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Autor: Muto, Kiyoshi / Nagata, Masayuki

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Dynamic Aseismic Design Procedure and Example of High-rise Building in Japan

Etude parasismique dynamique des bâtiments de grande hauteur et exemple japonais

Dynamische Berechnungsmethode der Erdbebenwirkung an einem Hochhaus in Japan

KIYOSHI MUTO
Member, Japan Academy
Vice-President, Kajima Corporation
Tokyo, Japan

MASAYUKI NAGATA
Senior Research Engineer
Muto Institute of Structural Mechanics
Tokyo, Japan

1. ASEISMIC DESIGN PROCEDURE

In Japan, aseismic design code called "seismic load coefficient method", in which the coefficient of 0.1G was regulated, was first adopted after the KWANTO Earthquake of 1923. When the "Building Law" was passed in 1950, the coefficient was altered to 0.2G, with the increment along the height of buildings, according to the change in allowable stresses. This design method is used for buildings lower than 45 meters in height. Under this method, the component stresses, ie., the above-mentioned seismic load combined with dead and live load stresses, must be within the allowable limits.

Since the 1950's, there has been considerable research on a variety of problems related to high rise buildings, for example, the effects of elastic and elastic-plastic vibrations. These efforts have yielded a unique "Dynamic Aseismic Design Method", which has allowed construction of buildings in excess of 45 meters. Since 1963, when the Minister of Construction first approved this, it has become possible to erect safer high-rise buildings that are also low cost.

1-1. Dynamic Design Procedure

The flow chart in Fig.1 shows the above-mentioned new dynamic aseismic design procedure called "feed-back system";

1) Assume the preliminary seismic load and its distribution.
2) Make static stress analyses of the structure.
3) Determine the preliminary structural design (the conventional design is finished at this step).
4) Establish a mathematical model to simulate the behavior of the preliminary designed structure.
5) Select suitable input earthquake waves among recorded waves at locations having similar ground conditions in the past and amplify their intensities to several different levels such as that of severe earthquakes and hypothetically the worst earthquakes.
6) Carry out earthquake response analyses covering the elastic and/or elastic-plastic ranges.
7) Check response values (stresses and strains) according to the design criteira. (In usual office buildings, for expected severe earthquakes, the stresses on all members must be less than the allowable values; similarly, if the story drift is less than 2cm, and for hypothetically

the worst earthquake, the structure may suffer some damage but must not be severely damaged)

8) If the safety judges are unsatisfactory (NO), modify the design until a satisfactory result is achieved (YES).

