

# STRUCTURAL EXAMINATION OF HIGH RISE BUILDINGS IN JAPAN

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## Introduction

In January 1964, the building height limitation which had been stipulated in the Japanese Building Code since 1921 was repealed. The revisions permit the construction of buildings exceeding 31 meters (100 ft) in height, provided that the buildings are constructed in accordance with the provisions of volume control as well as sky exposure restrictions.

As is commonly known, the seismic code for low buildings can not be applied to high-rise buildings. Also the wind velocity at higher levels has a different profile from that near the ground and this should also be considered in the structural design of tall buildings.

In order to assure the structural safety of tall buildings which are now permitted in this country, an Examination Board was set up in the Ministry of Construction under Dr Muto's chairmanship and its activities began in September 1964. The Board was transferred from the Ministry of Construction to the Building Center of Japan in August 1965.

During the three and half years ending March of 1968, the Examination Board has investigated and approved the structural design of 32 high-rise buildings.

As no seismic code is at present in force regarding the provisions for the safety of tall buildings, the role of the Board is important and the results of the examinations performed by the Board are considered to be very significant.

## Principals and procedures

All buildings over 45 meters in height and those exceeding 31 meters and not designed by the present seismic code are examined by the Board which consists of 20 specialists.

The safety of the structure is mainly investigated and, if necessary, other aspects of the building construction which may be important for the public safety is examined as well.

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Each building is judged individually by the Board, not the type of structure in general. The Board sometimes points out problems to be discussed and further studied but it does not act as a consultant.

The report on the Board's findings is officially announced to help in promoting the structural design of high-rise buildings in the future.

The architect's and engineer's office presents documents and drawings of the structural design of a tall building to the Building Center of Japan and explains the outline of the structural design to all members of the Board. After this hearing, a sub-committee consisting of appropriate members of the Board is organized to investigate the design in detail. The detailed conclusions made by the sub-committee are reported to the Board and the decision on approval is made by vote of the Board members.

It should be noticed that this examination is a preliminary one in connection with the Japanese Building Code Article 38+ and that the final decision is subjected to the approval of the Minister of Construction.

The main items to be examined by the Board are as follows:

- a) Supporting ground -- settlements of the building, subsoil effect on the vibrational behavior of the structure.
- b) Structural planning -- arrangement of the structural elements resisting earthquake and wind forces, transmission of stresses in the structure.
- c) Foundation structure -- unit pressure on the supporting ground due to vertical and horizontal loads, uplifting, construction of tie beams, slabs, basement walls, etc.
- d) Main structure -- strengths and ductilities of structural elements resisting horizontal loads.
- e) Seismic analysis -- input earthquake motions for dynamic analysis, vibration models and their periods, damping and restoring force characteristics, story shears, overturning moments, interstory drifts, ductility factors, consideration of torsional effects, etc.
- f) Analysis for wind loads -- design velocity pressure, velocity distribution along the building height, coefficients of wind force, story shears, overturning moments, interstory drifts, etc.

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+ Article 38 (Special Materials and Methods of Construction)

The provisions of this Chapter (Chapter II Building Site, Construction and Building Equipment) and of the orders and by-law based thereon shall not apply to special building materials or special methods of construction where the Minister of Construction deems that the said building materials or methods of construction are equal or superior to those under these provisions.

Generally, when new construction is to be employed, justification by experimental work on the proposed construction is required to be presented to the Board.

### Summary of structural design of high-rise buildings

The structural design and the related dynamic analyses of about 30 high-rise buildings so far examined by the Board are summarized below.

