration, even at low levels (< 0.01 g), is that of SISMEX (Prince *et al.*, 1973; Prince and Rodríguez, 1977), whose field and central recording stations are located about 400 to 500 km from the epicenter, Fig. 2.

The main characteristics of the records obtained by operational instruments at the time of the mainshock has been summarized in Table 1. Aftershocks A and B in Table 1 refer to the following events: of all the aftershocks that followed the main event there were two within an hour that produced measurable accelerations in SISMEX stations (Espinosa, J. M. *et al.*, 1978) and were felt in Mexico City. These two aftershocks are marked A and B in Fig. 3, which shows in a compressed time scale the records provided by the 5 SP vertical geophones of the SISMEX telemetry network (Espinosa, J. M. *et al.*, 1978) during the mainshock and the subsequent 94 minutes. Fig. 3 is a play back of an analog tape which included the five seismic signals shown and the minute marks of a time code generator that was found to be 0.036 sec slow when compared with, WWV time.

The main portion of the three accelerograms that were recovered from the Oaxaca City SMA-1 strong motion instrument are shown in

Fig. 4 (mainshock) and Figs. 5a, b (aftershocks marked A and B in Fig. 3). Since there is lack of absolute time in these records there is no certainty that they correspond to those aftershocks. However, once it is accepted that the record in Fig. 4 is that of the main event, the relation of those in Fig. 5 to aftershocks A and B is given credence by the following facts:

a) Records in Figs. 5a and 5b appear later than the mainshock on the film that was collected in Oaxaca City on December 3, 1978. Therefore, no aftershocks after that date need be considered.

b) The peak accelerations in the last record are from about 0.46 to 0.63 times those of the mainshock. According to PDE information (1), the most likely event to produce such accelerations in Oaxaca City within the specified period is precisely aftershock B in Fig. 3, which ocurred slightly less than one hour after the mainshock and had a magnitude M_b = 5.8, the highest of all aftershocks. This event was clearly felt in Mexico City.

The above arguments, the relative duration of events in Fig. 3 and the magnitude of the peak accelerations in the middle record (fig. 4a) seem to indicate its association with aftershock A in Fig. 3.

2.2 *Instruments deployed for aftershock recording*

At least two groups from the United States installed strong-motion instruments for aftershock recording in the epicentral are. One was from the University of California, San Diego (Suarez, F. *et. al.*, 1979) whose selection of sites is shown in Fig. 6. This group obtained only very small and unimportant records (Brune, J. N., 1979); no further reference to these will be made.

The second group, from the Seismic Engineering Branch of the U. S. Geological Survey (USGS), deployed a combination of 10 analog and one digital strong motion instruments in the neighborhood of the epicentral area, as shown in Fig. 6. These accelerographs were operational from about December 8, 1978 to May 1979. Only three of the analog

instruments were triggered by aftershocks before the end of January 1979; all the pertinent data for these recordings is presented in Table 2. As this table shows, the peak accelerations produced by the recorded aftershocks do not exceed 40 to 60 gals for magnitudes (M_b) close to 5, even at epicentral distances of considerably less than 100 km according to USGS (PDE) determinatons. If, as shown in Singh, S. K. *et al.*, 1980 and Ponce, L. *et al.*, 1978), these determinations also tend to be in error to the East, the corresponding epicentral distances to the recording sites would be reduced. These observations are consistent with the association of the third Oaxaca City accelerogram with aftershock B in Fig. 3.
celerogram with aftershock B in Fig 3.

3. DATA PROCESSING AND INITIAL RESULTS

While the detailed processing and interpretation of strong motion data still continues well into 1979, some results pertaining to the mainshock accelerogram obtained in Oaxaca City are presented in this report.

Negative contact copies of the original record were the starting point for the processing undertaken independently by two collaborating groups: that of the Institute of Engineering, University of Mexico (I of E) and that of the Menlo Park Branch of the USGS. The first results are shown in Figs. 7 to 9, for the NS, Vertical and EW components, respectively. In the upper part of these figures are the time histories of acceleration, velocity and displacement as obtained at the I of E; the lower part shows the corresponding curves derived by the USGS group.

It is to be noted that the acceleration time histories in Figs. 7-9 approximate one another very closely and that the peak values agree within about 2 percent. Differences in velocity and displacement are somewhat larger but deemed within reasonable limits if it is remembered that though the two groups have used the same basic computer programs (Trifunac, M. D. and Lee, V., 1973), the digitization apparatus and techiques, the starting and finishing points, and the filtering criteria, were completely independent.

The peak accelerations indicated in Figs. 7-9 for all three components are lower, by as much as 10 percent, than the preliminary values (Espinosa, J. M. *et al.*, 1978) reproduced in Table 1. These differences can be explained in part by errors in measuring the small amplitudes of the original record and also, to some extent, by the instrument correction and filtering process.

The strong motion accelerograms shown in Figs. 4 and 5 may provide an indication about hypocentral distance. It has been observed (Hudson, D. E., 1979) that the vertical starter of the SMA-1 accelerograph is often triggered by the arrival of P. Once this is accepted and the response time of the Oaxaca City instrument (of the order of 0.1 sec, Halverson, H. T., 1973) is regarded as constant for the mainshock and aftershocks A and B, the following estimates for minimum hypocentral distances of the latter events may be derived from the known parameters of the mainshock.

