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37. *Earthquake Strain Measurements in the ERI Main Building.*

Part 1.

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Abstract

In order to investigate the earthquake response of buildings, the measurement of strains and stresses in the ERI main building during an earthquake was scheduled in 1962 and started to operate in 1963. During the construction of the building 29 strain meters were installed in the reinforced concrete columns and girders to detect the earthquake strains in concrete and in reinforcing bars, and 21 earth pressure meters were installed at each footing to measure the earth pressure during an earthquake. The outline of the building and the instrumentation are described, and some records are illustrated and compared with computed values.

1. Introduction

In order to investigate the earthquake response of buildings, an attempt has been made to measure the strains and stresses of a real building during a real earthquake. Although there have been many acceleration records of buildings mostly for medium earthquakes obtained with SMAC and other types of accelerographs, the strains and stresses in the main structural frames cannot be determined without the aid of stress analysis including that for non-structural elements. The measurement of the strains and stresses of main frames is the only way to obtain these values directly and, therefore, considered to be a great importance.

When the construction of the new ERI (Earthquake Research Institute) building was started in the Hongo campus of the University of Tokyo in 1962, this building was selected to be instrumented by various kinds of dynamic strain meters and earth pressure meters. The accelerations at the top, middle and bottom of the building were scheduled to be recorded with SMAC accelerographs, and the relative displacements of the third and fourth story were also to be measured.

The main purpose of this project is to know the dynamic strains and stresses in relation to the ground acceleration and accelerations of the superstructure and then to use the results to improve the theory of earthquake response and the dynamic design method of buildings.

A similar project was scheduled in the University of California, details and some results being presented by C.M. Duke and R.A. Brisbane.[1)]

The present paper describes the outline of the building and the instrumentation and illustrates some recorded strains and stresses together with theoretically computed values.

2. Outline of the building

The building in which the various meters are installed is a five story reinforced concrete structure with basement. It is 15.8×60 m in plan as shown in Fig. 1. Referring to Fig. 1, line 1 to 5 was first constructed during 1962–1963 and line 5 to 11 was added during 1964–1965. These two parts are structurally continuous having no expansion joint at line 5.

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 (see Fig. 2), and are the reinforced concrete shear walls in the transverse direction. There are auxiliary reinforced concrete open frames and concrete or concrete block partition walls in both directions.

The building rests on loam and sand layers at about 5 meters below ground level and has individual footings. The soil profile and the penetration test results are shown in Fig. 3.

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

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1) C. M. DUKE and R. A. BRISBANE, *Bull. Seism. Soc. Amer.*, **45** (1955), 83.

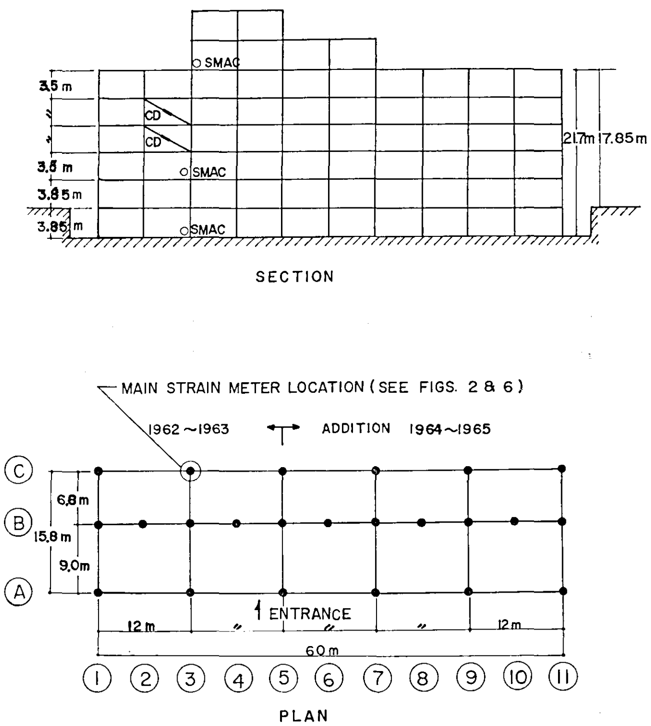

Fig. 1. Plan and section of ERI new building.

