A VELOCITY TYPE STRONG MOTION SEISMOGRAPH WITH WIDE FREQUENCY AND DYNAMIC RANGE

Ikuei MURAMATU [I]

SUMMARY

As the upper boundaries of particle velocities of several strong earthquakemotions are almost constant over a wide frequency range, the author developed a velocity type strong motion seismograph with the dynamic range from 100 to 0.01 kines over the period range from 0.05 to 50 seconds. The main part of this seismometer is composed of two fan shaped pendulums coupled by thin piano wires, so that the forces of non-oscillating directions are eliminated. As the whole system of the coupled pendulums is immersed in high viscous silicon oil, it has enough strength to resist against destructive earthquakes.

INTRODUCTION

Long period components in strong earthquake motions have been a topic of keen attentions because the natural periods of the modern large buildings and civil engineering structures have become gradually longer, and because the recent studies on the earthquake source mechanism have shown that long period seismic waves are generated in the case of large earthquakes. Accordingly, a number of investigations have been carried out for finding out long period components of waves in the time history of ground displacements, which might be obtained by integrating the acceleration seismograms, but the results of integration are not always reliable, particularly for the earthquake motions with long duration time. On the other hand, so-called displacement seismographs have often been off-scale for large earthquakes. It may therefore be said that we do not yet know accurately what is the destructive earthquake motion.

ON THE MAXIMUM VALUES OF THE STRONG EARTHQUAKE MOTIONS

Many records of the strong earthquake motions obtained by various seismographs are collected and the amplitudes and the corresponding periods of remarkable waves in these seismograms are plotted in Fig.1 (Muramatu(1976)). Accordingly, the ground motions plotted in Fig.1 indicate the upper boundaries of the strong earthquake motions in time domain. Since the almost ground motions plotted here are obtained from accelerograms and their integrations, it is difficult to recognize long period components longer than about 5 seconds even if they were contained. The long period ground motions at Tokyo in Fig.1 are estimated from the Ewing's seismogram shown in Fig.2 considering the characteristics of the instrument after Nasu(1971). We can see in Fig.1 that the maximum particle velocities are almost constant for wide range of periods from 0.1 to 20 seconds and the values are about 20-30 kines, expeting the strong motions at Pacoima dam and at Parkfield.

On the other hand, it is shown theoretically that the large earthquake fault generates the longer period body wave corresponding to the rise time of the fault dislocation which becomes several ten seconds for some large earthquakes. Brune(1970) indicates further that there is a limited value of the particle velocity on a fault surface and the maximum value is about 100

I Professor of Gifu University, Japan.

kines and the corresponding acceleration is 2g for 0.1 seconds.

DESIGN OF A VELOCITY TYPE STRONG MOTION SEISMOMETER

Fig.1 suggests us that a velocity type seismometer is suitable to observe the strong motions of large earthquakes. The period range is desiable to cover from 0.1 seconds or shorter to 20 seconds or longer. Basic requirment for the design of the velocity seismometer is to have a large dynamic range with high fidelity because the records of weak motions which occur frequently are also significant in the research of strong earthquake motions.

The author has therefore designed a velocity type strong motion seismometer to fulfill the requirment in the following items:

1) The sensitivity is flat over the period range from 0.05 to 50 seconds and the dynamic range covers from 100 to 0.01 kines.
2) The dynamic characteristics of the pendulum are not affected by the forces of non-oscillating directions.
3) It has enough strength to resist against the ground motion of 1g.
4) The size is to be small.

Improved Matuzawa's coupled pendulum system. Matuzawa(1938) had devised a coupled pendulum system as shown in Fig.3 which was composed of two fan-shaped pendulums combined by thin belts. One is suspending, another is inverted. Some authors had been already proposed various coupled pendulum systems in order to eliminate the forces of non-oscillating directions in the case of large ground motions, but Matuzawa's system has the following merits for our purposes; 1) it can avoid solid friction because the pendulums are beared by springs only and 2) in principle, there is no expansion and shrinking of the belts by the deflection of the pendulums when the belts are tangential to the fan-shaped surfaces of the pendulums. In spite of large advantage in the Matuzawa's pendulum system, the fatal defect was seen in the unstableness of the system. As it seemed that the instability is caused by the self-weight of the inverted pendulum, the author improved the status in placing the coupled two pendulums in a same horizontal level as shown in Fig.4.

The equation of motion of the pendulum system in Fig.4 are as follows: For the left pendulum

$$I\ddot{\theta} = -K\theta - R\dot{\theta} + m\ddot{x}b\cos\theta + m\ddot{y}b\sin\theta - Aa, \quad \text{----------} (1)$$

where A is the tension in the belts. It is noticed that when $\ddot{y}$ is zero, A is zero. For the right pendulum

$$I\ddot{\theta} = -k\theta - R\dot{\theta} + m\ddot{x}b\cos\theta - m\ddot{y}b\sin\theta + Aa. \quad \text{----------} (2)$$

Eliminating A from Eqs.(1) and (2), y-component forces vanish simultaneously and we have

$$I\ddot{\theta} = -K\theta - R\dot{\theta} + m\ddot{x}b\cos\theta \quad \text{----------} (3)$$

In the case when there is an inclination φ to the direction x, the equation of motion is

$$I\ddot{\theta} = -K\theta - R\dot{\theta} + m(\ddot{x} + g\sin\varphi)b\cos\theta \quad \text{----------} (4)$$

In static state, that is $\dot{\theta} = \ddot{\theta} = \ddot{x} = 0$ in Eq.(4), and when $\theta^2 \ll 1$, we have the following equilibrium equation

$$K\theta = mbg\sin\varphi \quad \text{----------} (5)$$

The design of the horizontal component seismometer of the coupled pendulum system is shown in Fig.5. In this design piano wire are used as the coupling belts and cross springs are used for the falcrums. The improved coupled pendulum system is better than the Matuzawa's in the dynamical stability. The vertical component seismometer of the coupled pendulum system is shown in Fig.6. As the equations of motion are similar to those for the horizontal seismometer, we omit them.