Event	S-Trigger Time (sec)	Focal distance (km)
Mainshock	16	148
Aftershock A	13	121
id B	13	121

Values other than the focal distance from the mainshock should only be taken as indicative, for they are based on approximate values of S-trigger times and the assumption of equal propagation velocities for the three events. In any case, the suggestion of shorter focal distances for aftershocks A and B than for the mainshock is in agreement with PDE information for the last of the three events considered ("Preliminary Determination of Epicenters", 1978).

4. MAXIMUM ACCELERATIONS AND EPICENTRAL DISTANCES

The Peruvian earthquakes of October 17, 1966 and May 31, 1970 produced strong motion records which were deemed unusual mainly because when their peak accelerations are plotted against epicentral distances, they are seen to exceed, by factors of about 2 to 4, the trends established by numerous other major earthquakes (Cloud, W. K. and Pérez, V., 1971). The maximum accelerations recorded in Oaxaca City during the November 29, 1978 earthquake are on the (upper) boundary of such trends and somewhat beyond. The small black squares in Fig. 10 represent the peak accelerations included in Table 1 for the mainshock. Except for one point at almost 500 km, all are close to the upper boundary indicated. In particular, the peak value at Oaxaca City (220 gals) has been plotted as a dark rectangle: its extreme left corresponds to the epicentral distance derived from preliminary USGS determination ("Preliminary Determination of Epicenters", 1978) and the right end to the revised epicenter (Ponce, L. *et al.*, 1978).

It is also of interest to note that one of the most recent and complete reports on attenuation of peak acceleration with distance in the Western United States, which considers accelerograms recorded during 57 earthquakes from 1933 to 1971 (Trifunac, M. D. and Brady, A. G., 1976), would predict only about one-fifth of the peak acceleration recorded in Oaxaca City. From this and similar observations it might be inferred that the characteristics of strong ground motion produced by earthquakes generated in a region, widely recognized as a subduction zone, are significantly different from those of motion associated with strike and/or dip-slip phenomena which are the most usual in California.

5. REPORTED DAMAGE

Weak adobe houses are abundant in the area most affected by the November 29, 1978 Oaxaca earthquake. According to the damage statistics compiled by State authorities (Ponce, L., Núñez-Cornú and Sumín de Portilla, 1979), the heaviest damage was experienced in the Loxicha region at an average epicentral distance of 30 km. On the other hand, the degree of damage experienced in towns such as Puerto Escondido (Δ = 30 km) and Puerto Angel (Δ = 35 km) was much lower than would normally be expected from a M_S = 7.8 earthquake. The generalized damage occurring in similar constrution during recent events of considerably lower magnitude, such as the Managua (December 23, 1971) and Guatemala (Februay 4, 1976) earthquakes is in some conflict with the relatively light damage observed in Oaxaca. Although this relatively low damage level of the 1978 Oaxaca earthquake might also be suggestive of significantly different effects on adobe structures from strike-slip and certain subduction earthquakes, the severe damage experienced in the past in the same general area of the Pacific Coast clearly points in the opposite direction.

The peak ground acceleration recorded during an earthquake has for a long time been the one quantity most often used to describe the severity of the motion. However, it has been recently reported that peak accelerations as high as 0.54 g and 0.85 g were recorded in Acapulco during earthquakes which caused negligible damage (Prince, J. and I. Navarro, 1979). Acapuldo is 350 km WNW from the Oaxaca November 29 earthquake epicenter.

Among construction materials, adobe might be considered as having simpler mechanical properties than for example, reinforced concrete. The fact that neither magnitude nor peak ground acceleration necessarily determine the degree of damage in adobe houses seems to indicate that there are other important elements that are not properly taken into account. Factors from both the Geophysics and the Engineering fields, such as the rate of strain release and energy focussing on the one hand, and collapse mechanisms on the other, to name just a few, still deserve the concerted efforts of many people.

6. CONCLUSION

The November 29, 1978 Oaxaca, Mexico earthquake has provided seismological data of unusual completeness in contrast with the scarcity of strong-motion recordings of direct engineering application. Although useful, the few accelerograms obtained leave unresolved several important questions about construction behavior in the epicentral area, attenuation of ground motion with distance, local effects depending mainly on soil conditions, etc., which are of engineering interest. The intallation of a significant number of additional strong-motion accelerographs in the subduction zone of the Pacific Coast is considered to be of the utmost importance.

7. ACKNOWLEDGEMENTS

The Ministry of Human Settlements and Public Works (SAHOP) and the Federal Commission of Electricity (CFE) are the owners of most of the permanent strong motion instrumentation referred to in this report. Their continued support is gratefully acknowledged. The information on the earthquake provided by the Institute of Geophysics has been invaluable: special mention should be made of Dr. Ignacio Galindo, Director and Dr. Lautaro Ponce.

