EARTHQUAKE MEASUREMENTS IN AND AROUND A REINFORCED CONCRETE BUILDING

by

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SYNOPSIS

The measurements of strains and ground motions in an existing reinforced concrete building and its surrounding subsoil have been made as a long term observation project. Various kinds of instruments used in this project are 31 Carlson type strain and stress meters, 2 relative displacement meters, 21 earth pressure meters, 11 electro-magnetic seismometers, and 3 SMAC type strong motion accelerographs. Some observational data obtained during the period 1963-1967 are illustrated. Analysis is made for strain records in building frames and dynamic characteristics of subsoil layers with the aid of the results of some auxiliary experimental and analytical studies.

INTRODUCTION

Recent development in the computer technic enables us to evaluate the earthquake response of buildings, in which some dynamic model of buildings and some earthquake input to that model are employed. The present question in this subject is how to find out the reasonable dynamic model and suitable earthquake input rather than how to calculate the response of dynamic model to the earthquake motion. It is intended in this study to measure the strains and ground motions in an existing building and surrounding subsoil during a real earthquake as a long term observation project to get an answer to the above question.

The ERI (Earthquake Research Institute) main building in the Hongo campus of the University of Tokyo was selected as a "test building" and instrumented by various kinds of strain meters, earth pressure meters and seismometers. The subsoil layer, on which the test building is constructed, was also instrumented by several underground seismometers at different depths under the ground.

The main purpose of this study is first to know the dynamic strains and stresses of the structural members in relation to the acceleration or displacement of the building during an earthquake, second to clarify the interaction problem between subsoil and superstructure system and the earthquake input to that system, and finally, to use the results for improvement of the theory of earthquake response and the dynamic design method of buildings.

OUTLINE OF THE BUILDING AND SUBSOIL

Building

The ERI main building is a five story (partly six story) reinforced concrete structure with one story basement. It is 15.8 x 60m in plan as shown in Fig. 1.

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The west part of the building was first constructed during 1962-1963, and the rest of it was added during 1964-1965. These two parts are structurally continuous having no expansion joint between them.

The main lateral resisting elements of this building are the walled type reinforced concrete frames, which have a walled girder (spandrel) and a walled column, in the longitudinal direction (Fig. 2), and are the reinforced concrete shear walls in the transverse direction. In both directions there are slightly reinforced concrete and concrete block partition walls that are considered non-structural members (Fig. 3). The building rests on loam and sand layers at about 5 meters below the ground level and has individual footings.

The antiseismic design of the building was made in accordance with Japanese building standard law and AIJ (Architectural Institute of Japan) structural standards.

Subsoil

The subsoil below the test building consists of several layers. They are the Kwanto loam layer, alternative layers of fine sand and sandy loam, alternative layers of fine sand and silty or clayey sand, and the gravel layer, downward from the surface. The water level is 8.8m below the ground level. The soil profile and the penetration test results (N-value) are shown in Fig. 4.

INSTRUMENTATIONS

Various kinds of instruments used in this project are as follows:

i) 29 Carlson type strain meters and 2 stress meters to detect the strain in concrete and reinforcement steel bars and stress in concrete of a main structural frame, ii) 2 relative displacement meters to record the relative displacement in the 3rd and 4th stories, iii) 21 earth pressure meters to record the earth pressure in each footing of the building and at the face of the retaining wall, iv) 11 electromagnetic type seismometers to record either displacement or acceleration in a horizontal direction (convertible) at the soil layer below the building and inside the building and v) 3 SMAC type strong motion accelerographs to record the acceleration at the top, middle and bottom of the building.

Strains, relative displacements and earth pressures

The Carlson type detectors were used to measure dynamic strains, relative-displacements and earth pressures as this type of instruments has shown satisfactory results in its stability over 30 years, which is most important in long-term observation. These detectors were installed during the construction work of the building at the location shown in Figs. 5 and 7. As is seen in these figures, 29 strain meters either for concrete or for reinforcing steel bars are concentrically installed in and around the column D-3 while 21 earth pressure meters are scatteringly installed at the bottom of the footings and at the face of the retaining wall.

The block diagram indicating the instrumentation for the observation of strains and earth pressures is shown in Fig. 8. Strains and earth-pressures are recorded photographically with a galvanometer. Three electromagnetic oscillographs are used as a recorder, and each one is fitted with eight galvanometers of which the resonant frequency is 17 cps. Strains and earth pressures, which will produce one mm of oscillograph trace deflection, are listed in Table 2. It is possible to measure the strains after the non-structural member such as the partition wall is subjected to cracks and decreases its rigidity. The routine observation is made by a mechano-electric starter of which the triggering device is a 0.3 sec non-damped horizontal pendulum with the geometrical magnification of about 20.

Earthquake motion of the underground and the building

The electromagnetic seismometers were used to measure the earthquake motion under, around and inside the test building. The location of the seismometers is shown in Fig. 6. Seismometers A, B, C, D and E are placed along the vertical line from the top of the building to the soil layer 42 m below the surface. Seismometers F, G and H are arranged also along the vertical line and are 60 m distant south from the above group in a horizontal direction, intending to clarify the subsoil superstructure interaction by comparing the records of two groups, the former group being affected by the superstructure while the latter being expected to be free from the interaction effect. Seismometer K is arranged at the depth of 82 m below the ground level. This is expected to supply the comparatively pure earthquake, which may not be affected by free surface. Each seismometer under the ground was installed at the bottom of a bore-hole, which was refilled after the installation so that the seismic waves would not be affected by the bore-hole.

The pendulum of the seismometer is damped heavily with silicon oil ($h \doteqdot 5$), and the output voltage of the seismometer having the natural frequency of 5 cps is proportional to the ground acceleration. By coupling this seismometer directly to the galvanometer having the natural frequency of 0.5 cps the oscillograph record proportional to the ground displacement can be obtained within the frequency range of 1.0 to 20 cps and this recording system was used to get ground displacement. To obtain the ground acceleration the galvanometer having the natural frequency of 30 to 100 cps was used. The sensitivity and range of instruments are shown in Table 2. The routine observation is made in the similar way to that in the strains and earth pressures.

SMAC accelerograph

The location of the SMAC accelerograph is shown in Fig. 5. It starts automatically to record earthquakes greater than 10 gals. The acceleration corresponding to one mm trace on the recording paper is 25 gals.

ILLUSTRATION OF RECORDS

During the period 1963-1967, the strains, relative displacements and earth pressures have been recorded due to 7 earthquakes (Intensity III according to JMA Intensity Scale), and seismograms due to 24 earthquakes (Intensity I, II or III). Earthquake data are listed in Table 1.

Strains, relative displacements and earth pressures

Fig. 10 shows the reproduced strains, relative displacements and earth pressures recorded during the earthquake No. S-05. As is seen in the figure, the dominant period of the records is about 0.3 sec, which coincides with the natural period of this building determined by forced vibration test.

Earthquake motion of the underground and the building

First, the displacement records of earthquake motion were obtained to know the dynamic behavior of the subsoil superstructure system, especially in connection with the stress and displacement of the building. And then, the recording system was changed to record the accelerations in order to distinguish the higher frequency range.

