Earthquake response analysis of a reinforced concrete building having four box columns

Vc

DISCUSSION PRÉPARÉE / VORBEREITETE DISKUSSION / PREPARED DISCUSSION

Earthquake Response Analysis of a Reinforced Concrete Building having Four Box Columns

Analyse de la réponse aux séismes d'un bâtiment en béton armé avec quatre poteaux en caissons

Berechnung der Erdbebenreaktion eines Stahlbetongebäudes mit vier Kastensäulen

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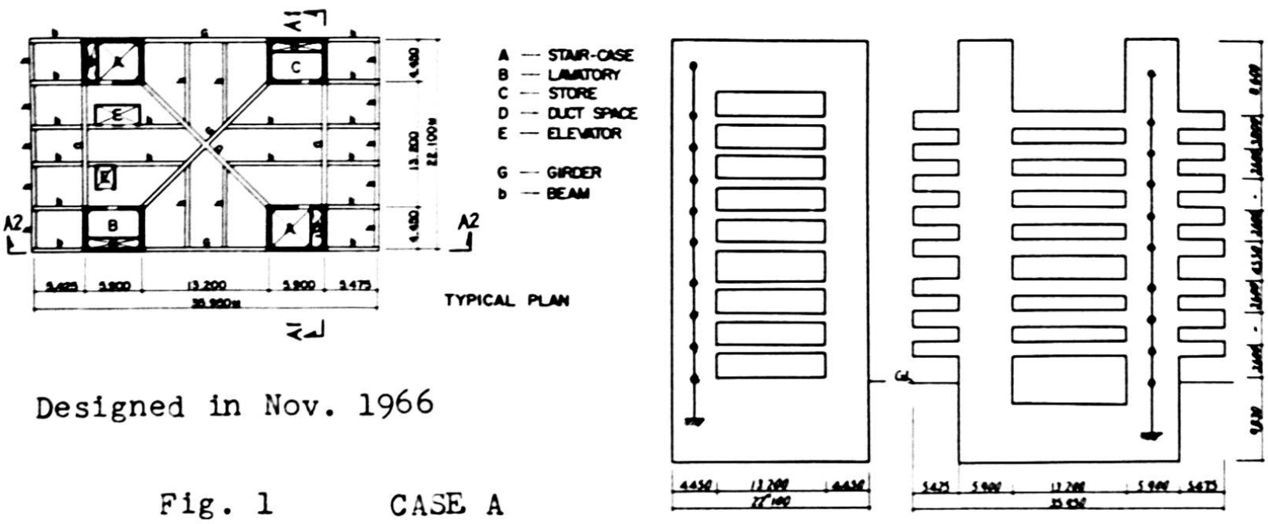
In an attempt to ascertain the earthquake response characteristics of medium-rise (30 to 45 meters in height) reinforced concrete buildings having shear walls, the authors have made analytical studies on a number of buildings of the type described above. The building (shown in Fig. 1), whose response characteristics are discussed in this paper, represents such buildings.

It is a common practice in Japan that the analysis of external vibrational force as well as the structural design of buildings is based on the loads prescribed in the national building code. Then, the structural response to the external vibrational force is analized to verify the appropriateness of the design. Methods of analysing such a structural response have been remarkably improved in these past years. Among them, non-linear earthquake response analysis of bending-shear type mass system seems to be favorably accepted by the increasing number of structural engineers in Japan recently.

It, however, is important for practising engineers that they should have some means to make fairly accurate assessment of a building's response to vibrational forces at the preliminary design stage so that a rational design will result thereby insuring a reasonably earthquake-resistant structure.

In this paper, an attempt will be made to deduce some earthquake response characteristics of the buildings of the type previously described from a variety of response analyses conducted by the authors while they were designing the building shown in Fig. 1. It is hoped that the results of such analyses may serve in future as a source of some useful information for preliminary structural design of similar buildings.



Designed in Nov. 1966

Fig. 1 CASE A

SECTION A1 SECTION A2

1. Earthquake Motions and Method of Analysis.

a. Earthquake Motions used in the Analysis.

As shown in Table 1, two ground motions, which were selected from among a number of typical earthquake motions recorded in Japan, were used for the purpose of this analysis. Of these two, the ground motion recorded in Akita represented typical earthquake motion in the soft ground while that recorded in Sendai represented one in the hard ground. Further, the N-S component of El Centro earthquake which is often used for this sort of analysis was also included so as to make possible a comparative study.

As indicated in the table, the maximum acceleration of these earthquakes were all different from one another; therefore, they were converted into the motions having a maximum acceleration of 100 gals. Fig. 2 shows the spectrum of each earthquake motion used for the analysis.