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TABLE 1 PEAK ACCELERATIONS AND EPICENTRAL DISTANCES FROM PERMANENT INSTRUMENTS

STATION	INSTR. TYPE	DIRECTION	EPICENTRAL DISTANCE (km)	PEAK ACCELERATION (gals) NS	VERT	EW	DURATION (sec)
MAINSHOCK							
Oaxaca, Oax.	SMA-1	N 3.46 E	147	220	90	158	69
Minatitlán, Ver.	RFT-250	N 45.60 E	344	45	26	53	180
Pajaritos, Ver.	RFT-250	N 45.81 E	366	24	X	21	141
Malpaso, Corona	AR240	N 66.69 E	375	X*	X	X**	34
Malpaso, Base	AR240	N 66.69 E	375	X*	X	X**	31
Malpaso, Marg.Der	AR240	N 66.69 E	375	X*	X	X**	40
Puebla, Pue.	SISMEX	N 22.30 W	394	13	10	22	58+
Cd. Universitaria, D.F.	SISMEX	N 33.79 W	469	24	5	21	114+
Hospital ABC, D.F.	SISMEX	N 34.00 W	471	5	4	4	3+
Ed. Hidalgo, D.F.	AR240	N 32.43 W	479	22	X	19	188
AFTERSHOCK A							
Oaxaca, Oax.	SMA-1	?	?	56	38	42	44
Puebla, Pue.	SISMEX	?	?	3	1	3	-
Cd. Universitaria, D.F.	SISMEX	?	?	2	1	2	-
Hospital ABC,D.F.	SISMEX	?	?	a	a	a	-
AFTERSHOCK B							
Oaxaca, Oax.	SMA-1	?	?	102	48	100	55
Puebla, Pue.	SISMEX	?	?	4	1	6	17+
Cd. Universitaria D.F.	SISMEX	?	?	4	2	6	19+
Hospital ABC D.F	SISMEX	?	?	a	a	a	-

a <1 gal
\+ acceleration <4 gals
* Longitudinal ** Transverse

TABLE 2 PEAK GROUND ACCELERATIONS IN SOUTHERN OAXACA DURING AFTERSHOCKS OF THE 29 NOVEMBER 1978 OAXACA, MEXICO EARTHQUAKE (STRONG MOTION AFTERSHOCK INSTRUMENTATION)

DATA (UT)	Hour (UT)	Minute	Mb	STATION (See fig 6) Rancho Rosedal (15.90 N, 96.93 W)				Puerto Escondido (15.85 N, 97.11 W)				San Gabriel Mixtepec (16.08 N, 97.10 W)			
				PEAK ACCELERATIONS (gals*) AND EPICENTRAL DISTANCES (km)											
				S68E	V	N22E	Δ,km	N48E	V	S42E	Δ,km	N70W	V	N20E	Δ,km
091278	11	03		10	10	20	-								
121278	14	01										16	14	16	-
191278	18	10										60	50	55	-
201278	03	52										38	10	30	-
281278	19	20	4.7									38	26	38	72
281278	19	49	5.3	30	15	27	63								
291278	19	56						06	06	06	-				
291278	23	08						06	06	08	-				
100179	04	30	5.2									30	06	33	77
Instrument installation **				181278 (23:30)				091278 (14:39)				091278 (18:20)			
Instrument removal				170179 (21:17)				170179 (16:10)				180179 (16:01)			

* 1 gal= $1 cm/sec^2$

** or last test run before first triggering

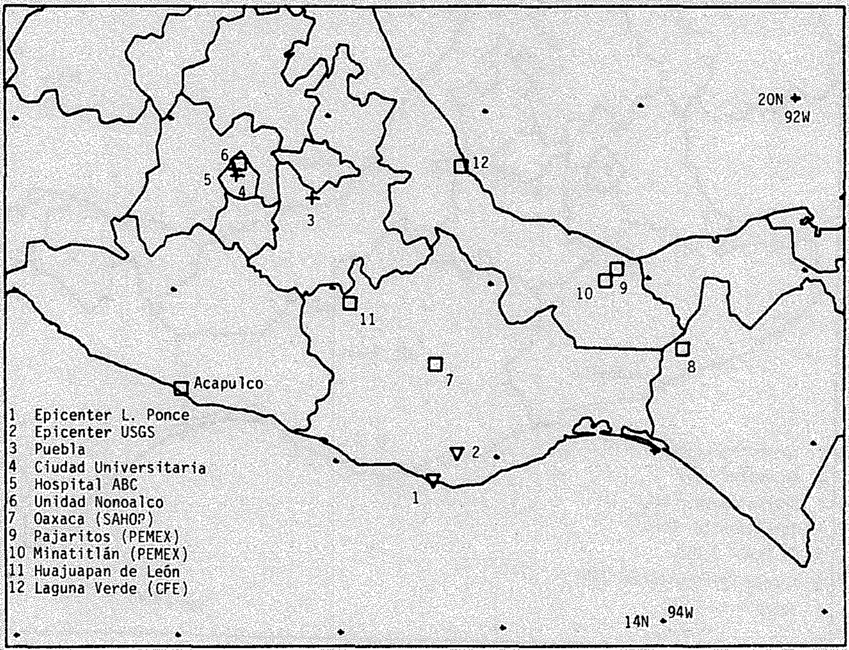

FIG 1 ACCELERATION RECORDING STATIONS: SISMEX (+) AND STRONG MOTION ACCELEROGRAPHS (□)