Measurement of the relative displacement. The relative displacement of the pendulum is transformed into electric voltage by using a magnesensor or a differential transformer. The latter is better than the former because the latter is not affected by the external magnetic field.

TEST

Free oscillation test. An example of the free oscillation record is shown in Fig.7 and from it the value of solid friction or its equvalent force is determined smaller than 0.0001 gals. Therefore, our velocity seismometer can detect a weak motion of 0.001 kines for the period of 50 seconds.

Damping oil. When silicon oil with viscosity of 30,000 c stokes (or 10,000 c stokes) is used for damping, the damping constant,h, becomes about 120 (or 40) times of the critical. Then the deflection of the pendulum is about 1 mm (or 3 mm) for 100 kines of ground motion and eddy does not occur and the force proportional to second power of the relative velocity of pendulum can be neglected.

Test by means of a large shaking table. The set of three components of the velocity seismometer is fixed on a large shaking table and the sensitivity and the effects of the force of non-oscillating directions are examined. Out-put voltages from three components by a large vibration test on one direction are shown in Fig.8 and in Table 1. As the shaking table, particularly the vertical shaking table may generate the vibration of other components, it may be thought that the effects of the force of non-oscillating direction are smaller than several percents even for the in-put over 1g.

The sensitivity curves are shown in Fig.9.

Table 1. The largest effects of the forces of non-oscillating directions obtained from Fig.8. e_{H1} etc is the output voltage of each component.

V-direction shaking ;	e_{H1}/e_V =0.08,	e_{H2}/e_V =0.08
H1-direction shaking;	e_{H2}/e_{H1}=0.005,	e_V/e_{H1} =0.02
H2-direction shaking;	e_{H1}/e_{H2}=0.015,	e_V/e_{H2} =0.006

TEMPERATURE COMPENSATING CIRCUIT

Sensitivity of velocity seismometer depends on the viscosity of damping oil which changes with room temperature. Therefore, we connect a temperature compensating circuit with a thermister to the output of the seismometer. Fig.10 shows the temperature dependences of the viscosity of the silicon oil, the resistance of a thermister and the resistance of a compound thermister, respectively. When the compound thermister shown in Fig.10 is used in the feed-back circuit of an operational amplifier which is connected to the output of the transformer, the output voltage of the amplifier becomes independent on temperature. The external appearance of a set of three component seismometers with the temperature compensating circuit is shown in Fig.11.

RECORDING SYSTEM

The velocity seismometer developed here is a kind of tranceducer. We have further developed a recording system which is called SAMTAC-14V where the three component particle velocities of ground motion and the time cord of crystal clock are recorded by digitalized signal in a cassette tape with a delay time of 10 seconds. The crystal clock is automatically corrected by the time signal from NHK(Nippon Hoso Kyokai). AGC(automatic Gain Control) changes 1 kine range to 100 kines range. Start level is variable. Strength of the apparatus of SAMTAC-14V is tested by a large shaking table. The external appearance is shown in Fig.12.

SOME SEISMOGRAMS OBTAINED BY THE VELOCITY SEISMOGRAPH

Fig.13 shows the seismograms of the Near Izu-Oshima earthquake, Jan. 14, 1978, observed by the velocity type strong motion seismograph at Shibaura in Tokyo and that by a strain meter at Haneda in Tokyo obtained by J. Tamura(1978). We can see that the velocity seismogram bears resambrance to the strain seismogram in long period waves. Fig.14 shows the seismograms obtained at two observation points in Shizuoka Prefecture simultaneously. Comparing these seismograms, we can see that the initial motions of P-waves and S-waves are corresponding well and that the later waves express the vibrational characteristics at each site.

COMPARISON ON THE RECORDING RANGES WITH OTHER SEISMOGRAPHS

The recording ranges of some seismographs which are used widely nowadays are shown in Fig.15. The thick lines indicate the ground motions corresponding to the full scale of these seismographs are all 30 mm. The range of thin closed line denoted by A indicates the earthquake motions shown in Fig.1. We can understand that the earthquake motions of which the periods are longer than several seconds are all scaled out in the record of so-called displacement seismographs and they are buried in the shorter motions in the record of so-called acceleration seismographs. Oblique lines indicate the ground motions corresponding to the Japanese seismic intensity scale. Broken line indicates the lower limit to be recorded by VS-100 which is the high sensitive range of the velocity type strong motion seismograph. By the way, the recording ranges of some highest sensitive seismographs are shown.

CONCLUSION

Many records of the strong earthquake motions indicate that the upper boundaries of particle velocities are almost constant for wide period range from 0.1 to 20 seconds and the values are almost 20-30 kines. Accordingly, it may be thought that a velocity type seismometer is suitable to observe the strong earthquake motion. By the way, weak motions which occur frequently are also valuable to study the properties of earthquake motions. Therefore, the author developed a velocity type strong motion seismograph which can record the earthquake motions from 100 to 0.01 kines with high fidelity over the periods from 0.05 to 50 seconds.

The main part of this seismograph is a coupled pendulum system which had been designed by Matuzawa(1938) and improved by the author here. The whole system of the coupled pendulums is immersed in high viscous silicon oil and the relative displacement of the pendulum is transformed into voltage. The dependence of sensitivity on temperature is compensated by an electric circuit with a compound thermister.

The velocity type strong motion seismograph reported here already recorded several felt earthquakes satisfactorily and we can expect further that it will also record successfully the destructive earthquake motions caused by a large earthquake, if it occurs.

REFERENCES

Brune, J.N. (1970), "Tectonic stress and the spectra of seismic shear waves", Jour. Geophy. Res., 75 4997-5009.

Matuzawa, T. (1938), "Ein Lange-periodiger Seismograph fur Starke Beben", Jour. Fac. Sci. (Tokyo Imp. Univ.), Sec. 2, 5 59-67.

Muramatu, I. (1976), "The maximum valueand the duration of the strong earthquake motions", Zisin 2(Jour. Seis. Soc. Japan), 29 223-232.

