THE STRONG MOTION ACCELEROGRAPH

by

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ABSTRACT

The increasing emphasis by engineering seismologists and earthquake engineers on the acquisition of true ground acceleration data has stimulated the development of several new strong motion accelerographs. This is of interest to the seismologist concerned with continuous data acquisition beyond the range of the standard seismic instruments, and of interest to the structural or earthquake engineer requiring acceleration data to calculate or evaluate structural response to strong local seismic shocks. A summarization of the characteristics of the significant strong motion accelerographs of the various countries is presented, together with available information on world-wide strong motion accelerograph installations, and typical strong motion accelerograph records.

INTRODUCTION

Although interest in strong motion seismography dates back as far as 136 A.D., when the Chinese scientist and philosopher, Chang Heng (Choko), devised his famous dragon seismoscope, it wasn't until the introduction of the USC&GS Standard Accelerograph in 1932 that precision instrumentation became available to measure true ground motion and building response during strong local earthquakes. Since much of our present strong motion instrumentation is derived from this pioneering development, it is probable that this dates our modern earthquake engineering instrumentation technology. Two of the early pioneers in the earthquake engineering field, Dr. K. Suyehiro of Japan and Mr. John R. Freeman of the United States, were instrumental in educating the public and the various governments to the need for improved earthquake engineering, and were successful also in influencing other capable scientists and engineers to devote themselves to this important field.

The subsequent development in Japan of the SMAC-A and DC-2 Accelerographs in 1953 provided the basis of what is today the most extensive strong motion net in the world, consisting of well over 100 accelerographs in Japan alone. The United States, however, is not far behind in total accelerograph installations and is rapidly acquiring more instruments to broaden the area of coverage, primarily through the USC&GS. Recent strong motion installations in Alaska, for example, which I understand will ultimately comprise about 15-20 stations, will help to assure the future acquisition of earthquake engineering data in that seismically active area. None of these instruments were installed prior to the March, 1964, Alaskan earthquake, however, and it still remains true that critical strong motion data from catastrophic earthquakes, such as those in Alaska and Chile, has not yet been obtained in sufficient quantity to be of significant value.

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Engineering seismologists have been accused, at times, of actually hoping for the occurrence of more catastrophic earthquakes to provide additional information on the seismicity of a given area, or to provide data on response of certain types of buildings to very strong earthquakes. While such earthquakes are very useful in providing the ultimate test of structures under dynamic conditions, there is always the probable risk of extensive structural repairs, or even total destruction. Thus, although the importance of instrumenting structures to record the occasional catastrophic earthquake is undeniable, the frequency of occurrence of smaller earthquakes is so much greater, it is apparent that most of the seismic and seismic response data required for earthquake engineering progress must come from the smaller strong motion shocks, and a few of the more recent accelerograph developments restrict the upper acceleration limit to only 0.5 g and extend the lower limit to perhaps 0.005 g.

Complaints are sometimes heard concerning the high prices charged for commercial strong motion instrumentation. Unfortunately, the demand for this type of instrumentation is not yet comparable to, for example, the demand for new automobiles in the United States, and the resultant small production runs, therefore, cannot absorb the cost of high production tooling, which could substantially reduce the selling price. Until the demand for precision strong motion accelerographs substantially increases or a major scientific break-through in accelerograph design occurs, it appears that prices for accurate and reliable commercial accelerographs will continue in the $3000-4000 range.

However, when comparing the cost of rebuilding a city following a disastrous quake to the cost of strong motion instrumenting the same city initially to provide earthquake engineering data essential for reducing subsequent damage, it is evident that truly "an ounce of prevention is worth a pound of cure." The price of cataloging all strong motion earthquakes as to seismic areas and types of building response is small indeed compared to the cost of rebuilding even one small city.

As engineers and engineering seismologists become more acquainted with modern instrumentation techniques, however, there will be an increased demand for not only more strong motion instruments, particularly accelerographs, but for more advanced types of these instruments. This trend can be seen in the newer types of accelerographs discussed in this paper, and is even more apparent when reading the developments of the last four years in these Proceedings of the Third World Conference.

In the field of strong motion accelerographs, the next big step will be to magnetic tape recording because of the tremendous versatility of this recording medium. Since this type of accelerograph will likely be somewhat more expensive than the present types of commercial accelerographs, the commercial development of a magnetic tape accelerograph will largely depend on the active interest shown by the ultimate users. For most near future applications, it is highly probable that the present types of accelerographs shown in Table I will very adequately provide strong motion data for most users for some time to come.

Since seismic engineering data is of international interest, it might be well to note (for those not already informed) the formation of a permanent UNESCO committee to establish a permanent world-wide network of strong motion stations providing complete dissemination of all recorded and analyzed strong motion data to all participating stations. This is an outstanding program with obvious international advantages and should be supported whole-heartedly. Free exchange of strong motion data of this type cannot help but further the cause of earthquake engineering.

The seven strong motion accelerographs reviewed in the following pages provide a relatively good introduction to the field of earthquake engineering instrumentation. Although other types of strong motion instruments, such as seismoscopes, etc., are commercially available, these are primarily intended as supplemental instruments to the precision accelerographs. To the extent design information has been made available, the presentation of the characteristics of each instrument has been objective and factual, thereby providing, I hope, a definitive and useful reference in the engineering strong motion field.

OBSERVATORY VS. ENGINEERING STRONG MOTION INSTRUMENTS

It is sometimes assumed by those unacquainted with earthquake engineering instrumentation that the seismic records provided by seismic observatories are sufficient also for the earthquake engineer. While there is no doubt these records are often very useful to the engineer in at least providing statistical data on the frequency of occurrence of earthquakes in a given area, it must be remembered that "strong motion" observatory instruments are quite different from "strong motion" engineering instruments. To the observatory seismologist accustomed to the detection of distant teleseisms on very sensitive seismographs with very high magnifications, the observatory strong motion instrument is very often two Wood-Anderson Torsion Seismometers of 0.8 second period and 2800 magnification providing a displacement record on photographic drum recorders. This combination is very often used, for example, to provide records for the assignment of Richter Scale magnitudes, but is much too sensitive to properly detect and record the strong local earthquake. If a displacement record of a strong local shock is desired, very often the dynamic range of the seismograph station can be extended by the use of additional torsion seismometers, similar to the Wood-Anderson, but with a magnification of only 100, or even 4, for the very strong local shocks. These can record also on a photographic drum recorder, or are often used on a 35mm film recorder.

