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WORLDWIDE STRONG-MOTION INSTRUMENTS

CHARLES F. KNUDSON*

INTRODUCTION

The oldest strong-motion seismograph on record, an ornamental, carved dragon and toad seismoscope, was installed in China in AD 132 by Chang Heng. Eighteen hundred years elapsed before a real satisfactory strong-motion seismograph was developed and installed in the United States. Dr. K. Suyehiro, of Japan, and Mr. John R. Freeman, of the United States, were early pioneers in earthquake engineering, and their influence awakened the public and the Government to the necessity of funding much needed earthquake engineering research. As a result of this awakened interest, a congressional appropriation was made available to the U.S. Coast and Geodetic Survey in 1931 for engineering seismology. Through the cooperative efforts of the National Bureau of Standards, Massachusetts Institute of Technology, University of Virginia, and the U.S. Coast and Geodetic Survey, an accelerograph was developed, and the first four were then installed in July, 1932 in southern California. This installation was well-timed. Quoting from a report by N. H. Heck : "Three months ago at Long Beach, California, for the first time in the history of earthquake study, the acceleration of a destructive shock was measured at a distance of less than 20 miles from the point of origin. A short time before the destructive earthquake of March 10, 1933, the U S. Coast and Geodetic Survey had completed the installation of three accelerograph stations in the Los Angeles-Long Beach area. Excellent records of the earthquake accelerations were obtained at these stations. The results are unusually important to engineers as well as seismologists in showing much greater acceleration than had been thought likely to occur in southern California."

The increased demand for more precise earthquake engineering information has led to development of new instruments throughout the world. Japan now leads the United States in the number of strong-motion seismographs. Japan had 510 stations as of March 31, 1969, compared to the 375 in the United States as of December 31, 1969. Other countries throughout the circum-Pacific and Alpide earthquake belts have built or purchased and installed strong-motion instruments in their own earthquake-prone regions. Descriptions of the various strong-motion instruments in use and their locations in the different countries of the world are given for the following countries in this paper : Japan, United States, New Zealand, Canada, Argentina, Venezuela, Mexico, Chile, El Salvador, Costa Rica, Nicaragua, India, Guatemala, Peru, Colombia, Ecuador, Panama, Russia, and Pakistan. The continual demand for more strong-motion instruments soon makes any listing obsolete. The author has endeavored therefore to only list in this paper all the known strong-motion instruments installed as of January 1, 1970.

The world map, figure 1, showing the location of strong-motion seismographs, might also be used as a map to locate destructive earthquakes, for a concentration of strong-motion instruments will usually be found wherever any recent destructive earthquakes have occurred. As a result of the 1964 Alaska earthquake, 15 strong-motion seismographs and 100 seismoscopes were purchased and installed in an Alaskan network of stations. Following the El Salvador earthquake of May 3, 1965, three accelerographs and 25 seismoscopes were purchased and installed. The July,

* Assistant Chief, Seismological Field Survey, U. S. Coast and Geodetic Survey, ESSA.

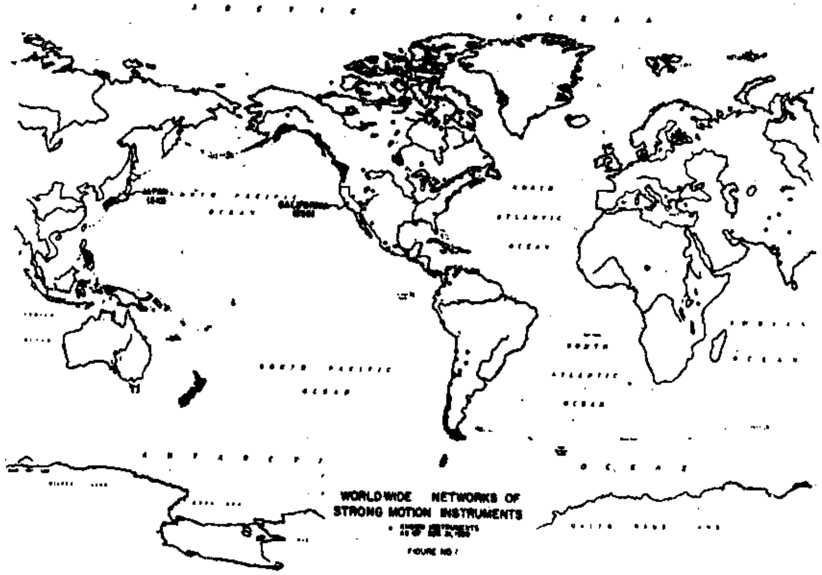


Fig. 1. World-wide networks of strong-motion instruments.

1967, Caracas, Venezuela, earthquake resulted in the purchase and installation of 10 new strong-motion seismographs.

JAPAN

Figure 2 is a map of Japan showing the location of the 510 strong-motion instruments installed there as of March 31, 1969. The Japanese have come a long way since their report of June, 1956, of 10 SMAC instrument installations to the present-day number of over 500.

In 1951, a "Committee for the Standard Strong-motion Accelerograph" was formed. Through the work of this committee a strong-motion seismograph named "SMAC-type" was manufactured and the first model was installed in July, 1953. In order that as many strong-motion accelerographs be installed throughout Japan as is possible within budgetary limitations, a reasonably priced instrument, the "DC Accelerograph," was also developed. Figures 3 and 4 are pictures of these Japanese instruments. The SMAC-type accelerograph was improved throughout the years in the order of Model A, B, 5–B2, C, C2, D, to today's Model E. The SMAC-E uses scratch recording on 3–mm film rather than the 290–mm waxed paper used on the earlier models. The characteristics of the Japanese strong-motion instruments are given in table 1.

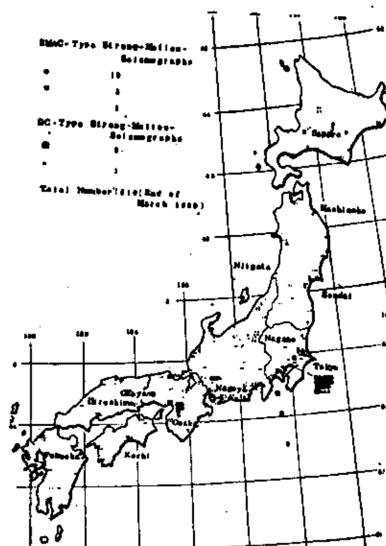


Fig. 2. Distribution of accelerographs installed.

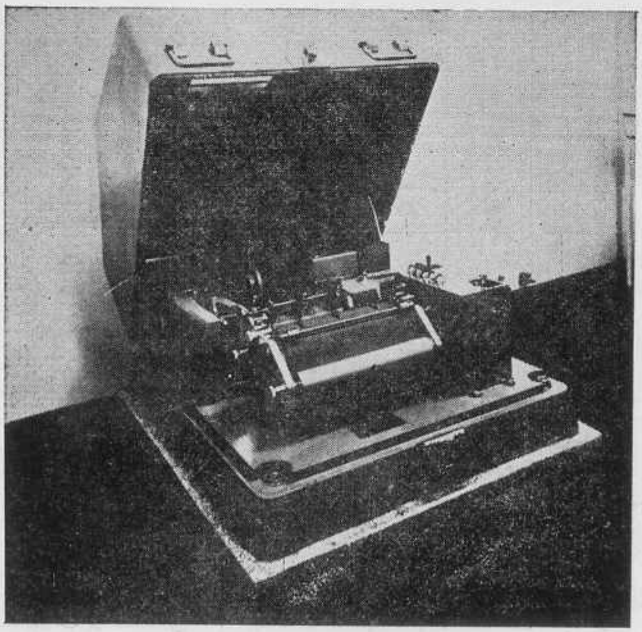


Fig. 3. Akashi SMAC-A strong-motion accelerograph.

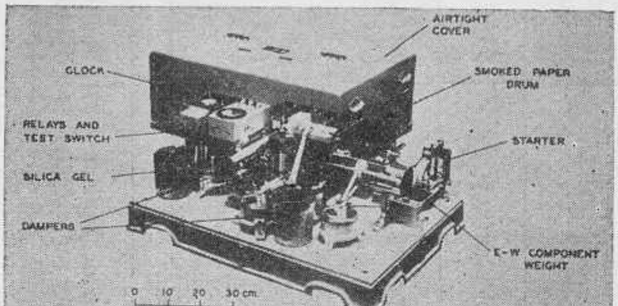


Fig. 4. Japanese type DC-3 strong-motion earthquake accelerograph.