Nasu, S. (1971), "Ground motion of destructive earthquake(2)", Journal of Architecture, No. 237.

Tamura, J. (1978), "Observation of dynamic behaviour of a submerged tunnel during earthquakes", Report of the special research on naturl disaster No. A-53-1, 141-146.

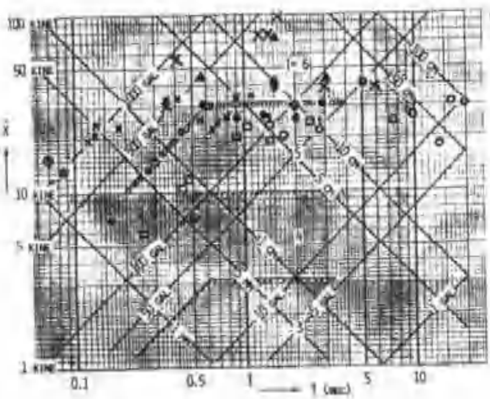

Fig.1 Upper boundaries of the strong earthquake ground motions recorded until now.

Nagoya	(1891.10.28)	I*=6	M=8.0
Tokyo	(1923, 9, 1)	6	7.9
Niigata	(1964, 6,16)	5	7.5
Matsushiro	(1965, 5,28)	5	4.9
Hachinohe	(1968, 5,16)	5	7.9
El Centro	(1940, 5,18)	(6)	6.9
Parkfield	(1966, 6,27)	(6)	5.6
Pacoima Dam	(1971, 2, 9)	6	6.6
Gazli, USSR	(1976, 5,17)	6	7.3
Bucharest	(1977, 3, 5)	6	7.2

* Japanese seismic intensity scale

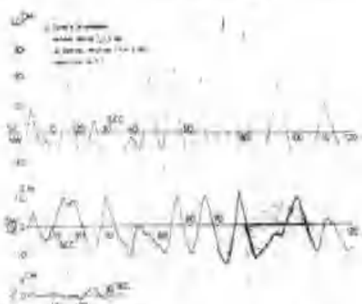

Fig.2 Ewing's seismogram of the Kanto earthquake, 1923, at Tokyo University. The original is a disk record. Characteristics of the seismograph: natural period=6.0 sec, no damper, friction(equivalent h =0.045), magnification=1, length of the pendulum=51 cm, weight of the pendulum=25 kg(after Nasu(1971)).

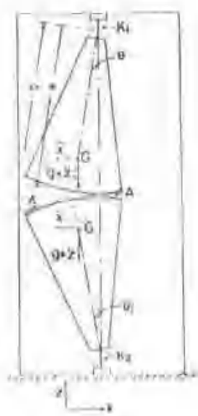

Fig.3 Matuzawa's coupled pendulum system and its principle.

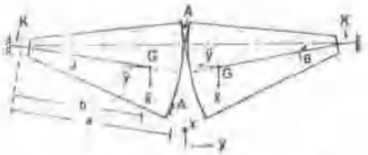

Fig.6 Structure of the vertical component seismometer and its behaviour.

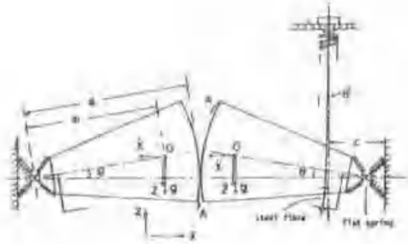

Fig.4 improved coupled pendulum system of a horizontal seismometer and its behaviour(a ground plane).

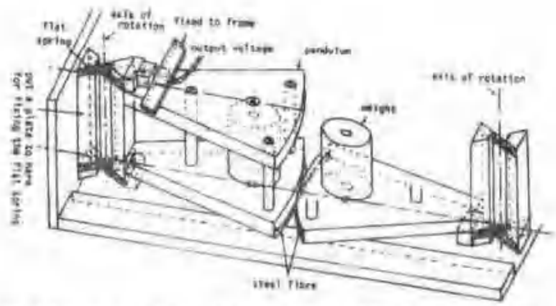

Fig.5 Illustration of the structure of the horizontal component seismometer

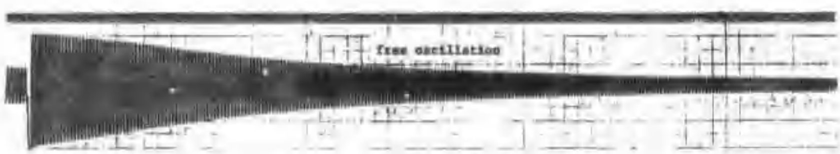

Fig.7 An example of free oscillation of the coupled pendulum system.

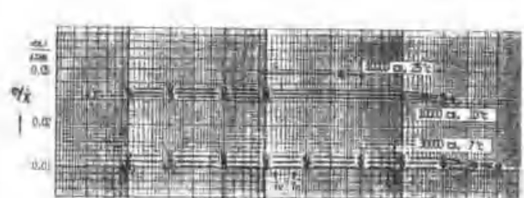

Fig.8 Sensitivity characteristics of the velocity type strong motion seismometer and the effect of the viscosity of damping oil on it. ● H_1, ○ H_2, ＊V.

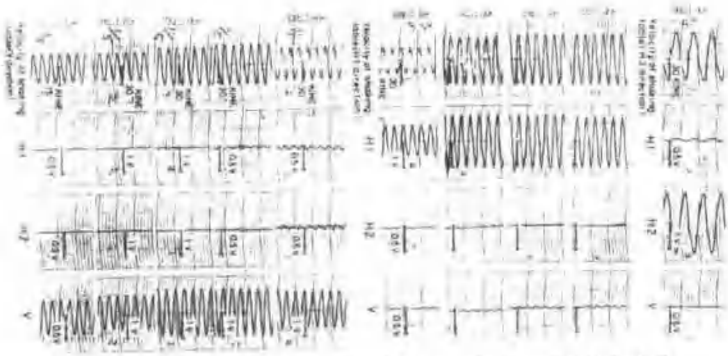

Fig.9 Effects of the non-oscillating direction forces. Simultaneous records of the shaking table and three component seismometers.