However, to determine the response of a structure to strong local earthquakes for structural engineering purposes, the acceleration of the ground and structure must be known as a function of time. This type of information is obtained from the strong motion accelerograph which provides the engineer with seismic intensity and structural response information directly in terms of acceleration. Since engineering equations are most often directly concerned with acceleration, this is not only a mathematical convenience for the engineer, but avoids the possible error involved in double-differentiation of a visible displacement trace with respect to time.

Other features of the engineering strong motion instrument which are unique include:

1. Standby capability on little or no power using a starting pendulum which actuates the seismograph to full operation only when a strong motion earthquake is detected. The recording film or paper then operates at a comparatively high rate of constant velocity (usually 1 to 2 cm/sec. for paper) to more adequately separate the high frequency components of structural significance.

2. High natural frequency of the seismic detectors (usually 10-20 cps) to provide a broad frequency bandpass in the acceleration portion of the frequency response curve.

3. Power line independence since all accelerographs developed to date operate directly from wet or dry cell batteries, with the charge on the wet cells maintained by an AC trickle charger, either external or integral with the accelerograph. This feature avoids the possible loss of record occasionally experienced by seismological laboratories when a strong earthquake breaks the power lines.

4. Portability is a feature of most accelerographs to permit the instrument to be readily deployed from the basic installation to the location of strong earthquakes occurring anywhere in the world. This is of distinct advantage in capturing the strong aftershocks of destructive earthquakes, which are often sufficient intensity to provide important structural information.

SIGNIFICANT STRONG MOTION ACCELEROGRAPHS

USC&GS Standard" Accelerograph - USA

The seismograph, shown in Figure 1, is the oldest of the modern-type strong motion seismographs, having first come into existence somewhat following the allocation of Federal funds to the USC&GS in 1931 for a strong motion program. The original instruments included only the Wenner and McComb accelerometers, but some have subsequently been modified to include Carder and Coast Survey displacement meters for the horizontal components. Although some 30 years old, this strong motion seismograph has provided extensive and reliable service and is presently in operation in the United States and Central and South America, as shown in the tabulation below, from the January 1963 report entitled "Strong-Motion Stations-Instrumental Data," published by the USC&GS:

United States of America	
Accelerograph only	32
Accelerograph plus Carder Displ. Meters	28
Accelerograph plus Coast Survey Meters	5

South and Central America
Accelerograph only 7

Although somewhat larger than is necessary, according to the present trend for miniaturization, this instrument has an excellent record for reliability and versatility extending over the past thirty years. Some of the features of the newest versions of this seismograph include:

1. A total of 12 traces: 3 components of acceleration, 2 components of displacement, fixed traces for each of the above, and two timing traces.

2. Exceptionally easy-to-adjust light traces, as seismograph is assembled in "breadboard" fashion on a mounting plate.

3. Adjustable period, sensitivity, and damping on the accelerometers.

4. Photographic paper recording.

5. Relay-release (break-circuit) starting system for faster starting.

Since these strong motion seismographs are not commerical instruments, there is no standard price available, however, experience to date has indicated a probable price of $4000 to $8000, depending on the components desired and the availability of competent and inexpensive manufacturers.

The strong motion seismograph records of the 22 March 1957 earthquake at San Francisco are shown in composite form in Figure 3. These were taken by USC&GS standard strong motion seismographs and are reproduced from an article in the California Division of Mines Report No. 57, authored by Mr. William K. Cloud of the USC&GS.

Figure 3 is reproduced here because of the unusual fact that twelve strong motion seismographs were near the epicenter of the earthquake. The amplification factor between the basement installation and upper floors of several buildings shows very clearly. For further information as to underlying geologic structure, analysis of data, type of damage, etc., California Division of Mines Report No. 57 is highly recommended.

Figure 1 shows only the accelerograph version of the USC&GS standard seismograph. The Carder displacement meters were added to about half of the standard seismographs and are of about 2-second period. The Coast Survey displacement meters are installed on only about half a dozen of the standard seismographs and are of about 10-second period.

<u>USC&GS Mark II Accelerograph - USA</u>

The prototype USC&GS Mark II strong motion seismograph shown in Figure 2 is, in effect, a miniaturized version of the standard USC&GS instrument. It was developed in 1962 and 1963 by the Albuquerque Seismological Laboratory of the USC&GS.

The Mark II seismograph is a 70mm film recorder, as opposed to photographic paper recording on the standard USC&GS model. The film is contained in a light-tight magazine, which can be exchanged for a new magazine when desired, without fogging the film. The film can be magnified 4 times to approximately the same record produced by the standard USC&GS model.

The three accelerometers and two displacement meters are essentially miniature versions of the Wenner and McComb accelerometers and the Carder displacement meters used on the standard model, using higher efficiency magnets, etc., to achieve miniaturization.

The timing motor is a 115 VAC synchronous motor using a slotted (5 slots) vane driven at 60 rpm to actuate the 25 VDC electro-magnetic timing markers. The film drive motor is also a 115 VAC synchronous motor with a geared drive. Both motors are dependent on a precision power source for accuracy and, therefore, require either the standard commercial 115 VAC, 60 cps power, or a relatively high-quality 24 VDC/115 VAC, 60 cps inverter. The light source is 6 VAC stepped down from the 115 VAC power source. The control system which is a relay-release type, triggered by the starting pendulum, is 24 VDC.

The magnetically damped starting pendulum responds to a minimum horizontal component of acceleration nominally equivalent to about 0.01 g.

Also to be included in this seismograph is a calibration capability similar to that of the UED AR-240. The accelerometer and displacement meter damping system will be slightly modified to accommodate this feature.