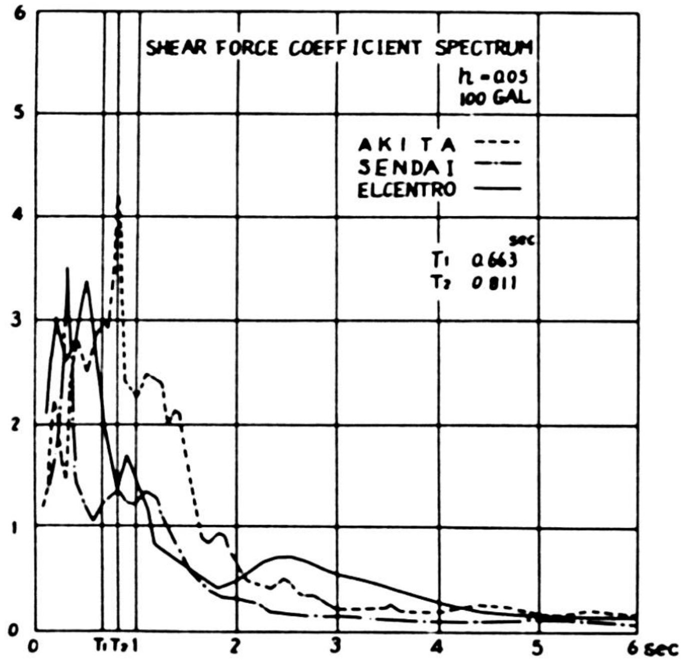


Fig. 2 LINEAR RESPONSE SPECTRUM OF ONE MASS SYSTEM

Table 1

Earthquake Names	Date	Max. Accel.	Symbols
Akita 502 NS	Jun.16 '64	90 gals	--------
Sendai 501 EW	Apr.30 '62	45 gals	—·—·—
El Centro Calif. NS	May 18 '40	319 gals	———

b. Method of Analysis.

Response Analysis for Bending-Shear Type Vibrational System.

For the purpose of making a non-linear earthquake response analysis of bending-shear type multi-mass point system, the following differential equation was used.

$$m_i \ddot{y}_i + \sum_{j=1}^{n} (1 + r_I \frac{d}{dt}) K_{ij} \cdot y_i = -m_i \ddot{y}_0$$

where, m_i : mass at the mass point i

y_i : displacement of mass point i relative to the ground in cm

r_I : coefficient of internal friction

k_{ij} : elastic coefficient matrix (the reaction which occurs in the direction of vibratory motion at mass point i when a unit elastic deflection is caused at point j)

$\ddot{y}_0$: acceleration of ground motion

The modes (the first to the fourth) were computed by the above formula, and the responses at a specific time were amalgamated. To do this, the responses at various given times were computed by means of numerical integration using Runge-Kutta's approximation formula. For damping coefficient (h_n), the value h_1=0.05 was used, and it was related to frequency (ω_n) as follows:

$$h_n/\omega_n = r_I/2 = \text{constant}$$

where, n = number of modes

Response Analysis for Shear-Type Vibrational System.

The linear earthquake response analysis for shear-type multi-mass point system was made by the use of the following differential equation.

$$m_i \ddot{y}_i + (1 + r_I \frac{d}{dt}) \{ K_i (y_i - y_{i-1}) + K_{i+1} (y_i - y_{i+1}) \} = -m_i \ddot{y}_0$$

where, m_i : mass at the mass point i

y_i : displacement of mass point i relative to the ground in cm

r_I : coefficient of internal friction

k_i : spring constant of story i

$\ddot{y}_0$: acceleration of ground motion

The values of responses were computed by applying a series of numerical integrations to this differential equation by using linear acceleration method. Further, the damping coefficient was determined based on the same assumption as used for bending-shear type system previously discussed. As for the spring constant, the value as computed on the basis of design lateral loads was used.

Table 2 Natural Periods for 1st Mode to 4th Mode

	1st	2nd	3rd	4th
Direction A1	0.663	0.147	0.069	0.043
Direction A2	0.811	0.173	0.073	0.043

2. Response Analysis

The building now being discussed was of simple framing design which gave no particular problem for its structural studies. In view of this, it was decided to have each story of the building represented by one mass point in both A_1 and A_2 directions by the use of the slope-deflection method in which deformation due to shear and axial force as well as rigid zone are taken into consideration, and the elastic coefficient matrix was computed accordingly. Then, the linear response analysis of bending-shear type vibrational system was conducted.

The periods are as shown in Table 2, and the exitation functions for Frame A_1 and Frame A_2 are as shown in Fig. 3 and Fig. 4 respectively.

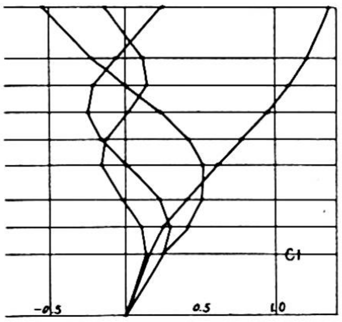


Fig. 3

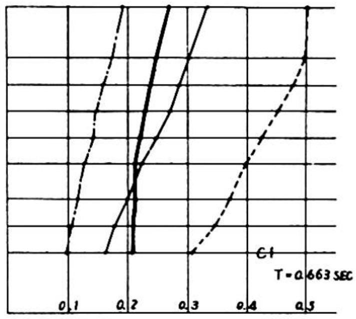


Fig. 5

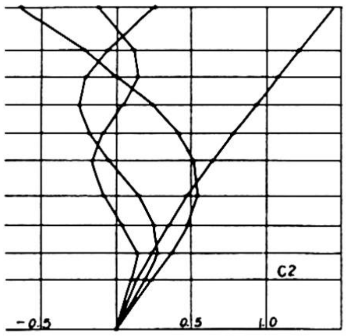


Fig. 4

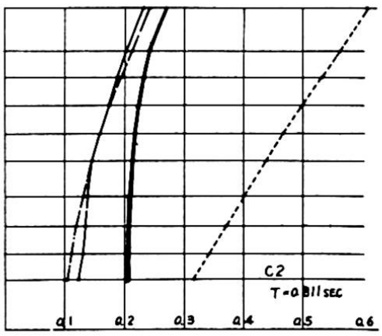


Fig. 6

AKITA ------
SENDAI —·—
EL CENTRO ———

The response values were expressed as shear force coefficient or by symbol Qf. These are shown in Fig. 5 and Fig. 6 for Frame A_1 and Frame A_2 respectively. (The term "shear force coefficient" as used here demotes the shear force acting on the i-th story divided by the summation of individual weight from the top down to the i-th story in question.) In Fig. 5 and Fig. 6, the shear force coefficient corresponding to the lateral loads adopted for the design of this building are shown in bold lines.

