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High-rise Reinforced Concrete Building in Japan

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Abstract

The history of the high-rise reinforced concrete(RC) building in Japan starts from the condominium of 20 stories designed in 1972. The high-rise RC building of 56 stories is built now. This paper surveyed the high-rise RC buildings designed from 1972 till 2001 year about height of a building, structure form, material strength, etc. Moreover, two high-rise RC buildings with the seismic isolation system completed recently are introduced. One building is the present highest building with the seismic isolation system, and the other one is built with the pre-cast member.

Keywords: High-rise building, Reinforcement concrete, High strength material, Seismic isolation system, Japan

1. Introduction

The kasumigaseki building constructed with steel in 1968 year is the first high-rise building of Japan. It is possible to construct the kasumigaseki by means of growth of structure analysis using a computer and a development of large H section steel.

Afterwards, many high-rise steel structure office building was constructed. In case of reinforced concrete, the Shiinamachi apartment constructed in 1972 year is the first high-rise reinforced concrete (RC) structure building. A new RC national project aiming at 60 floors (height 180m) was carried out from 1988 till 1993, and a new technique of structure design, material, and construction etc. was developed. From about 1990 year, a tall condominium of RC or steel reinforced concrete (SRC) structure fell to be constructed. Lately, The RC structure is increasing than SRC structure. The reason is as follows.

- Change of structural design from working stress design to ultimate strength design
- Development of analysis technique by development of computer
- Development of high strength material: Concrete, main reinforcing bar, shear reinforcing bar
- Development of high performance member
- High quality construction due to industrialized system
- Decrease of building construction cost

This paper surveys the development process of high-rise RC structure building, and introduces the tallest Japanese RC condominium with a seismic isolation system constructed in 2004 year and the RC condominium with pre-cast members.

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2. Historic trend of high-rise RC structure building

2.1. Number of buildings

Fig.1 shows the number of the designed high-rise RC structure buildings[1]. These data were shown in the Building Letter No.1 (1967) ~ No.427 (2001.1) published by The Building Center of Japan (BCJ).

Here, till 1980, the definition of a high-rise building is 45m or more in height, and it is a building with a height of 60m or more in 1981 and afterwards. According to development of large scale condominium in the 1980's, technical development on high-rise RC building around 30 floors building with economical merit was carried out by many companies. The result has appeared in the increase of high-rise RC building after 1986. The structure design around ten buildings per year was made from 1990 till 1994, it increases further in 1995 and afterwards, and it is designed 20-30 buildings per year. Ishikawa divided a design year into three periods (1975~1989: establishment period, 1990~1994: expansion period, 1995~2001: acceleration period)[1]. Table.1 shows actual results of high-rise RC structure of each period. The number of the highest stories of ground story comes up to 41 stories at establishment period, 45 stories at expansion period, and 56 stories at acceleration period. The mean value is about 27 stories in establishment period and expansion period, and about 28.7 stories in acceleration period. The aspect ratio comes up to 4.01 in establishment period, 4.81 in expansion period, and 5.43 in acceleration period. The maximum value of area/column comes up to 26.1m^2 in establishment period, 34.6m^2 in expansion period, and 41.9m^2 in acceleration period. According to development of structural technique and high strength material, the length of span becomes longer, and area/column is getting bigger.

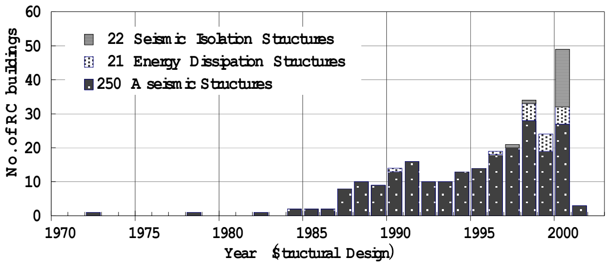


Fig. 1. Annual of high-rise building structural design in Japan

Table 1. Actual results of high-rise RC building

		Period I	Period II	Period III
		1972-1989	1990-1994	1995-2001.1
Number of Buildings	total	36	63	147
	average	2	12.6	22.5
Stories	max	41	45	56
	average	27.4	27.3	28.6
Aspect ratio	max	4.02	4.81	5.43
	average	2.8	2.9	3.3
Area/Column (m^2)	max	26.1	34.6	41.9
	average	19.7	20.8	23.4

2.2. Structural characteristic

In the high-rise RC building in 1986, pure rahmen structures which consisted of about 5m span were mainly adopted. Tube structure was applied after that in 1988, and flexibility expansion of a plane plan was realized. In 1995 year, the double tube structure system which consisted of the short span inside tube and the long span outside tube was adopted.