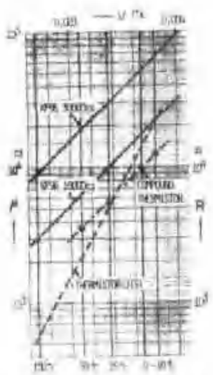

Fig.10 Effects of temperature on the viscosity of silicon oil and on the resistance of some thermister. real line; viscosity of silicon oil. broken line; resistance of thermister. chain line; resistance of compound thermister.

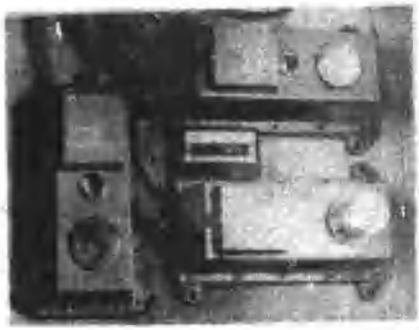

Fig.11 Exterior appearance of a set of three components of the velocity type strong motion seismometer.

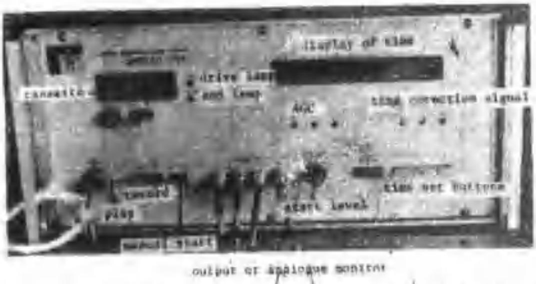

Fig.12 Recording apparatus of the velocity type strong motion seismograph. SAMTAC-14V.

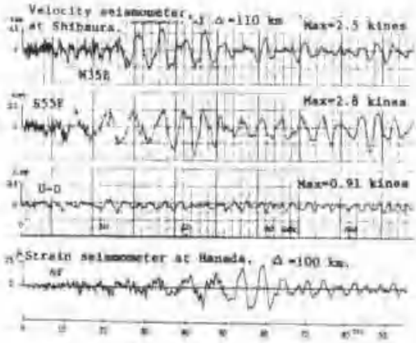

Fig.13 Seismograms of the Near Izu-Oshima earthquake, Jan.14, 1978, M=7.0, h=0,

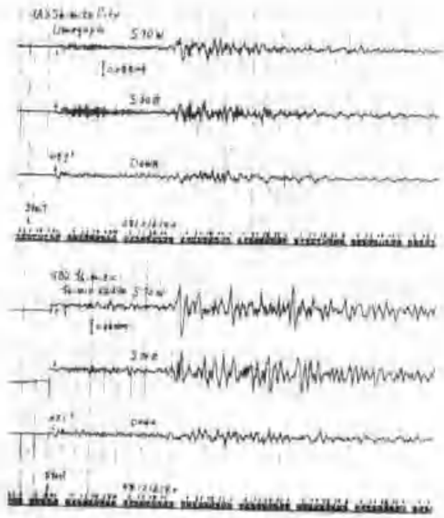

Fig.14 Seismograms of the S off Chiba Prefecture, Aug,12, 1979, M=5.7, h=50 km. Δ =200 km

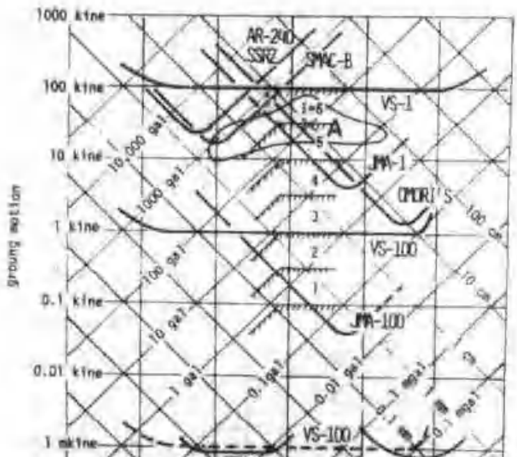

Fig.15 Recording ranges of various seismographs which are widely used nowadays. It is assumed that the values of full-scale of their records are all 10 mm. Thick lines; the earthquake motions corresponding to full-scale of each seismograph. Closed line denoted by A; the earthquake motions shown in Fig.1. Oblique lines; Japanese seismic intensity scale. Broken line; lower limit of ground motions to be recorded by VS-100.

U.S. STRONG MOTION PROGRAMS

R. D. Borcherdt and R. B. Matthiesen
U.S. Geological Survey, Menlo Park, California, USA 94025

SUMMARY

Safeguarding life and property from the destructive effects of earthquakes is a major national as well as world-wide problem. Since the most widespread destructive effects of earthquakes are due to strong shaking, either directly through shaking-induced structural damage, or indirectly through shaking-induced ground failures, effective programs to measure strong ground motions generated by earthquakes are vital to national as well as international efforts to reduce earthquake hazards. Strong-motion programs in the United States are supported by a number of federal and state agencies with coordination provided by a national program operated by the United States Geological Survey and supported by the National Science Foundation. The cooperative national program is designed to collect, analyze, and disseminate structural response and ground motion data. Agencies developing centers to process strong-motion data include U.S. Geological Survey, the California Division of Mines and Geology, the University of Southern California, and Stanford University. Automatic digitization procedures and interactive software being developed at the centers permit rapid processing and dissemination of the data to interested researchers. The extreme importance of obtaining strong-motion data at distances less than 40 kilometers from large (M>7) earthquakes provides an urgent need for international cooperative efforts to acquire and disseminate near-field strong-motion data.

INTRODUCTION

Earthquake strong motion data provide the basis for design of critical structures as well as the basis for research on fundamental problems related to engineering design, earthquake processes, and internal structure of the earth. Consequently, effective programs to record strong motions generated by large earthquakes are vital to national as well as international efforts designed to reduce earthquake hazards.