Table 1. Comparison of performances of various types of accelerographs

Characteristics \ Name	SMAC-A (A2)	SMAC-B (B2)	SMAC-C (C2)	SMAC-D	SMAC-E	DC-2 (DC-3)
Component	2 Horizontal 1 Vertical	ditto	ditto	ditto	ditto	2 Horizontal (DC-3...2H. IV.)
Type	Horiz. pendulum	ditto	Inverted pendulum	Horiz. pendulum	ditto	ditto
Weight of bob (kg)	5.0	5.1	5.1	5-3	4.3	8.5
Natural period (sec)	0.1(A2... (A2...0.14)	0 1 (B2...0.14)	0.1 (C2...0.14)	0.05	0.05	0.1
Sensitivity (gals/mm)	25 (A2...12.5)	25 (B2...12.5)	25 (C2...12.5)	100 (12.5)	200 (25)	12.5 DC.3...25)
Damping	Critical	ditto	ditto	60% critical	ditto	ditto
Damping mechanism Recording range (gals)	Air piston 10-1000 (A2...10-500)	ditto 10-1000 (B2...6-500)	ditto 10-1000 (C2...6-500)	ditto 5 - 500	ditto 10-1000	Oil piston 10-1000
Recording speed (mm/sec)	10	10	10	5 (adjustable 40)	2.5	10
Recording medium	Waxed paper	ditto	ditto	Scratched Record Film	ditto	Smoked paper DC-3...Waxed paper

Recording drive	Hand-wound spring motor	ditto	Micro-motor	DC motor	ditto	Micro-motor
Recording time duration	3 min	ditto	ditto	1.5 min.	1.5 min	3 min
No. repeat cycles	3	5	5	100	100	1
Starter	Elect. contact made by vertical motion	ditto	ditto	ditto	ditto	ditto
Period of starter pendulum (sec)	0.3	0.3	0.3	0.3	0.3	0.3
Starter threshold (gals)	10	10 (B2…5)	10 (C2…5)	5	10 (adjustable to 5)	10
Auxiliary starter	Mechanical, works at 100 gals.	ditto	ditto			
Time marking	1 sec. 1/2 sec. or 1/5 sec.	1 sec.	1 sec.	1/5 sec	1/5 sec.	1 sec.
Power supply	8 dry cells	4 dry cells	4 dry cells	10 dry cells	10 dry cells	3 dry cells (DC-3…4)
Size overall (cm)	56×48×84	54×54×37	68×61×28	45×45×35	45×45×35	59×48×35 (DC-3…60×80×40)

The Japanese network of strong-motion instruments gradually expanded, and as a result of encouragement given by the Seismological Society of Japan, the Architectural Institute of Japan, and the Japan Society of Civil Engineers, the number of accelographs set up in buildings at nongovernmental expense increased. In 1958, the SMAC was first installed in a dam. In 1962, it is noted that accelerographs were installed in public works construction, such as harbors and bridges. Table 2 shows the distribution of accelerographs as to type of location in Japan, and table 3 lists the organizations responsible for the accelerograph.

Table 2. Distribution of Accelerographs

(As of March 31, 1969)

Installed at \ Number of Accelerographs	Fixed in the Construction	Fixed at the Ground Level	TOTAL
Building	192	10	202
Bridge	65	51	106
Railway	20	36	56
Harbour	3	43	46
Telephone Office	37	0	37
Power Plant	12	1	13
Atomic Power Plant	5	14	19
Dam	11	7	18
River	2	4	6
Road	0	7	7
TOTAL	347	173	510

Table 3. **Distribution of accelerographs, classified the kinds of organisations where they are installed**
(As of the end of March 1969)

Types / Organisations	SMAC								DC type	Sum Total
	A-type	A2-type	B-type	B2-type	C-type	C2-type	D-type	Total		
Hokkaido Developmental Agency				4				4		4
National Research Center for Disaster Prevention				2				2		2
Earthquake Research Institute, University of Tokyo	8		19	2	4	2		35	5	40
Port and Harbour Research Institute, Ministry of Transporation				45				45		45
Public Work Research Institute, Ministry of Construction				39			8	47		47
Building Research Institute, Ministry of Construction	10		3	1				14	14	28
Regional Construction Bureans, Ministry of Construction	1			20		1		22		22
Japanese National Railways	1		21	41	4	2		69		69
Nippon Telegraph and Telephone Public Corporation			28	12				40		40
Power Reactor Stations	1		7	6			1	15	1	16
Public Corporations				9				9		9
Urban and Rural Prefectures	4		9	47				60		60
Electric Power Companies			8	5				13	1	14
Universities	1		4	2				7	5	12
Non-governmental Institutions	13	1	41	25	11	2	9	102		102
Total	39	1	140	260	19	7	18	484	26	510

UNITED STATES

The locations of the 375 strong-motion instruments in the U.S. Coast and Geodetic Survey network of stations are shown in figure 5. This network includes 15

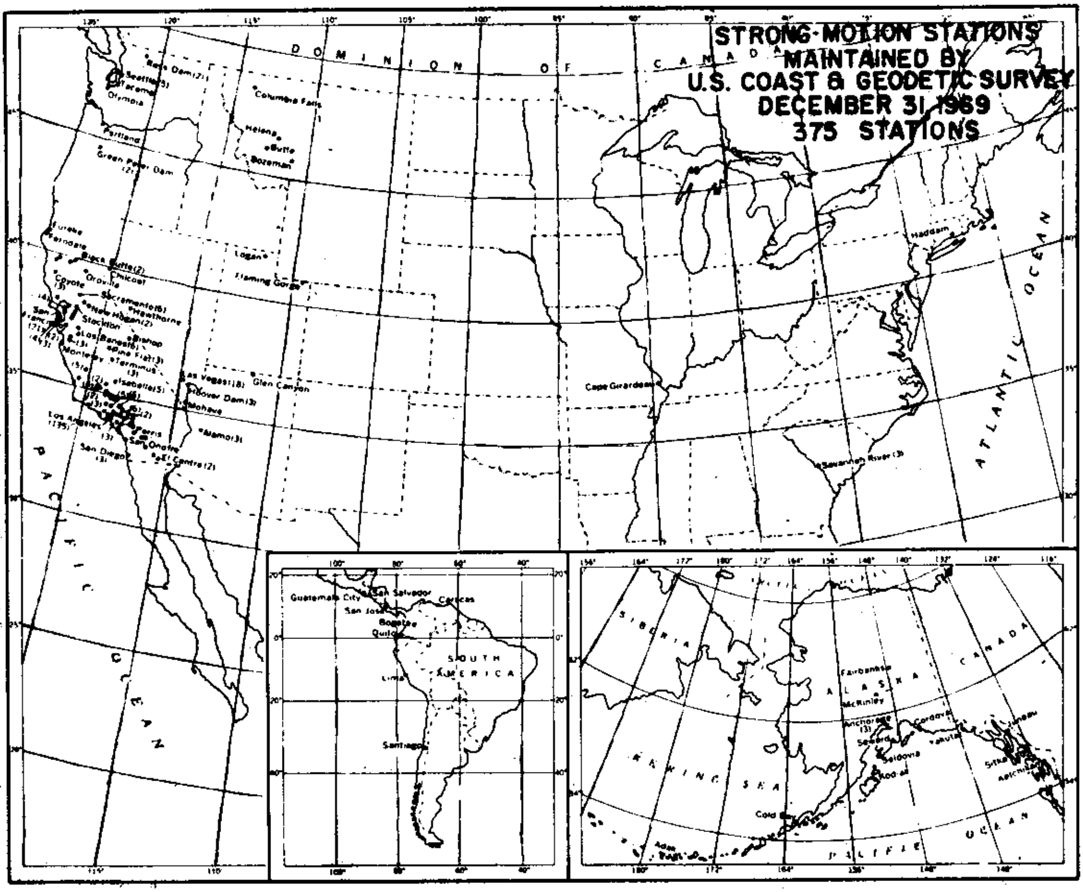


Fig. 5. Strong-motion stations maintained by U.S. Coast and Geodetic Survey, December 31, 1969–375 stations.

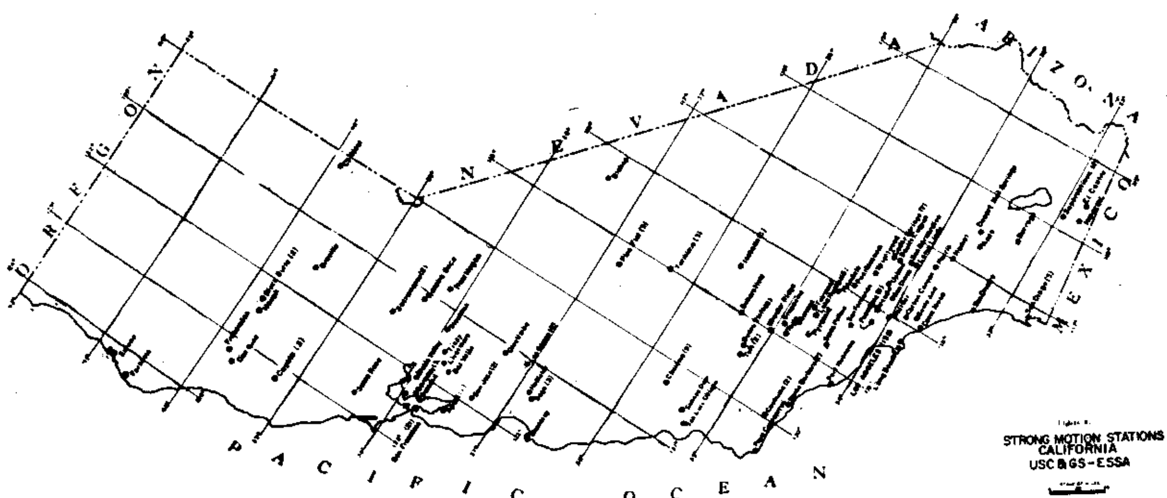


Fig. 6. Strong-motion stations–California–USC&GS, ESSA.