In addition to the prototype unit shown, five Mark II Accelerographs have been manufactured and will have been largely installed by the time of the Third World Conference. It is anticipated also that one will be exhibited at the Conference, but may differ somewhat from the characteristics shown above and in Table I since development work is continuing, primarily to simplify electrical circuitry.

<u>SMAC-A, -B, & -C Accelerographs - Japan</u>

The SMAC-B strong motion seismograph shown in Figure 4 was developed between 1951 and 1953 by the Japanese "Committee for the Standard Strong Motion Accelerograph," supported by a grant from the Japanese Government. Installation of the first SMAC-A Accelerograph at the Earthquake Research Institute in Tokyo in 1953 started the first earthquake observation project in Japan.

The SMAC-A Accelerograph was a considerably larger instrument than the present SMAC-B and SMAC-B2 instruments, but both have approximately the same characteristics. The SMAC line of accelerographs is manufactured by Akashi Seisakusho, Ltd., Tokyo.

Some of the unique features of this instrument include:

1. Waxed paper roll recording medium.

2. Hand-wound spring motor for paper drive.

3. Accelerometer air damping.

4. Heavy steel case for maximum protection against falling debris, dust, and dampness.

5. Integral dry cell batteries, or optional alkaline batteries, automatically recharged.

The Japanese Government, through the Ministry of Construction and other offices, has supported the strong motion program in Japan by procuring SMAC and DC instruments for installation in strategic areas and buildings.

In December, 1956, the Japanese Strong Motion Earthquake Observation Committee assumed the responsibility of maintaining, collecting, and analyzing the data from the system of strong motion seismographs in Japan. Figure 7 shows a typical strong motion record of relatively low intensity recorded by a SMAC and a DC-2 Accelerograph.

In addition to the SMAC-A, -B, and -B2 instruments there are now also available wall-mount models, SMAC-C and -C2, but prices on these models are available only through the manufacturer.

DC-3 Strong Motion Accelerograph - Japan

The Japanese DC line of strong motion seismographs developed as an outgrowth of the same "Strong Motion Acceleration Committee" that designed and constructed the SMAC strong motion seismograph. In their vibration studies of buildings, it was noted that the vertical components of vibration were usually small compared with the horizontal components. Since cost is a factor in Japan, just as in the United States, the vertical component was eliminated to reduce the cost and thereby permit construction of additional instruments for broader strong motion coverage. The original DC-2 seismograph developed in 1955, therefore, included only two horizontal component accelerometers of 0.1 second period, and was intended to be used in combination with the SMAC accelerograph to record vibration in various portions of a structure under study.

However, the newer model DC-3 Accelerograph shown in Figure 5 includes the vertical component of acceleration, and as can be seen from the comparison chart in Table I, now compares favorably with the SMAC-B accelerograph. The major differences appear to be in the damping medium, the recording medium, the type of recording motor drive, and the over-all weight.

Unique features of the DC-3 include:

1. A visible recording medium (smoked paper).

2. Integral dry cell batteries (6-volt DC operation).

3. Selectable time marking.

4. Heavy steel case for maximum protection.

The Hosaka Company also makes the Ishimoto Accelerograph, as well as other instruments classified as strong motion accelerometers and seismographs.

The DC and SMAC instruments are designed to operate from a common starter if desired.

Figure 7 shows a typical strong motion record of relatively low intensity recorded by a SMAC and a DC-2 Accelerograph. A DC-3 record had not been made available for inclusion at the time of this writing.

UED AR-240 Accelerograph - USA

The United ElectroDynamics, Inc., AR-240 Strong Motion Accelerograph shown in Figure 6 is the latest of the commercial accelerographs, having been on the market only since September of 1963. A considerable amount of preliminary investigation was undertaken to select the characteristics considered most desirable by authorities in the seismological and earthquake engineering fields. For this reason, I feel the AR-240, and other accessory instrumentation, will be of significant assistance in the acquisition of strong motion data on a world-wide basis. Some of the salient features of the AR-240 are:

1. Continuous strong motion acceleration record from about 0.1 second after the initial actuating pendulum contact to 7 seconds after the last pendulum contact.

2. Storage capacity of 150-foot roll of photographic paper recording of three orthogonal components of acceleration.

3. A total of eight recorded traces, comprising three fixed reference traces, three variable accelerometer traces, and two timing traces.

4. Light-weight (60 pounds total, not including the external batteries) and compact size (16 x 16 x 14 inches).

5. Integral calibration of seismometer period and damping.

6. Constant velocity paper speed of 2 cm/sec.

7. Adjustable sensitivity to 7.5 g and range of 0.01 to 1.0 g.

Summarizing the operation of the AR-240 rather briefly, the initial strong earth motion actuates the horizontal component actuating pendulum, thus closing the platinum pendulum contacts, which in turn releases the telephone-type relays controlling the drive motor, timing and control circuits, and light source. This type of relay control coupled with a transistorized light source circuit provides a start delay time of only about 0.1 second from initial contact to full operation.

The adjustable pendulum contact gap permits selection of gap setting from 0 to 0.060 inch. Depending on the frequency of the actuating ground motion, the minimum acceleration required to close the pendulum contacts can be less than 0.01 g.

The AR-240 will continue to record for a period of seven seconds beyond the last contact of the actuating pendulum. Since the photographic paper record is stored in a light-proof, take-up magazine, it is readily possible to remove the take-up magazine and replace it with another, while processing the first record.

The period and damping calibration can be made during each periodic inspection of the strong motion installation, and thus provides a permanent record of these parameters immediately preceding or following strong motion recording.

The three Lehner-Griffith seismometers used are evolved from the well-known Wood-Anderson torsion seismometers, using a small mirror, mounted directly on the taut suspension, and electro-magnetic damping.

The light-tight cover and camera-type magazines permit operation without the necessity of a closed vault, and installation can, therefore, be in almost any accessible corner.