Fig. 11 shows the reproduced displacement during the earthquake No. D-02 and Figs. 12 and 13 the reproduced acceleration during the earthquake No. A-11 in the building and at the subsoil layers. The Fourier spectra for the records at the top (S_R) and bottom (S_{BM}) of the building, at the ground level (S_{GL}) and at the layer 41 m and 42 m deep below the ground level (S_{41}), (S_{42}) are shown in Figs. 11 and 12, and those at the layer 0.5 m and 82 m deep below the ground level in Fig. 13. As is seen in the figures of Fourier spectra, there are some differences in the frequency characteristics depending on the location of the seismometer. This differences in period characteristics due to the depth of soil layer may be important when considering the dynamic model of underground structures.

Fig. 14 shows the acceleration record taken with the SMAC accelerograph during the earthquake No. S-05.

DYNAMIC CHARACTERISTICS OF THE TEST BUILDING AND THE UNDERGROUND STRUCTURE

Forced vibration test

The forced vibration test using a vibrator was made to know the dynamic characteristics of the test building. The results are shown in Figs. 15 and 16 indicating the resonance curve and mode shape in longitudinal and transverse direction, respectively. The fundamental natural period of the building determined by this test is 0.29 in longitudinal direction and 0.32 in transverse derection. It is noticed that in transverse direction the rocking vibration is predominant.

Microtremor measurements

Simultaneous measurements of microtremor at the top and bottom of the building in two horizontal directions were made with electromagnetic seismometer having the natural frequency of 5 cps to get dynamic properties of the building. Three of the 50 sec continuous good records were used for analysis. By taking the spectral ratio of the auto-correlation function of the top and botton records shown in Figs. 17 (c) and 18 (c), the natural period of the building was determined as 0.26-0.28 and 0.28-0.29 sec in longitudinal and transverse direction, respectively.

Analyzed horizontal rigidities of the building

Longitudinal direction:

In frames A and D, which are of walled type frame as shown in Fig. 2, the lateral rigidity of each story was obtained by means of Muto's D-method considering the bending and shearing deformation and the effect of rigid zones at the end of the members. Frame B consists of a moment resisting frame and the infilled concrete partition walls with openings and Frame C is of concrete partition walls with openings (Fig. 3). The rigidity of these partition walls was not taken account in the antiseismic design of this building because they were considered non-structural elements. However, it is unquestionable that they contribute to the lateral rigidity considerably until they fail. The rocking effect was disregarded in this analysis because the forced vibration test showed the very small percentage of rocking component. Table 3 shows the computed lateral rigidity of each story together with the rigidity obtained from the forced vibration test using the relation between mode shape and inertia forces. These rigidities coincide with each other very well. It should be noted that disregarding the non-structural elements causes considerable underestimation for the lateral rigidity of the building.

Transverse direction:

In addition to the coupled shear walls there are some concrete block partition walls in the transverse direction. As in case of longitudinal direction, these partition walls, which are also considered non-structural elements, were taken account in the rigidity estimation. Whole structures were analyzed considering the bending and shearing deformation of concrete walls, the shearing deformation of concrete block walls, and the bending deformation of the connecting beams. The deformation due to foundation rotation (rocking) was also considered using the soil coefficient of 4 kg/cm, which is the average value for Kwanto loam layer. As the results the rocking ratio (a ratio of the horizontal displacement at the top due to rocking to the total horizontal displacement became 82%. According to the forced vibration test the rocking ratio (including swaying) was estimated as 60-80%. The computed rigidities are not compared with experimental ones directly because of large percentage of rocking but the comparison is made for the fundamental natural period as shown in Table 4, which will be explained later.

S-wave velocity determination by explosion test

The S-wave velocity in the various soil layers was determined by explosion test, which was developed by Shima and Ohta[1], to get dynamic characteristics of subsoil during an earthquake. The test was made by generating the S-wave due to explosion of gunpowder inside the iron pipe installed in the bore-hole at a depth of about 80 m under the ground. The S-wave transmitted through the subsoil was observed using electromagnetic seismometers located on the ground surface at intervals of 5 m in the radial direction from the bore hole. The S-wave velocity in the various soil layers was determined from the travel time curve drawn for each shot in various depths (every 5.5 m depth from 3 m to 69 m deep). The underground structure for S-wave velocities thus determined is shown in Fig. 19. The density (ρ) in various soil layers is given by the boring test results.

The transfer function of the soil layer of 41 m deep for various coefficients of viscosity (ε) was obtained from the spectral ratio of the calculated amplitude at the surface and 41 m below the surface when the incident S-wave is given vertically and upward under the layer of 41 m below the surface. Fig. 20 is the result showing the frequency characteristics, in which the peak value appears at 0.43, 0.18, 0.11 and 0.03 sec.

ANALYSIS OF OBSERVATIONAL DATA

Earthquake Strain

Some of the significant quantities measured from the strain records in Fig. 10 are listed in Table 6 with comparison of corresponding computed results. The computed strains and relative displacements are obtained in the following way: first, the building is reduced to a shear type multi-mass vibratory system as determined in the preceding section; secondly, using the accelerogram taken with the SMAC accelerograph at the basement as an input the total shear in each story is determined; and finally, the strains and relative displacements are computed by frame analysis considering the effect of rigid zone and canopy. It can be seen from Table 6 that the observed strains and relative displacement coincide with computed values fairly well.

Natural period of the building

The natural period of the building was determined from the observational data of the earthquake by taking the spectral ratio of the top and bottom records shown in Figs. 11 and 12. Figs. 17 (a), 18 (a), 17 (b) and 18 (b) show the spectral ratio of the displacement in EW and NS components and the acceleration in EW and NS components, respectively. The results are obtained to be 0.26-0.30 sec in longitudinal and 0.28-0.32 sec in transverse direction. These values are listed in Table 4 together with those obtained by analysis, microtremor and vibration test. Among the values in longitudinal direction in Table 4 the calculated one was obtained using the analyzed rigidities in Table 3 and the tested one by vibrator was obtained by eliminating the effect of swaying so that all the values can be compared under same conditions. As is seen in the table they coincide with each other very well. The second raw in Table 4 shows the natural period in transverse direction in which the rocking and swaying components were eliminated. The calculated value is very close to the tested one. The third raw in Table 4 shows the periods including rocking and they agree with each other fairly well.

Earthquake ground motion

The predominant period of the underground structure was also determined from the observational data of the earthquake in the similar way to that of the building. The results are shown in Table 5. As is seen in the table, these values coincide with the values obtained analytically using S-wave velocity. Figs. 21 and 22 show the spectral ratio between the ground surface (GL) and the underground layers (-41) or (-82) using the spectra shown in Figs. 12 and 13. It is seen in the figures that the spectral ratio S(GL)/S(82) has the peak value in the longer period range than that of S(GL)/S(41).

CONCLUDING REMARKS

Through the five years operation of earthquake measurements of strains and ground motions in and around a five story reinforced concrete building, the following significant features on the superstructure and subsoil were investigated.