instruments located outside of the Continental United States, in Alaska ; and also 8 instruments maintained by the Coast and Geodetic Survey in Central and South America. It took over 30 years from the installation of the first strong-motion seismograph before the Coast and Geodetic Survey network had 100 or more instruments but in the last 7 years 300 strong-motion instruments were installed in this network. The seismic provision of the building code requiring 3 strong-motion seismographs in new high-rise buildings was first adopted by Los Angeles City in 1965 and has now been

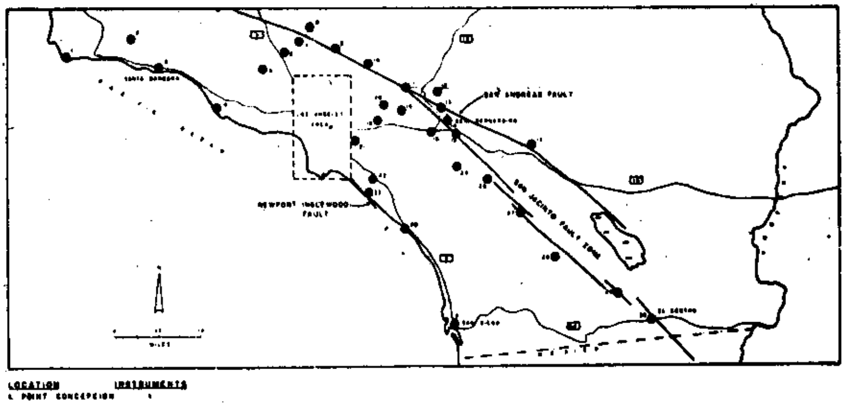


Fig. 7. Location of strong-motion seismographs in the southern California area operated by the Coast and Geodetic Survey, October 1969.

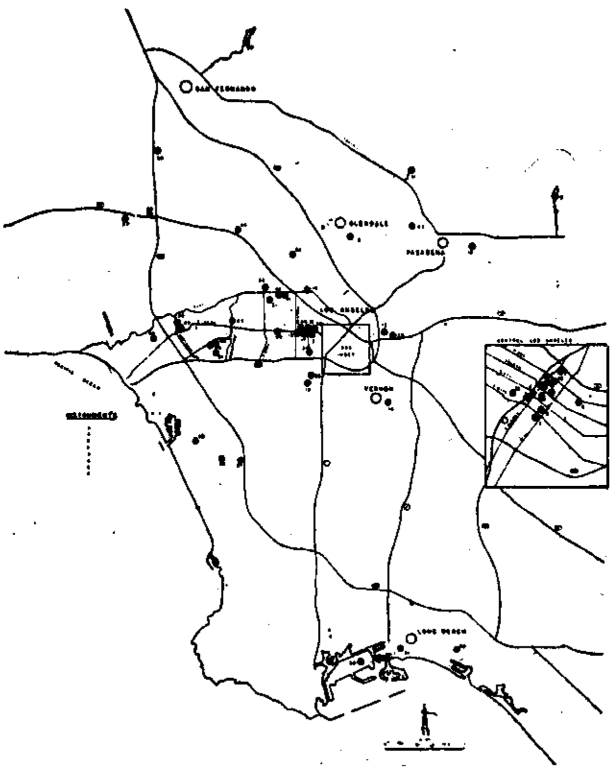


Fig. 8. Location of strong-motion seismographs in the Los Angeles area, October 1969.

adopted by the following local California governments : Alhambra, Anaheim, Bakersfield, Berkeley, Beverly Hills, El Segundo, Fullerton, Hayward, Orange County, Palo Alto, and Torrance. This seismic provision has resulted in a tremendous growth in the number of new strong-motion installations. Southern California has seen the greatest growth in new strong-motion instruments. Figure 6 shows where the instruments are located in California ; figure 7 shows the locations of southern California instruments ; and figure 8 shows the stations in the Los Angeles City area. The Santa Rosa earthquake of October 1, 1969, indicated a need for more strong-motion instruments in the San Francisco Bay area. It is now planned to add to the number of San Francisco Bay area instruments, which are shown in figure 9.

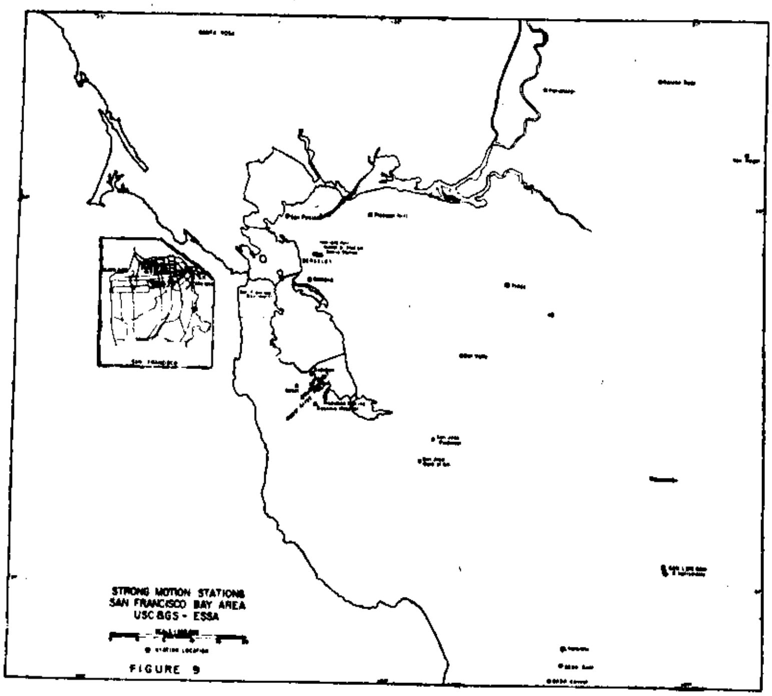


Fig. 9. Strong-motion stations, San Francisco Bay area, USC&GS, ESSA.

Numerous agencies, cities, and organizations have bought strong-motion instruments and requested that they be maintained within the Coast and Geodetic network. Table 4 is a listing of the cooperating agencies and organizations involved and the present number of instruments.

The instruments now in use in the United States network of strong-motion stations include the following types : Standard USC&GS Seismograph, Weed Seismograph, USC&GS Displacement Meter, AR-240, RFT-250, RMT-280, MO-2, SMA-1, and the Seismoscope. Never and more improved instruments continue to be developed but the older instruments remain in use as there is no surplus of strong-motion instruments.

DISTRIBUTION OF INSTRUMENTS

	Organization	No. of Instruments
1.	Coast and Geodetic Survey (Calif. and Western U.S.)	73
2.	Coast and Geodetic Survey (Nevada)	18
3.	Coast and Geodetic Survey (Outside of U.S.)	8

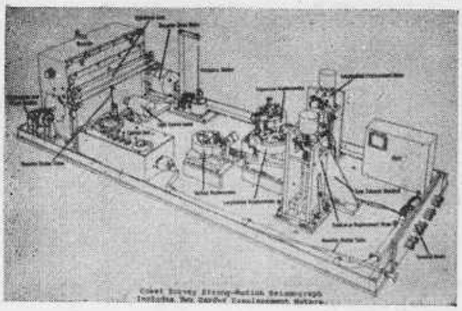
	Organization	No. of Instruments
4.	Los Angeles Bldgs. (Required by Ordinance)	120
5.	Cal. State Dept. of Water Resources	44
6.	U.S. Corps of Engineers	27
7.	California Institute of Technology	23
8.	U.S. Bureau of Reclamation	11
9.	Cal. State Office of Architecture and Construction	8
10.	University of California at Berkeley	6
11.	Haddan Neck, Conn. Nuclear	1
12.	Savannah River Nuclear	3
13.	Bethlehem Pacific Steel Company	2
14.	Contra Costa Jr. College District	2
15.	Southern California Edison Company	1
16.	Los Angeles Dept. of Water and Power	3
17.	Los Angeles Flood Control District	3
18.	City of Glendale	1
19.	Lawrence Radiation Laboratory	1
20.	U.S. Navy Research and Evaluation Laboratory	1
21.	Pacific Telephone and Telegraph Company	1
22.	Redwood City Gen. Improvement Dist. 1-64	3
23.	City of Seattle, Washington	2
24.	San Luis Obispo County Flood Control	1
25.	Sacramento Municipal Utilities District	1
26.	Bank of America	4
27.	Bay Area Rapid Transit District	4
28.	San Diego Gas and Electric	2

(Table 4)