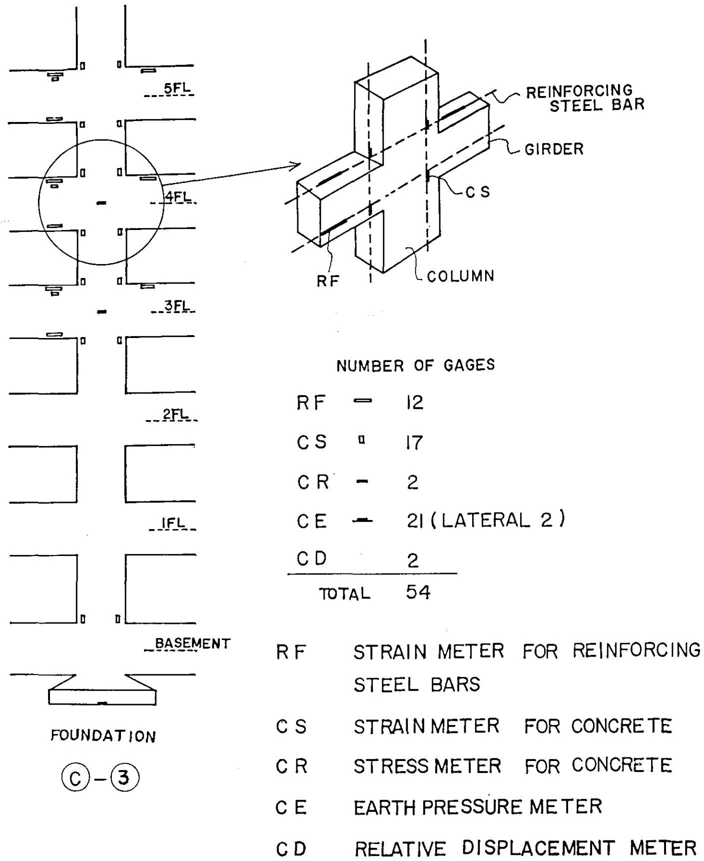

Fig. 2. Location of strain meters, etc. (1).

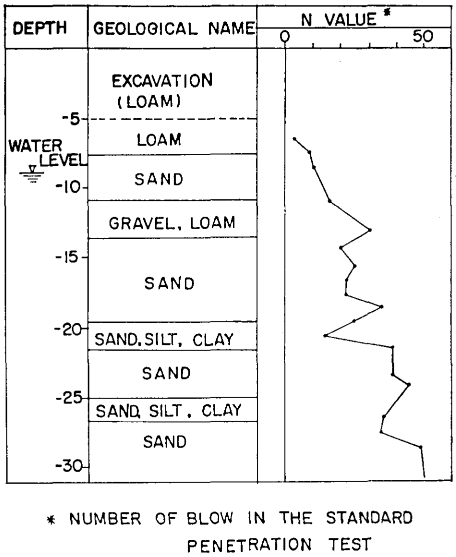

Fig. 3. Soil profile of the building site.

3. Instrumentation

For the measurement of dynamic strains and stresses in concrete and in reinforcing steel bars (reinforcement) as well as in soil, various types of detectors are now commercially available. The most important point to be duly considered in the choice of the instruments is their stability in long-time operation.

The Carlson type detectors, which have produced satisfactory results in application to civil engineering structures over 30 years, were used in this study. The location of these detectors is shown in Figs. 2 and 6. As is seen in Fig. 6, 29 strain meters and 2 stress meters are concentrically installed in and around the column C-3, while 21 earth pressure meters are scatteringly installed at the bottom of the footings and at the face of the retaining walls. The 2 relative displacement meters are the Carlson type joint meters connected to steel bars which are diagonally set from joint to joint of the frame at the third and fourth story.