- 1) A steel structure is generally adopted for high-rise buildings up to about 40 stories. However, a steel encased reinforced concrete (composite) structure is often used for buildings up to about 20 stories in height.
- 2) The type of structure for about 10 buildings is that of a space frame (ductile moment resisting) only and others of a space frame with shear walls or bracings to resist horizontal forces.
- 3) All high-rise buildings have basement floors of 2 to 5 stories. Many buildings have mat foundations located on gravel layer (the Tokyo gravel layer) but several have pier foundations.
- 4) The fundamental periods of vibration of the buildings are in the range of 0.7 to 5 seconds, increasing with the building heights. The periods of vibration of steel structures are greater than those of composite structures. (See Fig.1).
- 5) The design base shear coefficients  $C_B$  (most are story shear coefficients of the first story or of the first or second basement story) decrease with the increase of the fundamental periods of vibration  $T_1$ . The relation between  $C_B$  and  $T_1$  is generally in the range of  $C_B=0.36/T_1 - 0.18/T_1$  and the values of  $C_B$  are not less than 0.05. (See Fig.2).
- 6) The story shear coefficient of each story increases with the building height and the ratio of the story shear coefficient of the top story  $C_T$  to the base coefficient  $C_B$  is in the range of 2 to 4. (See Figs. 3 and 4).
- 7) In many cases, the damping factors (fraction of critical damping) used in the dynamic analyses are 5% and 2% for composite and steel structures respectively.
- 8) In the dynamic analysis, the building structure is treated as a multi-degree of freedom system fixed at the first floor or at the first basement floor, because the structure of the basement floors is in general rigidly constructed. The analysis to obtain elastic

response is usually made of a shear type system but sometimes of a bending-shear type or an equivalent shear type system considering the effect of bending. The elasto-plastic (non-linear) response of the structure is calculated on the basis of a shear type or an equivalent shear type system.

- 9) As an input earthquake motion for dynamic analysis, the El Centro 1940 NS accelerogram (this gives relatively higher response in the range of 2 to 5 second periods) with modified maximum intensity is used in every case. The Taft 1952 EW accelerogram (this gives relatively higher response in the range of 1.5 to 2 second periods) is often used together with El Centro record. Furthermore, when a building is constructed on the Tokyo gravel layer, Tokyo 101 NS and Sendai 501 NS accelerograms are used.
- 10) The main structural frame of the building is generally designed to remain in the elastic range considering earthquake motions with maximum accelerations of 200 to 350 gals. In this case the maximum interstory drift is usually limited to 2 cm. However, in the analysis mentioned above, seismic shear walls provided in the frame are sometimes permitted to yield into the plastic range with a ductility factor of 2 or less. The elasto-plastic response of the structure is sometimes examined considering a maximum ground acceleration of 500 gals.

### **Concluding remarks**

About thirty high-rise buildings have been investigated and approved by the Examination Board since the structural design of tall buildings was started three and a half years ago.

Reviewing the results of the examinations mentioned above, some conclusions concerning the trends in the structural design of high-rise buildings in Japan, can be made.

In the near future it is intended that data concerning the dynamic properties of tall buildings already constructed, especially the data of their response due to actual earthquakes, will be accumulated and analyzed.

Therefore, the installation of strong motion seismographs in tall buildings have been recommended by the Examination Board, and almost all buildings approved provide two or three seismographs to record their behavior during earthquakes.

It should be noted that the observed fundamental period of vibration of a tall building with small amplitude motion is about half that assumed in the structural design. This may be caused by the participation of the partition walls, window sashes and finishing materials in the structural rigidity, and the consideration of the effect of these secondary elements in the dynamic analysis should therefore be studied.

The damping properties of the higher modes of vibration of tall buildings should also be experimentally investigated.

As for the input earthquake ground motions (accelerations) and the intensities to be used in dynamic analysis, it would be desirable to determine standard motions or response spectra which take into account the seismicity of the site and the conditions of supporting ground such as dynamic properties, location below the ground level, etc.

It would also be desirable if the seismic design of high-rise buildings can be performed by static analysis. At present, however, structural design based on dynamic analysis is used in Japan.

It is expected that a static design method for high-rise building structures will be given in the revision of the present seismic code while dynamic analysis may still be permitted so that the advancement of seismic design of tall buildings will not be retarded, since the number of tall buildings will increase greatly in Japan in the future.