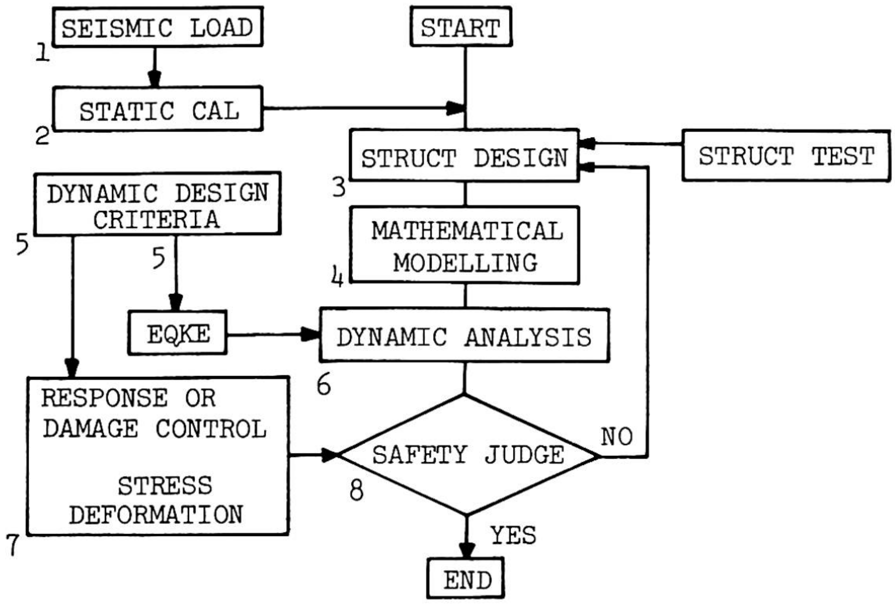


FIG.1 DYNAMIC DESIGN PROCEDURE

1-2. Dynamic Analyses

For dynamic analyses, the fundamental requirements are a rigorous vibration model and a computer program equipped to simulate as possible the actual behavior of the structure. To insure the adequacy of this process structural tests must be measured against the repeated lateral force and vibration results. Fig.2 shows structural tests on the steel frames and shearing walls. As shown in the lower part of this figure, the restorative qualities through both their elastic and elastic-plastic ranges serve as primary input date for the process known as FAPP-FASP system.

<u>FAPP</u> (Frame Analysis in consideration of Pure-shear Panel deformation)

FAPP is a computer program for rigorous analyses of high-rise frames such as open-, walled-, braced- and 3-dimensional frames as shown in Fig.3. In this FAPP method, it is assumed that framing is composed of four elements, ie., columns, beams, joint panels and braces, and bending, shearing and axial deformations on columns, bending, shearing and torsional deformations on beams, shearing deformations on joint panels, and axial deformation on braces are taken into account. Earthquake response analyses in the elastic range are easily carried out under this FAPP method as a coupled system for various kinds of frames.

<u>FASP</u> (Frame Analysis by Simplified Procedure)

FASP is a modified method especially for non-linear analyses as shown in Fig.4. In this method, a non-linear hysteresis loop for the bending and shearing rigidities of the FASP model (lumped-mass system) are evaluated by placing the results of step-by-step analyses of FAPP in elastic and elastic-plastic ranges, against the static, gradually increasing lateral force.

2. DESIGN EXAMPLE (55-story Office Building)

The design example introduced here is the Shinjuku Mitsui Building (SMB), which is the tallest highrise in Japan. (Fig.5) The S.M.B., located in the New Shinjuku Business Center of Tokyo, is a highrise office building with 3 basement floors and 55 storied tower, whose total height above ground is 210 meters.

The structure of the building consists of steel framing for the tower part from the 2nd through 55th stories, steel and reinforced concrete composite framing for the 3rd basement through the first story. The foundation and other surrounding lower portions are constructed with ordinary reinforced concrete. The over-all dimensions of the structural system for a typical office floor are 58.4 meters long and 44.4 meters wide, as shown in Fig.6(A). The columns of longitudinal direction are spaced at distances of 3.2 meters, and these in the transverse direction are spaced at 15.6 meters for the office section, and 13.2 meters for the core portion. Those columns are built-up box section (500 x 500mm). Beams are built-up I section (800mm high) and by castellated beams.

The wind and earthquake resisting system consists of rigidly connected framings interacting with the slitted reinforced concrete shear-walls installed in the core portion, and large diagonally braced frames at both ends as shown in Fig.6(B).