Presently, few strong-motion data exist for large (M>7) earthquakes at distances less than forty kilometers even though several such damaging earthquakes occur each year in different parts of the world. This lack of crucial data is due to inadequate instrumentation and defines an urgent need for expanding both national and international programs to collect and disseminate near-fault strong-motion data. Detailed recommendations for program expansion in the United States have been developed by Matthiesen (1978). Recommendations for increased international efforts have been developed by the International Workshop on Strong-Motion Earthquake Instrument Arrays (Iwan, 1978). Acquisition and dissemination of the necessary data will depend in part upon successful implementation of recommendations similar to those suggested in these reports. This paper briefly summarizes existing strong-motion programs in the United States and data centers involved with the processing and dissemination of strong-motion data.

STRONG-MOTION PROGRAMS

Strong-motion instrumentation programs in the United States are supported by a number of federal, state, and local agencies with varying degrees of coordination provided by a national program operated by the United States Geological Survey with funding provided under the Earthquake Hazard Reduction Act of 1977. The national program began with the installation of 51 standard accelerographs following the disastrous 1933 Long Beach earthquake in southern California. Since that time the number of strong-motion instrument locations in the United States (Fig. 1) has increased substantially with a number of federal and state agencies initiating programs as a result of the 1964 Alaska and 1971 San Fernando, California earthquakes.

Instrumentation programs currently being conducted at the federal level on a reimbursable basis by the U.S. Geological Survey include: Corps of Engineers (250 instruments installed on 70 dams, 55 of which are maintained by USGS and 15 by COE, with plans for 150 additional instruments to be installed), Bureau of Reclamation (34 instruments installed on 16 dams maintained by USGS with plans for 4 dams with downhole systems to be installed), Federal Highway Administration (four multi-channel systems installed on bridges), Veterans Administration (66 instruments installed at hospital sites and five multi-channel systems installed in buildings), and small programs for the General Services Administration and the Department of Energy.

Instrumentation owned and operated by the U.S. Geological Survey with support from the National Science Foundation include 273 instruments, 255 of which are installed to measure strong ground motion and 17 installed to measure building response. These instruments are located in southern California (90 instruments), northern California (52 instruments), the Pacific Northwest (16 instruments), the Mississippi Valley (17 instruments), Alaska (33 instruments), Hawaii (15 instruments), and Puerto Rico (6 instruments). An additional 250 seismoscopes are also maintained (170 in California and 80 in Alaska). A network of 80 strong-motion accelerographs are being installed with NSF support in the Los Angeles, California area by the University of Southern California and a network of 20 accelerographs is operated by California Institute of Technology in the area of Pasadena, California.

The principal instrumentation program being conducted at the state level with state funding is the California Strong Motion Instrumentation Program. This program is one of the largest in the U.S. with over 400 instruments (43 structures) currently installed and plans to install over 1000 instruments. This program is independent of other U.S. strong-motion programs but network planning and data processing are closely coordinated with the national program.

Other state and local instrumentation programs operated on a reimbursable basis by the U.S. Geological Survey include: Metropolitan Water District of Southern California (25 instruments), California Department of Water Resources (60 instruments maintained cooperatively), California Department of Transportation (4 multi-channel analog systems installed on bridges), and the Washington Department of Highways (3 multi-channel digital systems installed on bridges).

Local instrumentation programs operated and funded by the host agency include: Los Angeles Department of Water and Power, United Water Conservation District, Los Angeles County Flood Control District, and a number of other small programs initiated primarily by public utility commissions and local building regulations. (More than 225 buildings of six stories or more are instrumented in the U.S. with most of these being a result of the Los Angeles Building Code passed in 1965, Rojahn and Matthiesen, 1977.)

Instrumentation objectives of the various programs vary from regulatory monitoring to basic research, with instrumentation guidelines prepared for buildings (Rojahn and Matthiesen, 1977), bridges (Raggett and Rojahn, 1978) and dams (Bolt and Hudson, 1975). More extensive guidelines for dams are presently being compiled (Rojahn, pers. comm., 1980). Details on established networks are available in published reports for central and eastern United States (Porcella, 1978), Imperial Valley, California (Porcella, 1978), central California (Porcella, 1979), Alaska (Porcella, 1979), and Hawaii (Porcella, 1977).

The most common type of strong-motion instrument utilized by the programs for measurement of ground motion and in some cases building response is a self-triggering tri-axial analog accelerograph designed to record signals up to 1 g on 70 mm photographic film. The system has a dynamic range of about 55 db at a sensitivity of 1.8 cm/g, a useable frequency bandwidth of about 0.06-35 Hz, and a natural frequency of 20-25 Hz with critical damping 60-70 percent. Many of the recently installed systems are also equipped to record an external time standard.

Other instruments utilized include both analog and digital multi-channel systems for measurement of ground motion in drill holes, and measurement of the responses of buildings, dams, and bridges. A summary of specifications for typical systems is provided by Iwan (1978) and Hudson (1979). With the improvements in field reliability, digital event recorders are becoming more useful.

Centers in the U.S. established to process strong-motion data are located at the U.S. Geological Survey in Menlo Park, California, the California Division of Mines and Geology in Sacramento, California, the University of Southern California, Los Angeles, California and Stanford University, Stanford, California. These centers utilize laser-scan automatic digitization procedures to process the analog film records. These procedures together with interactive computer software permit rapid processing and dissemination of the data to interested researchers.