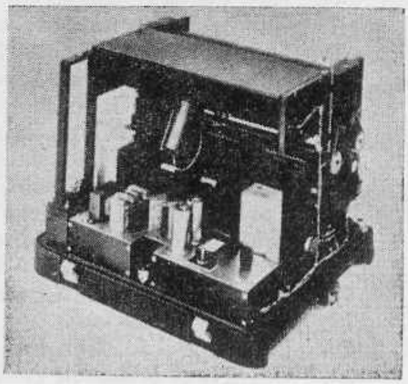
STANDARD USC&GS STRONG-MOTION SEISMOGRAPH

The seismograph, as shown in figure 10, is basically the same instrument as first developed in 1931. The early instrument had only the 3 Wenner and McComb accelerometers. This original accelerometer consisted of a loop-vane copper mass on a quadrifilar suspension attached to a frame. The mass was free to rotate between pole pieces of a permanent magnet. In 1933, a pivot and jewel suspension replaced the difficult to adjust quadrifilar suspension and this pivot and jewel suspension was then discarded in 1947 and replaced by the simpler present-day unifilar suspension. This unifilar accelerometer is the standard form of accelerometer now in use and the type that manufacturers of newer instruments have modeled their accelerometers after. The accelerometer has a pendulum period of from 0·035 second to 0·1 second, a static magnification of about 120, and a sensitivity of 2 to 26 millimeters per 0·1 gravity. Carder displacement meters were later added to the C&GS strong-motion seismograph. This meter, designed by Dr. D.S. Carder, of the Coast and Geodetic Survey, consists of an inverted pendulum that is suspended by cross hinges and stabilized by a torsion wire located in line with the axis of rotation. A mirror located on the axis of rotation is used to record the pendulum motion. By adjusting the position of the upper mass and varying the size of the torsion wire almost any static magnification up to 10 can be obtained. The magnification used in the standard USC&GS instrument is held at unity.

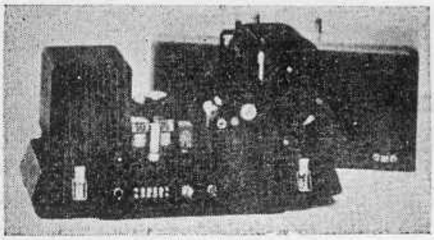
The original instrument had both a horizontal and vertical starter, but the vertical starter proved unsatisfactory as it required too frequent adjustment to its oil cups and restraining spring to remain operable. The present starter is a unifilar pendulum having a period of approximately 1 second. A platinum cone tip makes electrical contact with a platinum ring to start the instrument. Damping of the pendulum is provided by submerging the lower mass of the pendulum in a light oil. Experience has shown that by spacing the gap of the ring and cone from 0·4 mm to 0·7 mm the instruments can be depended on to record any earthquake of interest.



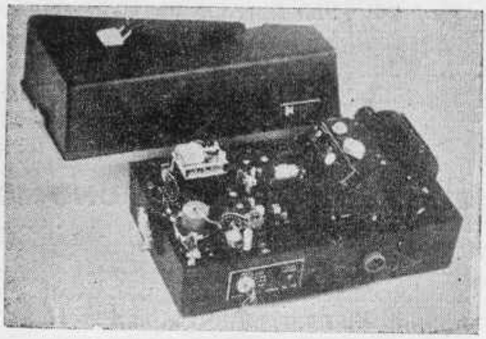
C&GS



AR–240



RFT



SMA–1

Fig. 10. Four types of strong-motion seismographs used in the United States network.

The original instrument recorded on 6-inch translating drums which were changed to 6- and 12-inch fixed drums and then to the present 12-inch camera or recorder, as shown in the instrument picture, figure 10.

WEED SEISMOGRAPH

Only 11 of the Weed instruments were built. This instrument was less expensive than the C&GS seismograph but also less accurate. It is still in use at a few stations. This compact instrument, measuring about 8 by 8 by 20 inches, is shown in figure 11. The Weed instrument consists of a cylindrical steady mass that weighs approximately 6 pounds and rests on three vertical wires in the form of an equilateral triangle. An oil damping device is attached to the mass. On top of the mass is a short rod to which slotted levers are coupled. These levers operate styli to record two directions of motion on the smoked underside of a glass plate. When triggered by a pendulum starter, a battery-powered solenoid device releases a clock mechanism which then pulls the glass plate in a direction opposite to the motion of the styli. Travel of the plate is limited to its 7-inch length. There are no time marks, so reliance must be placed on the accuracy of a drive clock which is somewhat uncertain.

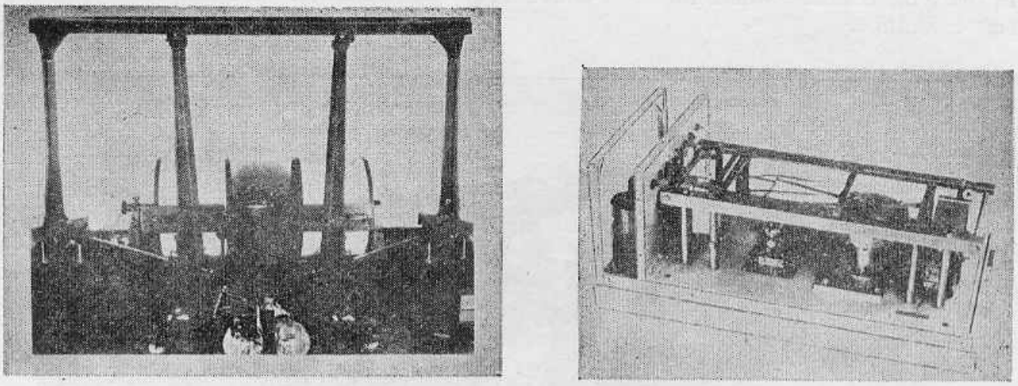


Fig. 11. Coast & Geodetic Survey strong-motion seismograph type 2 ; Weed strong-motion seismograph.

C&GS DISPLACEMENT METER

The C&GS displacement meter was designed by H. E. McComb and Edward C. Robison, of the Coast and Geodetic Survey, in 1932, and only 6 were built. Five of these instruments are still in use. The C&GS displacement meter is an ordinary seismograph consisting of two horizontal pendulums at right angles to each other, figure 11. The steady mass attached to eaeh boom weighs 1 pound, and optical arrangements are such that its magnification is unity and the period is adjusted to 10 seconds. The original oil damping has been changed to magnetic damping. The C&GS displacement meters are installed adjacent to other strong-motion seismographs and are usually operated by the same circuitry.

AR–240 SEISMOGRAPH

The Teledyne AR–240 strong-motion seismograph, figure 10, was quickly accepted following its introduction to the world market in September, 1963. The advantage of smaller size, daylight loading, and lower price caused the AR–240 to replace the standard USC&GS strong-motion seismograph in the United States. The AR–240 consists of 3 unifilar accelerometers, a 12–inch camera with separate lighttight supply and take-up magazines, an optical system supplying 8 traces to the 12–inch paper record a horizontal starting pendulum, an electronic unit with 7 basic assemblies : control module, control relay, timing module, lamp control, voltmeter, calibration circuit, and battery charger.

RFT–250 SEISMOGRAPH

The Teledyne RFT–250, figure 10, developed in 1967, soon replaced the AR–240, as this instrument was less expensive and more reliable. Basically the RFT–250 is the same as the AR–240, recording on 70-mm film instead of 12–inch paper and using an inverted-type pendulum as the starting device. The 70-mm film when enlarged 4 times is equivalent to the 12-inch paper record obtained from the standard USC&GS instrument and the AR–240. This RFT–250 has as its source of power self-contained rechargeable batteries. This independent power source saves a great deal of installation expense as it is no longer necessary to bring in electric power or use a thermoelectric generator to keep batteries charged and in operable condition.

MO–2 ACCELEROGRAPH

The MO–2, figure 12, was first introduced as a prototype laboratory model at the Third World Conference on Earthquake Engineering in New Zealand in 1965. As this instrument has been the least expensive accelerograph available anywhere in the world, it has gained wide distribution throughout the world and also has been used extensively in the United States where building codes require installation of 3 instruments in high-rise buildings.

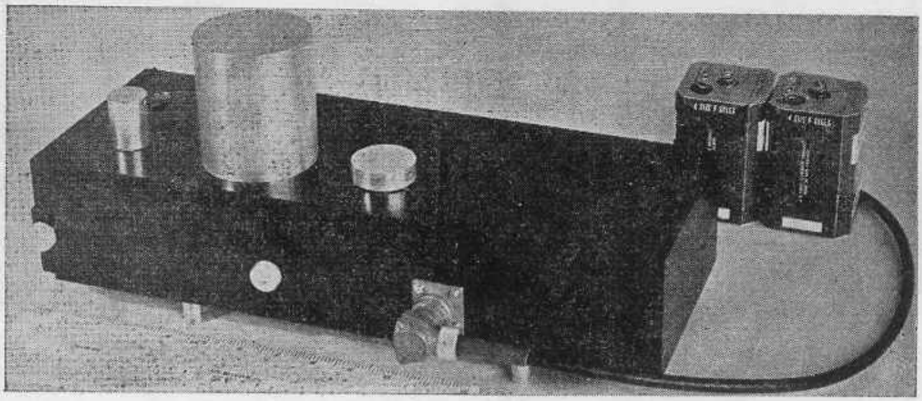


Fig. 12. MO–2.

