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Design and Construction of Tall Reinforced Concrete Buildings in a Seismic Country

Conception et réalisation de bâtiments de grande hauteur en béton armé dans un pays sujet aux tremblements de terre

Entwurf und Ausführung von hohen Stahlbetonbauten in einem erdbebengefährdeten Land

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SUMMARY
This paper outlines several innovations in the conception of tall reinforced concrete buildings in Japan. Due to the high seismicity, the structures must be designed and built to withstand large alternating forces and preserve large ductility. Taking the case of a 30-storied residential building as an example, design procedures and safety confirmation methods as well as construction practices are described.

RÉSUMÉ
Cette contribution présente plusieurs innovations concernant les bâtiments de grande hauteur en béton armé au Japon. Ductilité et résistance à de grandes forces alternées doivent être absolument respectées en zone de haute séismicité. Le cas d'un bâtiment résidentiel de 30 étages sert à illustrer la conception, les moyens utilisés pour assurer la sécurité ainsi que les méthodes de la construction proprement dite.

ZUSAMMENFASSUNG
Der Beitrag stellt verschiedene Innovationen in der Konzeption von hohen Stahlbetonbauten in Japan vor. Infolge der grossen Erdbebenbeanspruchung müssen die Bauten grosse wechselnde Beanspruchungen ertragen können und eine grosse Duktilität ausweisen. Anhand eines 30-stöckigen Hochhauses werden die Projektierung, die Ausführung und die Sicherheitsaspekte beschrieben.

1. INTRODUCTION

It had been considered until a decade ago that, due to occurences of frequent severe earthquakes in Japan and brittle behavior of concrete structure in general, the construction of a tall reinforced concrete building was impossible. Learning lessons from many damages by earthquakes such as Tokachioki(1968,Japan) and San Fernando (1971,USA), and driven by economic demands the authors developed a new design and construction method for tall reinforced concrete buildings after solving problems on aseismic capabilities. The method called HiRC was already successfully applied to several tall buildings as shown in the references. [1,2,3]

As of March 1987, the completed reinforced concrete buildings over 50 meters high in Japan are limited to those by HiRC design and construction method. This paper is a general report on the innovative method for design and construction of other 30 storied concrete buildings which are now under construction in the City of Kawasaki near Tokyo.

2. OUTLINE OF THE BUILDING

The building is of 30 stories with the eaves height of 87.2 meters and has 230 housing units. Typical framing plan is approximately 30 meters square with recessed central portions on the four exteriors as shown in Fig.1 - 3. Building structure is composed of moment resisting frames by pure reinforced concrete structurally separated from walls, which makes possible the flexible housing layout at every floor.

In order to resist severe earthquake stresses especially induced in exterior columns on the lower story, following three items are, although unprecedented in Japan, introduced in the design practice.
- to use high strength concrete up to 420kgf/cm. (Concrete up to the 360kgf/cm was used for previous buildings.)
- to provide additional core-reinforcing bars in exterior columns on the lower story.(Prestressing tendons were used in case of previous buildings in order to reduce high tensil stresses)
- to use large subsoil diaphram walls in addition to piles with enlarged base in consideration of potential liquefactions as well as vertical and horizontal loadings.

3. DESIGN PRINCIPLE

Seismic design of the building structure is conducted through two-stage designing. The first one is based on so called allowable stress design method, while the second is on ultimate strength design method. Design earthquake force applied in the former stage is defined by the preliminary earthquake response analysis, against which the stresses induced in beams and columns should be within allowable limits.

The second stage of design is to check the stresses of the column and joining portions on condition that all the beams have already yielded, which implies that strong-column and weak-beam design principle is indispensable and the design procedure should take a form of feedback system. Typical cross sections of columns and beams by the final design are shown in Fig.4. High strength concrete and additional core-reinforcing bars make the unit structural costs reasonable compared with those of the previous lower buildings.

