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2

GEOSCIENCE ASPECTS, PART II

●
STRONG MOTION INSTRUMENTATION AND
DATA COLLECTION

INFLUENCE OF LOCAL CONDITIONS ON GROUND MOTION

SIMULATED AND ARTIFICIALLY GENERATED
GROUND MOTIONS

SPECTRAL ANALYSIS AND INTERPRETATION OF
GROUND MOTION

TABLE OF CONTENTS

A VELOCITY TYPE STRONG MOTION SEISMOGRAPH WITH WIDE FREQUENCY AND DYNAMIC RANGE	1
Ikuei Muramatsu	
U.S. STRONG MOTION PROGRAMS	9
R.D. Borchardt, R.B. Matthiesen	
A METHOD FOR NUMERICAL CALCULATION OF DYNAMIC CHARACTERISTICS CONVERSION OF SEISMOMETERS	17
Yutaka Nakamura	
SAMPLING AND INTERPOLATION OF STRONG MOTION ACCELEROGRAMS	25
Arturo Arias, Horacio Sandoval	
RANDOM DIGITIZATION ERRORS AND RELIABILITY OF FOURIER SPECTRA OF STRONG-MOTION ACCELEROGRAMS	33
Arturo Arias, Horacio Sandoval	
RECENTLY DEVELOPED STRONG MOTION EARTHQUAKE INSTRUMENTS ARRAY IN JAPAN	41
Syun'itiro Omote, Kyoiti Ohmatsuzawa, Tokiharu Ohta	
INSTRUMENT ARRAYS FOR A NEAR FIELD STRONG MOTION EARTHQUAKE SURVEY IN ITALY	49
S. Polinari	
A METHODOLOGY FOR LOCATING STRONG MOTION ARRAYS	55
F.E. Udwadia, H. Miura	
ON- LINE CONTROL OF THE SINGLE COMPONENT SHAKING TABLE	63
M. Simova, D. Namugovski	
METHOD AND RESULTS OF THE STRONG MOTION MODELLING THE GAZLY EARTHQUAKE OF MAY 17, 1976.	70
J. Kopnichev, I. Nersesov, G. Shpilker	
EARTHQUAKE ENVIRONMENT SIMULATION BY PULSE GENERATORS	73
S.F. Masri, F.B. Safford	
A MECHANICAL MODEL FOR THE GENERATION OF ARTIFICIAL SEISMOGRAMS	81
Andrej Umek	
GROUND RESPONSE IN THE SALT LAKE CITY-OGDEN-PROVO, UTAH, URBAN CORRIDOR	89
Walter W.Hays, Robert D. Miller, Kenneth W. King	
ANALYSES ON SEISMIC GROUND MOTION PARAMETERS INCLUDING VERTICAL COMPONENTS	97
Yorihiko Ohsaki, Makoto Watabe, Masanobu Tohdoh	
NEW AUTOMATIC TRAIN STOPPING SYSTEM DURING EARTHQUAKE	105
Toshiro Fujiwara, Yutaka Nakamura	