SUMMARY

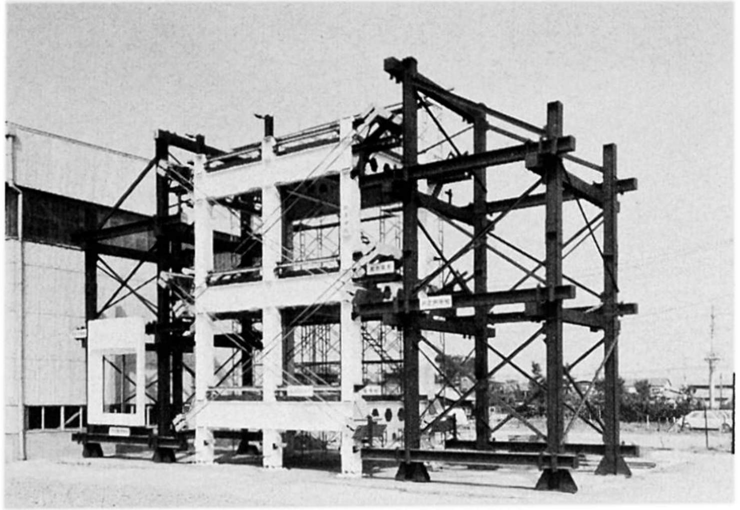
The feed-back dynamic design system has been accepted in Japan as the most advanced of its kind for tall buildings over 45 meters. Dynamic analysis using a rigorous computer program is indispensable in design procedure, as well as in earthquake observation and structural testing. By virtue of the major links in this system, we can control ultimate strength and deformation, quite apart from conventional safety factor concept.

RESUME

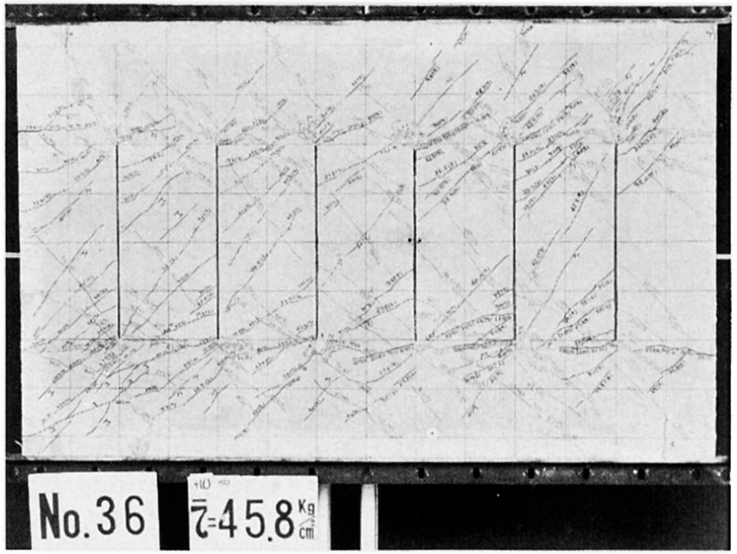
L'étude dynamique, par une méthode d'approximations successives, est reconnue comme la plus élaborée au Japon, pour les bâtiments de grande hauteur, de plus de 45 mètres. Une analyse dynamique, rigoureuse, par ordinateur, basée sur les observations sismiques et les résultats d'essais en laboratoires est indispensable. Lors du développement de chacune des boucles du programme, il est possible de contrôler l'état des contraintes limites et des déformations, indépendamment du facteur traditionnel de sécurité.

ZUSAMMENFASSUNG

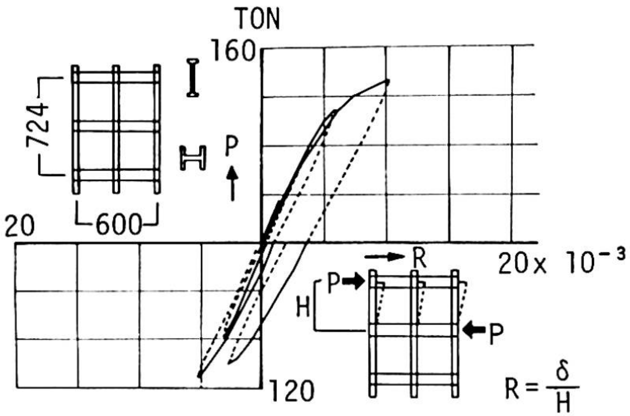
Die iterative dynamische Berechnungsmethode wurde als die fortschrittlichste Methode bei Hochhäusern über 45 m in Japan angenommen. Die dynamische Untersuchung mit Hilfe eines genauen Computer-Programmes ist unerlässlich für das Berechnungsverfahren sowie für die Beobachtung des Erdbebens und für die Prüfung von Konstruktionen. Die Methode gestattet die Grenzfestigkeit und Verformung, unabhängig vom üblichen Sicherheitsfaktor-Denken, zu überprüfen.