Considerations

Actually, the building now being discussed stands on a continuous layer of firm sandy gravelly soil; therefore, its behaviour under an earthquake will be assessed on the basis of response values computed for the ground motions recorded in Sendai (or El Centro). Figs. 5 and 6 indicates the response values corresponding with the maximum acceleration of ground motion which was taken as 1oo gals. From these figures, it can be known that at the base of the building, the response to the acceleration of ground motion of 2oo gals corresponds with the design lateral loads set out in the code; and at the top of the building, the response to the acceleration of 15o gals corresponds with the design lateral loads actually used for this building. Buildings of this type have, as shown by the studies in the past, a general tendency to give fairly larger earthquake response values at the top than at the bottom when considered in relation with the distribution of design lateral loads in the structure, so this phenomenon should be duly taken into account by the structural designer.

3. Evaluating the Method of Analysis.

Under strong earthquake motions with acceleration of 2oo gals or over, most of structural members usually enter the plastic range as was the case with this building. It, therefore, is necessary to make non-linear response analysis of bending shear type vibrational system if the structural response characteristics under very severe earthquakes are to be assessed with high accuracy. Such an analysis, however, is too complicated and time-consuming for practising engineers to make in the course of actual design for which both labor and time are almost always restricted. For this reason, engineers in practice usually proceed with the structural response from linear response with the aid of the research accomplishments in the past. Since quite a variety of linear analysis methods, some intended for precise computation and others for approximation, are now available, an attempt will be made here to evaluate some of these methods on a comparative basis by applying them to the structural problems of the subject building, and on the basis of such an evaluation, some adequate method for approximate analysis that may prove a handy tool for preliminary structural design will be proposed.

For the purpose of the present comparative appraisal, the following methods of analysis will be discussed.

For precise analysis: Response analysis of the 1st to the 4th mode of bending-shear type vibrational system (expressed by symbol BS)

For approximate analysis:

(1) Response analysis of shear type system (expressed by Symbol S)
(2) Response analysis of the 1st mode only of bending-shear type system (expressed by Symbol BS 1st)
(3) Response analysis of the 1st mode only to be computed from design lateral loads (expressed by Symbol S 1st), which is the method proposed by the authors.

a) Comparison of Factors in Bending-Shear Type System with Those in Shear Type System.

The difference in modes of these two systems are shown in

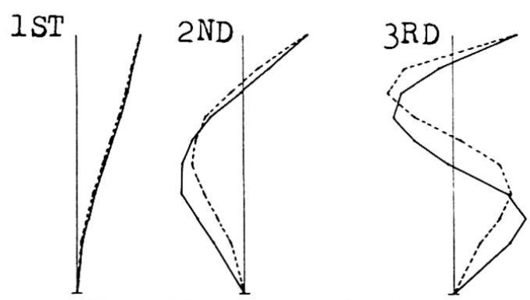


Fig. 7 Mode at Sec. A1

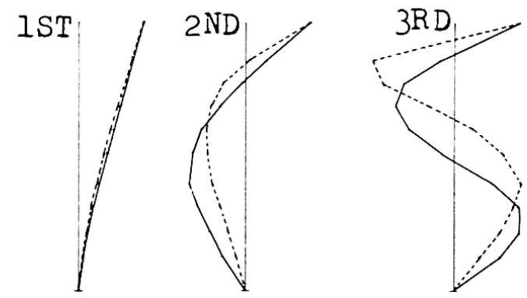


Fig. 8 Mode at Sec. A2

BS ————
S --------

Fig. 7 and Fig. 8 for Frame A1 and Frame A2 respectively. Natural periods and damping coefficients for the 1st to the 4th mode are indicated in Fig. 9. These diagrams indicate that there existed a large difference between the values for bending-shear type system and those for shear type system as to all factors that were analyzed, especially at the modes of higher order. It is believed that this substantial difference is due largely to the deformation of shear walls caused by bending, which gave greater influence in the vibrational modes of higher order.

b) <u>Comparison of Response Values (Shear Force Coefficient).</u>

To begin with, the results obtained by analysis of the 1st mode of bending-shear type system and those of shear type system will be studied. As shown in Fig. 10, no substantial difference was observed in the analysis results of these two systems. This is only too natural because the modes of these two systems were fairly alike as can be known from Fig. 7 and Fig. 8. The results of analyses (BS) 1st/BS and S/BS are shown in Fig. 11.