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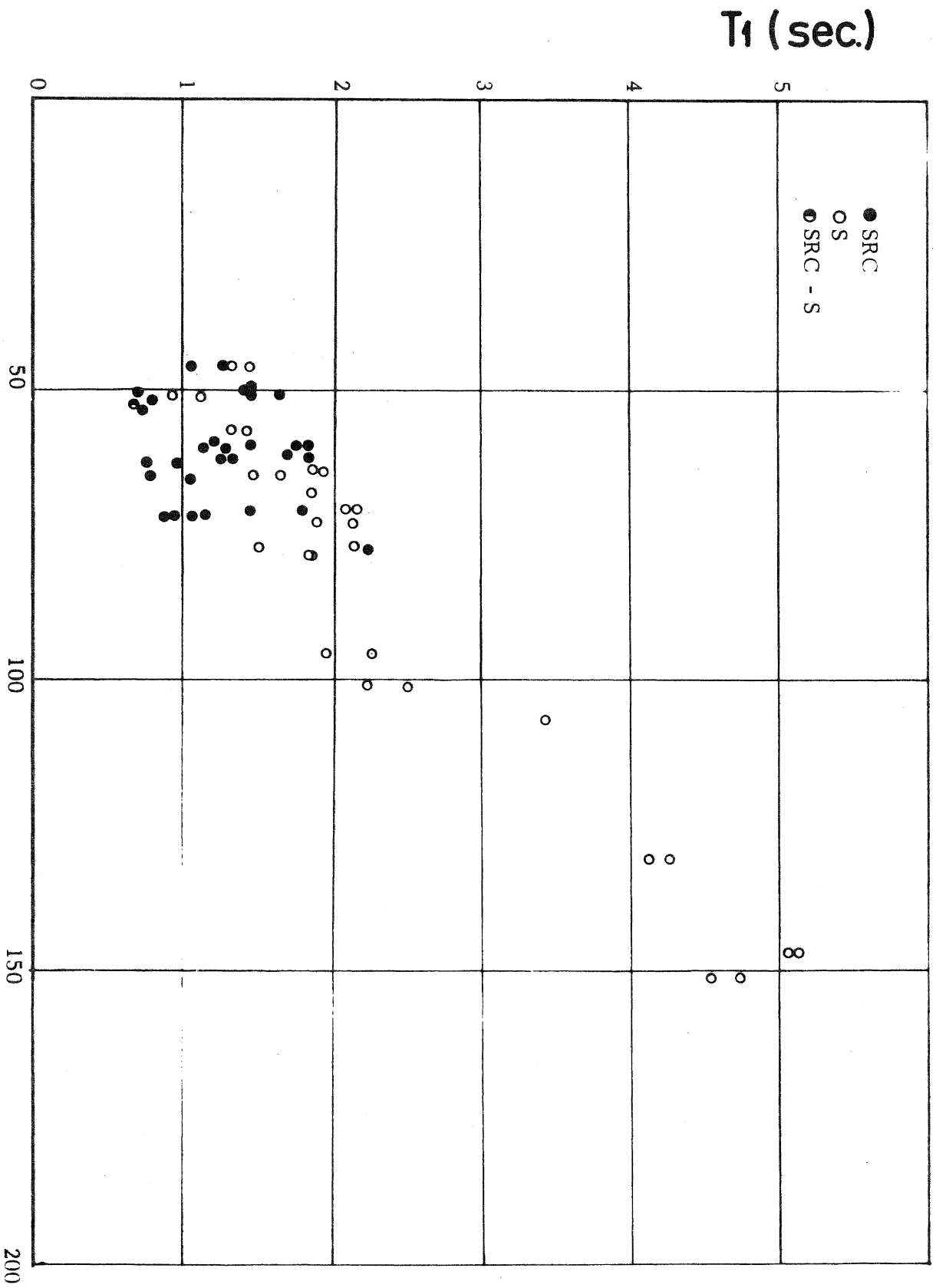


Fig. 1  
 Relation between building height above the ground level ( $H$ )  
 and fundamental period of vibration ( $T_1$ )

$H$  (m)