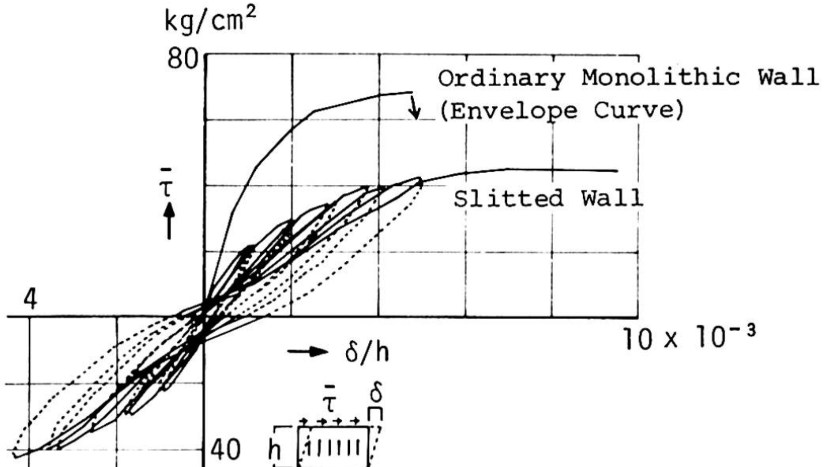
(a) General View of Full-Scale Test on Steel Frame



(a) Crack pattern in a Slitted Test-Wall---When the applied shear force is 45.8kg/cm^2, the cracks are distributed finely with no majar diagonal cracks.



(b) Load-Deflection Relationship of Full-Scale Test



(b) Shear Stress vs. Sway Deflection Angle---The deformability of the slitted wall is more than twice that of an ordinary monolithic wall.