The observed strains in the main frame were compared with computed strains. It was shown by this comparison that disregarding the participation of non-structural elements gave much difference from observed strains. Then the strains were determined taking the rigidity of non-structural elements into consideration with the aid of some experimental and analytical investigation, and these values coincide with observed ones fairly well. This shows the importance of non-structural elements in the dynamic behavior of building during an *earthquake.*

The observational data of earthquake motions at the subsoil layers and in the building were accumulated and analyzed. Especially the period characteristics were investigated with the aid of some experimental and analytical studies such as the forced vibration test, the microtremor measurements, the S-wave velocity determination test and the frame analysis including non-structural elements. The natural periods of the building computed from the masses and the lateral rigidities coincide well with those analyzed from the observational and experimental data. It should be noted that again the rigidity of non-structural elements were the significant portion of the lateral rigidities as in case of strains in the frame. Although the earthquake motions, for which the strains and accelerations were recorded, were not very strong, and accordingly the non-structural elements were not broken, it is possible to obtain the strain records for strong earthquake motions by the present observation system until the rigidity of non-structural elements is reduced due to cracking etc. As for the underground structure the predominant periods obtained analytically using S-wave velocities in various layers coincide well with those determined from the observational data.

As the present system of observation has been developed year by year, the complete simultaneous observation is not yet attained. For instance, the differences in the sensitivity of instruments exist between strains and earthquake motions. Further improvement in observational system is planned to obtain complete simultaneous records of all instruments in this project. After the completion of this system, it is expected to get enough data to solve the problems related to the earthquake response such as the establishment of the dynamic model of subsoil superstructure system including the damping characteristics and the determination of earthquake input to the system.

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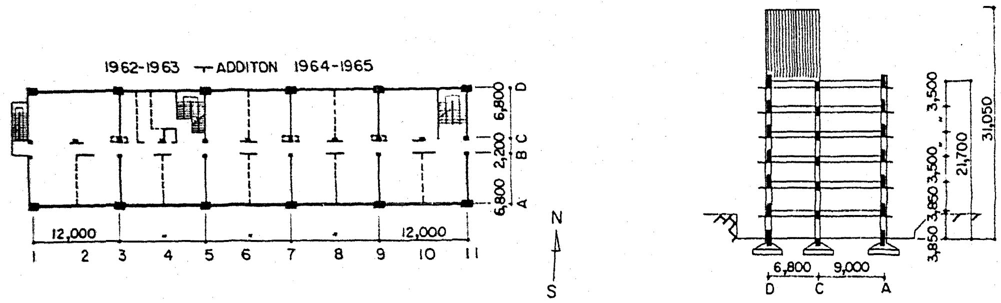

FIG. 1 PLAN AND SECTION OF THE TEST BUILDING

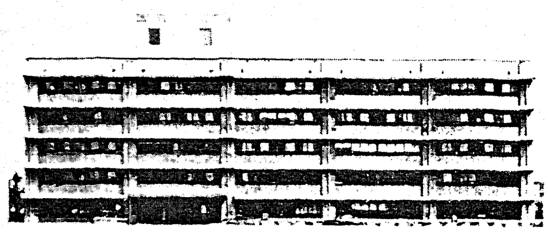

FIG. 2 FRONT VIEW OF THE TEST BUILDING

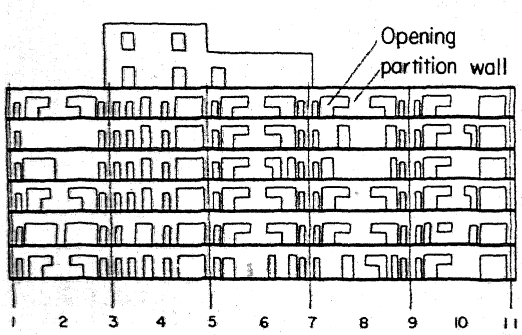

FIG. 3 FRAMING SECTION OF FRAME C

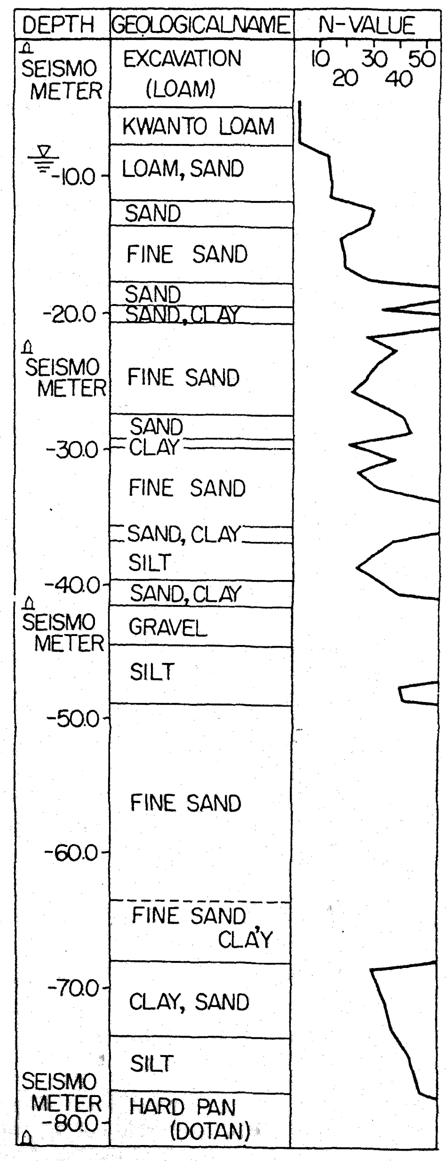

FIG. 4 SOIL PROFILE OF THE BUILDING SITE

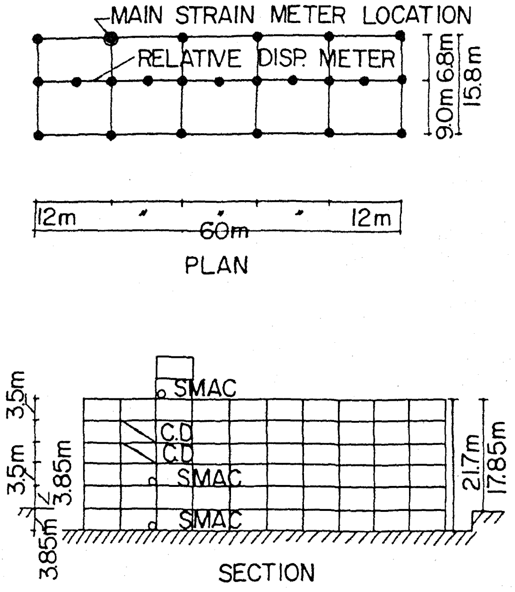

FIG. 5 LOCATION OF INSTRUMENTS (1)