AN ALTERNATIVE APPROACH TO MODELING EARTHQUAKE GROUND MOTION ATTENUATION IN THE WESTERN UNITED STATES	113
Ronald T. Eguchi	
TIME OF MAXIMUM RESPONSE OF SINGLE-DEGREE-OF-FREEDOM OSCILLATOR TO EARTHQUAKE EXCITATION	121
V.W. Lee	
AN ISOSEISMAL-ENERGY CORRELATION FOR USE IN EARTHQUAKE STRUCTURAL DESIGN	125
S.F. Borg.	
INSTRUMENTAL MEASUREMENT OF NATURAL VIBRATION PERIODS OF SOME HIGH-RISE REINFORCED CONCRETE BUILDINGS IN ISTANBUL REGION	127
Alkut Aytun	
SPECTRAL CHARACTERISTICS OF NEAR SOURCE STRONG GROUND MOTION	131
Jeff A. Johnson	
ACCELEROGRAM, INTENSITY, DAMAGE; A NEW CORRELATION FOR USE IN EARTHQUAKE ENGINEERING DESIGN	135
S.F. Borg	
A COMPARATIVE STUDY OF SITE DEPENDENT EARTHQUAKE RESPONSE ANALYSES TIME-HISTORY VERSUS SMOOTH RESPONSE SPECTRUM	138
Fred A. Webster, Jack R. Benjamin, Charles A. Kircher	
EFFECTS OF SITE GEOLOGY ON AMPLITUDES OF STRONG MOTION	145
M.D. Trifunac	
EFFECTS OF CANYON TOPOGRAPHY ON DYNAMIC SOIL-BRIDGE INTERACTION FOR INCIDENT PLANE SH WAVES	153
Jorge A. Esquivel Francisco J. Sanchez-Sesma	
EFFECT OF THREE-DIMENSIONAL TOPOGRAPHY ON EARTHQUAKE GROUND MOTION	161
Liao Zhenpeng, Yang Baipo, Yuan Yifan	
INFLUENCE OF GEOLOGICAL SOIL PROFILES ON THE AMPLITUDE OF SEISMIC WAVES	169
G.Grünthal, P. Bormann	
EARTHQUAKE GROUND MOTIONS INFLUENCED BY IRREGULARITIES OF SUB-SURFACE TOPOGRAPHIES	175
Kojiro Irikura	
EFFECTS OF SEISMIC AND GEOTECHNICAL CONDITIONS ON MAXIMUM GROUND ACCELERATIONS AND RESPONSE SPECTRA	183
Toshio Iwasaki, Kazuhiko Kawashima, Mitsuaki Saeki	
A SINGLE DEGREE OF FREEDOM MODEL FOR NON-LINEAR SOIL AMPLIFICATION	191
M. Erdik	

EFFECTS OF LOCAL SITE CONDITIONS ON DAMAGE TO BUILDINGS DURING AN EARTHQUAKE	199
Junichi Shibuya, Hideki Kimura, Toshio Shiga	
THE EFFECTS OF ELEVATION AND SITE CONDITIONS ON GROUND MOTION OF THE FERNANDO, CALIFORNIA EARTHQUAKE, 9 FEBRUARY 1971	207
F.K. Chang	
DESIGN FOR SPATIAL GROUND MOTIONS	215
H. Sandi	
ON NON STATIONARY CHARACTERISTICS ACCELEROGRAMS IN OSAKA PLAIN	223
Yoshihiro Takeuchi	
SPECTRAL CHARACTERISTICS OF HARD ROCK MOTIONS	231
Y. Ohsaki, Y. Sawada, K. Hayashi, B. Ohmura, C. Kumagai	
ON THE CHARACTERISTICS OF ACCELEROGRAMS RECORDED ON BEDROCK NEAR ORIGINS	239
Y. Sawada, S. Sasaki, H. Yajima, N. Yoshioka, A. Sakurai T. Takahashi	
ACCELERATION AND VELOCITY DISTRIBUTION OF THE VANCEA MARCH 4, 1977 EARTHQUAKE DETERMINED BY THE RESPONSE OF THE RIGID BODIES	247
M. Stojkovic, H. Kapsarov, S. Galbov	
EFFECTS OF THE GROUND CONDITION ON DYNAMIC CHARACTERISTICS OF STRUCTURES	251
Shintaro Ohba	
INFLUENCE OF SOME SOIL PARAMETERS ON THE MODIFYING EFFECT OF LOCAL SOIL CONDITIONS	255
H. Boncheva	
ISOSEISMAL MAP IN NEAR-FIELD WITH REGARD TO FAULT RUPTURE AND SITE GEOLOGICAL CONDITIONS	259
Saburoh Midorikawa, Hiroyoshi Kobayashi	
THE DURATION OF STRONG MOTION AND ITS DEPENDENCE ON THE RECORDING SITE GEOLOGY	263
Bruce D. Westermo	
RISK OPTIMIZATION CONSIDERING VIBRATIONAL BEHAVIOUR OF SUBSOIL	267
H. Tiedemann	
REPRESENTING EARTHQUAKE GROUND MOTIONS FOR DESIGN	271
Erik H. Vanmarck	
UNIFORM PROBABILITY RESPONSE SPECTRA FOR A SITE NEAR THE SAN ANDREAS FAULT	279
Rondall D. Wheaton, Ronald M. Polivka	