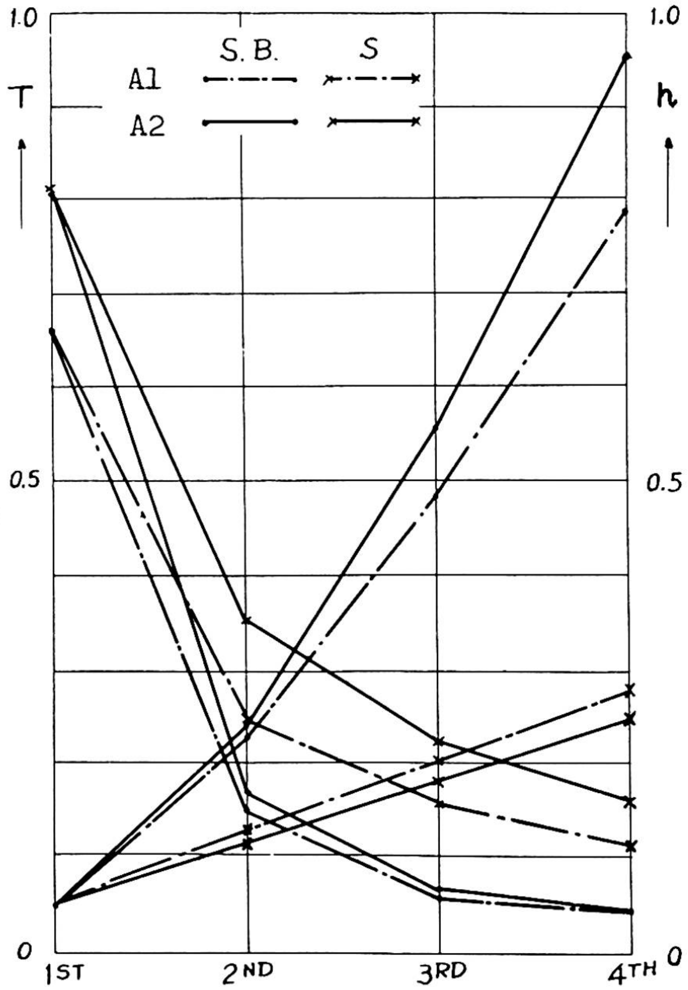


Fig. 9

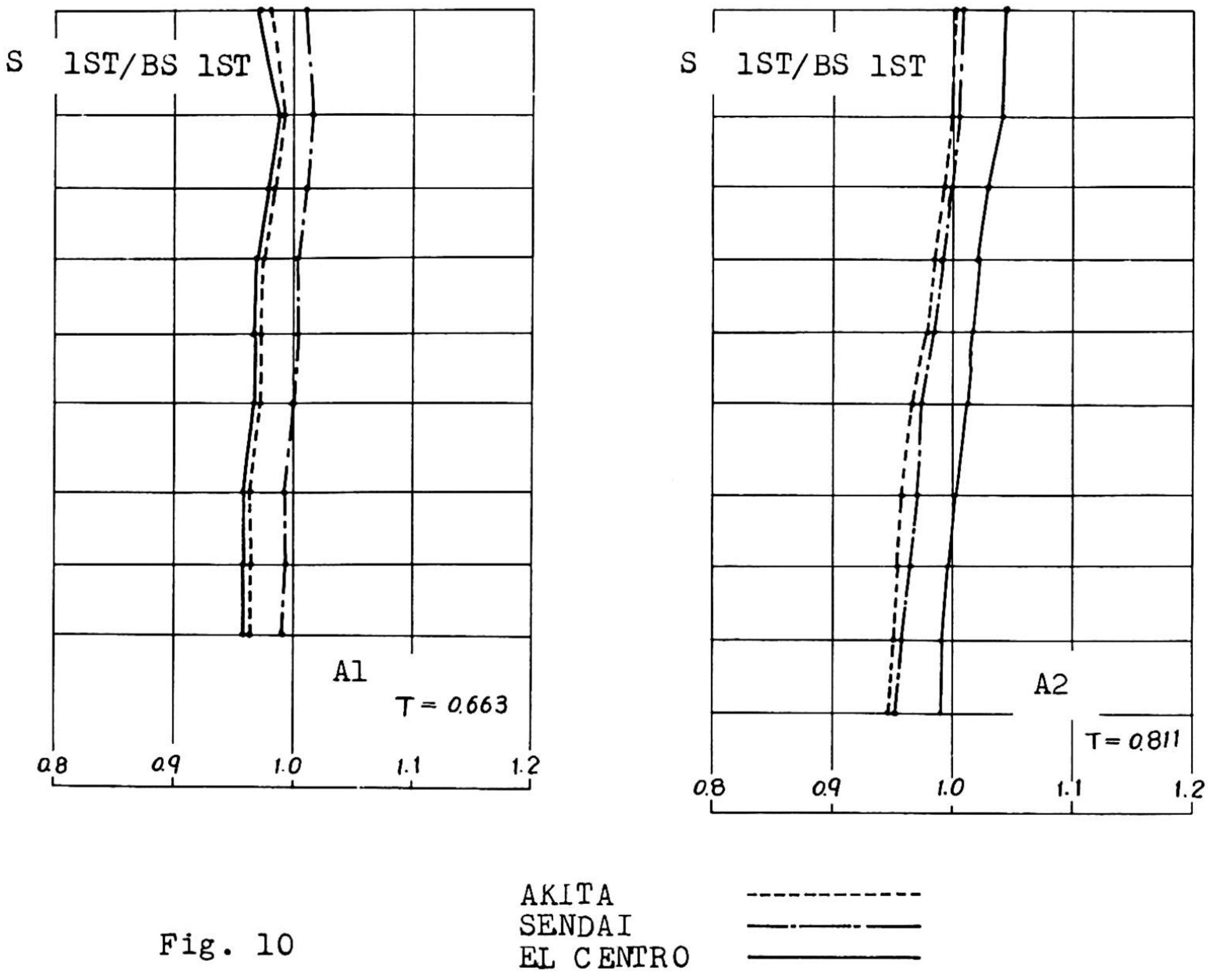


Fig. 10

Considerations.

For the purpose of these analyses, the damping coefficient, h, was determined on the assumption that there existed a relation h_n/ω_n = constant. Because of this assumption, rather high damping coefficients resulted for the mode of high order in case of the bending-shear type system, and this in turn led to the response values which were little affected by the modes of high order. Thus, the response values for the 1st mode turned out to be only slightly different from those for the modes of higher orders.

In the analysis of the shear type system, however, the effects of different vibration modes (Figs. 7 and 8) gave significant effects on the response values (see Fig. 9), and thus some complicated difference was observed due to the variation of modes.