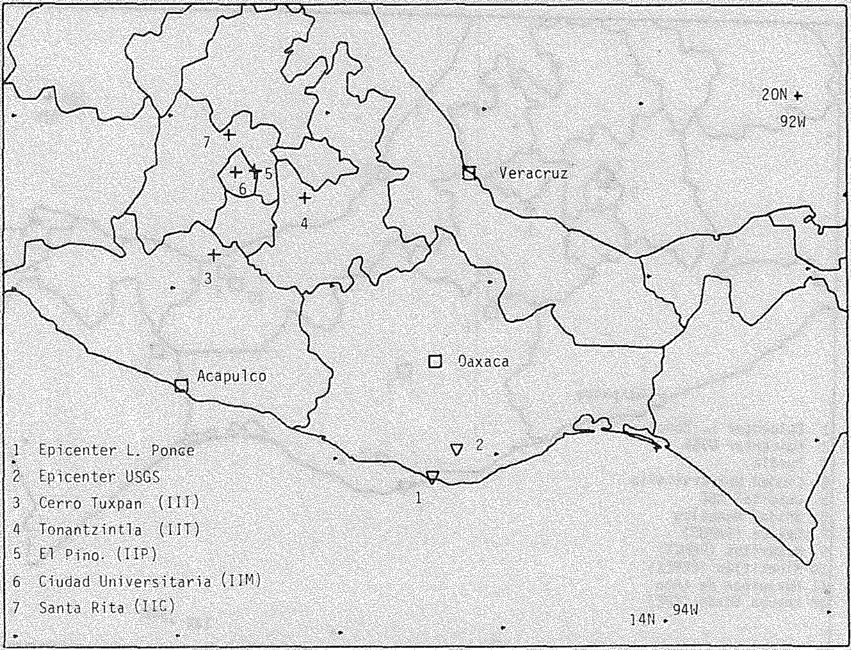

FIG 2 SISMEX SP VERTICAL GEOPHONES (+) AND MAINSHOCK EPICENTERS (▽)

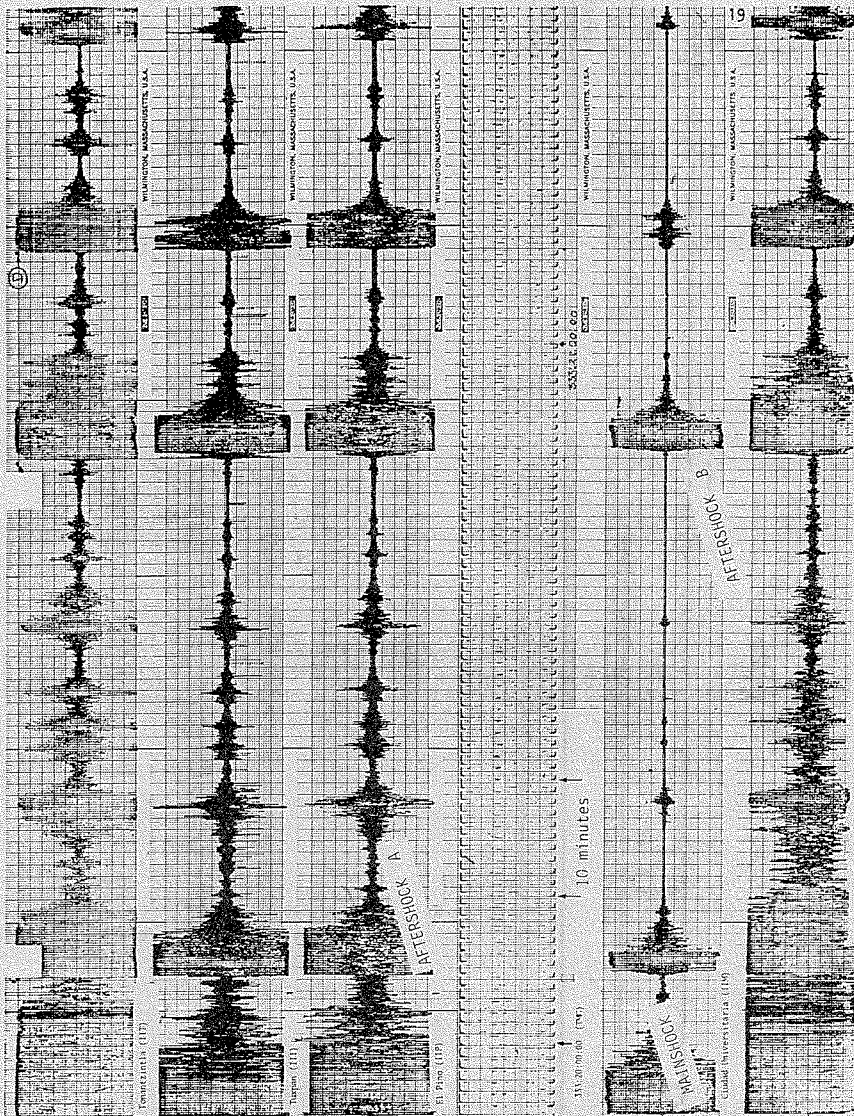

FIG 3 SEISMOGRAMS OF THE 5 SP VERTICAL SISMEX STATIONS-MAINSHOCK + 94 MIN (Ref 6)