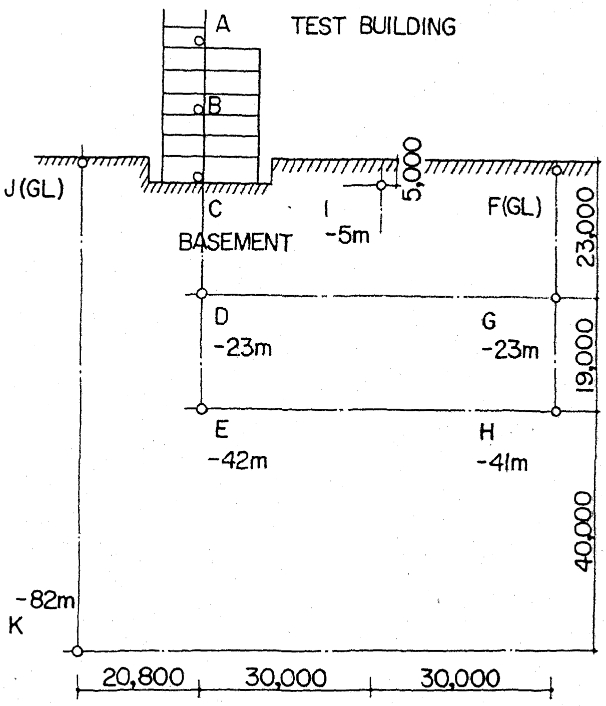

FIG. 6 LOCATION OF INSTRUMENTS (2) SEISMOMETERS

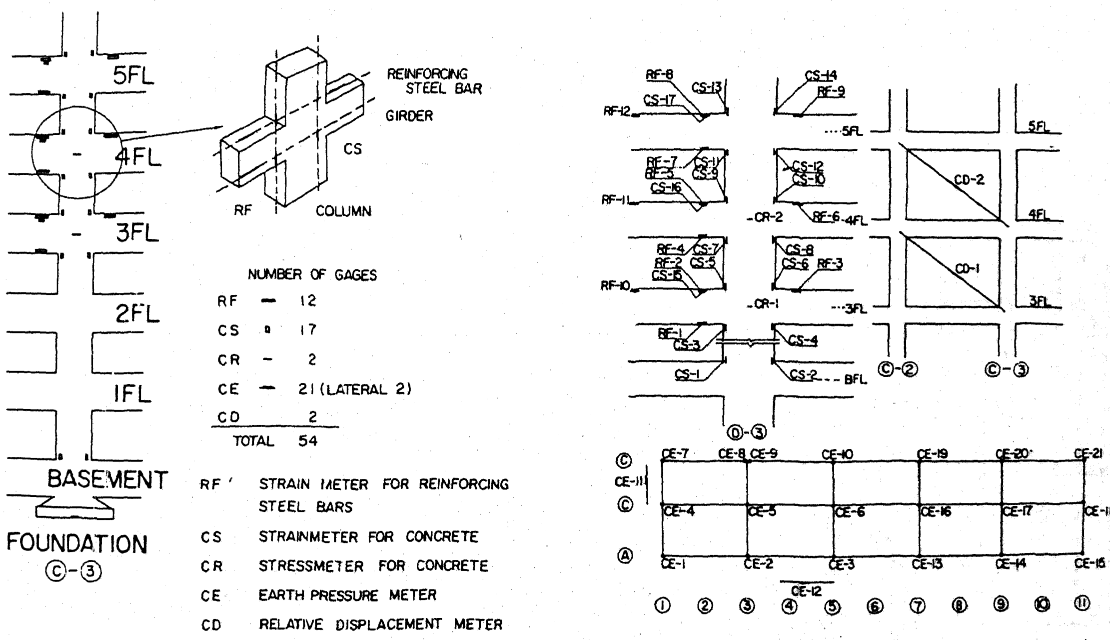

FIG. 7 LOCATION OF INSTRUMENTS (3)

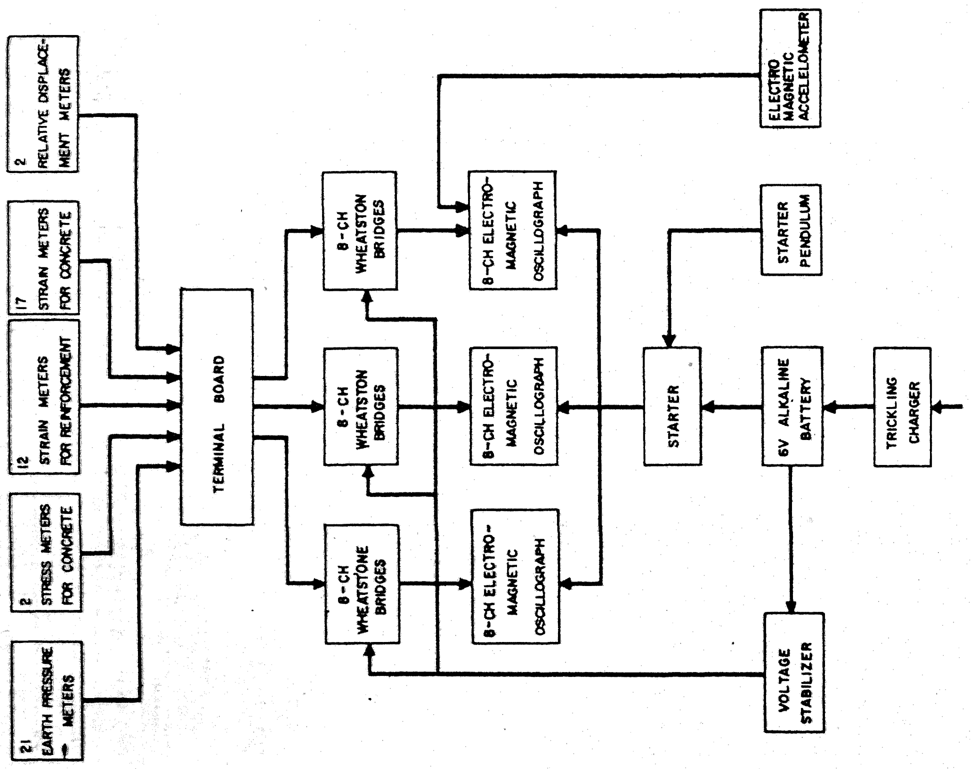

FIG. 8 INSTRUMENTATION DIAGRAM (1)

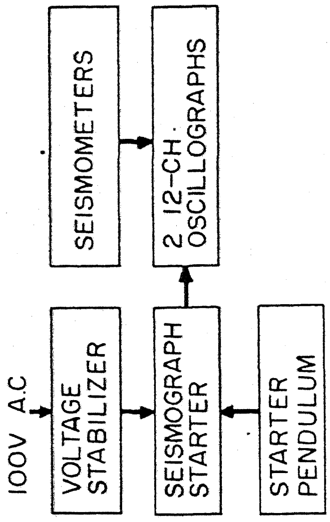

FIG. 9 INSTRUMENTATION DIAGRAM (2)