An approximate method of analysis should always be used with caution especially when such a method is intended to deduce the structural response to all types of vibrational modes from only one mode of lower degree, because in some buildings (for instance a building in Example B), their structural responses will be greatly affected by the modes of higher orders.

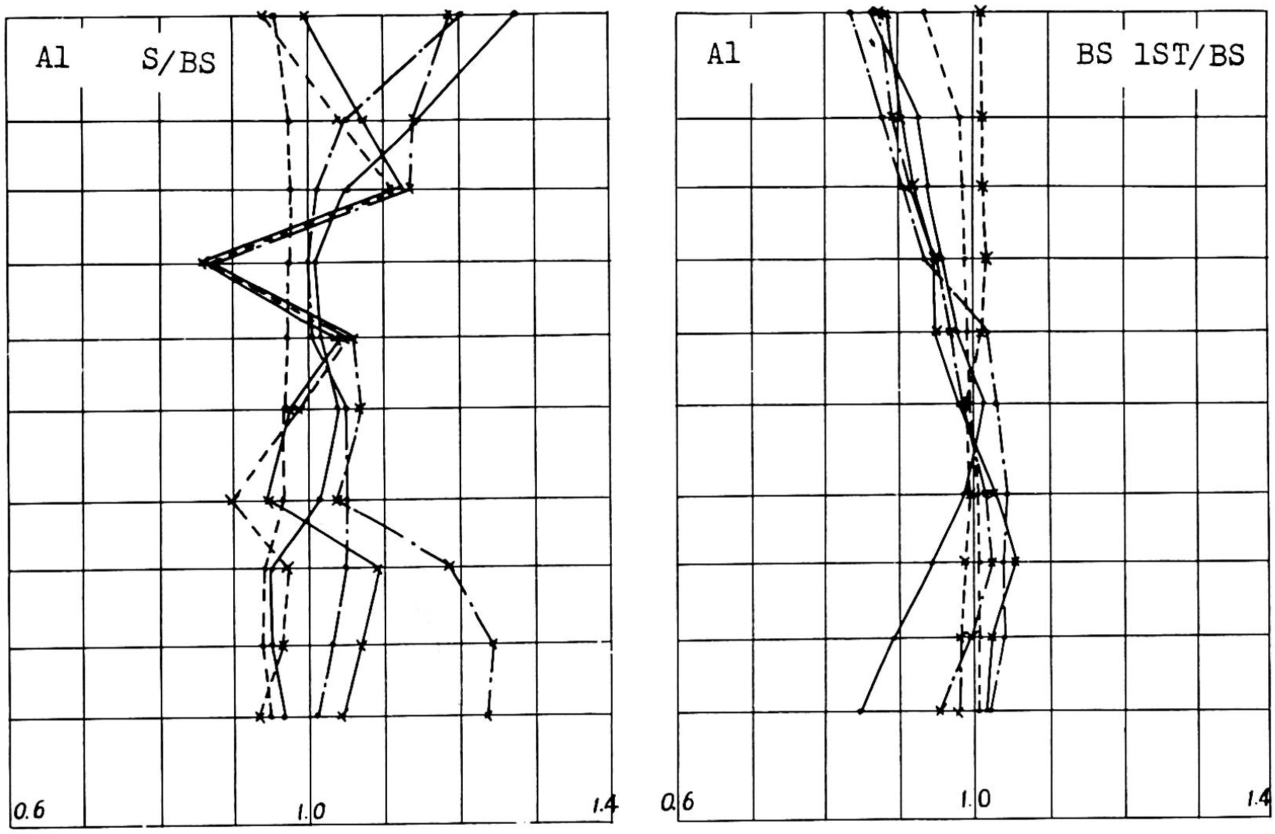
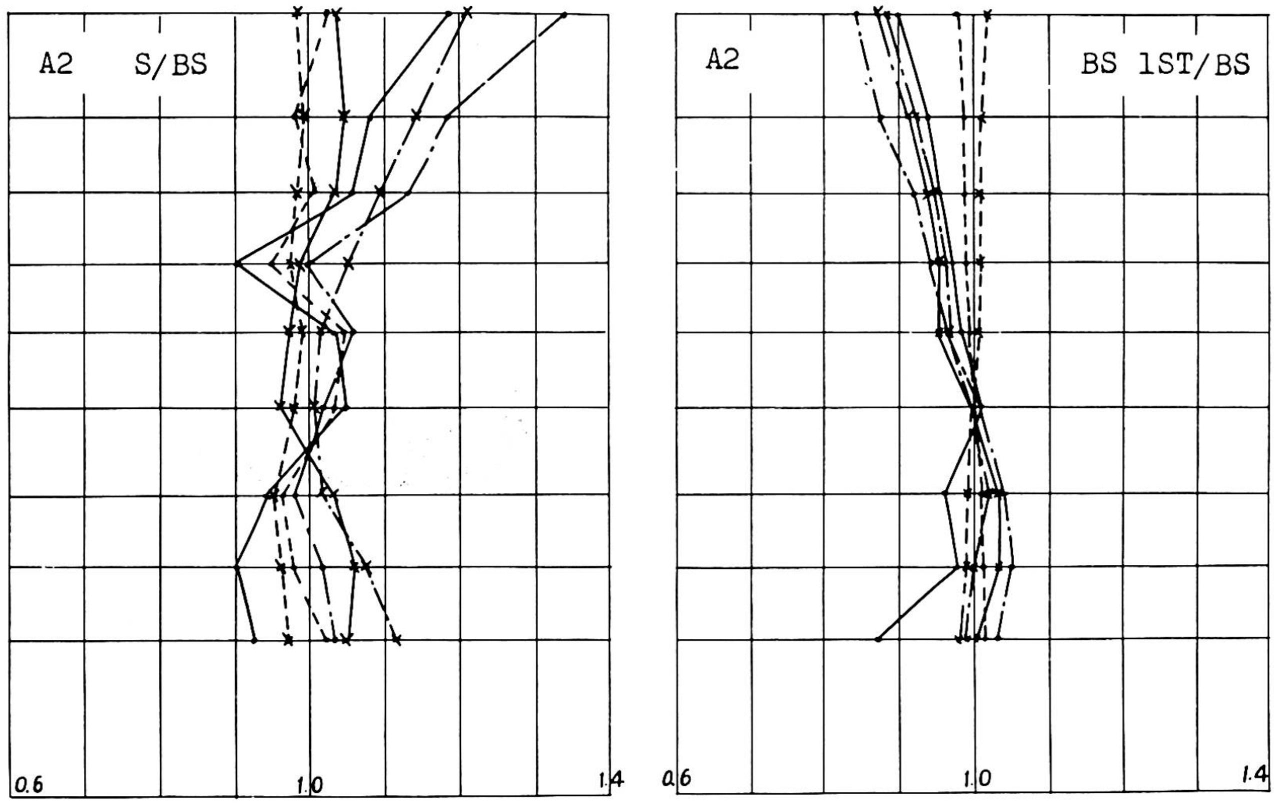