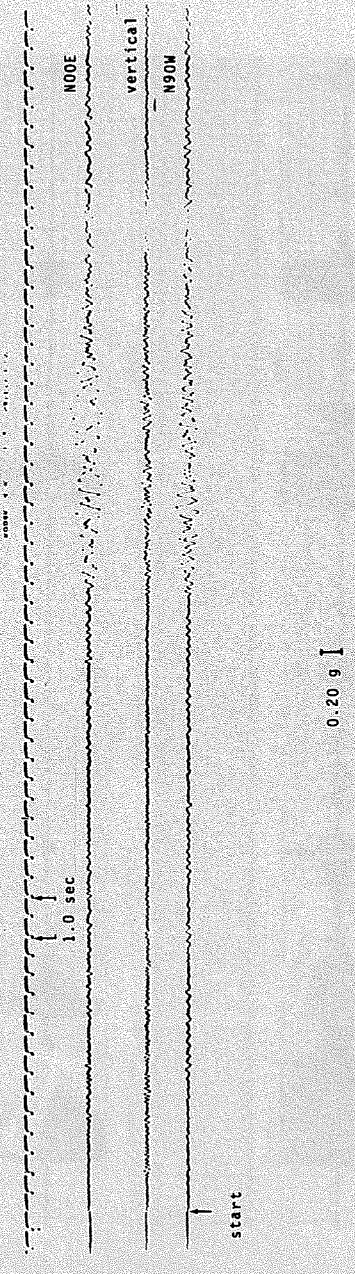

FIG 4. ACCELEROGRAM OF MAINSHOCK IN OAXACA CITY. NOVEMBER 29, 1978 OAXACA, MEXICO EARTHQUAKE

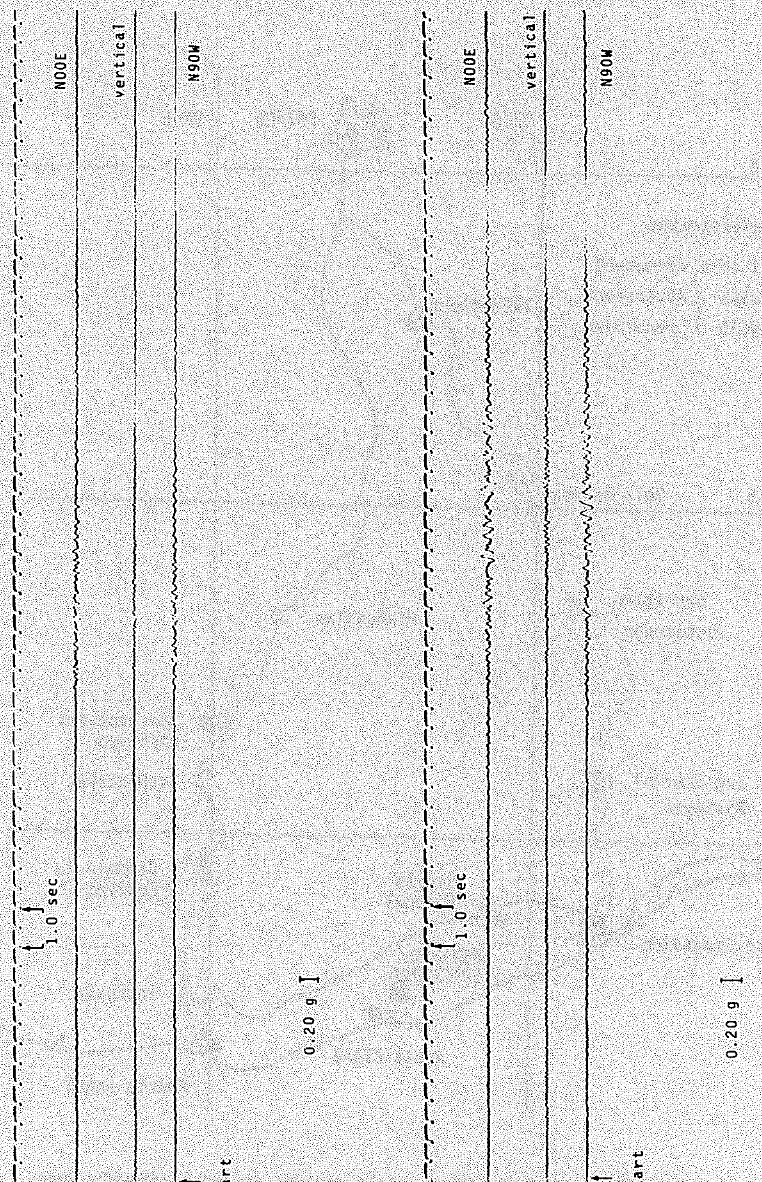

FIG 5. ACCELEROGRAMS OF AFTERSHOCKS A (TOP) AND B (BOTTOM) IN OAXACA CITY. NOVEMBER 29, 1978 OAXACA MEXICO EARTHQUAKE

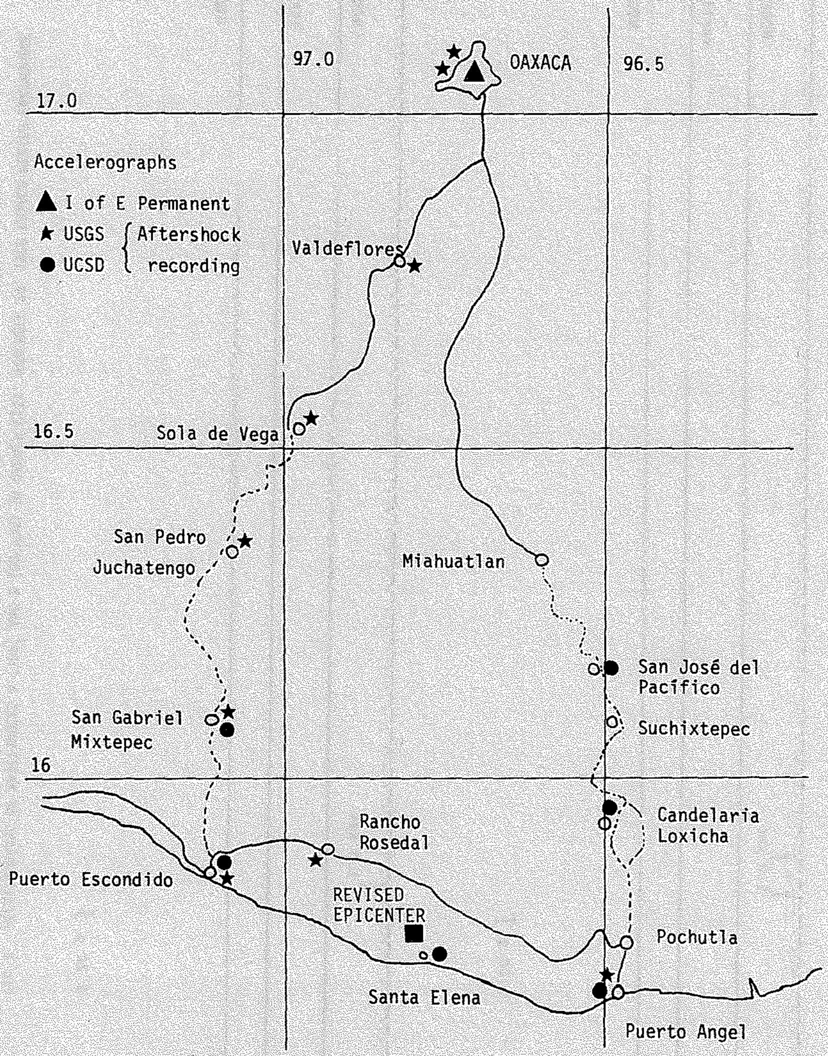

FIG 6. Strong motion accelerographs in the earthquake zone.