Fig.1 Building under construction

construction

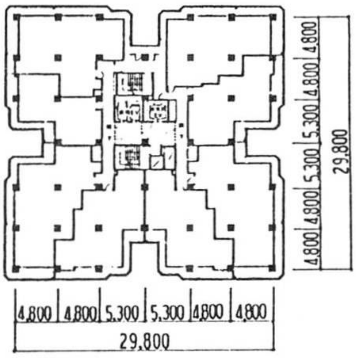


Fig.2 Typical floor plan

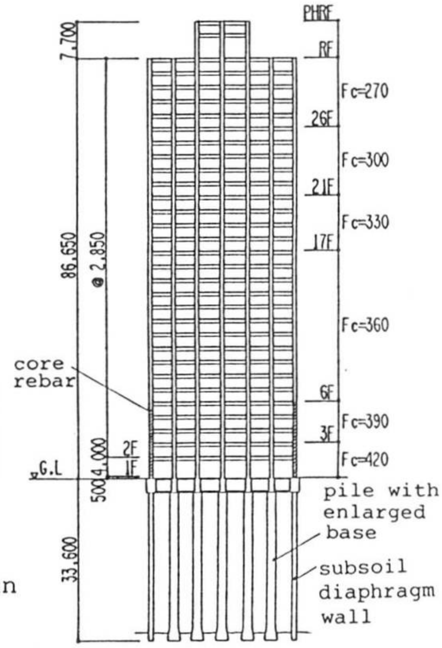
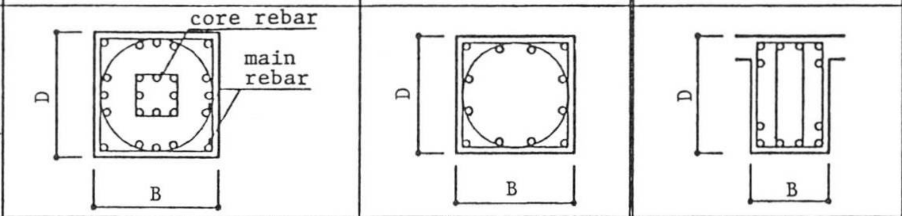
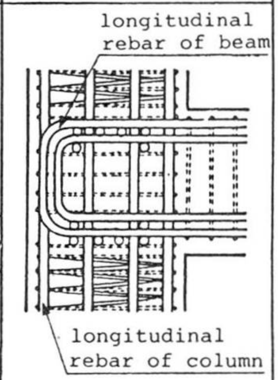


Fig.3 Framing elevation





	Exterior column				Interior column			Beam			U-shaped anchorage
Cross section											
floor	B x D	main rebar	core rebar	hoop	B x D	main rebar	hoop	B x D	main rebar	stirrup	
30 ↓ 2	800×800 ↓ 850×850	12-D32 ↓ 16-D41	— ↓ 8-D41	D13 @150 13φ @150 ↓ D16 @100 16φ @100	750×750 ↓ 800×800	12-D32 ↓ 16-D41	D13 @150 13φ @150 ↓ D16 @100 16φ @100	500×750 ↓ 600×1000	4-D25 2-D22 ↓ 4-D41 2-D38	4-D13@175 ↓ 4-D16@125	