Fig. 11

	T_1 - 0.663 sec	T_2 - 0.811
AKITA	×- - - - - -×	•- - - - - -•
SENDAI	×—·—·—×	•—·—·—•
EL CENTRO	×———×	•———•



4. Variation of Response due to Different Modes.

Since the building heretofore discussed (i.e., Example A) is somewhat unusual in Japan in terms of the structural features, two buildings of more common structural design will be discussed as a matter of comparison. These are shown in Fig. 14 and Fig. 15 as Examples B and C respectively, and their responses have been analyzed by assuming an equivalent 5-mass point system of shear type.

In order to enable to investigate the characteristic of response to vibration of different modes on a comparative basis, the natural periods were taken at 0.663 second which was the period for the 1st mode of Frame A_1 and at 0.811 second which was the period for the 1st mode of Frame A_2.

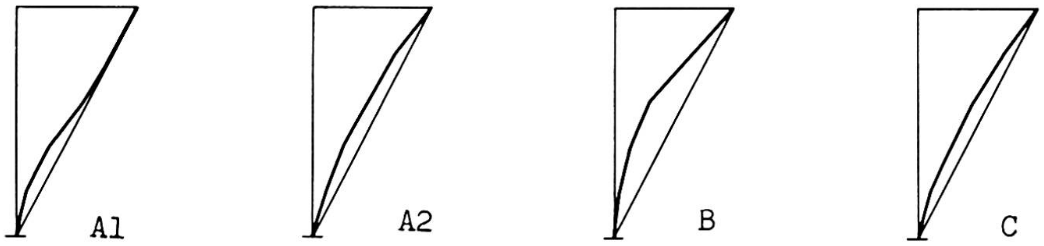


Fig. 12 FIRST MODE OF FOUR CASES

The modes of vibration obtained for the Frames A_1, A_2, B and C are shown in Fig. 12, and the response values in terms of shear force coefficient are shown in Fig. 13.

Considerations.

The comparative analysis has revealed that Frame B has the response characteristic which is quite different from other three cases evidently due to the effects of the higher mode vibration. The reason for this is presumed to be attributable to the fact that the 1st mode of vibration of Frame B is not linear. Japanese structural engineers should bear in mind that a building with this type of response characteristics often results if the building is designed faithfully in accordance with the lateral loads set forth in the Japanese national building code but in disregard of the building's vibration characteristics. The shear force coefficients widely vary with the types of earthquakes adopted for the analysis. This means that the difference in the spectra of the earthquakes shown in Fig. 2 has been directly reflected in the vibration characteristics. The results of these analyses seem to indicate that there are two "problem areas": one is a design problem which concerns the determination of the natural period of a building; and the other, the analysis problem which concerns the types of earthquakes to be used for the earthquake response analysis.

Acknowledgment.

The authors are gratefully indebted to Dr. H. Umemura, professor of structural engineering at Tokyo University for the guidance and help he extended to the authors both during the design of the building discussed here and during the preparation of this present paper.