The Carlson strain meter for concrete is the foundation for the other kinds of Carlson meter. This meter is tubular in shape and of 10 cm in length, with two piano wires wound in a coil. When a strain is applied to the meter, the piano wires lengthen or shorten differentially

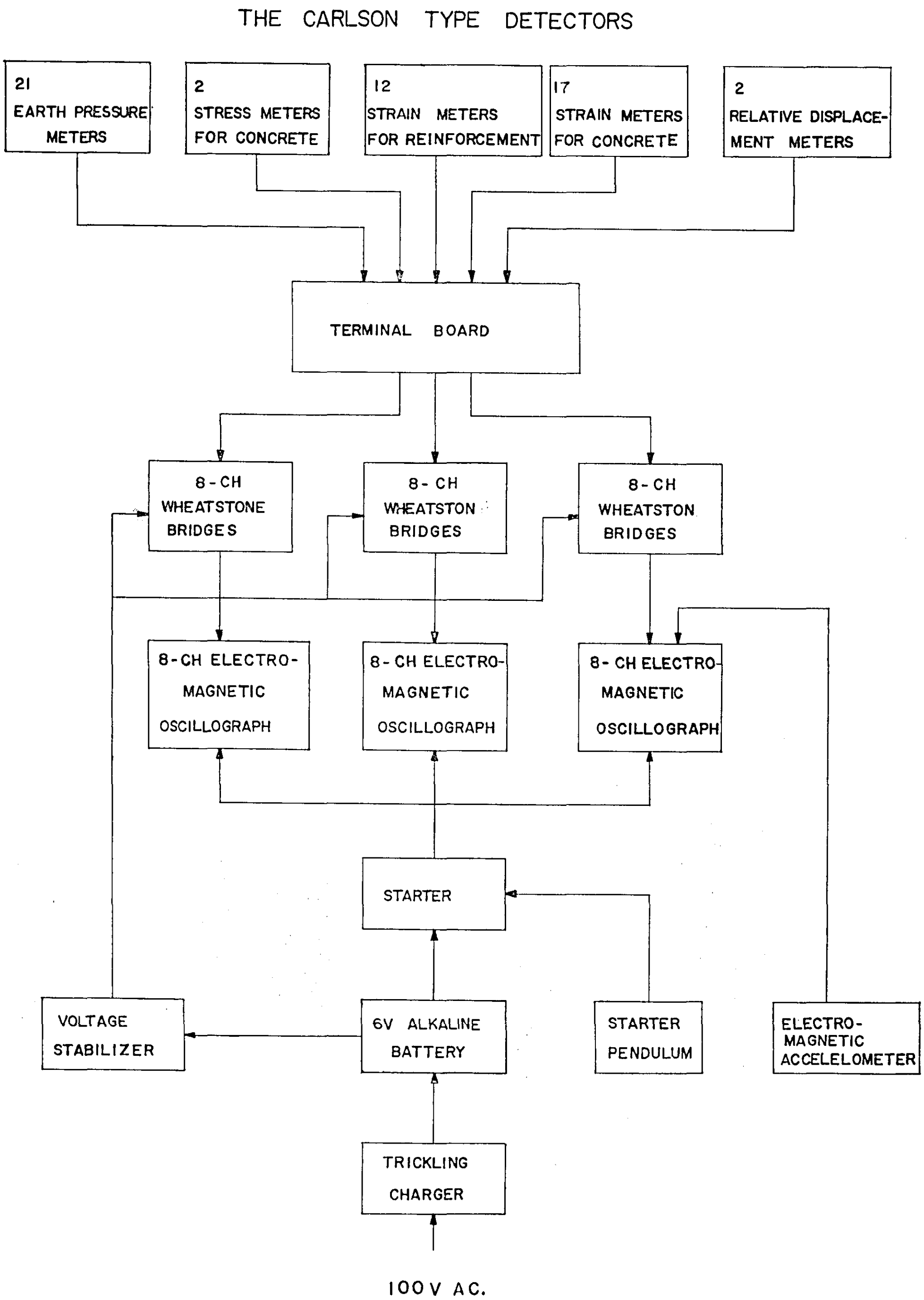

Fig. 4. Instrumentation diagram.

and their electric resistances change. The strain meter for reinforcement and the joint meter are similar in principle to the strain meter for concrete, except that the strain meter for reinforcement has a steel pipe having a section and an elastic constant equal to those of the reinforcement and the joint meter has an extended measuring range.