SIMULATION OF THREE-DIMENSIONAL EARTHQUAKE GROUND MOTIONS ALONG PRINCIPAL AXES	287
Makoto Watabe, Ryoji Iwasaka, Masanobu Tohdq Izuru Ohkawa	
SIMULATED EARTHQUAKE MOTIONS SCALED FOR MAGNITUDE, DISTANCE AND LOCAL SOIL CONDITIONS	295
Hiroyuki Kameda, Masata Sugito, Tadafumi Asamura	
DEVELOPMENT OF THE SEISMIC INPUT FOR USE IN THE SEISMIC SAFETY MARGINS RESEARCH PROGRAM	303
D.L. Bernreuter, D. H. Chung	
AN APPROACH TO SIMULATE A LARGE SET OF MULTICORRELATED RANDOM PROCESSES	311
Tatsuo Ohmachu, Yoshiaki Kimura	
THE GENERATION OF ARTIFICIAL ACCELEROGRAMS BY SUPERPOSITION OF SINUSOIDAL WAVES OF RANDOM DURATION	319
Muzafer İpek	
SITE-DEPENDENT EARTHQUAKE SIMULATION	327
Zeki Hasgür	
GENERATION OF SYNTHETIC EARTHQUAKE MOTIONS AND THEIR APPLICATION TO DYNAMIC RESPONSE ANALYSES	333
Tetsuo Kubo, Norio Suzuki	
STOCHASTIC FUNCTIONS IN EARTHQUAKE OCCURRENCE MODELS: A CRITICAL SURVEY	341
Nicola Pacilio, Mauro Basili	
A PROBABILISTIC MODEL FOR GROUND MOTION SPECTRA BASED ON RMS ACCELERATION	349
Martin W. Mc Cann, Haresh C. Shah, Robert J. Geller	
EFFECTS GROUND MOTION DURATION UPON EARTHQUAKE RESPONSE OF STRUCTURE	357
Sumio Nagahashi	
DESTRUCTIVE CAPABILITY OF EXTREME EARTHQUAKE MOTIONS EXAMINED IN TWO DIMENSIONS OF HORIZONTAL PLANE	365
H. Takizawa	
NEAR FIELD GROUND MOTION	373
V.V. Shteinberg, Yu.K. Chernov, T.G. Ivanova	
WAVE PROPAGATION METHOD OF SITE SEISMIC RESPONSE BY VISCO- ELASTOPLASTIC MODEL	379
Wang Zhiliang, Han Qingyu, Zhou Genshou	
RESPONSE SPECTRA OF EVOLUTIONARY EARTHQUAKE MODELS	387
P-T.D. Spanos	