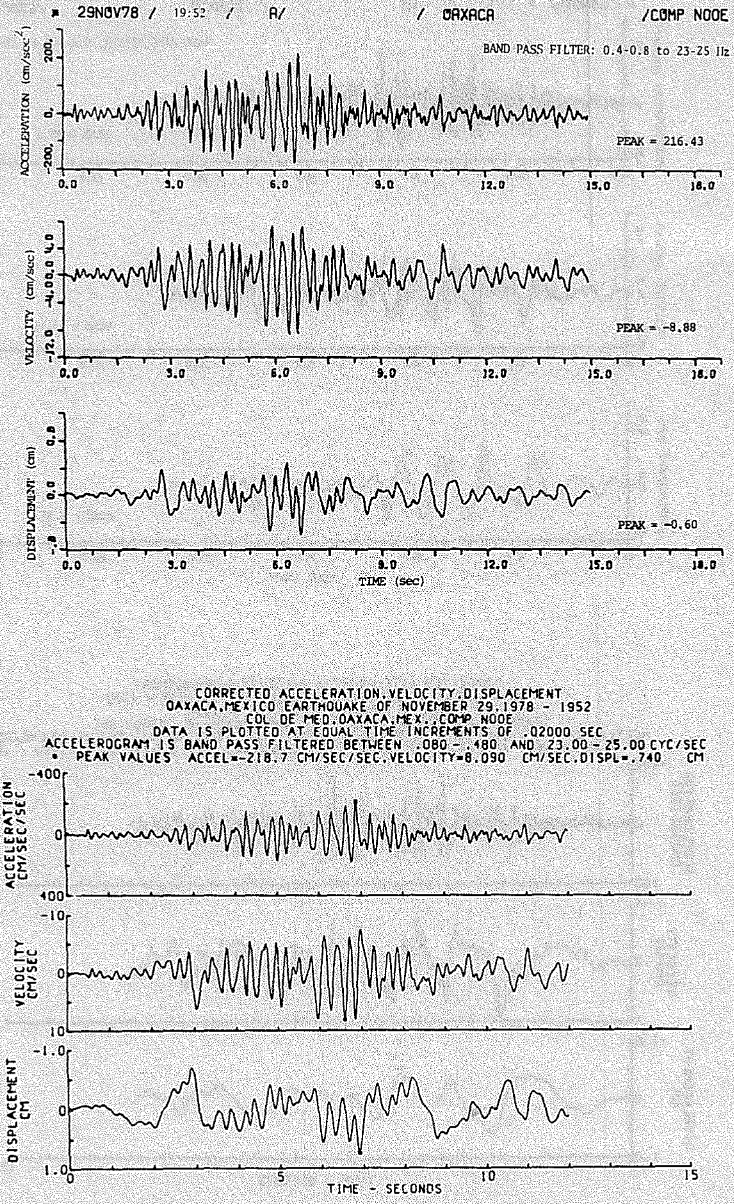

FIG 7. TIME HISTORIES OBTAINED BY THE INSTITUTE OF ENGINEERING (TOP) AND USGS (BOTTOM), N-S COMPONENT

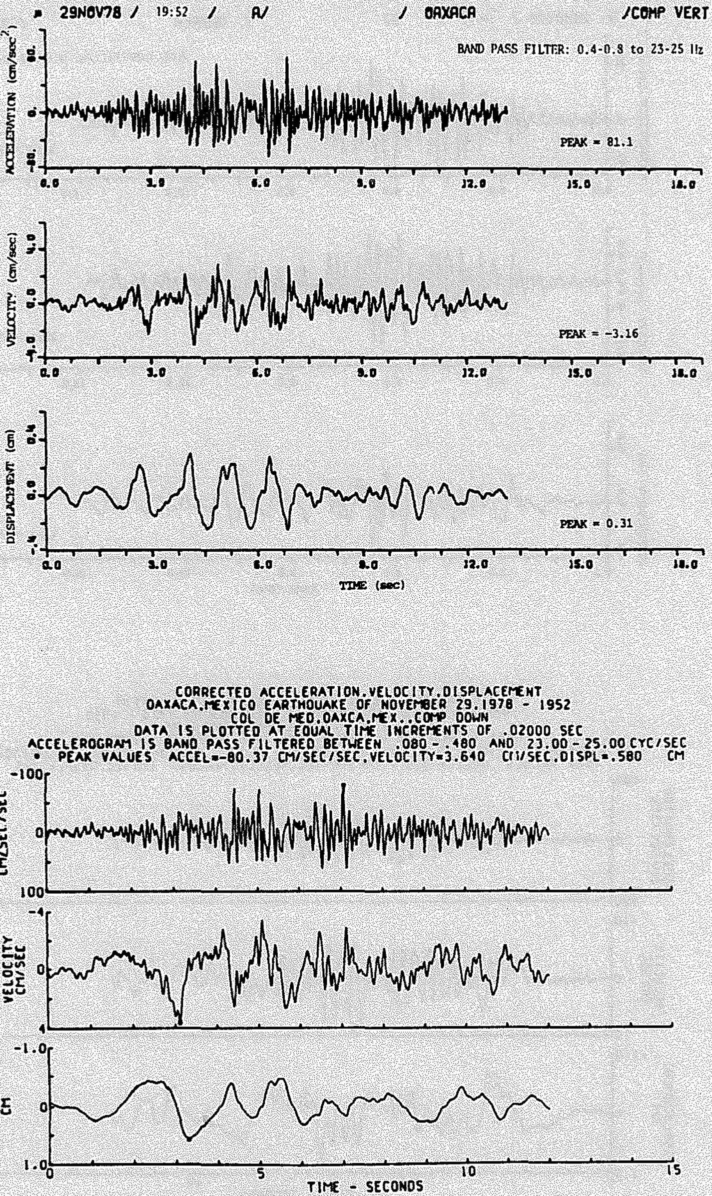

FIG 8. TIME HISTORIES OBTAINED BY THE