The MO–2 is small in size, uses a 35-mm film as a recording medium, and uses a velocity-sensitive vertical (moving-coil type) starter. The accelerometers are fluid-damped. The power supply is two 6-volt lead dioxide batteries mounted externally.

RMT–280 SEISMOGRAPH

The RMT–280 is the only commercial, self-contained magnetic tape accelerograph now available. The high price of the instrument and the difficult of analyzing the tape record has slowed acceptance of this instrument. The RMT–280 uses the principle of frequency modulated variable reluctance detection of the rotational displacement of the triaxial torsion accelerometers. FM recording is accomplished on a 1/4-inch-wide endless loop magnetic tape cartridge, which can provide up to one hour of continuous recording, but which also has a sensing tab on the tape which automatically stops the tape when the full cartridge has been recorded.

SMA–I SEISMOGRAPH

A new instrument company, KineMetrics, has just begun production of the SMA–1 accelerograph, figure 10. This instrument, selling for less than $2000, will probably be widely accepted for use in the expanding accelerograph network in the United States. The SMA–1 is small in size, 8 by 8 by 14 inches, weighs approximately 25 pounds, and has a watertight case. It records on 70-mm film using removable and interchangeable film supply and take-up magazines. Its power source is disposable or rechargeable D-size batteries. The instrument is designed with a vertical starter inside the case but can also use a horizontal starter or both horizontal and vertical starter.

THE SEISMOSCOPE

The seismoscope, figure 13, is a strong-motion instrument that was developed by the Coast and Geodetic Survey and the California Institute of Technology. This instrument was developed as a low-cost instrument to supplement the information obtained from the standard strong-motion seismographs. As of January 1, 1970, there were 377 seismoscopes installed in the Coast and Geodetic Survey station network. All of these instruments are installed within a few miles of a permanently located strong-motion seismograph.

The seismoscope consists of a free-conical pendulum that can move in any horizontal direction. The wire-flexured pivot-support of the pendulum moves with the ground, and the resulting angular deflections relative to the frame are recorded by a

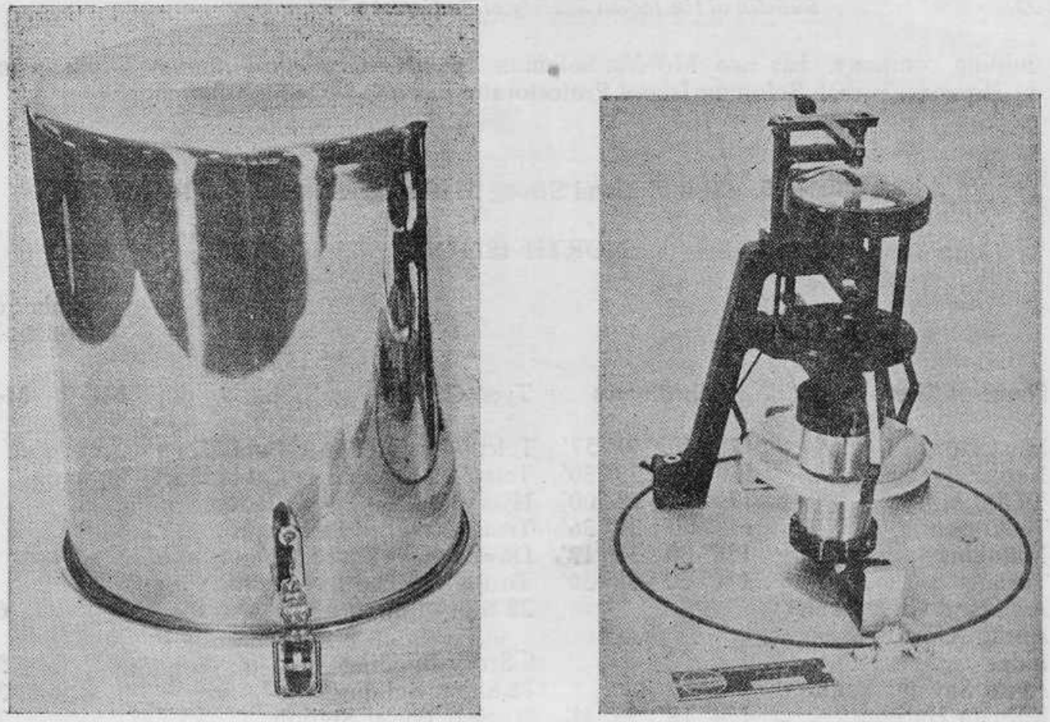


Fig. 13. Seismoscope.

scriber on a smoked, spherical watch glass. Eddy current damping is provided by an aluminum disk, in the form of a segment of a spherical shell, that moves between the poles of a permanent magnet system. Period of the device is approximately 0·75 second, and damping is approximately 10 percent critical.

NEW ZEALAND

The New Zealand MO–2 instrument has already been described under instruments used in the United States. As of March 4, 1970, New Zealand had 68 instruments installed. The location and number of these instruments are listed in table 5 and shown on the map, figure 14. Other Pacific area islands having strong-motion instruments are: Papua, New Guinea—Commonwealth Department has two MO–2's, one at Upper Ramu Dam site, and the Bureau of Mineral Resources in Port Moresby has the second MO–2; Bougainville Island—ConZinc Rinotino, a

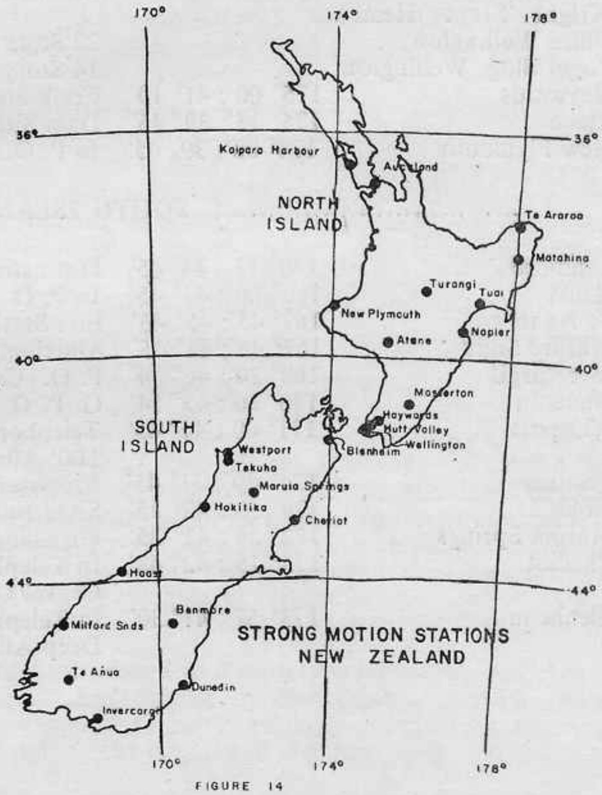


Fig. 14. Strong-motion stations–New Zealand.

mining company, has two Mo–2's; Solemon Islands—Geological Survey Department at Honiara, British Solomon Island Protectorate, has one MO–2 accelerograph.

Table 5. New Zealand Strong Motion Accelerograph Sites

NORTH ISLAND

Name of Site	Coordinates	Type Of Site	Number of Instruments MO-1	M-2
Masterton	175° 40′; 40° 57′	Telephone Exchange Cable Duct	1	
Napier	176° 54′; 39° 30′	Telephone Exchange Cable Duct	1	
Tuai	177° 12′; 39° 00′	Hydro Station Power House	1	
Te Araroa	178° 00′; 37° 36′	To Be Installed In March	1	
Matahina	178° 00′; 38° 12′	Downstream Face Of Dam	5	
Turangi	176° 00′; 38° 50′	To Be Installed In March	1	
Auckland Civic Center		22 Story Building		6
Auck. Univ. Sciences Bldg.		8 Story Building		5
Auck. Savings Bank.		12 Story Building		3
Kaipara Harbour	174° 18′; 36° 31′	Nuclear Power Station		2
Hutlt Valley	174° 55′; 41° 13′	Microzoning	5	
Welington		Microzoning		5
Wright Stvns Head Office Wellington		22 Story Building		4
Vogel Bldg. Wellington		14 Story Building		4
Haywards	175° 00′; 41° 10′	Cook Strt Power Cable Valve Room		1
Atene	175° 15′; 39° 45′	Dam Site		4
New Plymouth	174° 00′; 39° 05′	In P. O. Basement	1	
......SOUTH ISLAND......				
Benmore	170° 15′; 44° 45′	Downstream Face Of Dam		7
Haast	169° 00′; 43° 45′	In P. O. Near Sea-sand	1	
Te Anau	167° 45′; 45° 45′	Fire Station Alluvium Gravel	1	
Milford Snds	167° 45′; 44° 45′	Alluvium Gravel Near Mountains	1	
Invercargil	168° 20′; 46° 24′	P. O. Cable Duct-Wet Plain	1	
Dunedin	170° 30′; 45° 54′	G. P. O. Basement Reclaimed Lad	1	
Westport	171° 40′; 41° 45′	Telephone Exchange Approx. 100' Alluvium	1	
Tekuha	171° 40′; 41° 45′	Proposed Dam Site - Granite		1
Hokitiks	170° 50′; 42° 25′	Sited In P. O. Alluvial Gravel	1	
Maruia Springs	172° 20′; 42° 25′	On Shingle Bench Above River	1	
Cheviot	173° 15′; 42° 48′	In Telephone Exchange - Gravel Up to 100'	1	
Blenheim	173° 57′; 41° 30′	In Telephone Exchange - Deep Alluvium	1	
		TOTALS	21	47