ON THE DETERMINATION OF DISPLACEMENT FROM STRONG MOTION ACCELEROGRAMS	391
V.M. Grazier	
AN ANALYSIS OF ACCELEROGRAM AND RESPONSE PEAKS USING THE EXPONENTIAL DISTRIBUTION	395
Theodore C. Zsutty, Milton A. DeHerrera	
ON GROUND MOTIONS OF LONGER PERIODS IN STRONG EARTHQUAKES	399
Yoshimasa Kobayashi, Toshiro Fujiwara	
DISTANCE PARTITIONING IN ATTENUATION STUDIES	403
John A. Blume	
EVALUATION OF POTENTIAL DESTRUCTIVENESS FROM RECORDED STRONG MOTION ACCELEROGRAMS	411
T. Minami, Y. Sonoda, Y. Osawa	
PROCESSING AND ANALYSIS OF JAPANESE ACCELEROGRAMS AND COMPARISONS WITH U.S. STRONG MOTION DATA	419
C.B. Crouse, B.E. Turner	
ESTIMATION OF THE EXPECTED NEAR-FIELD MAXIMUM VELOCITY ON BEDROCK	427
Katsuhiko Ishida	
GEOPHYSICAL ESTIMATES OF SEISMIC SHEAR WAVE MOTION	435
Robin K. McGuire	
ON THE NEAR FIELD EARTHQUAKE MOTION IN INTRAPLATE ENVIRONMENTS'	443
Dimitri Papastamatiou	
GROUND MOTION IN THE EPICENTRAL REGION OF THE MAY 6, 1976 FRIULI EARTHQUAKE IN NORTH ITALY	451
Dimitri Papastamatiou, Margaret Asgian	
STUDY ON DYNAMIC GROUND CHARACTERISTICS IN RANGE OF SHORT AND LONG PREIODS	459
Yoshikazu Kitagawa, Yutaka Matsushima	
STOCHASTIC APPROACH ON IDEALIZED MODEL OF EARTHQUAKE GROUND MOTION	467
Masachiro Kawano	
OBSERVATION OF EARTHQUAKE RESPONSE OF GROUND WITH HORIZONTAL AND VERTICAL SEISMOMETER ARRAYS	475
Hajime Tsuchida, Setsuo Noda, Susumu Iai, Eiichi Kurata	
CAPACITY OF STRONG GROUND MOTION TO CAUSE STRUCTURAL DAMAGE	483
R. Araya, G.R. Saragoni	

GAUSSIAN PROPERTIES OF EARTHQUAKE GROUND MOTION	491
G.R. Saragoni, R. Alarcon, J. Crempien	
A STUDY ON THE CONTRIBUTION OF SURFACE WAVES TO STRONG GROUND MOTIONS	499
Kazuyoshi Kudo	
THE SEISMO-GEOLGICAL BACKGROUND AND THE EARTHQUAKE RESPONSE OF TYPICAL STRUCTURES IN BEIJING	507
Zhou Xiyuan, Tung Jingzheng, Fu Sheng cong, Zhang Zaimin	
MODEL OF NONSTATIONARY SEISMIC PROCESS	515
V.T. Rasskazovsky, I.H. Aliev	
ATTENUATION OF INTENSITIES IN INDIA	521
Umesh Chandra	
STUDY OF THE CHARACTERISTICS OF STRONG MOTION FOURIER SPECTRA ON BEDROCK	525
Katsuhiko Ishida	
NEW BASE-LINE CORRECTION METHOD FOR GROUND MOTION DATA	529
J.M. Mulay, U.S. Kumar	
STRONG MOTION INVESTIGATIONS IN THE CENTRAL UNITED STATES	533
Robert B. Herrmann, Otto W. Nuttli	
A MEASURE OF DURATION OF STRONG GROUND MOTION	537
Erik H. Vanmarcke, Shih-Sheng P. Lai	
RECENT DEVELOPMENTS IN AUTOMATIC DIGITIZATION OF ANALOG FILM RECORDS	545
M.D. Trifunac	
A COMPARISON OF STRONG MOTION EARTHQUAKE DATA BANKS FOR JAPAN AND THE WESTERN UNITED STATES	553
Donald E. Hudson	
EVOLUTIONARY SPECTRA FOR STRONG MOTION ACCELEROGRAMS	561
George C. Liang, C. Martin Duke	
ON THE CHINESE SEISMIC INTENSITY SCALE	569
Liu Huixian	
ON THE ATTENUATION OF PEAK VELOCITY	577
David M. Boore	
GROUND MOTION INTENSITY BASED ON EARTHQUAKE EFFECTS ON HISTORICAL MONUMENTS	585
Chik-Sing Yim, Joseph Penzien, Anil K. Chopra	