Fig.4 Typical cross sections

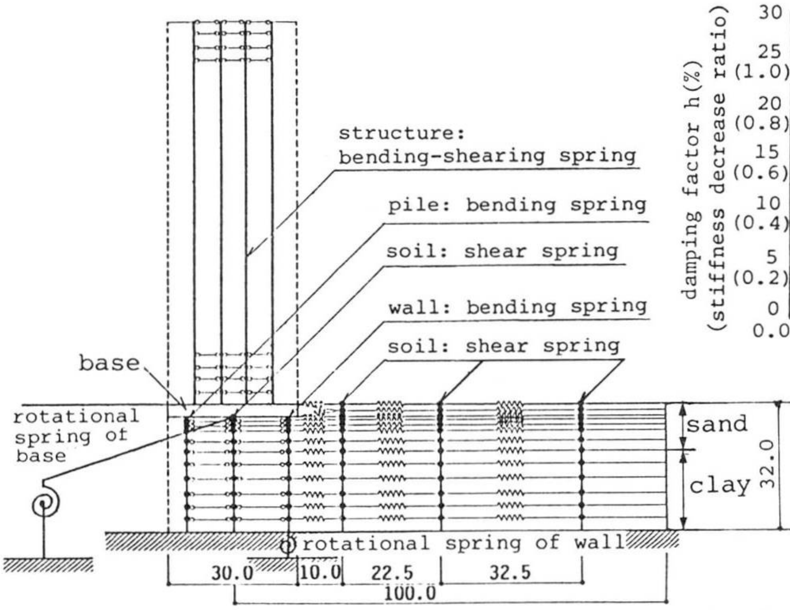


Fig.5 Modelling in earthquake response analysis

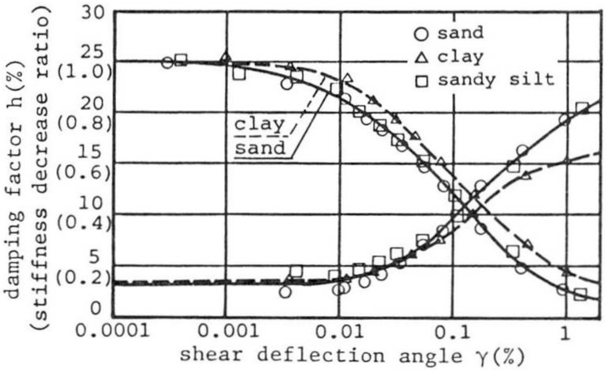


Fig.6 Dynamic characteristics of sub-soil

4. SAFETY CONFIRMATION

Safeness of this building against earthquakes are confirmed by the response analysis considering soil-pile-structure interaction as well as by the structural test of the component members.

4.1 EARTHQUAKE RESPONSE ANALYSIS

The vibration model used in the earthquake response analysis is shown in Fig.5, where bending-shearing springs equivalent to superstructure's framings are linked with each other using rigid floor assumption while shearing springs representing subsoil, are also connected by axial soil springs. Stiffness and damping factor of these subsoil elements are evaluated as shown in Fig.6 from experimental data using triaxial testing on boring samples from the construction site. Subsoil diaphragm and piles are also taken into account in the modelling, where rotational and horizontal movements of the foundation are defined by the bending and axial movements of these substructures.

The input earthquake wave is the EW component of the SENDAI TH038-1 which is one of the severest earthquake records in Japan. Intensity of the motion is defined to be 250 gals and 400 gals in maximum accelerations at the ground surface.

By the eigenvalue analysis on this model, it is recognized that the fundamental vibration periods are 1.85 second and 0.75 second which correspond to those of building and subsoil respectively. From the results of nonlinear response analysis in case of the earthquake with maximum acceleration of 250 gal, maximum responses are shown in Fig.7 and 8 as examples in the form of envelopes of shearing force and overturning moment that occured on each mass point. Stresses of members induced by these dynamic forces are recognized to be within allowable limits.

Nonlinear dynamic response analysis against the earthquake with maximum intensity of 400 gals is also conducted and the sufficient safeness of the designed building structure is confirmed in view of both strength and ductility.

4.2 Structural Test

Although previous testings on more than 100 specimens of structural members confirmed the appropriateness of design method [4], columns with additional core-reinforcing bars newly introduced in this building should be also confirmed using high strength concrete. Two specimens representing exterior columns on 2nd story are approximately 1/3 scale of actual members as shown in Fig.9. and are subjected to both horizontal and vertical earthquake forces after the axial fixed loading. No.1 specimen is loaded until final horizontal distortion under tensile field, while No.2 under compressive one.