Since the AR-240 is a relatively new instrument the world-wide distribution has just begun. However, between 50 and 60 have been installed in the United States (especially Alaska and California), Mexico, and India, and one is on display at the International Seismological Center in Tokyo.

As mentioned before, no acceleration record was obtained of the initial Alaskan shock in March, 1964, but several aftershocks of this quake were recorded. (See Figure 9)

UAR Accelerograph - USSR

In reading the various translations of Russian papers concerning strong motion instruments, it is apparent a number of various types of these instruments have been developed in the Soviet Union, at least through the laboratory prototype stage. Due in part to the language barrier and the difficulty of rapid communications, however, little information appears to be available concerning actual strong motion installations in the field. Perhaps future collaboration through the UNESCO program will eventually result in a wider dissemination by the USSR of this type of information, including the recorded data for various seismic areas and building types.

Since all Russian strong motion instruments are intended primarily for internal consumption, they essentially do not compete with the commercial types of accelerographs shown in Table I, and the UAR Accelerograph, shown in Figure 8, is included primarily to indicate the interest in strong motion seismography in the Soviet Union. Several other seismographs in the strong motion field have been developed by the Soviet Union, including a continuously-recording magnetic tape loop which transfers only strong motion records to another magnetic tape for storage; a Xerographic process recorder; and a phosphor-coated paper loop recording the impressed seismic image on photographic paper above a certain level.

The UAR Accelerograph described in Table I can also be modified to serve as a velocity meter or a displacement meter by changing the block of seismic detectors. Several versions of this accelerograph appear to have been developed through the prototype stage, including the version shown in the photograph, which includes a spring-loaded recording drum. The drum reportedly attains a constant speed of 1 cm/sec. (±10%) within 0.05 sec. of the starting impulse against the resistance of an eddy-current damping system.

New Zealand Accelerograph

The Physics and Engineering Laboratory in New Zealand has recently developed a three-component accelerograph which they anticipate will be somewhat less expensive than those presently available on the world market. As of this writing, however, no commercial arrangements have been made to market this instrument, although 30 are under construction for use in New Zealand, and will probably be installed by the time the Third World Conference is held.

Although a serious effort has apparently been made to keep the cost of this instrument to a minimum, several unique features have been included which are worthy of mention.

1. 35mm film recording. When enlarged 8 times this is the equivalent of the paper record used by several other accelerographs, and would provide a comparable sensitivity of 10 m/0.1 g. The reported 1.5 cm/sec. film speed when enlarged would thus be the equivalent of 12 cm/sec. of 12" wide paper, which is extremely fast.

2. Excellent portability due to the relatively small size and light weight.

3. Internal dry cells (12 VDC operation).

Conspicuous by its absence among the characteristics of the instrument is some means of time marking the film record. According to the designers the use of a precision DC motor drive makes unnecessary any provision for time marking the record.

As of this writing, a photograph of this accelerograph was not available and hence was not included. However, the accelerograph will undoubtedly be on exhibit at the Conference for the benefit of those attending.

The type EB Accelerograph reported in the July 1955 SSA Bulletin is evidently still in operation in New Zealand in perhaps six installations, but will undoubtedly be superseded by the newer accelerograph reported above. To the best of my knowledge this instrument has been used only in New Zealand and was never developed as a commercial instrument.

ACKNOWLEDGEMENTS

Much of the information contained in this paper was previously published by United ElectroDynamics, Inc., in December, 1963, as an in-house publication to further the general knowledge of strong motion instrumentation. It was also presented at the Western Regional Meeting of the AGU (American Geophysical Union) in December of 1963, but not subsequently published in the AGU Bulletin. Distribution of the UED in-house publication, however, was rather limited, and with the recent UNESCO interest, as well as a general world-wide increase of interest in strong motion seismography, it was deemed advisable to update the paper and resubmit it for international publication at the Third World Conference on Earthquake Engineering.

Appreciation is expressed to Dr. G. W. Housner and Dr. D. E. Hudson of the California Institute of Technology for their continued interest and material assistance in acquiring the added portions of the data and pictures contained in this paper.

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TABLE I

CHARACTERISTICS OF SIGNIFICANT STRONG-MOTION ACCELEROGRAPHS
(Based on best information available June 1964)