CANADA

A standard USC&GS strong-motion instrument was loaned to the Dominion Astrophysical Observatory of British Columbia, Canada, in early 1962. This instrument was used as a model for the production of an identical instrument by the Fairey Aviation Company in Canada. The first Fairey-type instrument was installed in January, 1963. A total of 10 of these Fairey instruments have been installed in Canada. The Teledyne AR–240 has proved to be less expensive, and 11 of these AR–240's have been installed in Canada. Table 6 lists location and type of instrument in Canada. Figure 15 is a map showing these station locations. Seismoscopes are also used in the Canadian network of stations as a supplement to the accelerograph. Forty-five seismoscopes have been installed in Canada. Twenty of these seismoscopes were built by the Fairey Aviation Company; the others are the Wilmot-type seismoscope made by Teledyne.

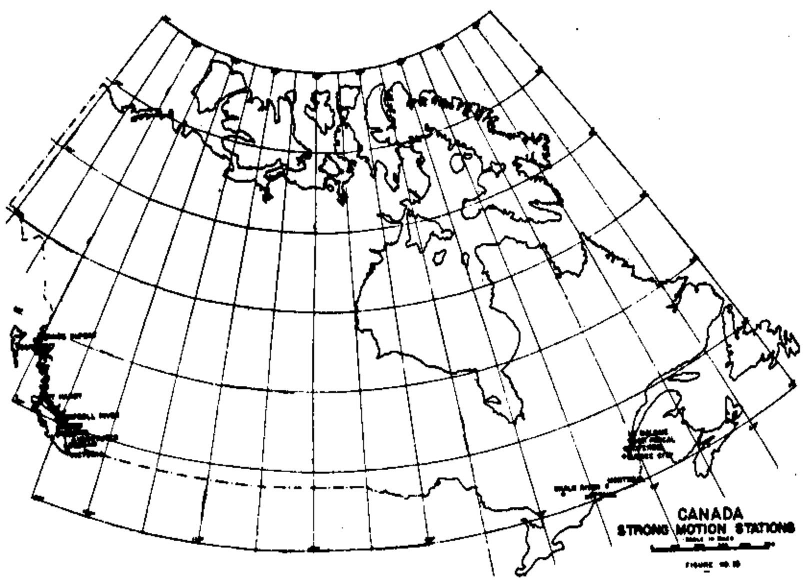


Fig. 15. Canada strong-motion stations.

TABLE 6. CANADA STRONG MOTION INSTRUMENTS

Location	Instr. Type	Seismoscope Number	Latitude	Longitude
La Malbaie, Quebec	AR 240	1	47°39′N	70°10′W
St. Fereol, Quebec	Fairey	1	47°07′N	70°52′W
Quebec City	AR 240	1		
Montreal	Fairey	1		
Ottawa, Ontario	AR 240	–		
Chalk River, Ontario	AR 240	4	46°01′N	77°27′W
Pascal, Quebec	AR240	–	47°32′N	69°48′W

BRITISH COLUMBIA

Location	Instr. Type	Seismoscope Number	Latitude	Longitude
Victoria Law Courts Bldg.	Fairey	14		
Victoria Elliot Bldg.	Fairey			
P. Alberni Macmillian	Fairey	6	49°16′N	124°49′W
Campbell River, Ladora Dam	Fairey		49°57′N	125°36′W
P. Hardy Seismic Vault	Fairey		50°42′N	127°26′W
Vancouver Civil Eng. Bldg.	Fairey	27		
Vancouver Hydro Bldg.	Fairey(2)			
N. Vancouver Cleveland	AR 240			
Duncan N. Cowichan Hosp.	AR 240		48°48′N	123°42′W
Comox St. Joseph's Hosp.	AR 240	2	49°41′N	124°59′W
Richmond Massey Tunnel	AR 240			
Sandspit Airport Term.	AR 240		53°15′N	131°30′W
Pr. Rupert Col. Cellulose	AR 240		54°18′N	130°19′W

ARGENTINA

Argentina has 6 strong-motion instruments and over 20 seismoscopes. The strong-motion instruments in use are 2 SMAC instruments and 4 Ishimoto instruments. These instruments are located at : Mendoza—a SMAC instrument; San Juan—1 SMAC and 1 Ishimoto instrument; La Rioja—Ishimoto instrument; Catamarca—Ishimoto instrument; JuJuy—Ishimoto instrument. The Engineering Group of the National University of Cuyo, at San Juan, built 40 seismoscopes modeled after the Wilmot seismoscope. Locations of both the seismoscopes and the 6 accelerographs are shown in figure 16.

Fig. 16. Strong-motion stations–Argentina.

VENEZUELA

Only one strong-motion instrument, a standard USC&GS instrument, was located in Venezuela at the time of the July, 1967, Ceracas, Venezuela, earthquake. This instrument failed to operate due to a battery failure. The need for strong-motion records was recognized, and since July 29, 1967, the instruments listed in table 7 have been purchased and installed. Figure 17 shows the location of strong-motion instruments in Venezuela. Nine of the 17 listed strong-motion instruments are installed in the City of Caracas.

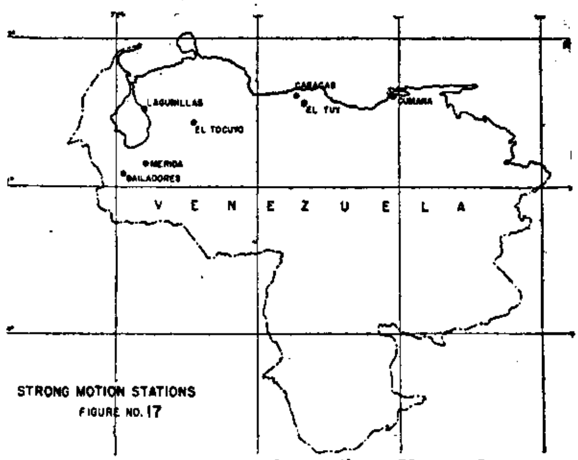


Fig. 17. Strong-motion stations–Venezuela.

TABLE 7. VENEZUELA STRONG-MOTION STATIONS

LOCATION	Tpye Instr.	Coordinates	Found Mat.	Elev. Meters	Oper. By
Observatorio Cagigal	Standard USC&GS	10° 30′ 24″ N 66° 55′ 39″ W	Schist	1035	Ven. Navy
La Floresta, Caracas	AR 240 RFT 250	10° 29′ 56″ N 66° 50′ 31″ W	Alluv. Colluv.	860	CPES
Santa Rosa, Caracas	AR 240 RFT 250	10° 30′ 22″ N 66° 53′ 33″ W	Colluv.	875	CPES
Las Mercedes, Caracas	RFT 250	10° 29′ 13″ N 66° 52′ 02″ W	Schist	880	CPES
Centro Simon Bolivar 23 Piso, Caracas	RFT 250	10° 30′ 21″ N 66° 54′ 44″ W	Schist	898	Cartog Nac.
Edificia Camejo Caracas	RFT 250	10° 30′ 20″ N 66° 54′ 43″ W	Colluv.	900	Cartog Nac.
Represa La Mariposa Caracas	RFT 250	10° 25′ 15″ N 66° 55′ 18″ W	Schist	960	INOS CPES
Represa "El Lagrtijo" El Tuy	RFT 250	10° 12′ 09″ N 66° 42′ 19″ W	Schist	240	INOS CPES
Hospital De Cumana Cumana	RFT 250	10° 28′ 20″ N 64° 09′ 42″ W	Alluv.	20	Cartog Nac.
Casa De La Mission Cartcgrafica, Cumana	RFT 250	10° 28′ 32″ N 64° 10′ 08″ W	Alluv.	8	Cartog Nac.
Observatorio Del Castillo, Cumana	Sprengther Short Period	10° 27′ 50″ N 64° 10′ 12″ W	Schist	34	Cartog Nac.
Oficina M.O.P. El Tocuyo	RFT 250	9° 47′ 00″ N 69° 47′ 42″ W	Schist Graphitic	418	Cartog Nac.
Campo Shell Lagunillas	RFT 250	10° 08′ 07″ N 71° 15′ 38″ W	Lake Sed.	4	Shell Oil
Univ. of Los Andes Merida	MO-2	8° 34′ 48″ N 71° 09′ 42″ W	Alluv.	1450	ULA
Bailadores, Merida	Helicorder Short Per.	8° 15′ 10″ N 71° 49′ 40″ W	Alluv.	1720	ULA

NOTE : CPES is Comision Presidencial Para el Estudia del Sismo.
Cartog Nac. is Direccion de Cartografia Nacional.
INOS is Instituto Nacional de Obras Sanitarias.
ULA is Universidad Los Andes.