STEEL FRAME

SLITTED WALL

FIG. 2 STRUCTURAL TESTS

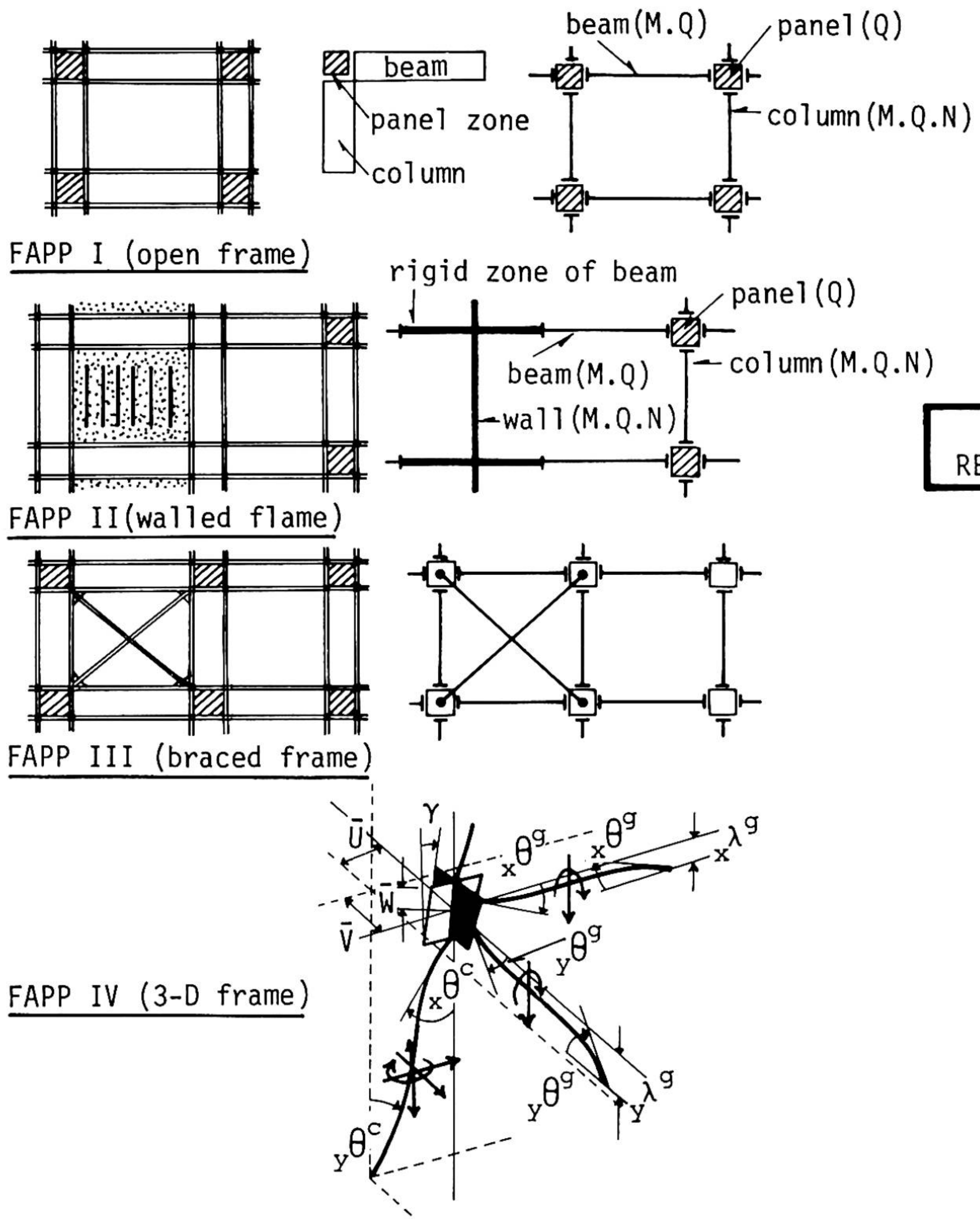


FIG.3 BASIC CONCEPT OF FAPP

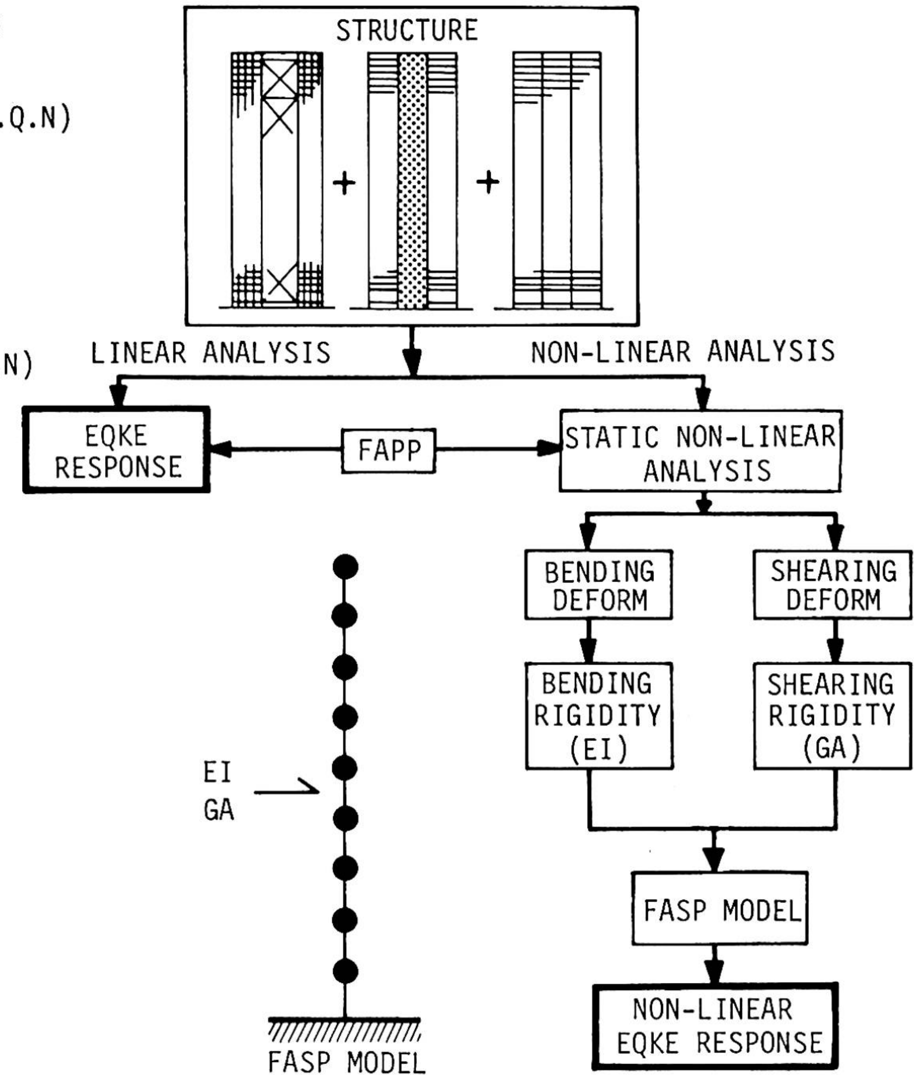