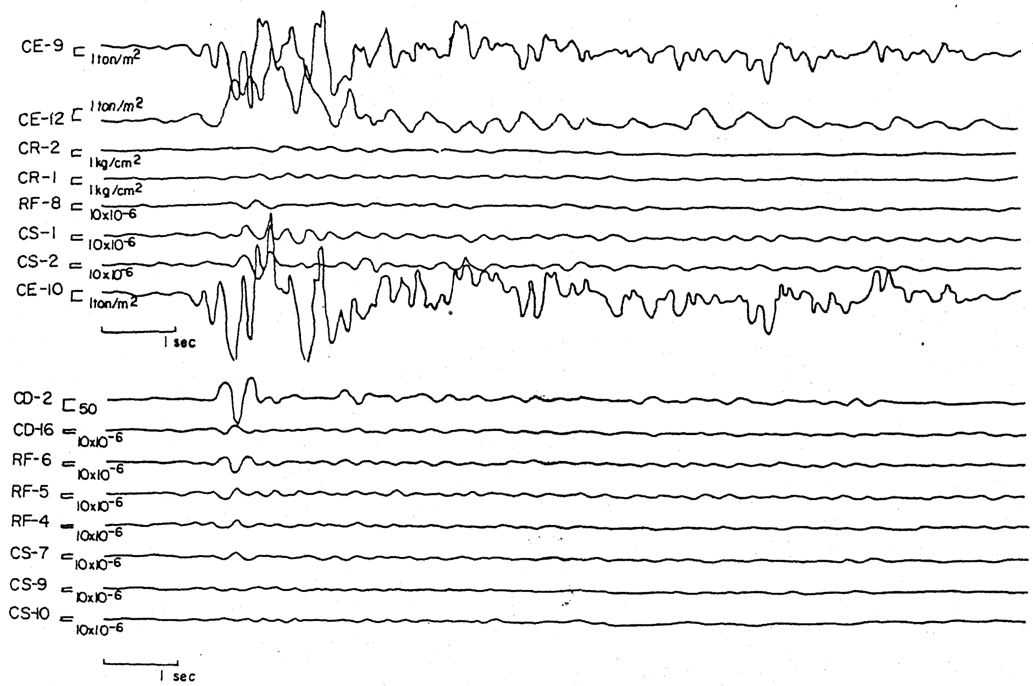

FIG. 10 RECORDS OF STRAINS ETC.

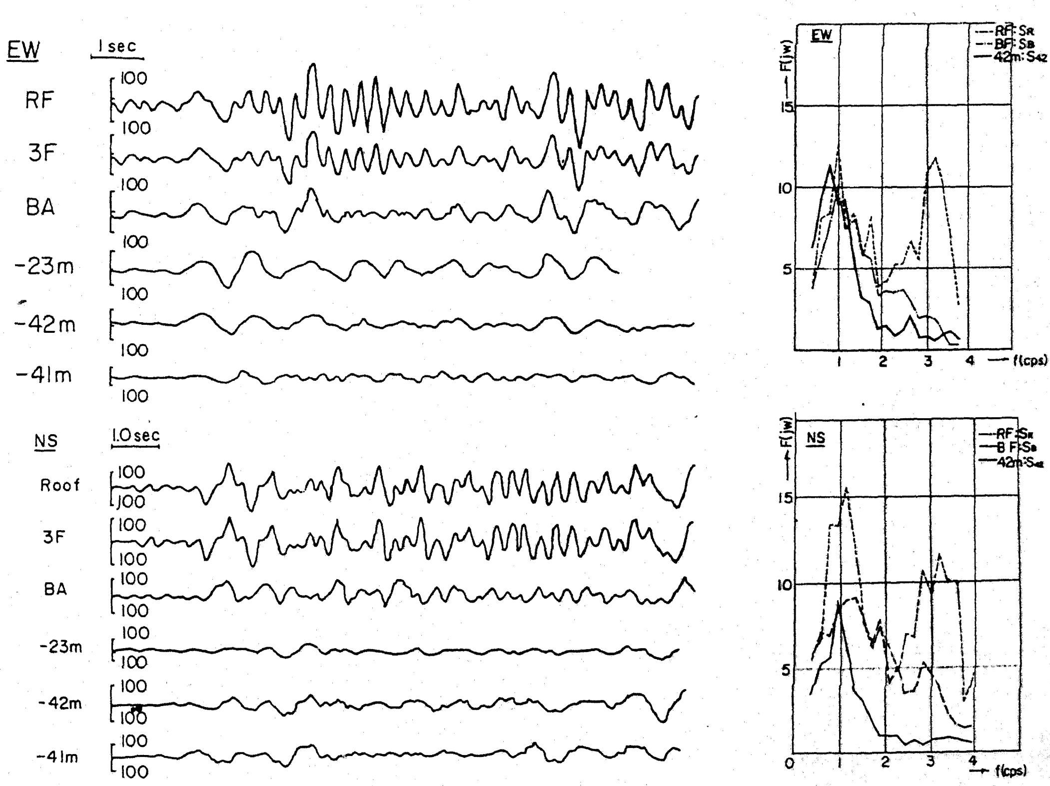

FIG. 11 RECORDS OF DISPLACEMENTS

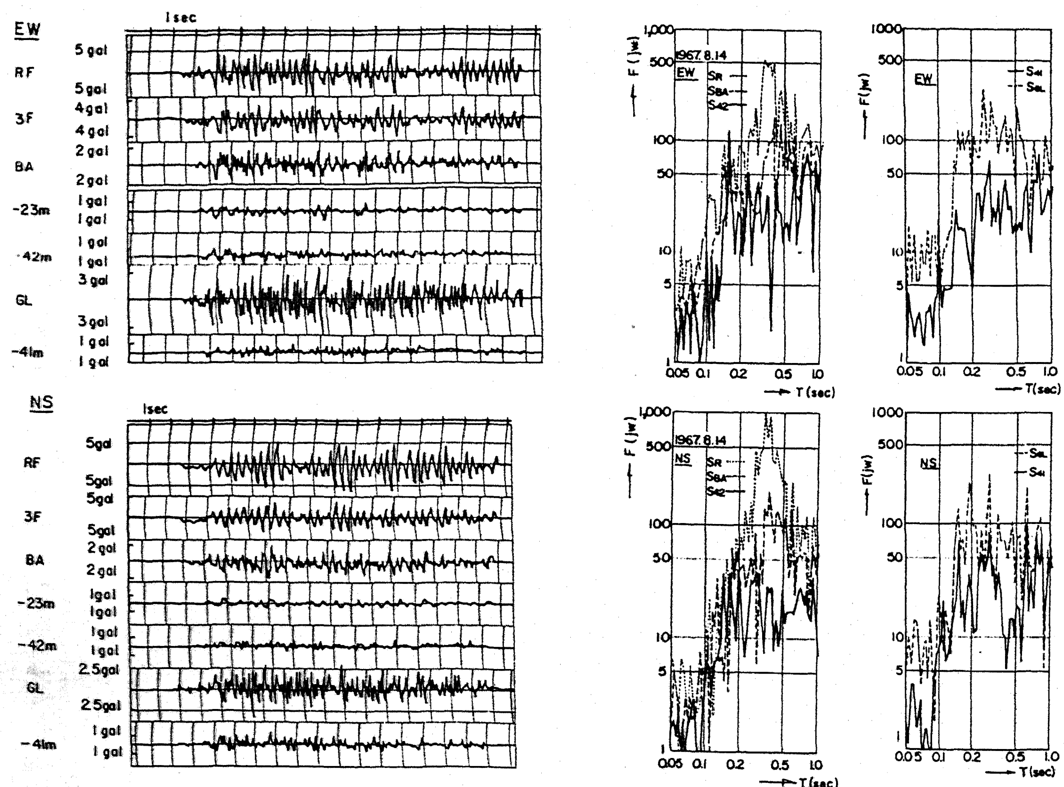

FIG. 12 RECORDS OF ACCELERATIONS (1)