MEXICO

Mexico has installed both Japanese SMAC-B-type and Teledyne AR-240-type instruments. The University has developed their own model seismoscope and have installed many of these along with the AR-240 and SMAC instruments. Mexico's first seismoscope made use of steel balls moving on a concave smoked glass surface and using methyl or ethyl alcohol as shock absorber. The records obtained from this model seismoscope proved difficult to interpret and therefore a new type of inexpensive seismoscope was developed. This new seismoscope has 4 pendulums, two horizontal and two vertical, recording on small glass plates. The vertical pendulums are of two different periods, and all the pendulums are electromagnetically damped. Table 8 gives the locations of the 25 AR-240 instruments in Mexico and the number of seismoscope components at these locations. As can be seen on the map, figure 18, 7 of the 11

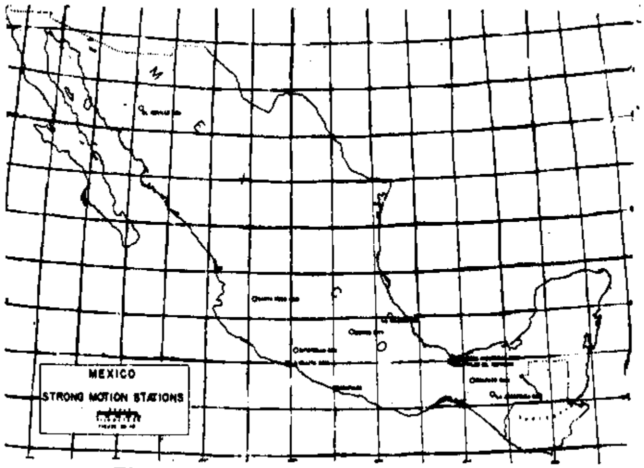


Fig. 18. Mexico strong-motion stations.

locations having strong-motion instruments in Mexico are at dam sites. Three of the 8 instruments in Mexico City are AR-240's ; the others are SMAC-B accelerographs. Two of the SMAC's are under the control of the University ; the other 3 are not being maintained by the University.

TABLE 8. STRONG MOTION INSTRUMENTS IN MEXICO

Location	Longitude	Latitude	Height Meter	No. of Accel.	No. of Seismo. Comp.
Mexico City	99·1° W	19·5° N	2240	8	—
Infiernillo Dam	101·8° W	18·4° N	180	5	40
El Novillo Dam	109·6° W	29·0° N	300	3	20
La Soledad Dam	97·5° W	20·0° N	800	3	20
Malpaso Dam	93·5° W	17·3° N	50	3	32
La Angostura Dam	92·8° W	16·4° N	530	1	—
Santa Rosa Dam	103·5° W	21·0° N	740	3	20
La Villita Dam	102 2° W	18·0° N	20	1	—
Minatitlan Oil Refinery	94·6° W	18·0° N	10	1	—
Pajaritos Industrial Zone	94·5° W	18·2° N	10	1	—
Acapulco	99·9° W	16·8° N	20	1	40

CHILE

Chile, like California, is one of the most earthquake-prone regions of the world. The need for obtaining strong-motion records from major earthquakes in this region was recognized by the Coast and Geodetic Survey, and they installed a standard C&GS instrument in Santiago, Chile, in the Engineering Building at the University during March, 1944. In the late 1950's, a Japanese SMAC instrument was installed at this same location. The University of California began a cooperative research program with the University of Chile in 1967. The instrumentation phase of this program calls for the establishment of a strong-motion network of 57 accelerographs. These instruments, now being installed, are fabricated at the University and are modeled after the standard C&GS strong-motion instrument also called the "Montana-type." The first 10 built at the University were almost identical to the standard C&GS instrument, but the later models were modified in design, making the instrument more compact and improving the operational and maintenance capabilities. Forty seismoscopes, similar in construction to the U. S. Wilmot-type seismoscope, were designed and built by the University of Chile. Half of these are in place at Concepcion and the other half were being installed in Valdivia as reported early in 1969. Site locations for the accelerographs were selected with a view to obtaining at least one record from a strong earthquake occurring anywhere in seismically active Chile. When more than one instrument was installed in the same city, the criterion for placement was to locate them on different types of soil. Table 9 is a listing of the existing and planned future accelerographs. The map, figure 19, shows the locations of these stations.

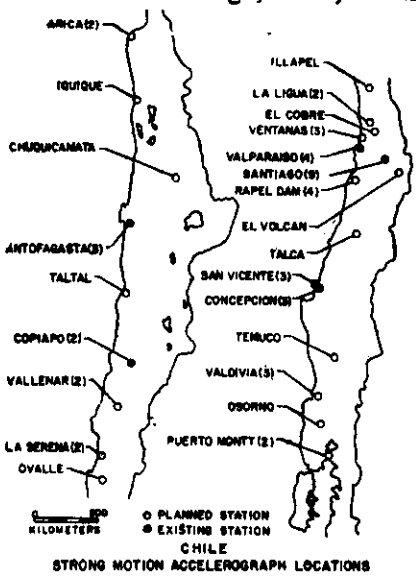


Fig. 19. Chile-Strong-motion accelerograph locations

TABLE 9. CHILE—ACCELEROGRAPH LOCATIONS

City	Location	Soil
1. Arica	Port of Arica Building at Morro	Bed Rock
	U. of Chile campus, center of city near ocean	Unconsolidated quaternary sediments with shallow ground water
2. Iquique	Plaza de Armas	Bed rock
3. Chuquicamata	House near Anaconda Admin. Bldg.	Very firm alluvium
4. Antofagasta	U. of Chile, S. of city near ocean	Bed rock
	Warehouse in port	Artificial fill
	Baquedano, school	Pampa, firm alluvium
5. Taltal	Oil tanks to north	Bed rock

City	Location	Soil
6. Copiapo	School of mines	Bed rock
	Intendencia, at Plaza	Soft fluvial material
7. Vallenar	Corfo Sulfuric Acid plant	Firm gravel
	Escuela para Ninas near Esduela St.	Soft sand and silt
8. La Serena	Bethlehem Admin. Bldg., Romeral	Firm gravel
	Railraod Station	Soft alluvium
9. Ovalle	Paloma dam abutment	Alluvium
10. Illapel	Small Building on Hosp. land	Soft fluvial sediments
11. La Ligua	School in central part of city	Moderately firm alluv.
	School in higher part	Bed rock
12. El Cobre	Relave Chico	Copper flotation tailings
13. Ventanas	Chilectra 1 story bldg.	Soft sediments
	Chilectra boiler building	Soft sediments
	Quintero	Bed rock
14. Valparaiso	Navy Inst. of Geography	Bed rock
	U. of Chile School of Architecture near port	Artificial fill
	Plaza of Vina del Mar	Soft Sediments
	Casiño of Vina	Soft Sediments
15. Santiago	Cerro Santa Lucia	Bed rock
	Laboratorio de Estructuras U. of Chile	Firm gravel
	Electrical Eng. Bldg. U. of Chile Fac. C. F. y M.	Firm gravel
	Poblacion Sta. Julia, park area	Silt
	Poblacion Sta. Julia, 4 story	Silt
	Conchali, school	Fine saturated sediments high water table
	Conchali, future large bldg.	Fine saturated sediments high water table
	Endesa 14 story bldg.	Firm gravel
	Park near Endesa 14 story bldg.	Firm gravel
16. El Colcan	U. of Chile Seismograph Station Queltehues	Bed rock
17. Rapel Dam	Away from dam	Bed rock
	Near dam	Bed rock
	Dam foundation	Bed rock
	Dam crest	Concrete arch dam
18. Talca	U. of Chile campus near Plaza de Armas	Coarse fluvial material
19. Concepcion	U. Concep. Seismograph Sta.	Bed rock
	Central Plaza	Bio-Bio sand
	P. de Valdivia Bldg.	Bio-Bio sand

City	Location	Soil
20. San Vicente	Peninsula de Tumbes	Bed rock
	CAP Plant, Huachipato	Sand and Silt
	CAP Plant, Huachipato, new open hearth Bldg.	Sand and Silt
21. Temuco	1 story public bldg. near Plaza de Armas	Firm fluvial Sediments
22. Valdivia	U. A. Seismograph Sta.	Bed rock
	Plaza Republica	Sand and Silt
	Large Bldg. near Plaza Republica	Sand and Silt
23. Osorno	U. of the Chile Seismograph Sta.	Firm fluvial sediments
24. Puerto Montt	1 story public bldg. near Plaza	Alluvium
	Warehouse bldg. in port	Artificial fill

EL SALVADOR

The first strong-motion instrument, a standard C&GS instrument, was installed at the Observatory in San Salvador in 1964. Three AR–240's and 25 seismoscopes were purchased as a result of the May, 1965, El Salvador earthquake. One of the AR–240's is installed at the new Airport Terminal Building ; the other two are installed in buildings in the City of San Salvador. Site Selections for locations of the 25 seismoscopes were based on local geology.