CHARACTERISTIC	USC&GS-STANDARD	USC&GS - MARK II	AKASHI SMAC - B/SMAC-B2	HOSAKA DC-3	UED AR-240	NEW ZEALAND (NO MODEL NO.)	RUSSIA UAR
Components							
Accelerometers	2 horiz. and 1 vertical	2 horiz. and 1 vertical	2 horiz. and 1 vertical	2 horiz. and 1 vertical	2 horiz. and 1 vertical	2 horiz. and 1 vertical	2 horiz. and 1 vertical
Displacement Meters	2 horiz.	2 horiz.	None	None	None at present	None	None
Natural Period (in sec.)							
Accelerometers	Adjustable (0.001-0.15)	Adjustable (0.03-0.10)	0.10/0.14	0.10	0.055-0.065	0.03	0.05
Displacement Meters	Adj. 0.5-5.0 sec. (Carder) 10-sec. nominal (Coast Survey)	Adj. 5 sec. nominal	None	None	None at present		None
Sensitivity (in mm/0.1g)							
Accelerometers	Adjustable 6-20	Adjustable 6-20	4.0/6.5	4.0	Adjustable 5.0-7.5	1.25	1.6
Damping (% of critical)							
Accelerometers	Adjustable 60% nominal	Adjustable 65% nominal	100%	100% (silicone oil)	Adjustable 55-65%	Not known	70%
Displacement Meters	Adjustable 60% nominal	Approx. same as standard model	None	None	None at present	None	None
Damping Mechanism							
Accelerometers	Magnetic	Electromagnetic	Air Piston	Oil Piston	Electromagnetic	Not known	Electromagnetic
Displacement Meters	Magnetic	Electromagnetic	None	None	None at present	None	None
Recording Range	0.001-1.0g (usually 1.0 in California)	0.01-1.0g	0.01-1.0g/0.006-0.5g	0.025-1.0g	0.01-1.0g	0.01g to 1.0g	0.025g to 1.0g
Traces and Trace Width	12 total 5 fixed-x, y, z and displ. 5 variable-x, y, z and displ. 2 timing-each side Width: 0.05-0.075cm (depending on lamp current and development)	12 total 5 fixed-x, y, z and displ. 5 variable-x, y, z and displ. 2 timing-each side Width: < 0.003" on 70mm film	4 total 0 fixed 3 variable - x, y, z, 1 timing Width: Not known	4 total 0 fixed 3 variable - x, y, z, 1 timing Width: Not known	8 total 3 fixed-x, y, z, 3 variable - x, y, z 2 timing-each side Width: 0.010-0.015"	4 total 1 fixed 3 variable 0 timing Width: 0.003" on 35mm film	3 total 0 fixed 3 variable 0 timing Width: Not known
Time Marking	2 per second	5 per second ± 1%-5th mark acc. (115vac syn. motor and timing vane)	1 or 5 per second-clock with elec. cont.	5, 2, or 1 per second	2 per second ± 1%	None - dependent on precision paper drive	None
Recording Medium, Speed and Duration	Photo. paper roll at 1 cm/sec. (alternate drum) Duration: 1-1/4 min. and repeatable for 5 cycles	70mm film roll-50 feet at 1 cm/sec Duration: 1-20 sec. after last strong seismic shock and repeatable to end of film roll	Waxed paper roll at 1 cm/sec. Duration: 3 min. - able to start 5 times	Smoked paper drum at 1 cm/sec. Duration: 3 min. and repeatable for 3 cycles	Photo. paper roll 150 ft. at 2 cm/sec. Duration: 7 sec. after last strong seismic shock and repeatable to end of paper roll	35mm film 20 feet total 35mm film 20 ft. total duration: 45 sec. @ 1.5 cm/sec Starts 9 times	Photo paper on drum Photo paper on drum Duration: 60 sec. Not repeatable
Recording Drive	DC electric motor	115 vac synchronous electric motor	Hand-wound spring motor	DC electric motor (6 vdc)	DC governed electric motor (12 vdc)	Precision 12 VDC electric motor	

TABLE I

CHARACTERISTICS OF SIGNIFICANT STRONG-MOTION ACCELEROGRAPHS (Cont)

(Based on best information available June 1964)

CHARACTERISTIC	USC&GS-STANDARD	USC&GS - MARK II	AKASHI SMAC - B/SMAC-B2	HOSAKA DC-3	UED AR-240	NEW ZEALAND (NO MODEL NO.)	RUSSIA UAR
Built-in Calibration System	None	Electrical impulse to record damping and period information	None	None	Electrical impulse to record damping and period information	None	None
Starter							
Component	Horizontal-closed relay	Horizontal-closed relay	Vertical	Vertical	Horizontal-closed relay	Horizontal	Horizontal
Type	Pendulum-elec. contact	Pendulum-elec. contact	Pendulum-elec. contact	Pendulum-elec. contact	Pendulum-elec. contact	Pendulum-emf (no contact)	Pendulum-elec. contact
Period	1 sec.	Approx. 0.6 sec.	0.3 sec.	0.3 sec.	Approx. 1 sec.	0.2 sec.	Not known
Sensitivity	0.05 cm displ. of center	Adjustable-better than 0.01g	0.01g/0.005g	0.01g	Adjustable to 0.060" gap	Velocity approx. 0.01g	Not known
Damping	30% critical-oil type	50% critical-electro-mag.	Not known	Not known	100% critical-eddy current	Low	Not known
Misc.	------	------	Plus. aux. mech. starter	------	------	------	------
Starting Time	Approx. 0.2 sec.	Approx. 0.2 sec.	Not known	Not known	Approx. 0.1-0.15 sec.	Approx. 0.1 sec.	0.05 sec. to uniform rotational speed
Power Supply	12 vdc external wet storage batteries with 115 vac 60 cps ext. trickle charger	24 vdc external wet storage batteries with 115 vac 60 cps ext. trickle charger and ext. dc-ac inverter	12 vdc internal dry cells (4 cells at 3 vdc each) or alkaline cells auto-charged	Internal dry cells (3 No. 5) - 6 vdc	12 vdc external wet storage batteries 115 vac internal trickle charger	12 vdc internal dry cells	100 vdc and 6 vdc dry cells
Size (inches) HxWxL	13 x 20 x 45	10 x 14 x 21	15 x 21 x 21-incl. batteries	16 x 24 x 31-incl. batteries	14 x 16 x 16	12 x 12 x 24	Not known
Weight (pounds)	135 with cover	Approx. 60 with aluminum cover	220 with steel cover	440 with steel cover	60 with aluminum cover	35	Not known
Manufacturer or Designer	USC&GS-not commercially available	USC&GS-commercially available from United Electro Dynamics, Inc. Pasadena, California	Akashi Seisakusho, Ltd. Tokyo, Japan	Hosaka Shindo Keiki Mfg. Co., Tokyo, Japan	United Electro-Dynamics, Inc., Pasadena, California	Physics & Engineering Lab. - Department of Scientific & Industrial Research	Earth Physics Institute, USSR Academy of Sciences
Present Price	Has been fabricated for $4000 to $8000 depending on quantity and components desired	Price on request	$ 4000	Assumed $4000	$3950	Estimated $1000 commercial version under discussion	Not available commercially
Other Accelerographs	------	------	Ishimoto, SMAC-A, and Akashi IAS-P accelerographs	DC-2 and Ishimoto accelerographs	------	Horizontal accel. vector seismoscope - no time base - est. $25.00 price, about 95 installed in New Zealand Strong motion seismograph type EB - 2 horiz. components - range 0 to 0.5g	Can also be modified to provide velocity or displacement record