A THEORETICAL EARTHQUAKE MODEL TO COMPLEMENT EMPIRICAL STUDIES OF STRONG GROUND MOTION ATTENUATION	593
Jean Savy, C. Allin Cornell	
PRELIMINARY ANALYSIS OF STRONG MOTION RECORDS OF THE TANGSHAN EARTHQUAKE AND ITS AFTERSHOCKS	601
Guo Yuxue, Peng Kezhong	
CHARACTERISTICS OF STRONG EARTHQUAKE GROUND MOTION IN THE PERIOD RANGE FROM 1 TO 15 SECONDS	609
Teiji Tanaka, Shizuyo Yoshizawa, Yutaka Osawa	
THE ATTENUATION CHARACTERISTICS OF NEAR FIELD GROUND MOTION DUE TO STRIKE SLIP FAULT MOTION	617
S.Yoshikawa, Y.T.Iwasaki, M.Tai, A.Kowada	
A COMPARISON OF GROUND RESPONSE IN THE LOS ANGELES REGION FROM NUCLEAR EXPLOSIONS AND THE 1971 SON FERNANDO EARTHQUAKE	625
A.M. Rogers, P.A. Covington, R.D. Borchardt	
REFINEMENTS IN CHARACTERIZING GROUND MOTIONS	633
H. Sandi	
RELATION BETWEEN THE FORMATION OF SOIL LAYERS AND THE VIBRATIONAL CHARACTERISTICS OF THE GROUND	637
Morio Takeuchi, Takaki Morioka, Makato Yamada	
INFLUENCE OF THE UNDERGROUND WATER OSCILLATION UPON THE AMPLITUDES AND PERIODS OF THE GROUND MICROSEISMIC NOISE	641
M. Stojkovic, D. Aleksovski	

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

Ikuei MURAMATU¹

SUMMARY

As the upper boundaries of particle velocities of several strong earthquake motions 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, excepting 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

¹ 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 desirable to cover from 0.1 seconds or shorter to 20 seconds or longer. Basic requirement 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 requirement 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

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

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

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

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

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

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

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

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

$$K\theta = mbg\sin\varphi \quad (5)$$

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 falcrams. 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 equivalent force is determined smaller than 0.0001 gals. Therefore, our velocity seismometer can detect a weak motion of 0.001 kins 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 kins 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 transducer. 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 resemblance 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.

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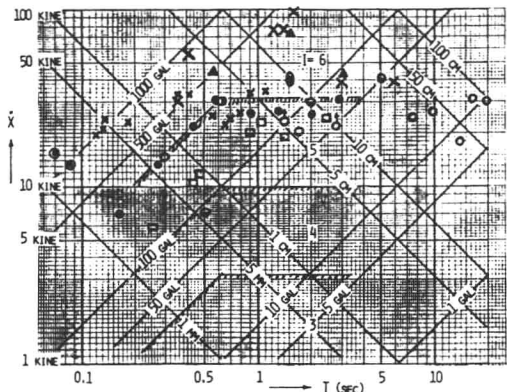


Fig. 1 Upper boundaries of the strong earthquake ground motions recorded until now.

○ 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
X Pacoima Dam	(1971, 2, 9)	6	6.6
x Gazli, USSR	(1976, 5, 17)	6	7.3
● Bucharest	(1977, 3, 5)	6	7.2

* Japanese seismic intensity scale

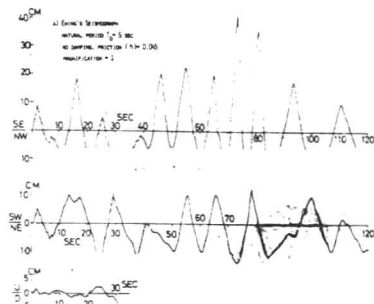


Fig. 2 Ewing's seismogram of the Kanto earthquake, 1923, at Tokyo University. The original is a disk record. Characteristics of the seismograph; natural period=6.0 sec, no damper, friction (equivalent $h=0.045$), magnification=1, length of the pendulum=51 cm, weight of the pendulum=25 kg (after Nasu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

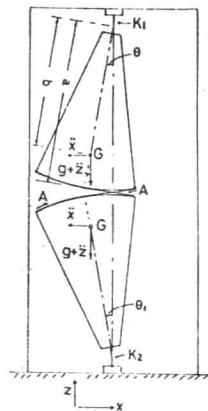


Fig. 3 Matuzawa's coupled pendulum system and its principle.

