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Design Practice, Standards and Research Trends for SRC Buildings in Japan

Tendance japonaise en matière de conception, normes et recherches
pour les bâtiments à ossature mixte

Entwurfstechnik, Normen und Forschungsentwicklungen für Stahl-Betonverbundkonstruktionen
in Japan

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Minoru Wakabayashi, born 1921 received Bachelor's degree 1946, Doctor's degree 1957 from the University of Tokyo, has been working on earthquake resistant design of steel, reinforced concrete and composite structures.

SUMMARY

This paper first reviews recent trends in the design and construction of steel reinforced concrete (SRC) buildings in Japan, taking into account relevant aspects such as physical, constructional and economic characteristics, as well as the experience of designers. Design specifications and research developments in Japan are then briefly discussed.

RÉSUMÉ

L'article présente la tendance japonaise en matière de conception et de construction des bâtiments à ossature mixte, prenant en considération des aspects importants tels que les caractéristiques physiques, mécaniques et économiques; l'expérience des ingénieurs est aussi prise en compte. La tendance des Normes et des recherches est brièvement esquissée.

ZUSAMMENFASSUNG

In diesem Artikel wird die Entwicklung von Entwurf und Ausführung von Verbundkonstruktionen in Japan aufgezeigt, wobei bedeutende Gesichtspunkte wie physikalische, bauliche und wirtschaftliche Eigenschaften sowie Erfahrungen von Konstrukteuren berücksichtigt werden. Ferner werden Konstruktionsrichtlinien und Forschungsentwicklungen in Japan kurz diskutiert.



1. INTRODUCTION

A structural system consisting of concrete encased columns and beams, which is called steel reinforced concrete (SRC), has been used in Japan, mainly for tall-building construction, since the Kanto Earthquake in 1923 (1). It is nowadays widely applied for mid-rise and high-rise buildings.

The paper discusses the characteristics of the SRC system and the reasons for its wide use in Japan, and briefly reviews design standards and recent research trends.

2. RECENT CONSTRUCTION OF SRC BUILDINGS

2.1 Amount of SRC Building Construction

The total gross floor area of building structures constructed in Japan in the last 5 years is about 160 million m^2 , the proportions for individual structural systems being as follows : SRC = 8% ; reinforced concrete (RC) = 21% ; steel (S) = 24% ; and timber = 46%. With regard to the total number of buildings, the share of the SRC system is only 0.4%. It should be pointed out, in this respect, that the gross floor area for an SRC building is usually quite large. Thus, the SRC system is often adopted in tall-building construction so that SRC buildings comprise about 50% of the buildings taller than 6 stories, as shown in Fig. 1. Investigation of the use of SRC buildings shows that offices account for 30%, and apartment houses for 60%, with the latter figure tending recently to increase.