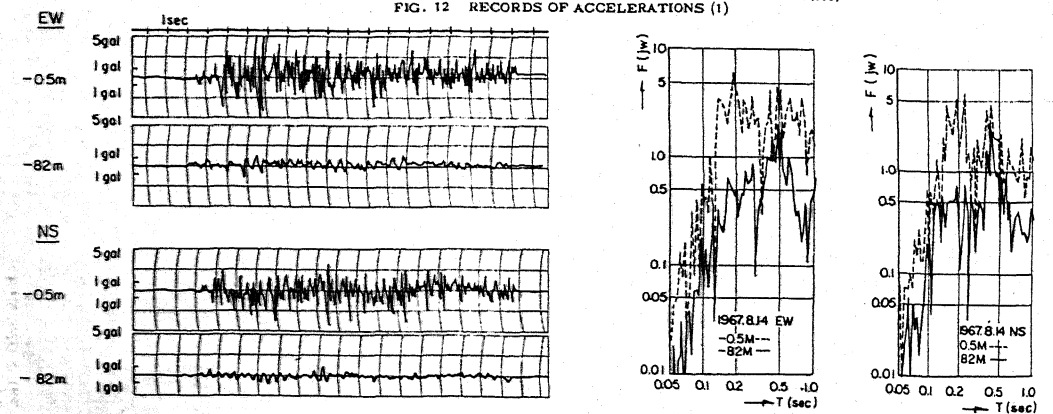

FIG. 13 RECORDS OF ACCELERATIONS (2)

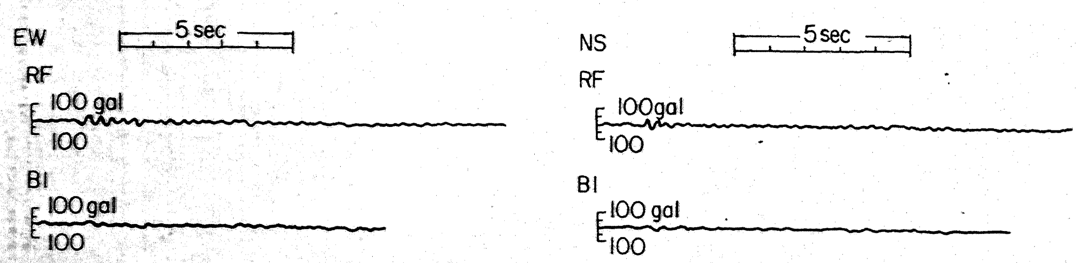

FIG. 14 RECORDS OF SMAC ACCELEROGRAMS

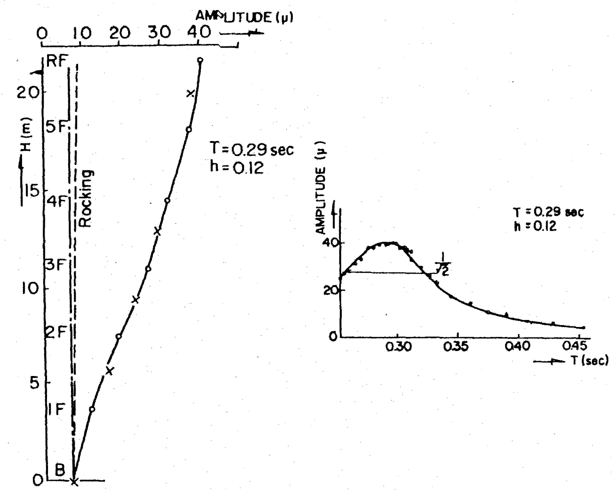

FIG. 15 RESONANCE CURVE AND MODE SHAPE IN THE LONGITUDINAL DIRECTION (EW)

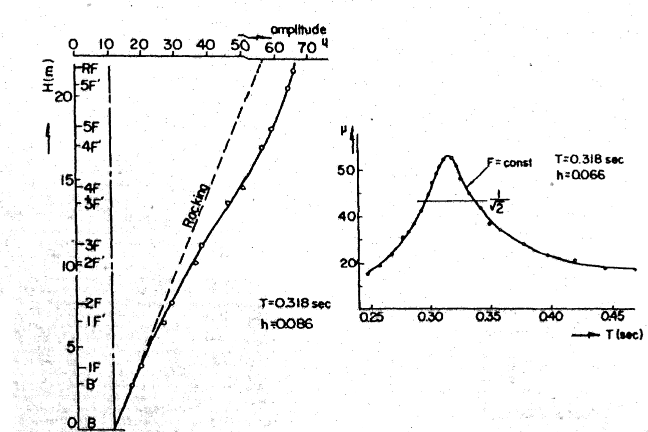

FIG. 16 RESONANCE CURVE AND MODE SHAPE IN THE TRANSVERSE DIRECTION (NS)

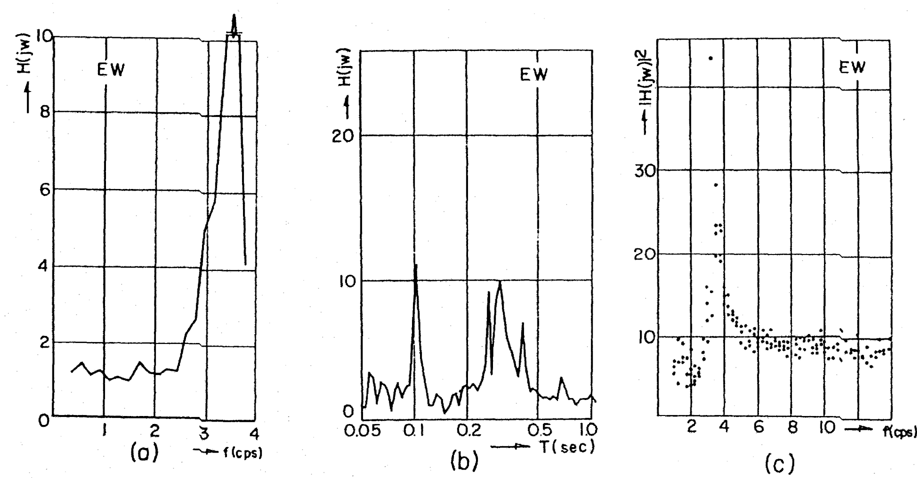

FIG. 17 SPECTRAL RATIO BETWEEN THE TOP AND BOTTOM OF THE BUILDING (EW)