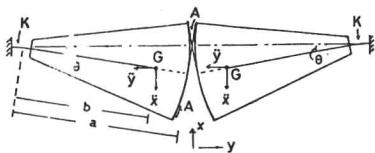


Fig.6 Structure of the vertical component seismometer and its behaviour.

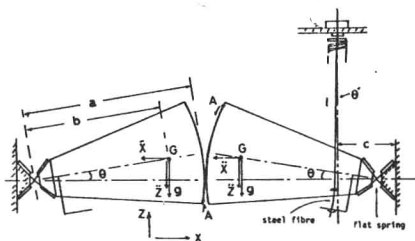


Fig.4 Improved coupled pendulum system of a horizontal seismometer and its behaviour (a ground plane).

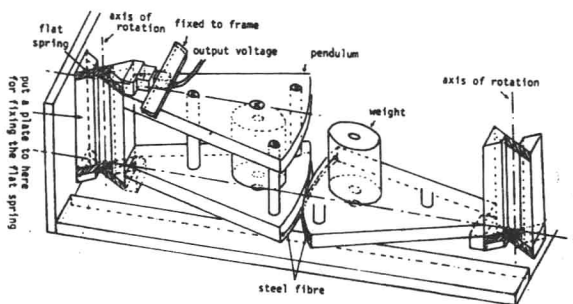


Fig.5 Illustration of the structure of the horizontal component seismometer

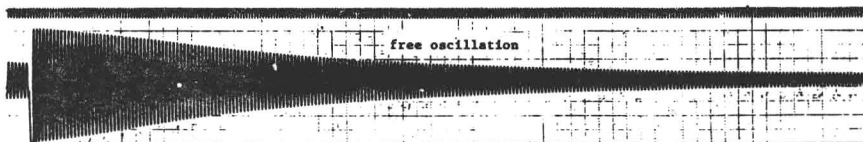


Fig.7 An example of free oscillation of the coupled pendulum system.

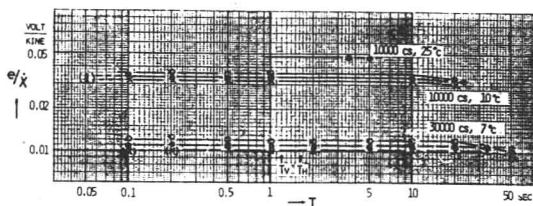


Fig.8 Sensitivity characteristics of the velocity type strong motion seismometer and the effect of the viscosity of damping oil on it. $\odot H_1$, $\circ H_2$, $\times V$.

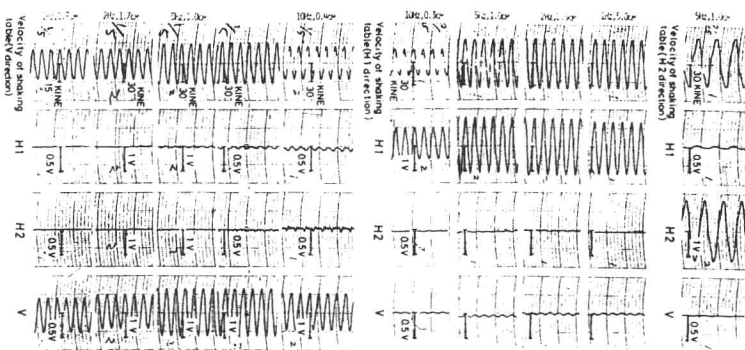


Fig.9 Effects of the non-oscillating direction forces. Simultaneous records of the shaking table and three component seismometers.

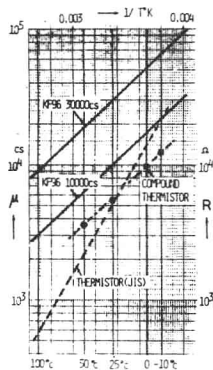


Fig.10 Effects of temperature on the viscosity of silicon oil and on the resistance of some thermister. real line; viscosity of silicon oil. broken line; resistance of thermister. chain line; resistance of compound thermister.