The stress meter for concrete consists of a transducer of the small strain meter and a pressure-receiving part formed with two diaphragms between which a thin mercury film is inserted. A minute displacement of the outer diaphragm caused by external pressure is magnified through the mercury film, and transmitted to the small inner diaphragm which is connected to the transducer.

The Carlson earth pressure meter is a flat disc with a built-in transducer and has a sensitivity much higher than the stress meter for concrete.

The change in resistance of the wires in the Carlson meter is measured by use of the Wheatstone bridge circuit and recorded photographically with a galvanometer.

Fig. 4 is the block diagram showing the instrumentation for the observation. The electric lead wires from the Carlson meters were initially ended at the terminal board. Then, two dozens of these wires were selected to be measured and were led to the three balancing boxes. Each balancing box contains eight sets of the Wheatstone bridges having a rheostatic arm for the zero adjustment and calibration.

Three electromagnetic oscillographs were employed as a recorder. The oscillogragh is fitted with eight galvanometers of which the resonant frequency is 17 c/s. The strains and stresses, which will produce one mm of oscillograph trace deflection, are listed in Table 1. The paper

Table 1. Sensitivity and range of instruments

Instrument	Maximum amplified values*	Measurable range
Earth pressure meter	0.03 kg/cm^2	+2 kg/cm^2 ~ −2kg/cm^2
Strain meter for reinforcing steel bars	7.6×10^{-6}	$+1000\times10^{-6}\sim-500\times10^{-6}$
Strain meter for concrete	6.5×10^{-6}	$+500\times10^{-6}\sim-1000\times10^{-6}$
Stress meter for concrete	0.42 kg/cm^2	+20 kg/cm^2 ~ −40 kg/cm^2
Relative displacement meter	0.013 mm	+2.5 mm ~ −2.5 mm

* per 1 mm on the recording paper.

speed and the timing marks are chosen to be 3 cm/sec and 0.1 sec, respectively.

The Carlson meters and oscillographs used here are manufactures of Kyowa Electronic Instruments Co., Ltd.

The routine observation is made by a mechano-electric starter, with a counter to indicate the number of operations. The triggering device is a 0.3 sec non-damped horizontal pendulum. The geometrical magnification is about 20. The recording time for each operation of the starter is adjustable from 10 sec to 3 minutes.

All the power for the instruments is supplied from a 6 V, 60 AH alkaline battery, which is continuously charged with a trickling AC charger. The voltage of 4.5 volts DC applied to the Carlson meters through the bridges is so stabilized that the locations of light spots of the galvanometers predetermined become free from the voltage variations of the battery.

A horizontal component electromagnetic accelerograph was installed on the basement floor slab to record the ground acceleration, of which the electrical output is fed to one of the three oscillographs and traced, together with those from the Carlson meters, on a recording paper. In this way, identification in time between the records of strain, stress etc. and the ones obtained by many other moderate or strong motion seismographs, which have been installed in and adjacent to the building, may be possible.

For keeping good operating conditions of the observation system, a brief inspection is desired at least once a month, while no battery servicing is necessary because of the use of an alkaline battery.

Calibration of the building instrumentation system is accomplished by application of forced vibration using a vibrator placed on the roof of the building.

4. Recorded strains and stresses

During the period 1964–1965 records were successfully obtained for six earthquakes. The data of these earthquakes are listed in Table 2, and the stage of the construction when each earthquake occurred is shown in Fig. 5.