The seismic isolation system was applied to the high-rise apartment building of 33 stories for the first time in 1990.

Adoption of the energy dissipation system increased after the Hyogo ken southern part earthquake in 1995, and this structure was applied to 16 buildings by January, 2000. The number of buildings which adopted the energy dissipation system was increasing quickly after the Hyogo ken earthquake.

Because a demand on not only safety but also amenity was rising, a building with a seismic isolation system is increasing rapidly after the Hyogo ken earthquake. In the high-rise RC building, it was first applied to the building of 21 stories in 1997. The high-rise RC building with it was total 10 buildings until 2000. 1.

2.3. Material characteristic

The number of the highest stories of the high-rise RC building, the kind of concrete strength, and main bar is shown in Table 2. Use of the high strength material in the high-rise RC building began from the steel SD 390(nominal yielding strength 390MPa) and the concrete strength Fc30 (design criteria strength 30MPa) used in the Shiinamachi apartment. Then, concrete strength was developed until Fc48 in 1980's. Fc60 was used for the first time in 1992, and SD490 was used for the column member. In the condominium of 45 stories, the concrete of Fc60 and the high strength steel of USD685 were used for the first time in 1993. The high strength steel of USD685 was used as a core steel of a column.

In 1995 and afterwards, the structure design which used the high strength concrete of Fc100 and the high strength steel of USD685 for the column started. The high-rise RC building of 56 stories was designed in 2000, the high strength concrete of Fc100 was used to the sixth floor, and USD685 was used as the main bar and the core steel to the ninth floor. This building was completed in February, 2004. It is the tallest RC building now in Japan (183.6m).

Although it is necessary to reduce a water cement ratio to raise concrete strength, fluidity falls and construction becomes difficult. Fluid reservation is simultaneously needed for utilization of the ultra high strength concrete. Furthermore, in case of high strength concrete over Fc80, exfoliation and scatter are easy to happen at the time of fire. In the building of 56 stories, in order to improve strength and fluidity, the ultra performance water reducing agent and cement mixing ultra fine particle mixture material silica fume was developed. Moreover, the AFR concrete for preventing exfoliation and scattering of the concrete in case of a fire was developed. ARF concrete is a concrete mixing composition fiber of polypropylene and so forth (Diameter: 0.012~0.2mm, Length: 5~20mm) by uniform quantity of volume ratio 0.1~0.35%.

Table 2. Material characteristic

Building	A	B	C	D	E	F	G	H	I
Design year	1972	1978	1984	1988	1992	1993	1995	1997	2000
Stories	20	25	30	31	39	45	41	43	56
Concrete	Fc 30	36	42	48	60	60	100	100	100
Steel	SD 390	390	390	390	490	685*	685	685	685

*Core steel Fc30:design criteria strength 30MPa
SD390: nominal yielding strength 390MPa

3. High-rise RC condominium with a seismic isolation system

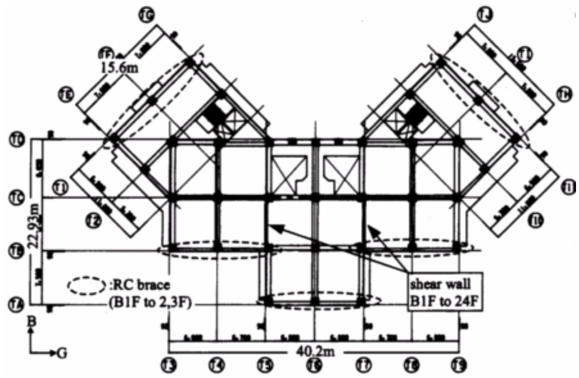
3.1. A 42-story RC building with base isolation system