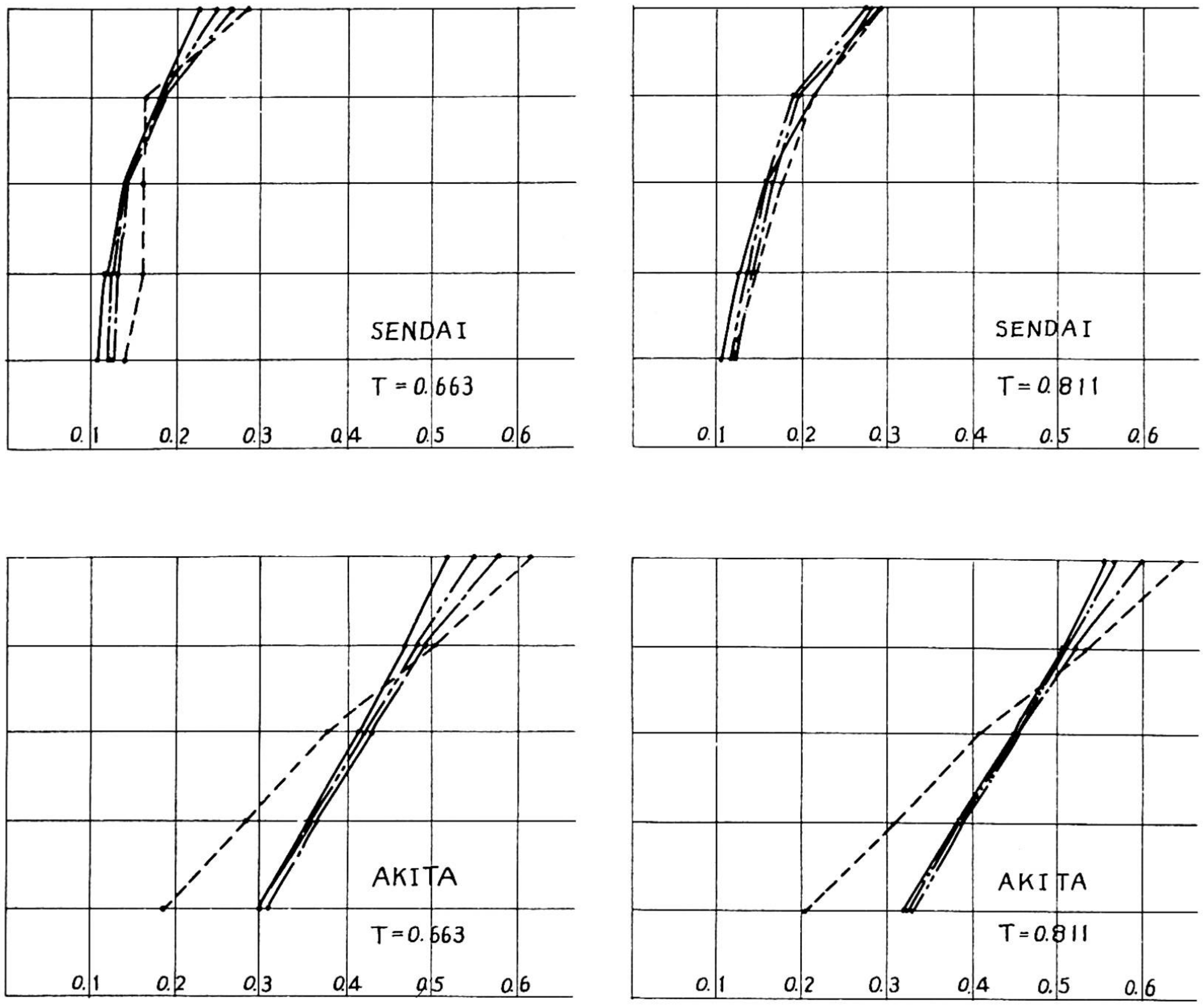
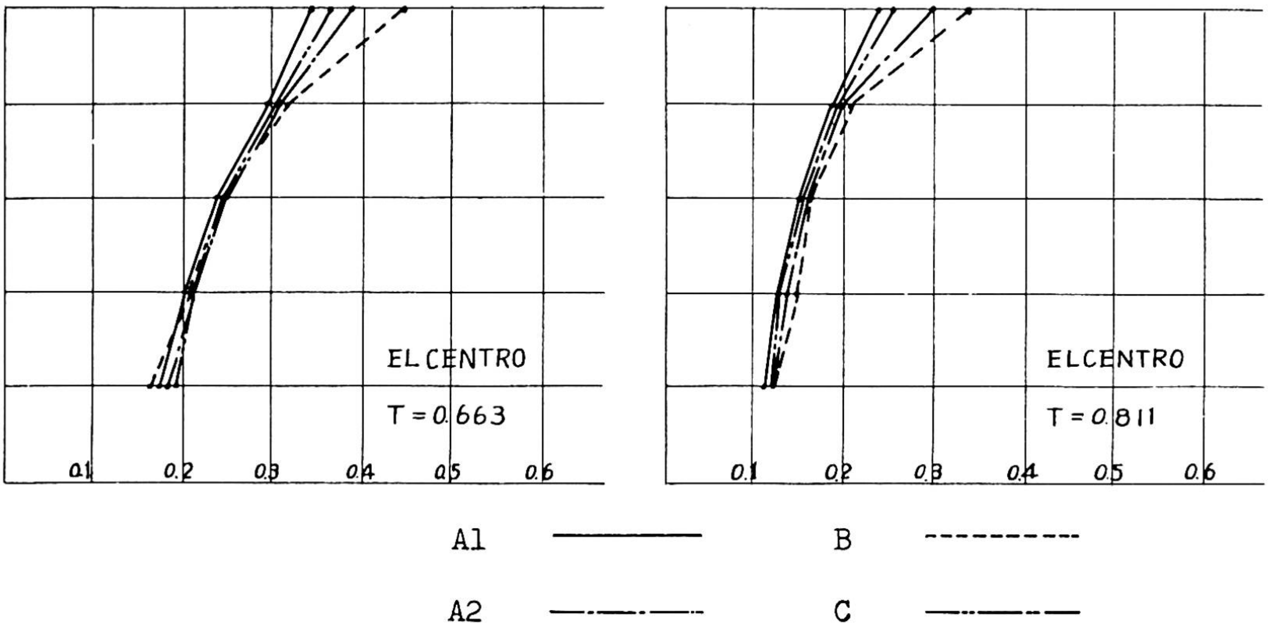
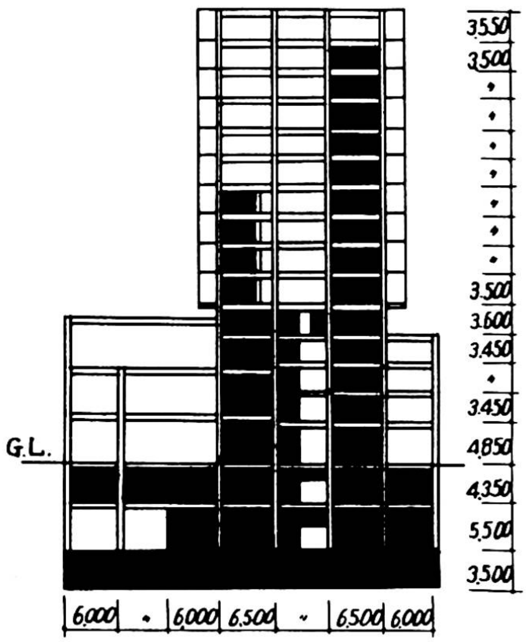