Fig. 7 shows the reproduced strains and stresses recorded during the No. 5 earthquake. The location of the gages is indicated in Fig. 6. As is seen in Fig. 7, the dominant period of the records is about

Table 2. Earthquake data

No.	1	2	3
Date	23^h30^m,	13^h01^m,	11^h20^m
	30^d, V, 1964	16^d, VI, 1964	22^d, VI, 1964
Epicentre	36.2°N, 141.3°E	38.4°N, 139.2°E	36.4°N, 140.1°E
Depth	40 km	40 km	40 km
Magnitude	6.5	7.7	5.1
Intensity (J.M.A.)	III: Tokyo	III: Tokyo	III: Tokyo
	IV: Mito	V: Niigata	

Niigata

No.	4	5	6
Date	04^h14^m,	08^h47^m,	08^h42^m,
	1^d, X, 1964	27^d, I, 1965	20^d, IV, 1965
Epicentre	36.1°N, 140°E	36.1°N, 139.8°E	34.9°N, 138.4°E
Depth	60 km	80 km	40 km
Magnitude	4.5	—	6.2
Intensity (J.M.A.)	III: Tokyo	III: Tokyo	III: Tokyo
		IV: Kakioka	IV: Funatsu

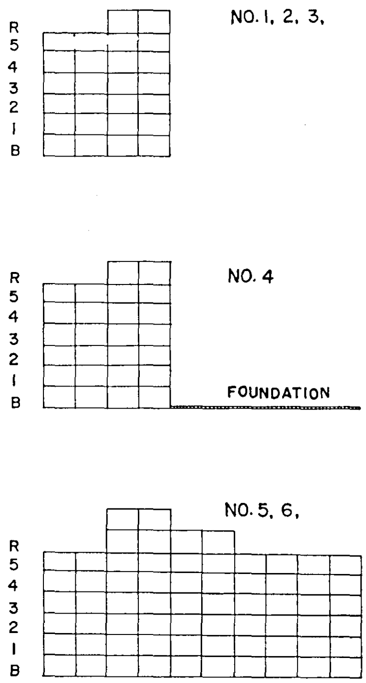

Fig. 5. Construction stages which correspond to earthquake records.

0.3 sec, which coincides with the natural period of this building in both directions determined by forced vibration test.

Some of the significant quantities measured from the records are listed in Table 3 with comparison of corresponding computed results. As the recorded values of the earth pressure indicate as being too large to compare with computed ones, they are not included in the table. The computed strains and relative displacement are obtained in the following way: first, the building is reduced to a shear type multi-mass