3.1.1 Building outline

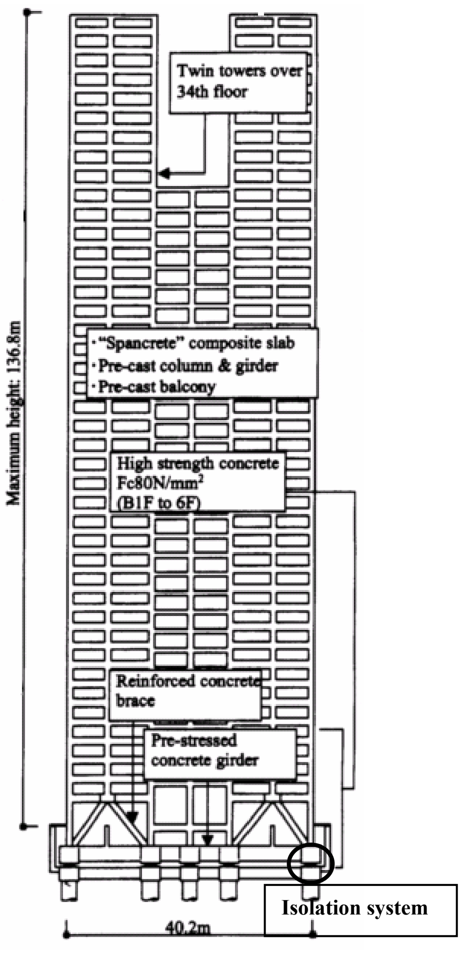
This building constructed near Osaka is the high-rise condominium of 42 stories with a seismic isolation system. This building was started work in march, 2001, and was be completed in march 2004. Design and construction of this building was carried out by Takenaka Corporation. The height of building is 136.8m, the number of stories is 42 stories, the penthouse is 1 story, and building area is 32,719cm^2.

3.1.2. Structure outline

This building is a plane shape setting up wing in both ends of a depression shape, and twin tower is being from 34 stories. Fig.2 shows the standard story figure and the street frame. The character of structure plan is as follows.



(a) Standard floor



(b) Street frame

Fig. 2. A 42-story RC building with base isolation system

(a) Upper structure

• In order to raise the isolation performance in case of an earthquake and to raise the habitability at the time of a storm, a shear wall is arranged by the 24th floor from the first basement level, and the rigidity of the direction of the building short axis is raised.

• For the counterplan of tensile stress occurring in the laminating rubber being brought up in high-rise building with a seismic isolation system and building of big aspect ratio, RC brace is arranged between the second floor and the first basement level.

• In order to prevent thrust force of RC brace under long term load, the pre-stressed large beam is set up in the first basement level.

• By using the pre-cast concrete(PCa) member manufactured in factories for beam and column of the building outside part, a non-scaffold method of construction is realized, and the floor consists of the pre-stressed composition hollow floor and the half PCa composition floor.

• The high strength concrete of Fc80 and reinforcement of SD490, D41 is used as structural material.

(b) The seismic isolation story

The seismic isolation system is set up under the first basement level floor

• In order to resist the load of 2,500tonf(s) at the maximum and to lengthen a seismic isolation cycle, natural laminating rubber system of a total 29 sets (a diameter is three kinds: 1,500, 1,400 and 1,300mm) are arranged directly under a column as support member.

• In order to secure the initial rigidity of a seismic isolation layer and habitability at the time of strong wind, 113 lead dampers and seven steel bar dampers are arranged.

• In order to mainly aim at reduction of a fall moment response of the short axis direction of the building, 14 oil dampers are arranged.

• The clearance of the seismic isolation system layer is 750mm.

(c) Seismic response analysis

• In case of level 2, the maximum story drift angle is about 1/500 at G direction and about 1/333 at B direction. These values satisfy standard angle 1/200. The displacement of isolated story is about 350mm at G direction, and about 270mm at B direction.