FIG.4 FAPP-FASP SYSTEM

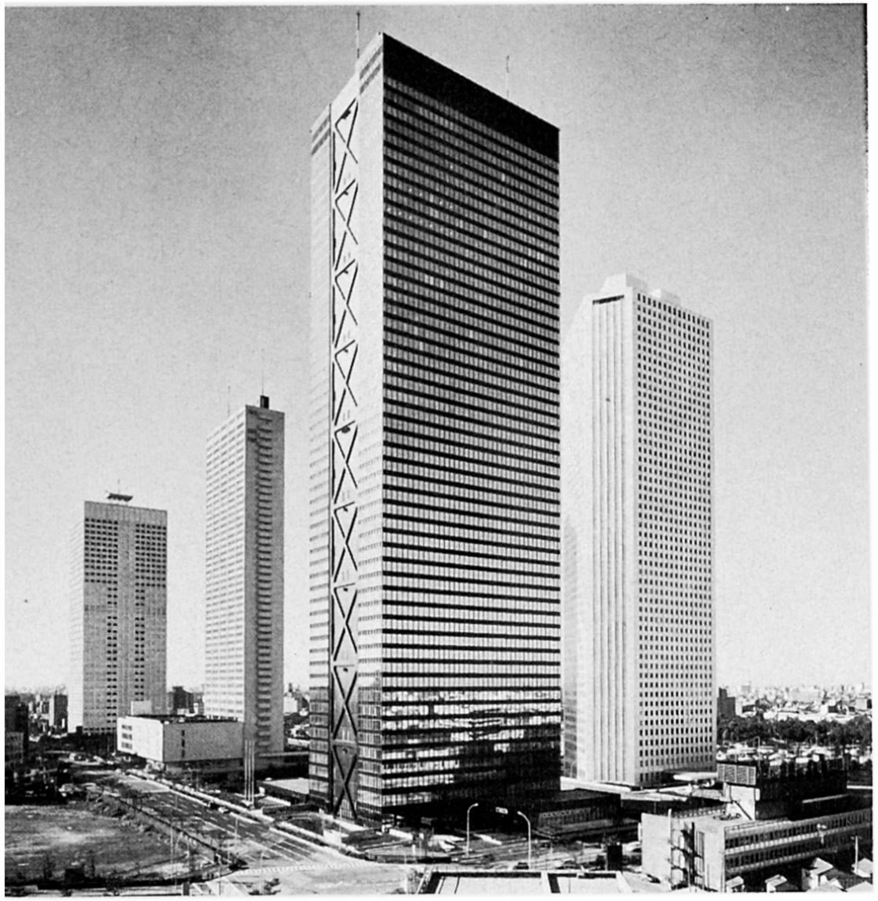
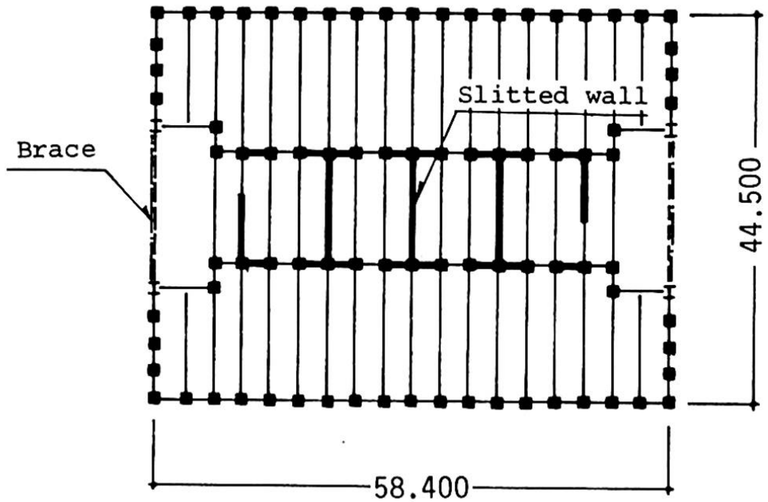
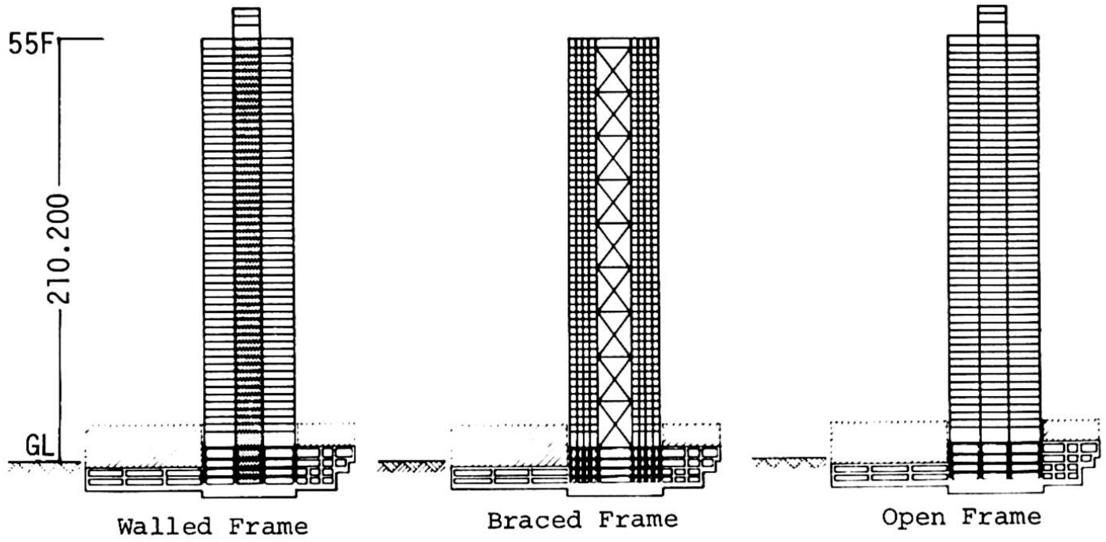


FIG. 5 SHINJUKU MITSUI BUILDING



(A) TYPICAL FLOOR PLAN



(B) EARTHQUAKE RESISTING FRAMES (TRANSVERSE)

FIG. 6 OUTLINE OF BUILDING STRUCTURE