Result of test shown in Fig.10 clarifies that the tensile column preserves its horizontal strength up to 2.5 times of the design shear stress with the deformation angle of 0.04 radian. Compressive column shown in Fig.11 reaches its horizontal ultimate strength under the deformation angle of 0.01 radian and also preserve its vertical load carrying capacity even until the deformation of 0.02 radian, which both prove sufficient abilities for an aseismic structural member.

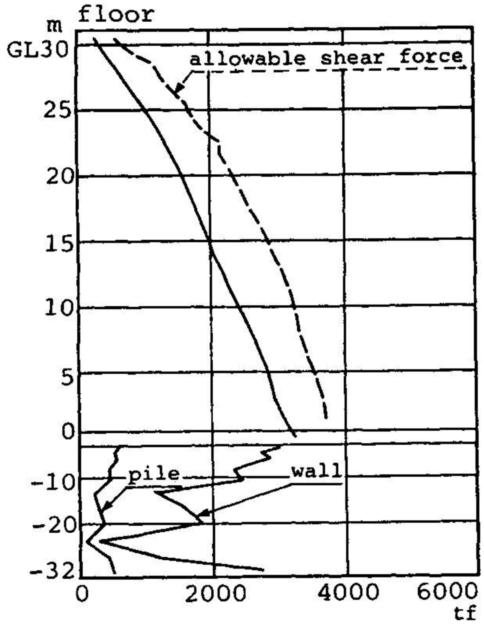


Fig.7 Maximum response shear force

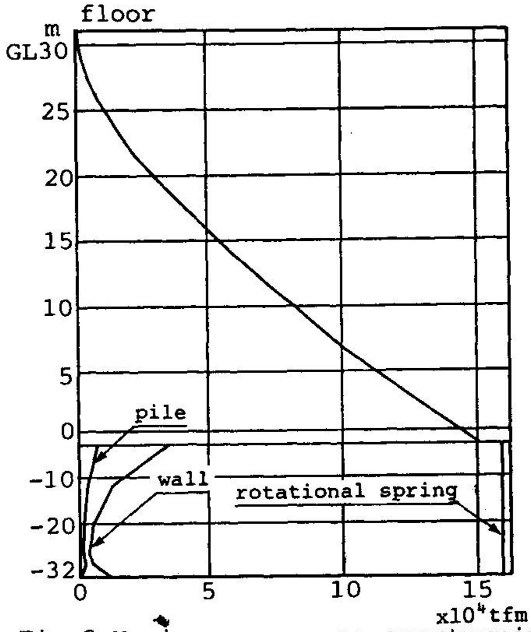


Fig.8 Maximum response overturning moment and bending moment

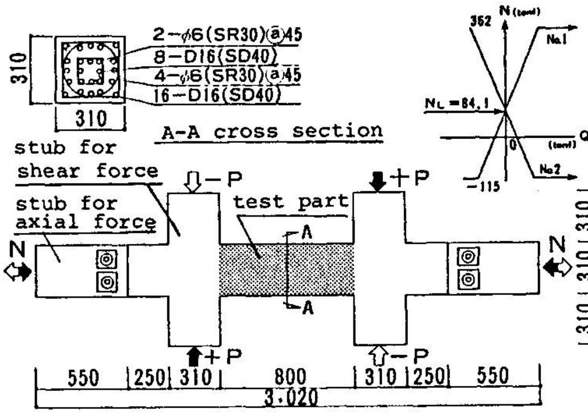


Fig.9 Specimen and loading pattern

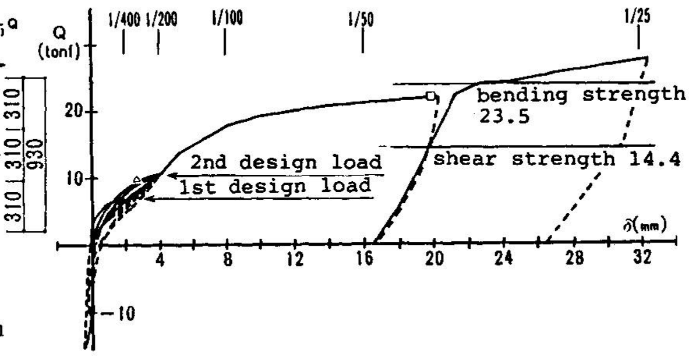


Fig.10 Load-deflection curve of No.1

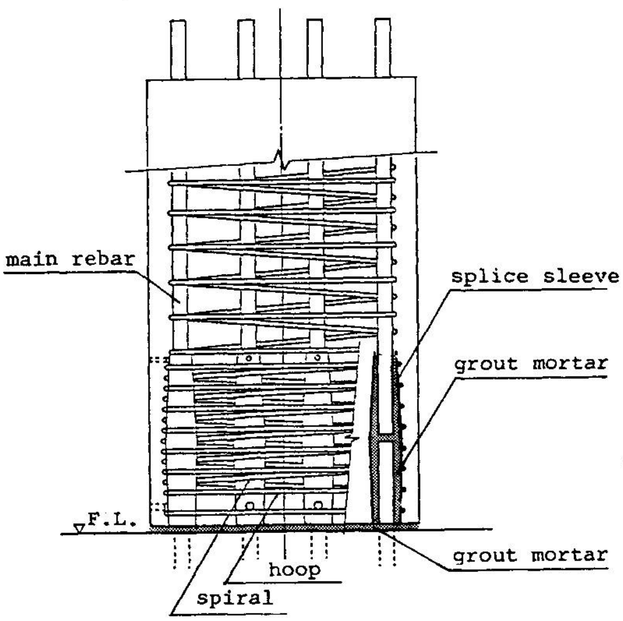


Fig.12 Pre-Cast Column

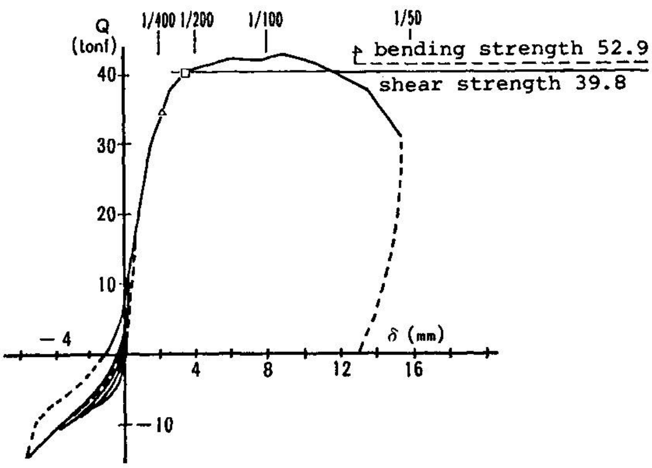


Fig.11 Load-deflection curve of No.2

5. INNOVATION IN CONSTRUCTION

Construction method in HiRC includes many sophiscated techniques such as prefabrication of reinforcing bars, U shaped anchorage, mechanical splices, integrated form work and so on. In this particular building, more over, upper storied column is to be made of pre-cast concrete as shown in Fig.12. The aim of this technique is to reduce the construction time from 8 days/floor to 7 days/floor as well as to conduct better quality control of whole works. As this application is also unprecedented in Japan, laboratory testings on structural behaviors are also conducted as well as on site testing on its practicabilities.

6. CONCLUDING REMARKS

Under very severe natural conditions, it needs long-term efforts in research and development to realization of building a tall reinforced concrete structure. Innovations in materials and methods are indispensable, but, they contribute fully to benefit not only to those concerned but also to general public. Using the methods described above, one of the urban renewal of the City of Kawasaki is to be fulfilled in coming year.

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