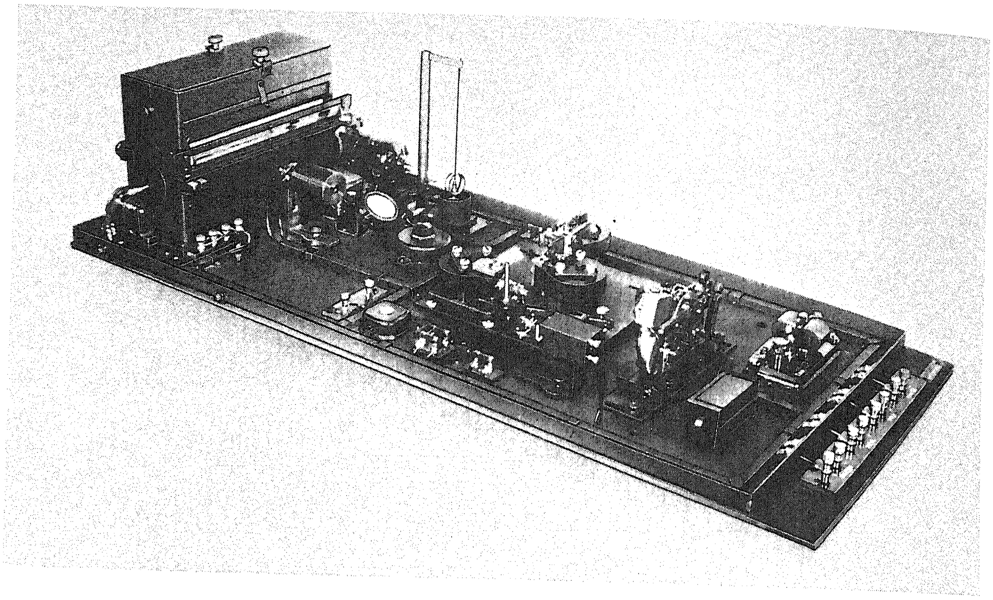

Fig.I U.S. Coast and Geodetic Survey Standard Strong-Motion Seismograph.