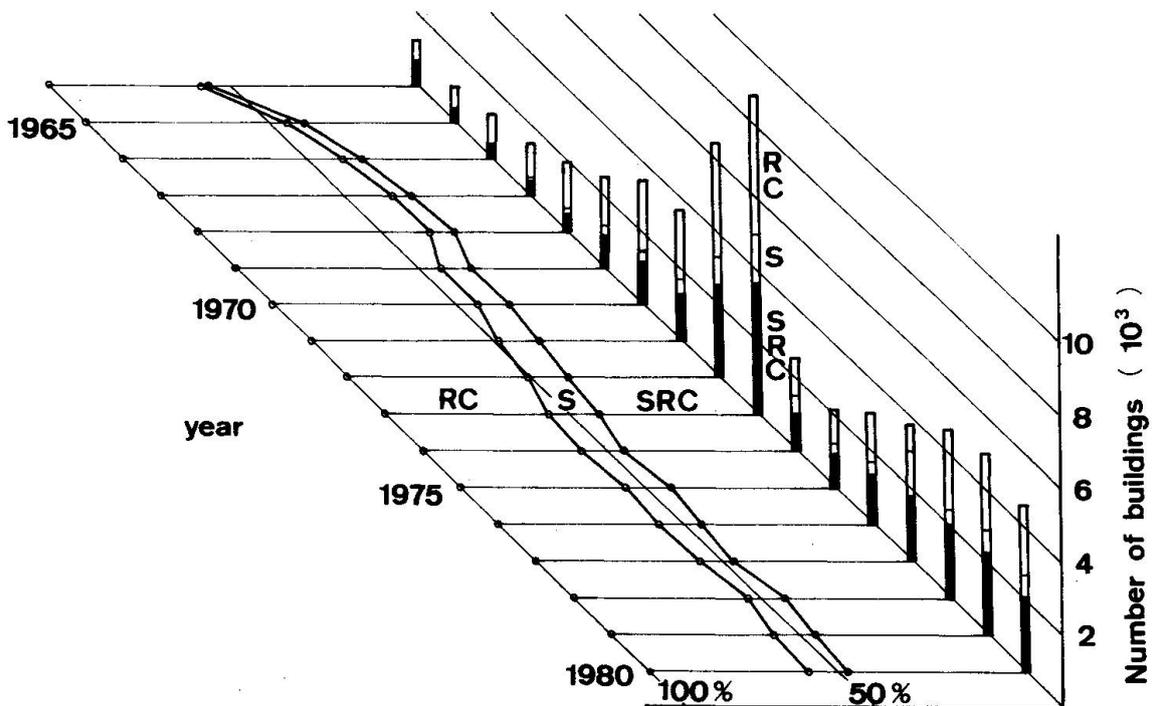


Fig. 1 Variations in the number of buildings taller than six stories with various types of construction systems every year.

2.2 Characteristics of SRC System

2.2.1 General Characteristics

The SRC structural system has several merits which are counted as reasons why the SRC system is selected.

Advantages of the SRC system over a reinforced concrete structural system are as follows:

1. Large ductility.
2. Large amounts of steel can be arranged in a limited area of cross section.
3. A steel skeleton can be used as a support of construction work.

Advantages over a steel structural system are as follows:

1. Great resistance to fire.
2. Concrete working as fireproof material can carry the load.
3. High rigidity.
4. Strong against buckling.
5. High dampening.

Therefore, as SRC system is effectively applied in the following situations:

1. When the reinforced concrete system is not adequate from the viewpoint of earthquake resisting ability, since the building is tall and the stresses in the lower story are large.
2. When the relative story deflection becomes excessively large if the steel system is applied, because of small rigidity.
3. When the span is too large and thus the floor area carried by a column is too large for the reinforced concrete system.
4. When the reinforced concrete system may not provide sufficient strength, and the steel system may suffer from vibration because of a large span.
5. When the reinforced concrete system is not adequate because a brittle type of shear failure may occur due to a mixed existence of short columns, although the building is low.
6. When torsional deformation and/or concentration of deformation is expected because the shape of the building and/or distribution of rigidity is not well balanced in the plan and/or along the height of the building.
7. When a smooth transfer of stresses is desired in the middle portion of a building of which the upper portion is constructed by the steel system and lower portion around the foundation is constructed by the reinforced concrete system.

2.2.2 Designers' Views of the SRC System

Designers' views on individual structural systems are one of the important factors, when a specific system is selected in the course of the design. Table 1 shows the results of an investigation of designers views on the performance of individual structural systems (2). Designers consider the SRC system as follows: the earthquake resisting capacity and the construction efficiency of the SRC system are between those of the reinforced concrete and the steel systems, living comfort is excellent, but structural details are more complicated than for the other two systems. As indicated in Table 1, the reinforced concrete and the SRC systems are often used for buildings such as houses and hospitals which require high dwelling performance, while the steel system is suited to buildings such as factories in which the work environment is more important than the dwelling performance.



2.2.3 Mechanical Characteristics

One of the most important mechanical features of the SRC system is its high ductility. Shear failure, often seen in reinforced concrete members and connections, does not often occur in the SRC system, and even if it occurs, the failure is not very brittle.

Figure 2 shows hysteresis loops of SRC and RC specimens subjected to cyclic shear with a constant axial thrust equal to 0 or 30% of the ultimate axial strength. It is observed that the SRC member shows larger ductility and more stable, spindle-shaped hysteresis loops than the RC member. These characteristics are also observed in the behavior of an SRC beam-to-column connection

		RC	SRC	S
earthquake resisting capacity	strength/weight ratio	C	B	A
	ductility	C	B	A
dwelling performance	rigidity	A	A	C
	sound insulation	A	A	C
	fire resistance	A	A	C
construction	term of works	C	B	A
design	details	simple	complex	fairly complex