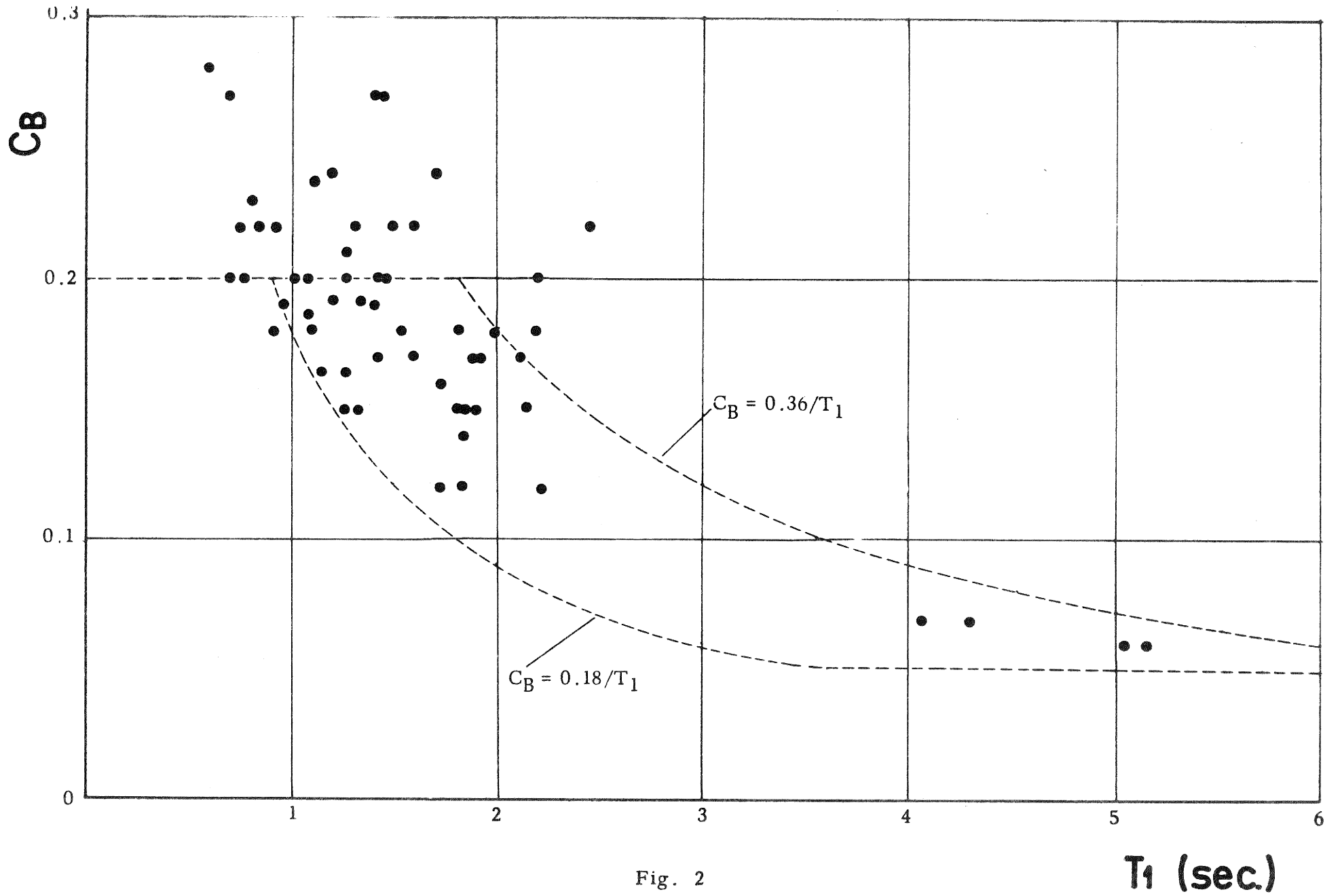


Fig. 2  
 Relation between base shear coefficient ( $C_B$ ) and  
 fundamental period of vibration ( $T_1$ )