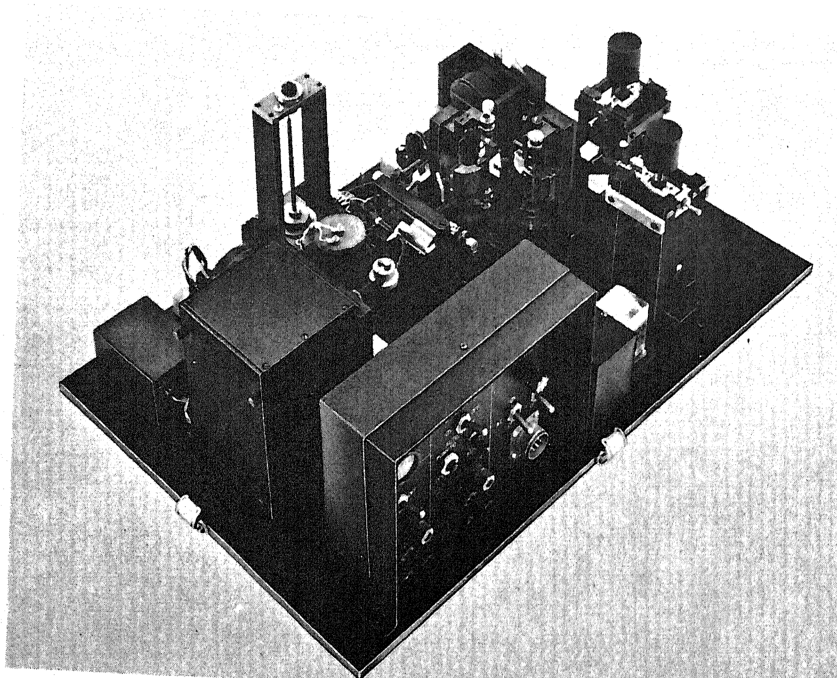

Figure 2 - USC&GS Mark II
Strong Motion Accelerograph

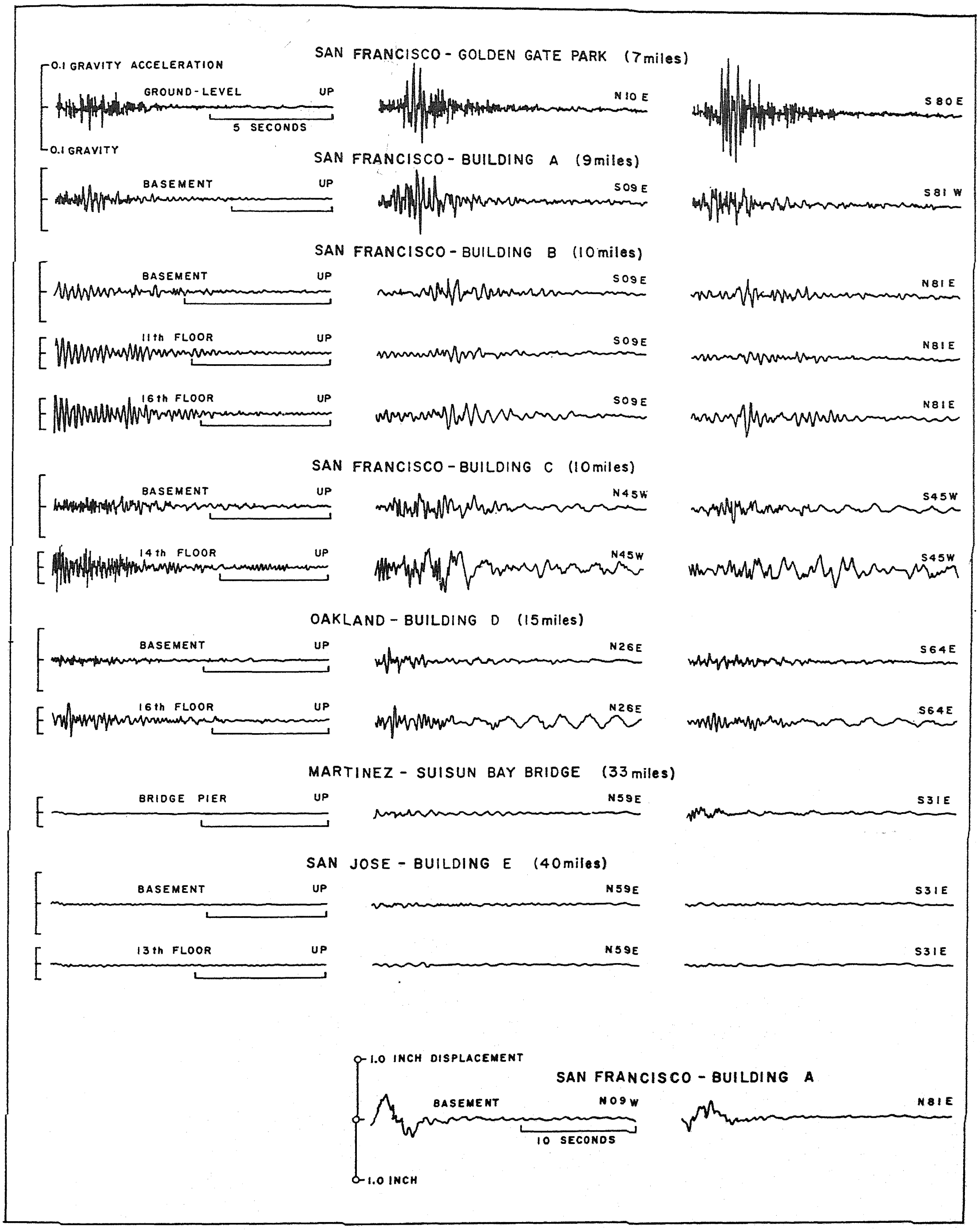

Fig. 3. U.S. Coast and Geodetic Survey, Strong-Motion Seismograms of the 22 March 1957 Main Shock at 11:44:21 P.S.T.