A : excellent B : good C : passable

Table 1 Performance of structural systems in view of structural planning

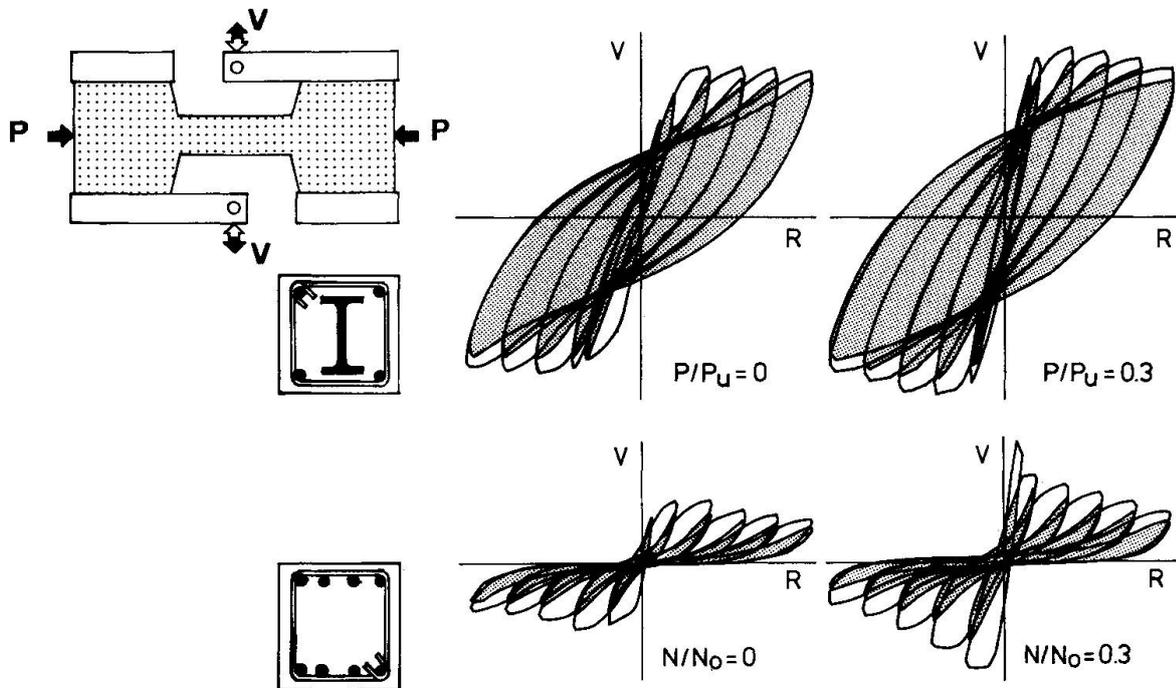


Fig. 2 Shear force-deformation relationships for columns under constant axial force and repeated shear and bending

failing in shear, shown in Fig. 3, where large ductility and energy dissipation capacity are obtained, even though the connection panel fails in shear.

If the axial thrust becomes large, reduced ductility is also observed in the behavior of an SRC beam-column failing in flexure; however, the reduction is not so severe as in the case of an RC beam-columns. This is mainly because the local buckling of plate elements of the concrete encased steel is rarer than the buckling of the longitudinal reinforcing bars. Once concrete crushing occurs, an RC member loses its integrity, while the steel itself behaves as an integral body, and thus the failure advances rather moderately in the case of an SRC member.

2.2.4 Construction Characteristics

Tabel 2 shows the evaluation of construction efficiency of general office buildings with various heights and structural systems. Overall evaluation reveals that the steel system is most efficient in general since form work is not used, and also that the SRC system becomes more efficient than the RC system as the height increases.