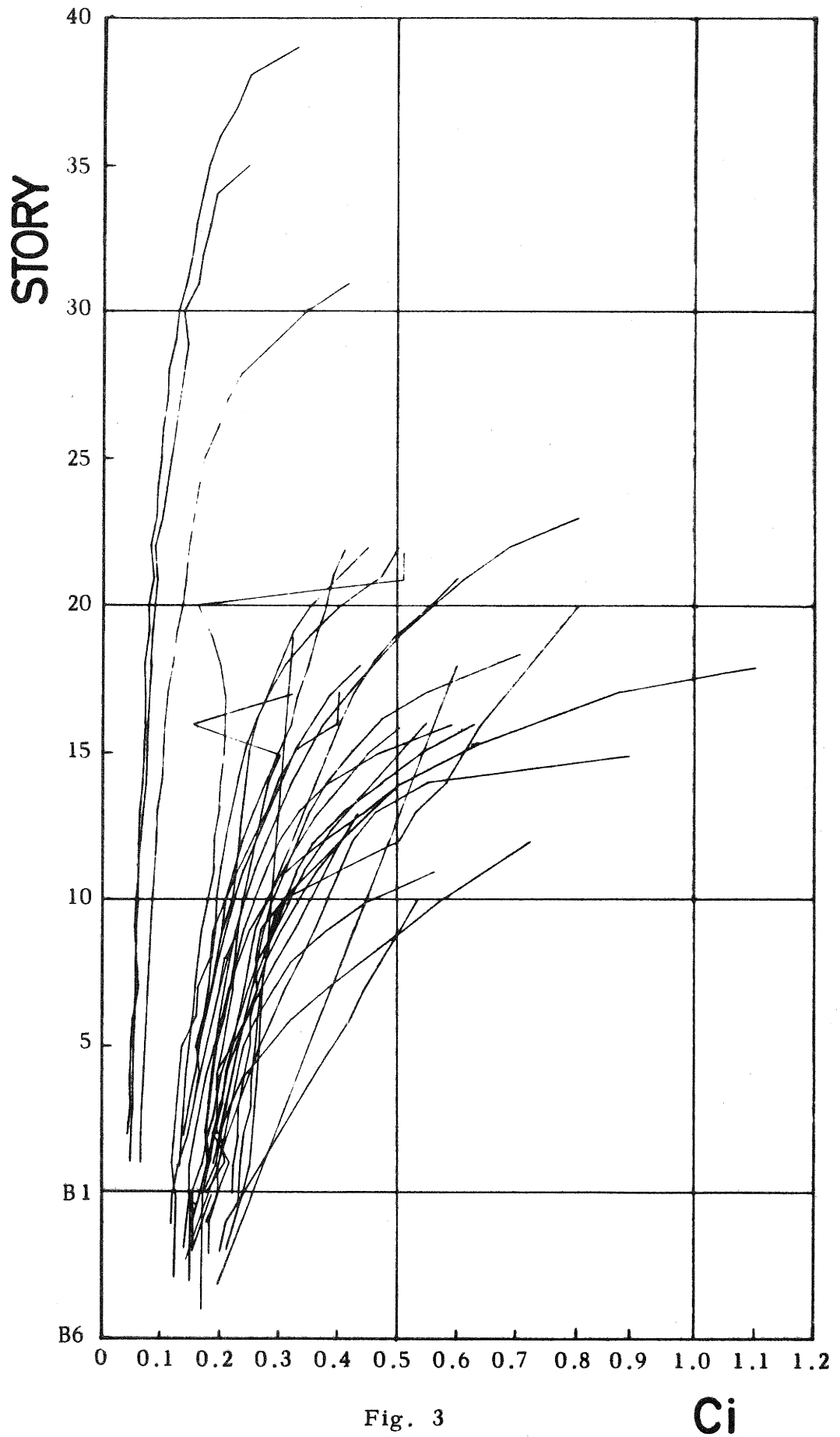


Fig. 3  
 Distribution of story shear coefficient of  
 each story ( $C_i$ ) along the building height