INSTITUTE OF ENGINEERING (TOP) AND USGS (BOTTOM), VERTICAL COMPONENT

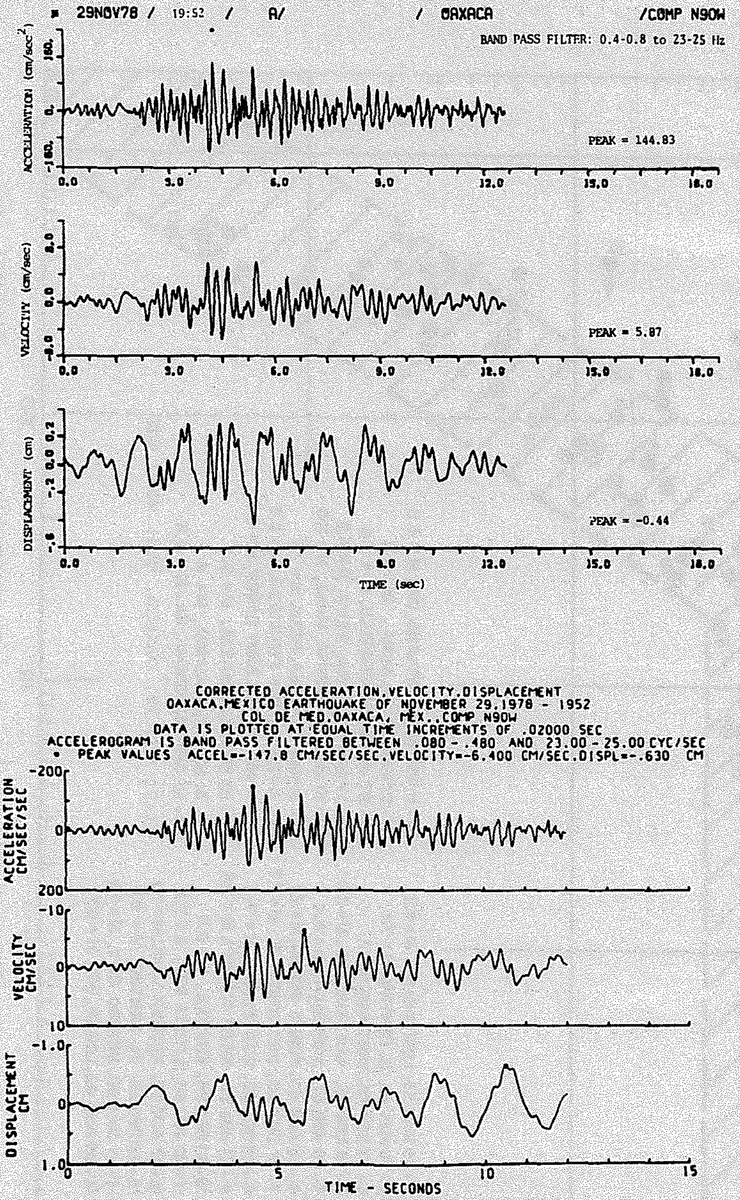

FIG 9. TIME HISTORIES OBTAINED BY THE INSTITUTE OF ENGINEERING (TOP) AND USGS (BOTTOM), E-W COMPONENT