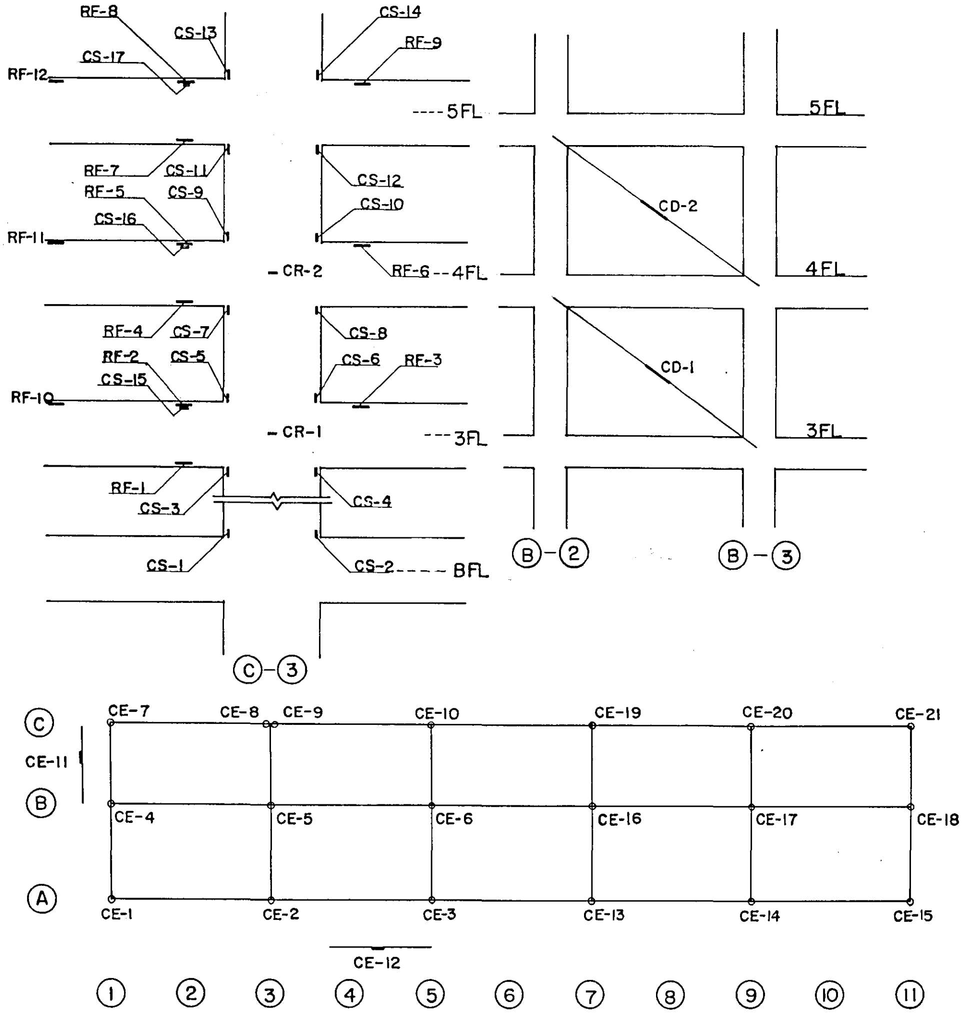

Fig. 6. Location of strain meters, etc. (2).