• The member stress of upper structure satisfies a condition under the short term allowable stress in level 1, and a condition under the elasticity limit strength in level 2.

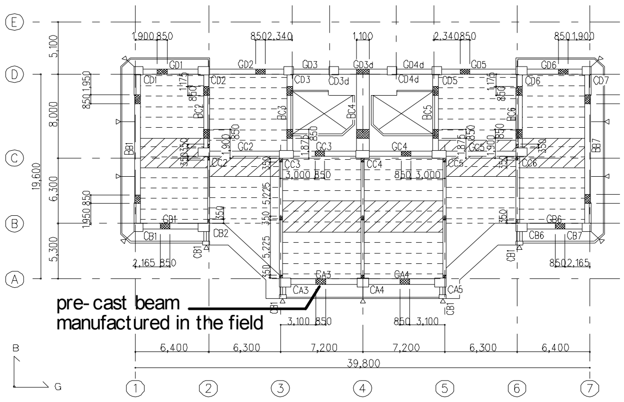
• The footing structure satisfies condition under the short term allowable stress in level 2.

Level 1: The earthquake motion level occurring rarely. Level 2: The earthquake motion level occuring very rarely.

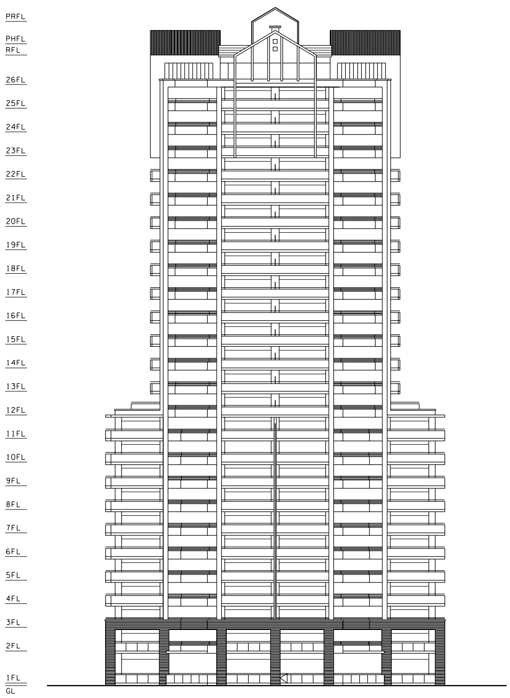
3.2. A 26-story pre-cast RC building

3.2.1. Building outline

This building is the high-rise condominium building with seismic isolation system constructed in Osaka, and the total number of house is 122. This building started work in September 2001, and was completed in November, 2003. This building was constructed by the Takenaka Corporation. The building height is 79.95m, the number of stories is 26 stories, and the building area is 15,496m^2. Fig.3 shows a standard story figure, and a street frame.



(a) Standard floor



The south elevation

(b) Street frame

Fig. 3. A 26-story pre-cast RC building

3.2.2. Structure outline

The structural character is as follows.

• The footing structure installing isolation system in one story column

• This building is mostly manufactured with pre-cast concrete.

• In order to use forms repeatedly, the member(column, beam) of same section was used. The strength of members corresponded with concrete strength and the diameter of reinforcement.

• High strength ARF concrete of Fc80 was used as the material of column.

• The flat hollow pre-cast pre-stressed concrete slab adopted as the floor system, the small beam was lost, and habitability and workability were raised.

In this building, aiming at shortening of construction duration, a curtailment of construction cost and improvement in quality, the pre-cast beam unit through column which began to become a subsequent standard method of construction was developed.

Photo 1. The pre-cast beam unit through column method of construction

4. Conclusion

The following devices realized high-rise RC building in Japan which is a seismic country in the apartment.

• Utilization of High strength material.

• The detailed structure design by an ultimate strength design and earthquake response analysis etc.

• Development of new structural system such as energy dissipation system and seismic isolation system and so on.

• Positive adoption of the industrialization method of construction according to pre-cast concrete. Rationalization of construction and reservation of high quality are achieved.

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