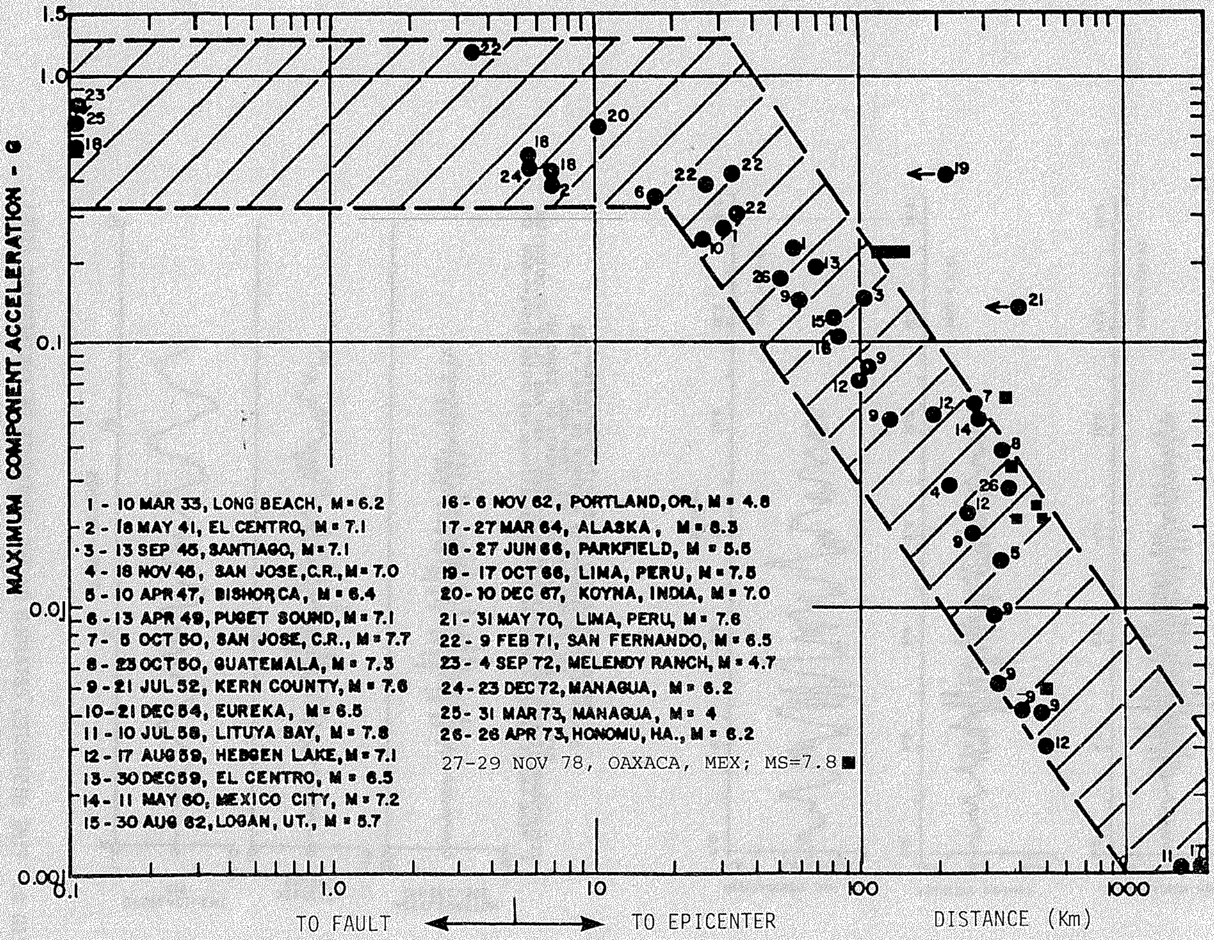

FIG 10 ATTENUATION OF MAXIMUM RECORDED ACCELERATION SHOWING THE OAXACA EARTHQUAKE DATA (AFTER CLOUD & PEREZ, 1971 and NIELSEN et al, 1977)

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