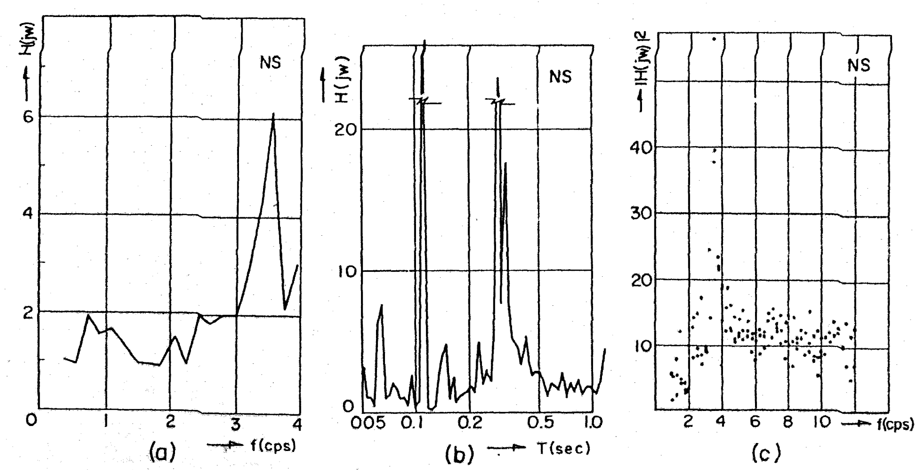

FIG. 18 SPECTRAL RATIO BETWEEN THE TOP AND BOTTOM OF THE BUILDING (NS)

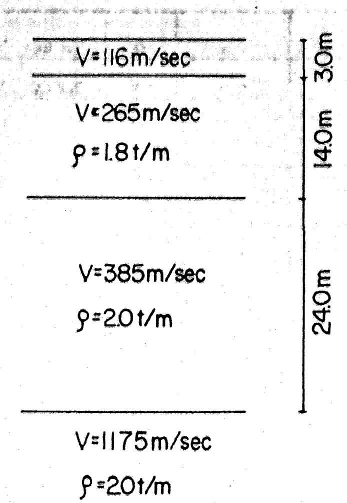

FIG. 19 UNDERGROUND STRUCTURE DETERMINED BY THE EXPLOSION TEST

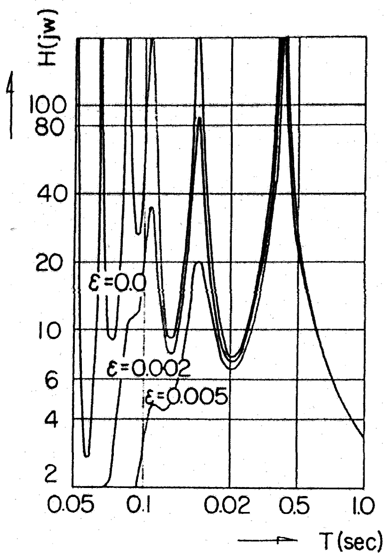

FIG. 20 FREQUENCY CHARACTERISTICS

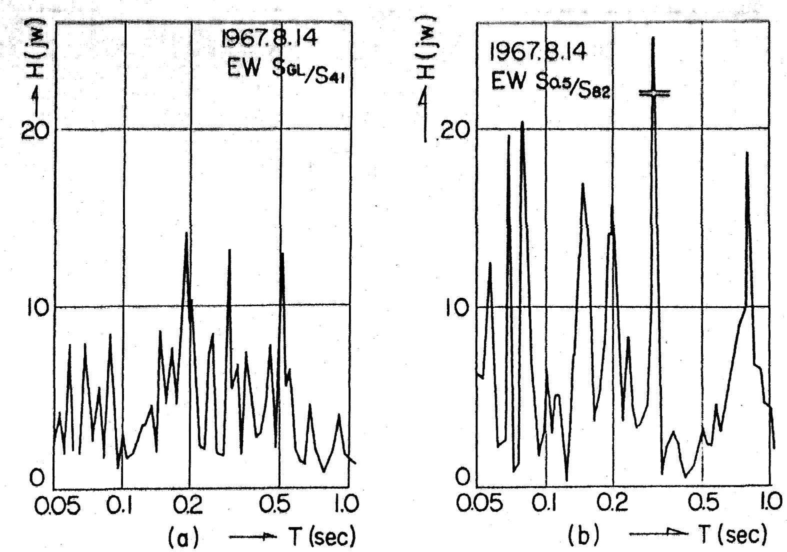

FIG. 21 SPECTRUM AND SPECTRAL RATIO BETWEEN GROUND SURFACE AND UNDERGROUND LAYERS (EW)

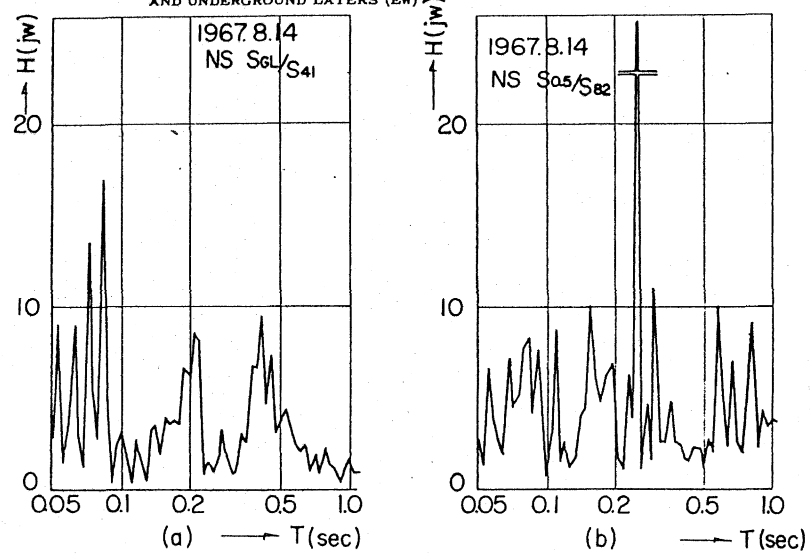

FIG. 22 SPECTRUM AND SPECTRAL RATIO BETWEEN GROUND SURFACE AND UNDERGROUND LAYERS (NS)

TABLE 1 EARTHQUAKE DATA

(a) DATA OF EARTHQUAKES FOR WHICH THE STRAINS AND SMAC RECORDS WERE OBTAINED

NO	Date	Epicentre	Depth	Magnitude	Intensity (J.M.A)
S-01	23h, 30m 30d, V, '64	36.2°N, 141.3°E	40km	6.5	IV : Mito III : Tokyo
S-02	13h, 01m 16d, VI, '64	38.4°N, 139.2°E	40	7.7	V : Niigata III : Tokyo
S-03	11h, 20m 22d, VI, '64	36.4°N, 140.1°E	40	5.1	III : Tokyo
S-04	04h, 14m 01d, X, '64	36.1°N, 140.0°E	60	4.5	III : Tokyo
S-05	08h, 47m 27d, I, '65	36.1°N, 139.8°E	80		IV : Kakioka III : Tokyo
S-06	08h, 42m 20d, IV, '65	34.9°N, 138.4°E	40	6.2	IV : Funatsu III : Tokyo
S-07	21h, 07m 19d, X, '67	36.3°N, 141.1°E	40		IV : Onahama III : Tokyo