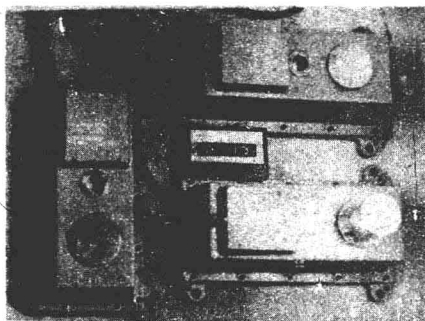


Fig.11 Exterior appearance of a set of three components of the velocity type strong motion seismometer.

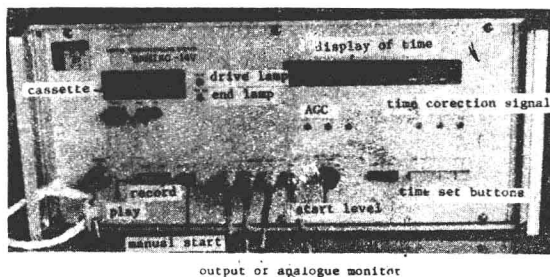


Fig.12 Recording apparatus of the velocity type strong motion seismograph, SAMTAC-14V.

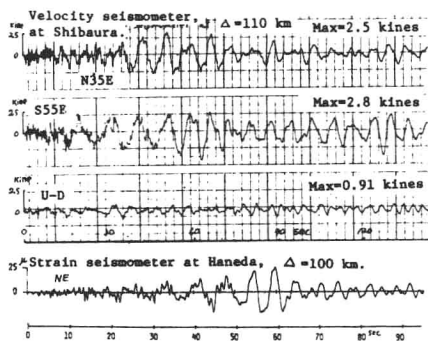


Fig.13 Seismograms of the Near Izu-Oshima earthquake, Jan.14, 1978, $M=7.0$, $h=0$.

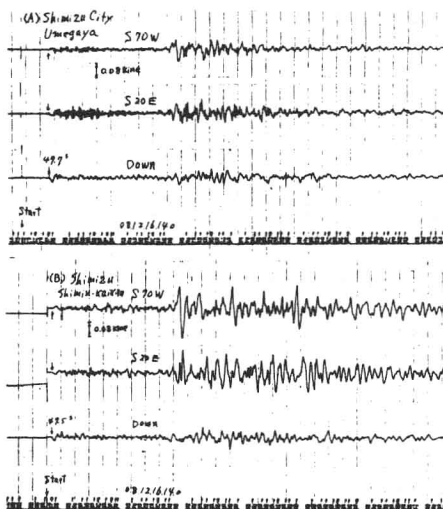


Fig.14 Seismograms of the S off Chiba Prefecture, Aug.12, 1979, $M=5.7$, $h=50$ km. $\Delta \approx 200$ km

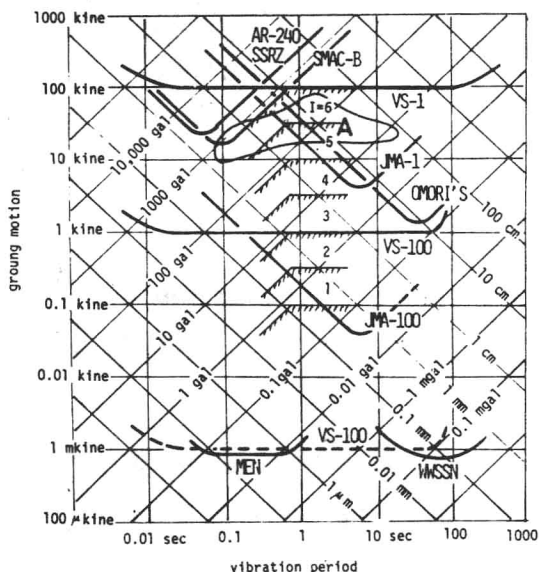


Fig.15 Recording ranges of various seismographs which are widely used nowadays. It is assumed that the values of full-scale of their records are all 30 mm. Thick lines; the earthquake motions corresponding to full-scale of each seismograph. Closed line denoted by A; the earthquake motions shown in Fig.1. Oblique lines; Japanese seismic intensity scale. Broken line; lower limit of ground motions to be recorded by VS-100.