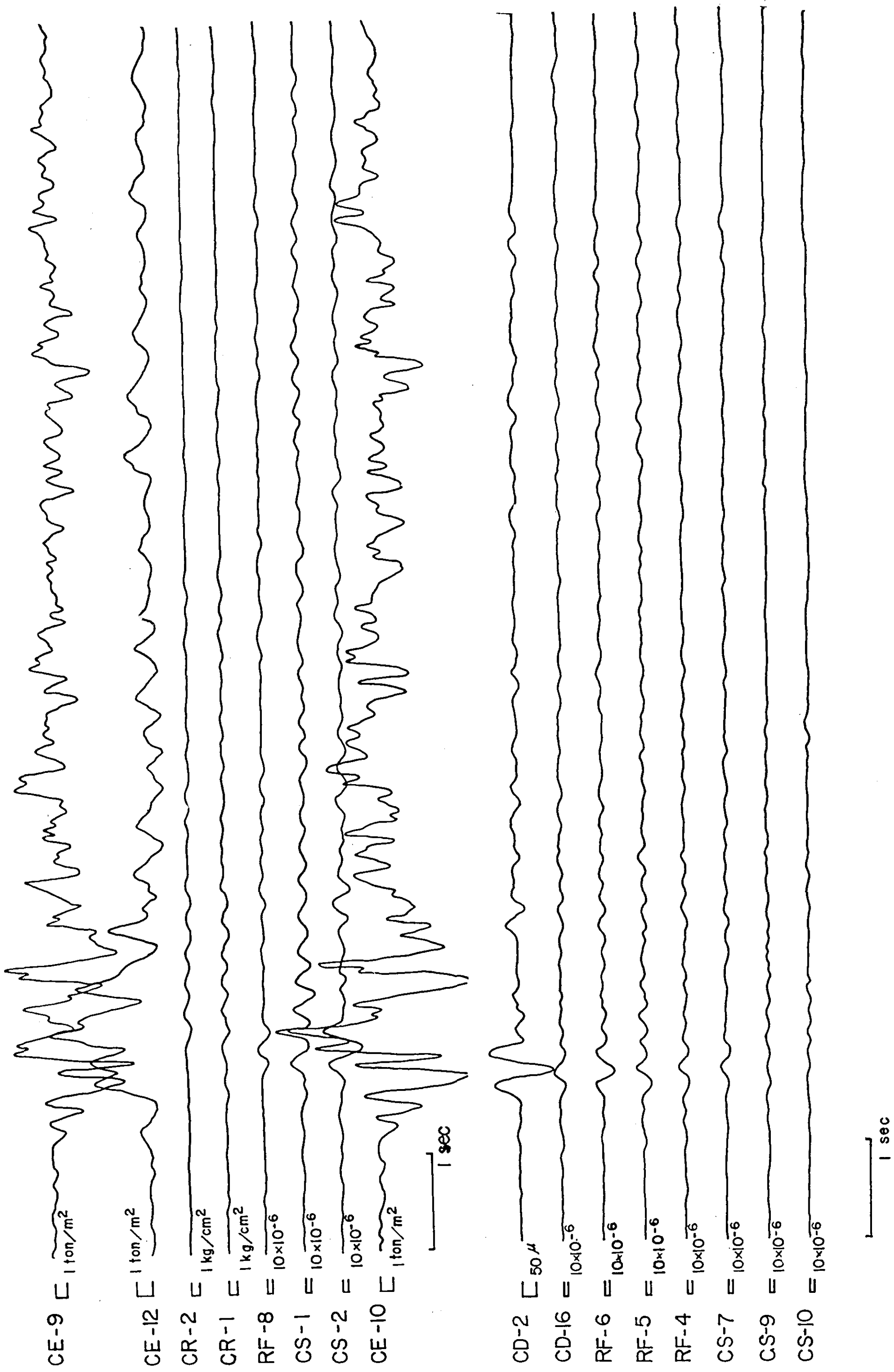

Fig. 7. Records of No. 5 earthquake.

Table 3. Comparison of recorded and computed values

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

vibratory system in which the stiffnesses (spring constants) are determined from the experimentally measured natural period and mode shape; 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 displacement are computed by the use of Muto's D-method considering the bending and shearing deformation and the effect of rigid zone at the end of the members.

It can be seen from Table 3 that the observed strains and relative displacement coincide with computed values fairly well.

The earth pressure records obtained during earthquake No. 5 indicate an inconsistency with other records, they being much larger than computed values in magnitude. This inconsistency must be clarified in future investigations.

Acknowledgment

The authors wish to express their sincere thanks to Professors H. Kawasumi, K. Kanai and H. Umemura for their kind advice during this investigation.

37. 地震研究所本館における地震時建物歪の測定（第1報）

地震研究所
大沢　　胖
田中貞二
村上雅也
細田良彦

地震研究所本館（鉄筋コンクリート造地上5階地下1階）が新築される際（1962~1965）骨組のなかに歪計・応力計・土圧計などを埋設して地震時の動的な歪や応力を測定する計画が立てられた．埋設された歪計の類はすべてカールソン式のもので，鉄筋コンクリート骨組内の鉄筋およびコンクリートの歪測定用が29個，コンクリート応力測定用2個，基礎底面の土圧測定用21個，3階と4階の相対変位測定用の継目計 2 個である．(Figs. 1, 2 および 6 参照)

測定の計器構成は Fig. 4 に示すようなもので，カールソン計器からの導線が平衡箱に入り，さらに電磁オッシロにつながり記録される．記録紙上の感度は Table 1 に示されているようなもので，地動加速度で数ガル以上といつたかなり大きな振動を対象に考えている．

これらの測定装置に加えて，この建物には強震計が屋上，2 階，地階の3ヶ所に据えられており，また地階には水平動電磁型加速度計1台が設置されて歪計との同時記録が得られるようにしてある．これら計器の記録は歪計記録の解析に役立てられる．

これまでに記録されたおもなものが Fig. 7 に示されており，またその解析結果との比較が Table 3 にまとめられている．実測と解析結果はおおむねよい一致を示している．ただし土圧計記録は解析値よりずつと大きい値を示しており，この点今後の研究課題である．