Current information about strong-motion data available in the western hemisphere can be easily accessed via the Strong Motion Information Retrieval Systems developed at the National Strong Motion Data Center in Menlo Park, California (Converse, 1978). The system provides users with information on data characteristics, recording environment, and archive location via computer terminal and telephone (415-329-8600). Digital and analog copies of the more significant strong-motion records collected in the United States are available from the National Geophysical and Solar Terrestrial Data Center (D62) in Boulder, Colorado, 80302 and the National Information Service for Earthquake Engineering, California Institute of Technology, Pasadena, California. (Analog copies are available on 35 or 70 mm film chips, and on paper; digital copies are available on punched cards and magnetic tape.) Two recent data sets of considerable significance to earthquake engineering are those collected from the Coyote Lake, California earthquake of August 6, 1979 (Porcella et al., 1979) and the Imperial Valley, California earthquake of October 15, 1979 (Porcella and Matthiesen, 1979). Each of the earthquakes yielded significant sets of near-field strong ground motion data from linear accelerograph arrays (Figs. 2 and 3) as well as data on the response and failure process of modern engineered structures (Figs. 2 and 3).

The Coyote Lake earthquake (M5.7) initiated at a depth of 9 km on the Calaveras fault, showed very small strike-slip displacements (less than 5 mm) along the ground surface for a distance of about 5-6 km, yielded more than 54 free-field accelerograph records at distances from 0.1 km to 114 km, and produced more than 22 recordings of building response mostly at distances greater than 40 km. The damage from this event in nearby communities was relatively minor, but the strong-motion data should prove especially useful for inferring the characteristics of the earthquake rupture process, the nature of near-field earthquake motions, and the influence of geology on strong ground motion.

The Imperial Valley earthquake (M6.4) occurred on a portion of the Imperial and Brawley faults that ruptured during the 1940 Imperial Valley Earthquake (M7.0). The Imperial Valley earthquake initiated at a depth of about 15 km on the Imperial fault, resulted in both strike-slip and dip-slip surface displacements (max. 55 and 20 cm, respectively), produced 33 free-field records in the U.S. and several others in northern Mexico (11 of these records were within 9 km of the fault), and yielded detailed recordings documenting the failure process of a six-story building (Rojahn and Ragsdale, 1980), the response of a highway overpass, and differential short-period ground motions. Comparison of the famous 1940 El Centro accelerogram with that obtained on a similar instrument at the same location (Fig. 4) shows that the 1979 event generated ground motions with similar peak amplitudes but substantially shorter durations. Peak horizontal accelerations recorded within 1 km of the surface rupture for the 1979 event range from 0.65 g to 0.72 g; the maximum peak vertical acceleration recorded was 1.74 g. Data from this earthquake should prove especially useful for studies of the response of engineered structures, the nature of near-field ground motions and comparative studies with the 1940 Imperial Valley earthquake.

REFERENCES

Bolt, B. A. and Hudson, D. E., 1975, Seismic instrumentation of dams, Jour. Geo. Eng. Div. ASCE, p. 1095-1104.

Converse, A. M., 1978, Strong-motion Information Retrieval System Users Manual, U.S. Geological Survey Open-File Report 79-289.

Hudson, D. E., 1979, Reading and interpreting strong motion accelerograms, Earthquake Eng. Res. Inst. Monograph, 112 p.

Iwan, W. D., 1978, Strong-motion earthquake instrument arrays, Proc. Int'l. Workshop on Strong-Motion Earthquake Instrument Arrays, May 2-5, 1978, Honolulu, Hawaii.

Matthiesen, R. B., 1978, On the development of strong-motion instrument networks in the United States, U.S. Geological Survey Open-File Report 78-1024, 91 p.

Porcella, R. L. (editor), 1977, Seismic Engineering Program Report, May-August 1977, U.S. Geological Survey Circular 762-B, 26 p.

Porcella, R. L., 1978, Strong-motion instrumentation in the central and eastern United States, Earthquake Notes, Eastern Section of the Seismological Society of America, v. 49, no. 2, p. 3-14.

Porcella, R. L., 1979, Seismic Engineering Program Report, January-April 1979, U.S. Geological Survey Circular 818-A, 20 p.

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

Porcella, R. L., Matthiesen, R. B., McJunkin, R. D., and Ragsdale, J. T., 1979, Compilation of strong-motion records from the August 6, 1979 Coyote Lake earthquake, U.S. Geological Survey Open-File Report 79-385, 71 p.

Raggett, J. D. and Rojahn, C., 1978, Use and interpretation of strong-motion records from highway bridges, Federal Highway Administration Report No. FHWA-RD-78-158, 168 p.

Rojahn, C. and Matthiesen, R. B., 1977, Earthquake response and instrumentation of buildings, Jour. Tech. Counc., ASCE, v. 103, no. TC1, p. 1-12.

Rojahn, C. and Ragsdale, J. T., 1980, A preliminary report on strong-motion records from the Imperial County Services Building, El Centro, California, U.S. Geological Survey Professional Paper, in press.