SENDAI
T = 0.663
0.1
0.2
0.3
0.4
0.5
0.6
SENDAI
T = 0.811
0.1
0.2
0.3
0.4
0.5
0.6
AKITA
T = 0.663
0.1
0.2
0.3
0.4
0.5
0.6
AKITA
T = 0.811
0.1
0.2
0.3
0.4
0.5
0.6

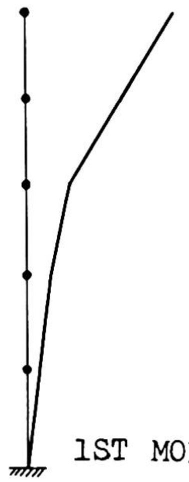
Fig. 13


EL CENTRO
T = 0.663
0.1
0.2
0.3
0.4
0.5
0.6
ELCENTRO
T = 0.811
0.1
0.2
0.3
0.4
0.5
0.6
A1
B
A2
C

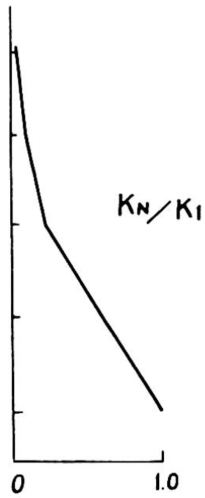


SECTION

Designed in 1963



1ST MODE



PLAN

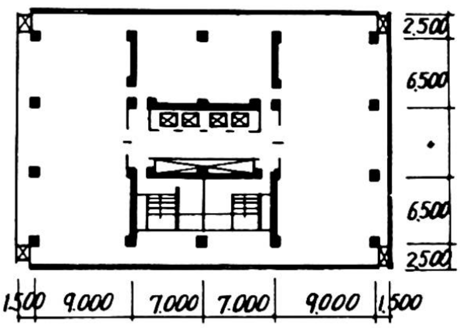
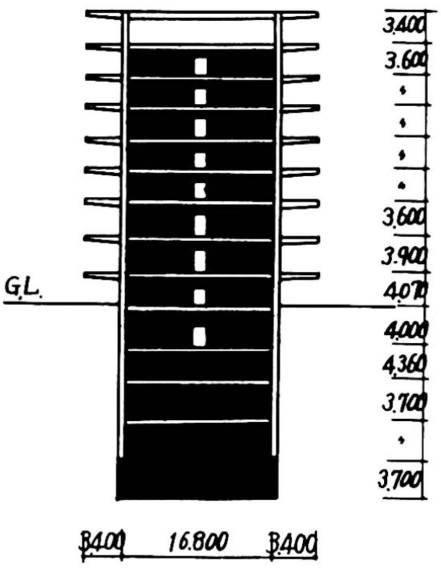
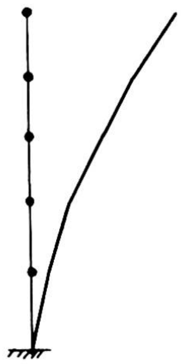


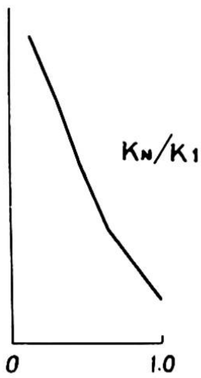
Fig. 14 CASE B



SECTION

Designed in 1964





1ST MODE

PARTIAL PLAN

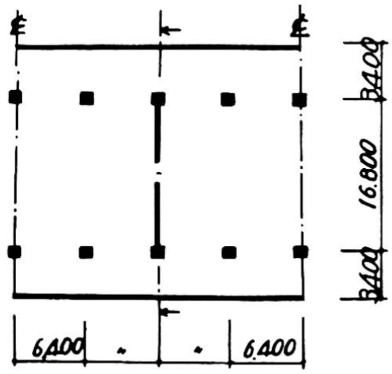


Fig. 15 CASE C

SUMMARY

In an attempt to ascertain the earthquake response characteristics of medium-rise (30 to 45 meters in height) reinforced concrete buildings having shear wall, the authors have made analytical studies on a number of buildings of the type described above. It is hoped that the results of such analyses may serve in future as a source of some useful information for preliminary structural design of similar buildings.

RÉSUMÉ

Pour obtenir des caractéristiques de secousses sismiques dans des constructions de hauteur moyenne (30 - 45 m) en béton armé avec murs de cisaillement, l'auteur a procédé à plusieurs réflections analytiques. Il espère que les résultats de cette analyse servent à pré-dimensionner des constructions simples.

ZUSAMMENFASSUNG

Der Verfasser hat, in der Absicht Erdbebencharakteristiken an mittelhohen Stahlbetongebäuden von 30 bis 45 Meter mit Schubwänden zu erhalten, einige analytische Ueberlegungen angestellt, hoffend, dass die Ergebnisse dieser Analyse in Zukunft als eine Quelle dienlicher Angaben für den vorläufigen Entwurf einfacher Bauten Verwendung finde.