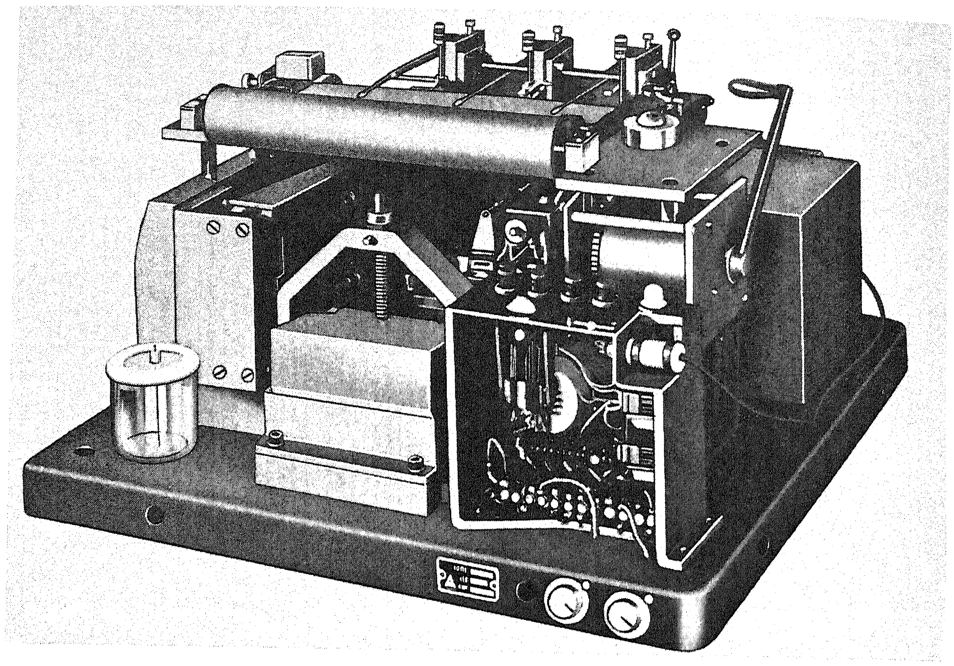

Figure 4 - Akashi SMAC-B
Strong Motion Accelerograph

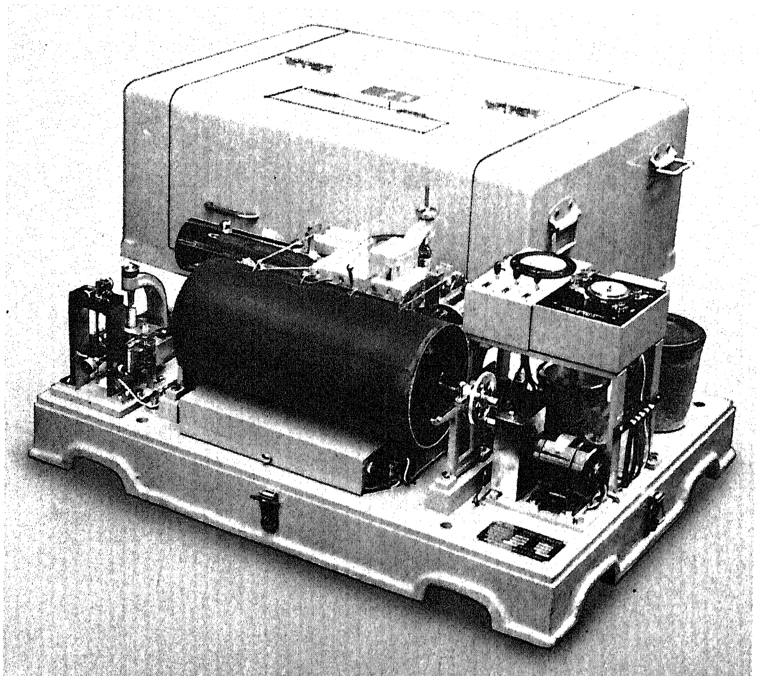

Figure 5 - Hosaka DC-3
Strong Motion Accelerograph

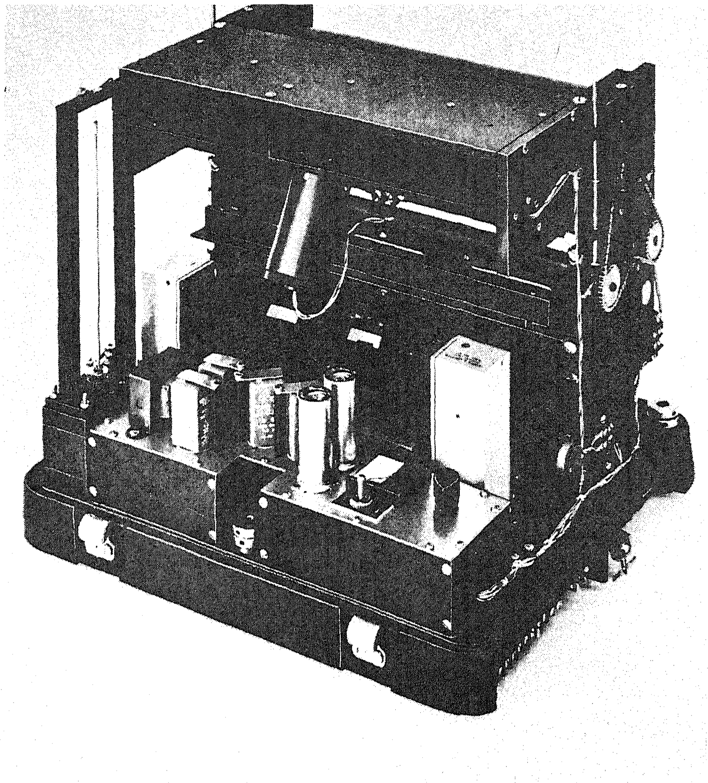

Figure 6 - UED AR-240
Strong Motion Accelerograph

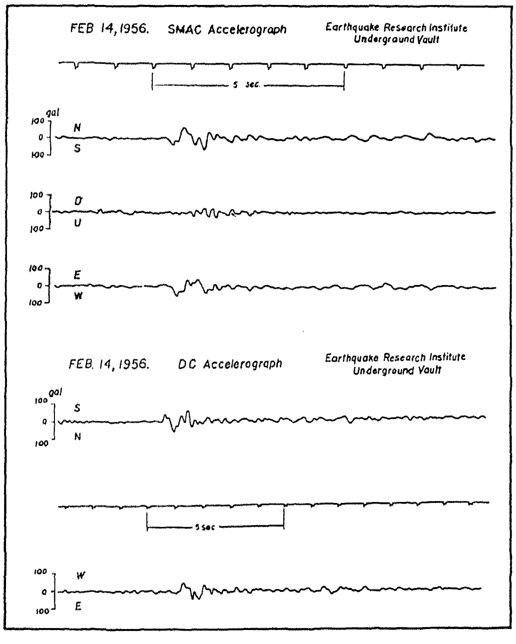

Fig. 7. Typical SMAC and DC-2 Strong-Motion Record

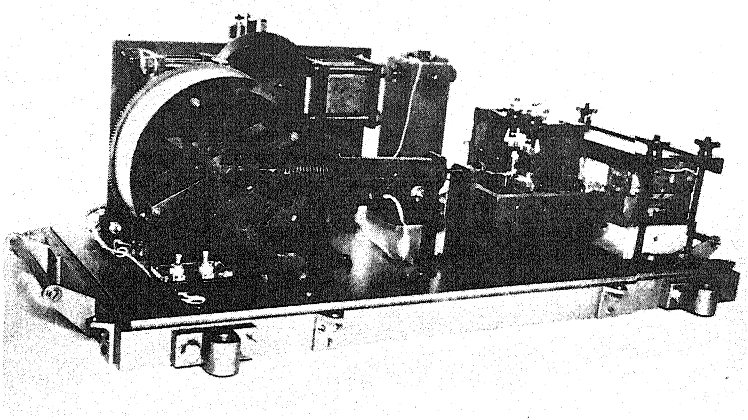

Figure 3 - USSR UAR
Strong Motion Accelerograph

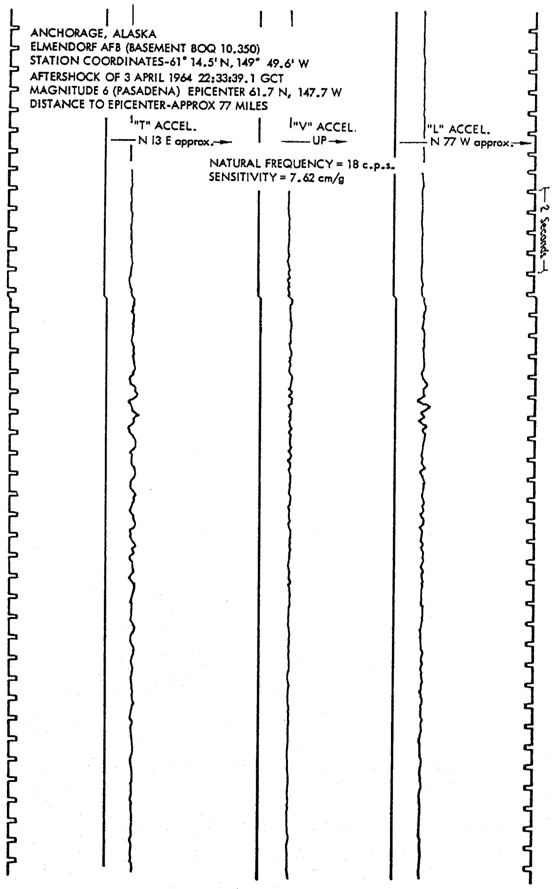

Figure 9 - AR-240 Alaskan
Aftershock Record

THE STRONG MOTION ACCELEROGRAPH

BY H. T. HALVERSON

COMMENT BY: JOHN C. MONNING - U.S.A.

The Uniform Building Code has an active committee considering a requirement to install three accelerographs in all buildings over six stories in height. If adopted, which is expected, this would apply to some 1200 cities using the Uniform Building Code.