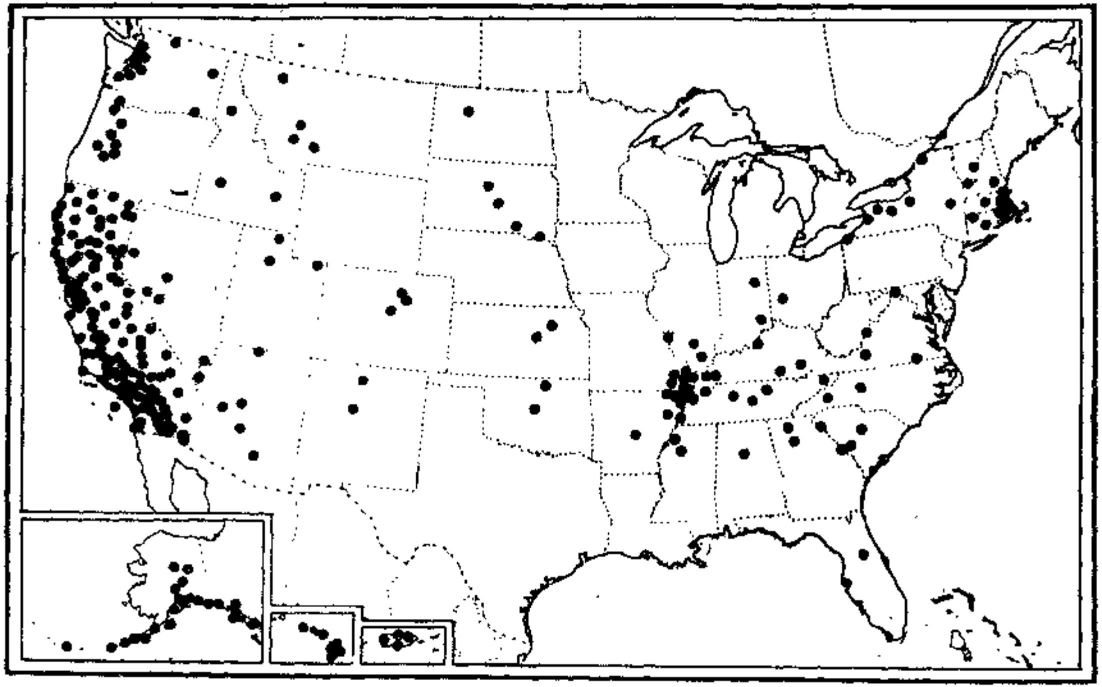

Figure 1. Location of strong-motion accelerographs in the United States (Matthiesen, 1978).

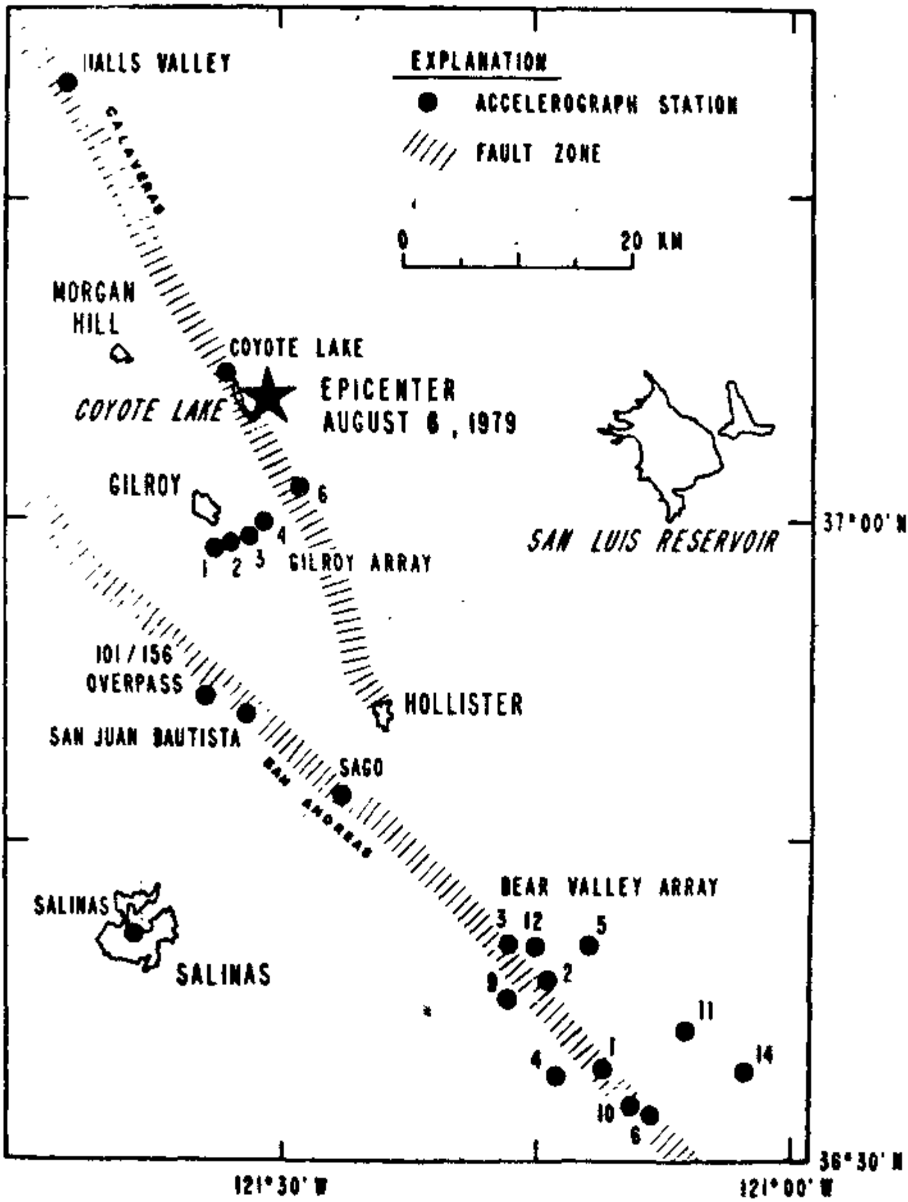

Figure 2. Location map of instrumentation arrays and stations close to epicenter of the Coyote Lake earthquake (Porcella et al., 1979).