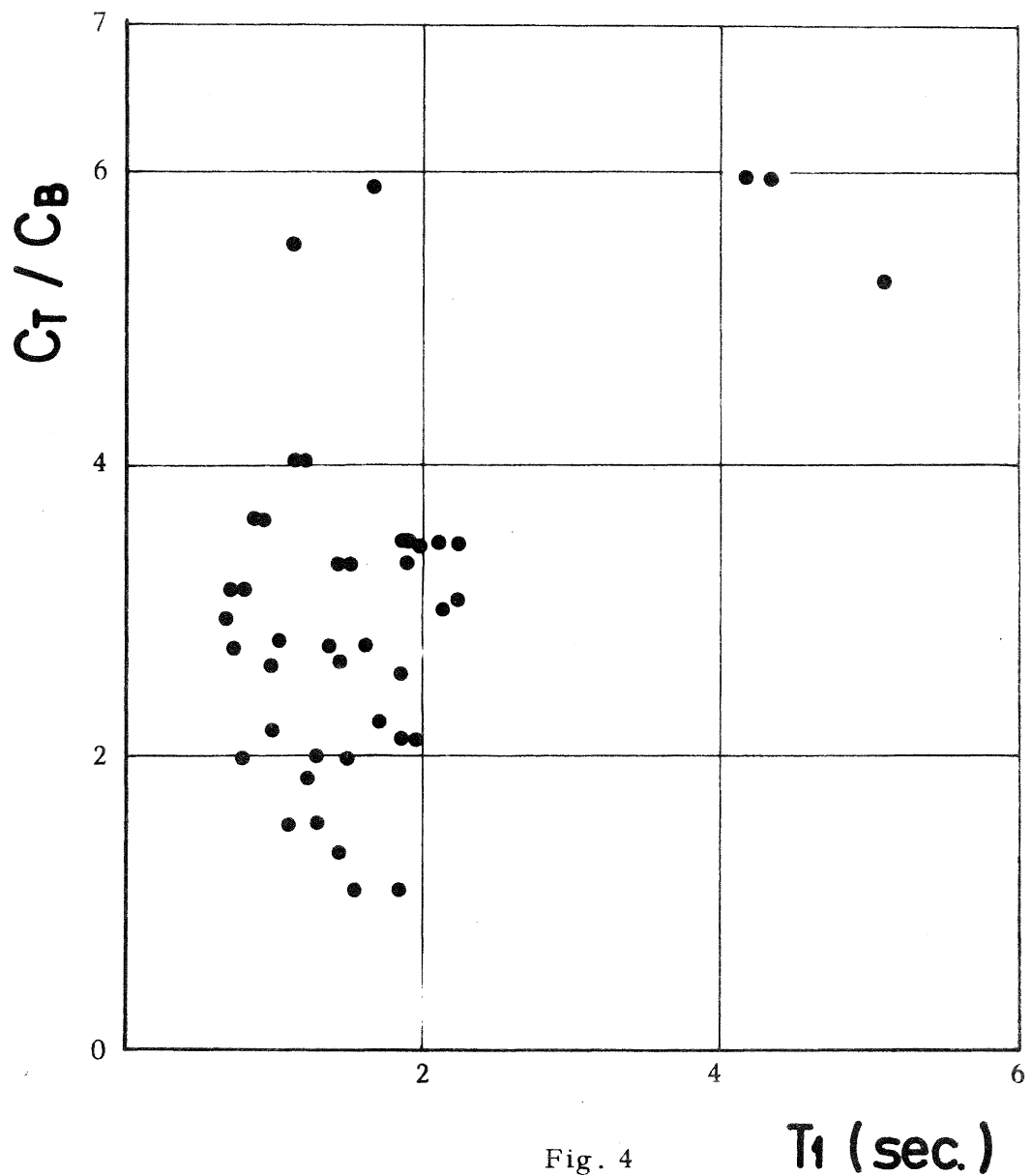


Fig. 4

Ratio of story shear coefficient of top story ( $C_T$ )  
to base shear coefficient ( $C_B$ ) as a function  
of the fundamental period ( $T_1$ )