(b) DATA OF EARTHQUAKES FOR WHICH THE DISPLACEMENT RECORDS WERE OBTAINED

NO	Date	Epicentre	Depth	Magnitude	Intensity (J.M.A)
D-01	04h, 15m 01d, X, '64	36.1°N, 140.0°E	60km	4.8	III : Tokyo
D-02	18h, 55m 22d, X, '64	36.6°N, 141.1°E	60	5.5	III : Utsunomiya II : Tokyo
D-03	14h, 57m 14d, XI, '64	36.5°N, 140.6°E	40	5.1	III : Onahama II : Tokyo
D-04	01h, 34m 21d, XI, '64	36.2°N, 139.2°E	60	4.8	III : Koufu II : Utsunomiya
D-05	02h, 49m 09d, XII, '64	34.6°N, 139.2°E	0	5.8	IV : Oshima II : Yokohama

(c) DATA OF EARTHQUAKES FOR WHICH THE ACCELERATION RECORDS WERE OBTAINED

NO	Date	Epicentre	Depth	Magnitude	Intensity (J.M.A)
A-01	05h, 03m 29d, VIII, '66	35.5°N, 139.9°E	80km		III : Ōshima I : Tokyo
A-02	22h, 20m 28d, X, '66	35.7°N, 140.3°E	60	5.0	III : Ōshima II : Tokyo
A-03	14h, 25m 26d, XI, '66	35.9°N, 140.2°E	100		II : Tokyo
A-04	20h, 04m 14d, XII, '66	36.2°N, 138.9°E	60	4.9	III : Utsunomiya II : Tokyo
A-05	20h, 59m 17d, I, '67	38.3°N, 142.2°E	30	6.3	IV : Sendai II : Tokyo
A-06	20h, 21m 13d, II, '67	36.1°N, 140.0°E	54.9	4.9	III : Utsunomiya II : Tokyo
A-07	17h, 17m 02d, III, '67	35.5°N, 140.1°E	80		III : Yokohama II : Tokyo
A-08	02h, 50m 19d, III, '67	36.3°N, 140.1°E	80		III : Tokyo
A-09	06h, 54m 21d, III, '67	36.2°N, 140.0°E	50	5.1	III : Utsunomiya II : Tokyo
A-10	11h, 42m 22d, V, '67	36.1°N, 139.8°E	70		III : Tokyo
A-11	21h, 13m 03d, VII, '67	36.1°N, 139.9°E	50	4.5	II : Utsunomiya I : Tokyo
A-12	05h, 07m 14d, VIII, '67	35.5°N, 135.8°E	360		III : Onahama II : Tokyo
A-13	22h, 38m 19d, VIII, '67	36.1°N, 140.9°E	100		II : Utsunomiya
A-14	11h, 06m 30d, VIII, '67	35.0°N, 140.0°E	70		III : Chiba II : Tokyo
A-15	17h, 09m 30d, VIII, '67	36.1°N, 140.3°E	80		III : Utsunomiya I : Tokyo
A-16	09h, 28m 15d, IX, '67	35.5°N, 141.1°E	40	5.6	III : Yokohama II : Tokyo
A-17	19h, 56m 19d, IX, '67	43.0°N, 145.1°E	90		IV : Kushiro I : Tokyo
A-18	09h, 32m 20d, IX, '67	36.1°N, 140.2°E	80		III : Tokyo
A-19	21h, 07m 19d, XI, '67	36.3°N, 141.1°E	40		III : Onahama II : Tokyo

TABLE 2 SENSITIVITY AND RANGE OF INSTRUMENTS

Instrument	Maximum amplified values	Measurable range
Earth pressure meter	0.03 kg/cm^2	+2kg/cm^2 ~ −2kg/cm^2
Strain meter for reinforcing steelbars	7.6 x 10^{-6}	+1,000x10^{-6} ~ -500x10^{-6}
Strain meter for concrete	6.5 x 10^{-6}	+500x10^{-6} ~ -1,000x10^{-6}
Stress meter for concrete	0.42 kg/cm^2	+20kg/cm^2 ~ -40kg/cm^2
Relative displacement meter	0.013 mm	+2.5mm ~ -2.5mm
Displacement of seismo meter	1/36 μ	+1mm ~ -1mm at Roof
Accelelation of seismometer	0.117 gal	+35gal/mm ~ -35gal/mm at Roof

per 1mm on the recording paper

TABLE 3 RATERAL RIGIDITY

Stories	Calculation				Determined by Vibration test
	Rigid frame	Rigid frame *	Partition wall	Total	
5	2,270 t/cm	3,350 t/cm	5,440 t/cm	8,790 t/cm	8,500 t/cm
4	2,570	3,500	6,600	10,100	8,800
3	2,920	4,010	6,230	10,240	10,800
2	3,160	5,240	4,130	9,370	10,700
1	3,420	5,850	3,820	9,670	12,600
B	5,970	18,370	5,360	23,730	23,500

*----- Considering Canopy

TABLE 4 FUNDAMENTAL NATURAL PERIOD OF THE BUILDING

	Calculated	Observed or Measured		
		Earthquake Observation	Microtremor Observation	Vibration Test
Longitudinal Direction	0.272 sec	0.26~0.30 sec	0.26~0.28 sec	0.253 sec
Transverse Direction	0.233	——	——	0.220
	*0.315 (82 %)**	*0.28~0.32	*0.28~0.29	*0.28 (60~80%)**

* ---- The periode including Rocking
** ---- Rocking ratio (Rocking displacement/Total displacement)

TABLE 5 NATURAL PERIOD OF THE UNDERGROUND STRUCTURE

	Calculation of under ground Structure for S-wave	Earthquake observation
1st	0.43 sec	0.40 sec
2nd	0.18	0.18
3rd	0.11	0.10
4th	0.08	0.08

TABLE 6 COMPARISON OF RECORDED AND COMPUTED STRAINS AND RELATIVE DISPLACEMENTS

	Gage number	Measued	Computed
Relative Displacement	CD-2	14 x 10^{-2} mm	13 x 10^{-2} mm
	CS-1	27 x 10^{-6}	29 x 10^{-6}
	CS-2	39 x 10^{-6}	29 x 10^{-6}
	CS-9	3 x 10^{-6}	5 x 10^{-6}
	CS-10	3 x 10^{-6}	5 x 10^{-6}
Strain	CS-7	11 x 10^{-6}	12 x 10^{-6}
	CS-16	14 x 10^{-6}	15 x 10^{-6}
	RF-5	15 x 10^{-6}	15 x 10^{-6}
	RF-6	18 x 10^{-6}	15 x 10^{-6}
	RF-8	10 x 10^{-6}	11 x 10^{-6}