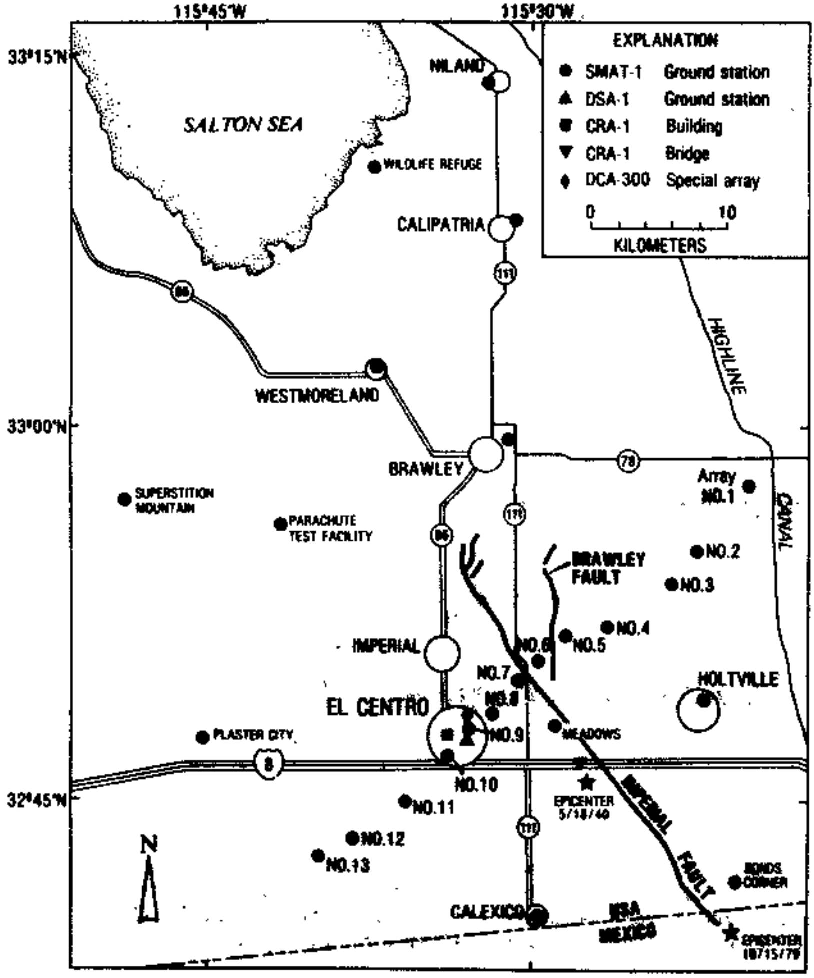

Figure 3. Strong-motion stations in the Imperial Valley, California (Porcella and Matthiesen, 1979).

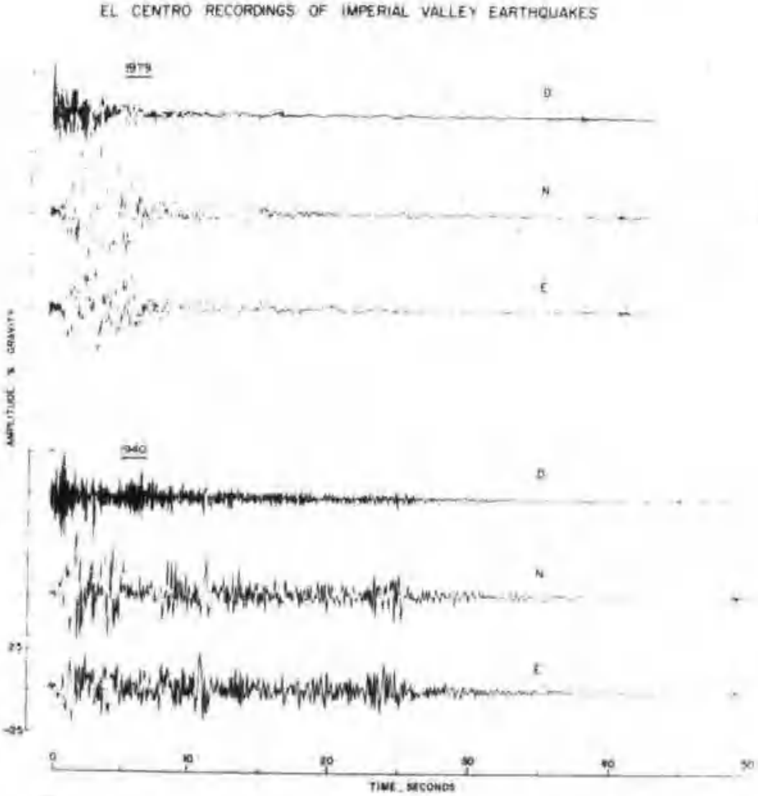

Figure 4. Strong ground motion recordings obtained from the 1940 and 1979 Imperial Valley earthquakes. The recordings of vertical (D) and horizontal (N, north-south; E, east-west) ground motion were obtained at the same site on similar AR-240 accelerographs (accelerograms after Joyner; 1980, pers. comm.).

A METHOD FOR NUMERICAL CALCULATION OF DYNAMIC-CHARACTERISTICS-CONVERSION OF SEISMOMETERS

by

Yutaka Nakamura[I]

SUMMARY

This paper presents a method for converting the numerical output waveform of a actual (real) seismometer into the output waveform of an imaginary (virtual) seismometer of desirable characteristics. The major drawback of conventional methods used for this purpose is their incapability of real-time processing. The proposed method for conversion of dynamic characteristics of seismometers is simple in nature and is capable of real-time processing which allows use of seismometers based on easy-to-handle accelerometers for measurement of velocity and displacements as well, bringing in a considerable saving in labor in measurement and maintenance.

INTRODUCTION

In earthquake engeneering, velocity and displacement waveforms are often obtained by integration of acceleration waveforms. If the characteristics of a seismometer used for vibration measurement is unsuitable, the vibration waveform observed is found to be very much distorted, necessiating a correction in order to infer the real vibration waveform. In other cases where vibration waveforms obtained by various measurements are compared, waveform processing to unify the instrument characteristics ("instrument characteristics conversion processing")is required for the output waveform of each instrument.

Calculation for correction of waveform distorsion can be performed by "instrument characteristics conversion processing". Further, "instrument characteristics conversion processing" also enables differentiation and integration of waveforms, which is understandable by the fact that the acceleration of earthquake motion is measured by short-period seismometers and its displacement by long-period seismometers. In this case, long-period and short-period components are filtered out in integration and differentiation, respectively, allowing automatic reduction of components liable to disturb differentiation and integration operations.

Conventional methods[1,2,4] related to diffentiation, integration and distortion-correction of waveform are not capable of real-time processing due to limited number of waveform data that can be processed. However, if such calculations can be performed on real-time basis with high accuracy being maintained, not only the use of an accelerometer, easier to be handled and installed than a displacement meter, will be allowed for continuous monitoring of displacement, but also the installation of only one seismometer will be required for obtaining acceleration, velocity and displacement on real time.

I. Senior Researcher, Structure Lab., Railway Technical Research Institute, Japanese National Railways