COSTA RICA

San Jose, Costa Rica, has 3 strong-motion instruments. The standard C&GS instrument was recently moved to a new location at the University in the basement of the Geology Building. The other two instruments are AR-240's. One is installed at the Social Security Building in the center of San Jose ; the other, at the new hospital building on the outskirts of the city.

NICARAGUA

Managua, Nicaragua, now has 4 AR–240's and 16 seismoscopes. Two of the AR–240's are installed in the modern 15-story Central Bank Building. One AR–240 is at the University and the fourth AR–240 was to be installed at the ESSO Refinery at Managua. Seven seismoscopes had been installed as of February, 1969. Ing. Francisco Hanson has had problems locating proper sites for the 9 other seismoscopes as people have been adverse to granting permission for location of instruments in their buildings, for they fear this would probably cause an earthquake to damage their buildings.

GUATEMALA

A standard C&GS instrument was installed at the Observatorio Nacional in 1947. The university at Guatemala purchased an RFT–250 and 3 seismoscopes which have been installed in buildings on the university grounds. Figure 20 is a map of Central America showing the location of the Guatemala station along with neighbouring stations in El Salvador, Costa Rica, and Nicaragua.

Fig. 20. Central America strong-motion stations.

INDIA

A standard C&GS instrument was shipped to the University of Roorkee, India, in 1962. It was to be used as a prototype in the development of their own instrument. The instrument, called RESAGRAPH (an acronym for Roorkee Earthquake School Accelerograph), has now been developed. Two of these instruments have been installed at Koyna and three more were to be located in the Himalayas in U. P. State, India. Four AR–240's were purchased for India—2 for New Delhi in 1964 and 2 for Koyna Dam in 1965. An RFT–250 was purchased in August, 1969, for UKAI Dam. The University of Roorkee's Annual Report in Earthquake Engineering for 1968–69 mentions that the strong-motion earthquake recording program has been continued with the establishment of 52 structural response recorder stations, and that strong-motion accelerographs are installed at the more important sites. The structural response recorders are simple, single-pendulum units, designed and manufactured at the University of Roorkee to supplement the more complex and expensive RESAGRAPH. An excellent strong-motion network is developing in India with the fabrication and installation of the new RESAGRAPHS. It was fortunate to have accelerographs operating at Koyna Dam during the seismic activity in 1967. Two important records were obtained, one from a 5·7 magnitude earthquake on September 13 and one from a 7·0 magnitude shock on December 11. The magnitude 7·0 earthquake showed a peak acceleration of over 0·5 *g*, which was the largest acceleration ever recorded by a strong-motion instrument.

PERU

Only one strong-motion instrument was installed in Peru up till the time of the May 31, 1970, Peruvian earthquake. This instrument was a standard C&GS instrument originally installed in Lima, Peru, in 1944. The Peruvian earthquake of October 17, 1966, emphasized the need for installation of more strong-motion instruments. Professor Julio Kuroiwa, of the National University of Engineering at Lima, Peru, had ready a proposal for installation of 8 accelerographs and 35 seismoscopes for Lima, Arequipa, and Ancon, Peru, at the time of this 1966 earthquake, but as no funding was available, no instruments were purchased. A disastrous earthquake often shakes loose previously unavailable funds for purchase of strong-motion instrumentation, and as a result of the May 31, 1970, earthquake more instruments will no doubt be installed.

COLOMBIA

A standard C&GS instrument was installed at Bogota, Colombia, in May, 1945.

This instrument is in the seismograph vault at the Instituto Geofisico de Los Andes Colombianos. The AEC Atlantic-Pacific Inter-Oceanic Canal Study Commission made available 10 standard C&GS instruments for installation in Panama and Colombia. The 10 instruments were installed in 1967 and 1968 at the following locations: Balboa, Heights, Panama City, Bogota, Cali, Medellin, Cartagena, Barranquilla, Monteria, and Manizales. The Instituto Geofisico is now under contract to continue to operate these 10 instruments. Figuie 21 is a map showing locations of these instruments and those of Peru and Ecuador.

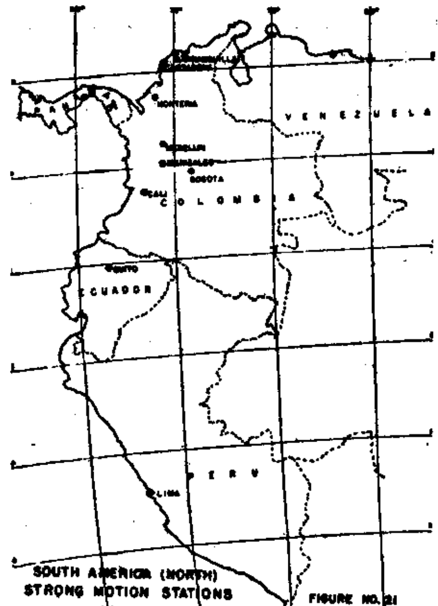


Fig. 21. South America (North) strong-motion stations

ECUADOR

Ecuador has only one strong-motion instrument, a standard C&GS accelerograph installed at the Quito Observatory in 1945.

PANAMA

In 1934, an early model G&GS accelerograph was installed at Balboa Heights Administration Building in Panama. This instrument was removed in 1965; then in 1967 the present 2 strong-motion instruments were installed at Panama City and Balboa Heights.

RUSSIA

Literature regarding the type of strong-motion instruments, location of instruments, and number now in place in Russia is in the process of being translated. The latest accelerograph in the U. S. S. R. network is similar to the standard C&GS accelerograph, with pendulums of ca 18 cps and damping ca 60 percent critical. A number of instruments have been specially designed for recording strong earthquakes. General characteristics of four of these instruments are as follows:

UAR —Accelerometer sensitivity 15 mm/*g*; recording speed 10 mm/sec

ESS —Pendulum period 1·5 sec; damping 0·3; magnification from 0·1 to 2·0

SMR-0 —Pendulum period 4 sec; damping 0·5; magnification 1

SMR-2 —Pendulum period 5 sec; damping 0·5; magnification 5

An ISO oscillograph model was developed at the beginning of 1963 for automatic recording of strong earthquakes with macroseismic intensities from 4·5 to 9-10. This instrument operates off dry batteries and can go without servicing for 6 months and can record up to 5 strong earthquakes during this time. The instruments mentioned above were reported as installed in various seismic areas of Russia. A displacement-type seismograph record was obtained from the April 26, 1966, Tashkent earthquake and a strong aftershock was also recorded on May 6, 1966 by a different strong-motion accelerograph at Tashkent.

PAKISTAN

Pakistan reported that they had obtained 4 standard C&GS accelerographs in 1956. These were installed at: Seismic vault of the Geophysical Observatory in Quetta; on the second floor of a 2-story building in Quetta; at Drosh (bordering Hindu Kush area); and in East Pakistan at Sylhet. An accelerograph system was purchased from Teledyne in 1968 for installation at Tarbela Dam.

EUROPE, ASIA, AND AFRICA

In the last 5 to 6 years other countries have installed strong-motion instruments but little information is available as to their exact locations. Teledyne, in the United States, has sold and shipped instruments to the following countries:

Greece, Athens—17 seismoscopes (1965)

Romania, Bucharest—2 MO-2's and 1 seismoscope (1969)

Yugoslavia, Rijeka—1 AR-240 (1966)

Italy, Rome—10 AR-240's, 1 RFT-250, 2 MO-2's (1968),
100 MO-2's (1970)

Afghanistan, Kabul—2 RFT-250's (1968)

Iran, Teheran and Shiraz—1 AR-240, 1 RMT-280 (1967),
1 RFT-250 (1969)

Turkey, Ankara—2 AR-240's and 6 seismoscopes (1968)

Kenya, Nairobi—1 seismoscope (1968)

STRONG-MOTION RECORDS

The importance of accurate records of ground motion during destructive earthquakes is emphasized each time a major earthquake occurs in a region having no strong-motion instruments within 10 to 20 miles of the epicentre. The acceleration of 0·3 *g* recorded at El Centro, California, in 1940, remained as the maximum acceleration recorded by a strong-motion instrument until the late 1960's. In 1966, an 0·5 *g* acceleration pulse was recorded by an accelerograph during the Parkfield, California, earthquake. The earthquake of December 11, 1967, at Koyna, India, produced a record with over 0·5 *g* acceleration.

The increase in the number of strong-motion instruments throughout the world has resulted in many more records useful to research workers in earthquake engineering. In order to make these records more readily available, the Japanese have published a series of volumes "Strong-motion Earthquake Records in Japan." The Japanese earthquake records are reproduced in full size. In the United States, the California Institute of Technology has, in close cooperation with the Coast and Geodetic Survey, begun publication of over 100 earthquake records considered to be of significant interest in earthquake engineering. These records are being published in digitized form and will include velocity, displacement, and response curves. Three volumes are planned, each volume issued in Parts A, B, C, etc., containing 20 earthquake records.

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