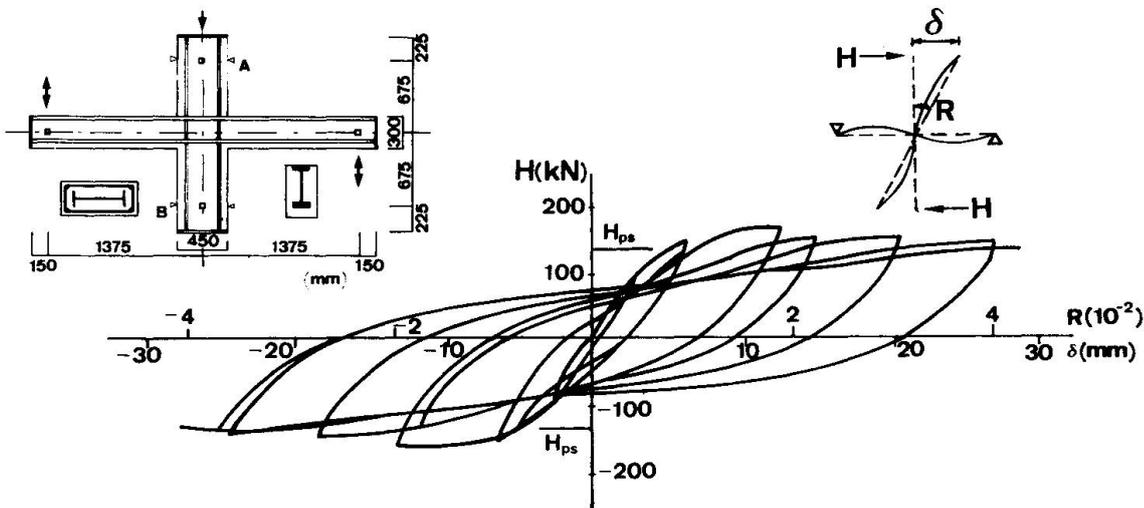


Fig. 3 Load-deformation relationships of an SRC beam-to-column connection

height	low-rise H < 25m			medium-rise 25 < H < 45m			high-rise 45m < H		
	RC	SRC	S	RC	SRC	S	RC	SRC	S
structural system	RC	SRC	S	RC	SRC	S	RC	SRC	S
general construction planning	B	C	B	C	B	A	C	B	A
planning of work progress	B	C	A	C	B	A	C	B	A
quality control	B	C	B	B	C	A	C	C	A
labor management	C	C	B	C	B	A	C	B	A
neighboring environmental pollution	B	C	C	B	C	C	C	C	C
safety supervision	B	C	B	C	C	B	C	C	B
synthetic assessment	B	C	A	C	B	A	C	B	A

A : excellent B : good C : passable

Table 2 Construction efficiency of general office buildings



2.2.5 Economic Characteristics

Unit cost of the structural component of a building is obtained by summing the quantities of concrete, forms, reinforcing bars and steel per unit floor area, multiplied by the corresponding unit costs. However, the unit cost is itself a function of total quantity of steel, and thus the unit cost rises with the increase in the amount of steel. The amount of steel per unit area of an SRC building increases with the increase in the number of stories, while the amount of concrete decreases, and the amount of reinforcing bars remains unchanged. Therefore, as the building becomes taller, the amount of steel can be replaced by cheaper reinforcing bars in the case of the SRC system, and thus tall SRC buildings are sometimes cheaper than tall steel buildings.

2.3 Reasons for the Selection of the SRC System

Table 3 shows the results of investigation by questionnaires on the reasons why the SRC system is selected in real construction practice. In addition to the reasons explained above in Sec. 2.2, there is an important administrative reason. The administrative authorities guide the structural designer, so that buildings taller than 7 to 8 stories are as a rule constructed by steel or SRC systems. This guidance is from the viewpoint of safety against earthquakes. Therefore, it can be said from the data in Table 3 that in more than 2/3 of the cases, the reasons for the selection of the SRC system are related to earthquake resisting capacity. Table 4 indicates the criteria for the selection of the structural system for office buildings. The SRC system is often used for the construction of mid-rise to high-rise buildings, i.e., 7- to 15-story buildings.

reasons	%
administrative reason (such as height limit)	36
to increase earthquake resisting capacity	34
to make the beam span longer	11
because of great importance of the building	8
to cut down the construction cost	4
to make the dwelling performance higher	2
no answer	4

Table 3 Reasons of selecting SRC structural system

	span length	< 10m	< 15m	> 15m
number of stories	1 - 6	RC	SRC	S
	7 - 15	SRC	SRC	S
	> 15	S	S	S

Table 4 Criteria for the selection of structural systems (Office buildings)

3. DESIGN STANDARDS

The first edition of the design standards for SRC systems in Japan was published by the Architectural Institute of Japan (AIJ) in 1958, based on the results of extensive experimental investigations carried out in the 1950's (3).

Until the publication of the standards, SRC systems had been designed either as steel or reinforced concrete systems, or by superposition method. However, the first edition adopted the last method, that is superposed strength method : the strength of an SRC member is given as the sum of the strengths of the steel and the reinforced concrete components.

The design standards for reinforced concrete systems were revised, based on the experiences in the Tokachi-Oki Earthquake in 1968, and the SRC standards were revised accordingly in 1975 (4). The main purpose of the revision was to prevent brittle shear failure in beam-columns.

In 1981, the Building Standards Act was revised to require the calculation of the story shear strength of the building for the check of earthquake resistance, except for small buildings. The SRC standards are now being revised to include provisions for the calculation of the ultimate story shear strength.

4. RESEARCH ACTIVITIES

Figure 4 shows the change in the total number of research papers on SRC systems, which have been published in the Transactions of AIJ and the Abstracts of the Annual Congress of AIJ. Also shown is the breakdown according to

- A: AIJ SRC Committee started
- B: First edition of AIJ Specification for SRC
- C: Second edition of AIJ Specification for SRC
- D: First edition of AIJ Specification for Encased Tubes
- E: Third edition of AIJ Specification for SRC
- F: First edition of AIJ Specification for Composite Beams
- G: Second edition of AIJ Specification for Encased Tubes
- H: Tokachi-Oki earthquake
- I: Miyagiken-Oki earthquake

- 1: Bending and compression
- 2: Shear
- 3: Beam-to-column connections
- 4: Column bases
- 5: Shear walls
- 6: Frames
- 7: Vibration
- 8: Encased tubes
- 9: Composite beams and slabs
- 10: Bond and solices

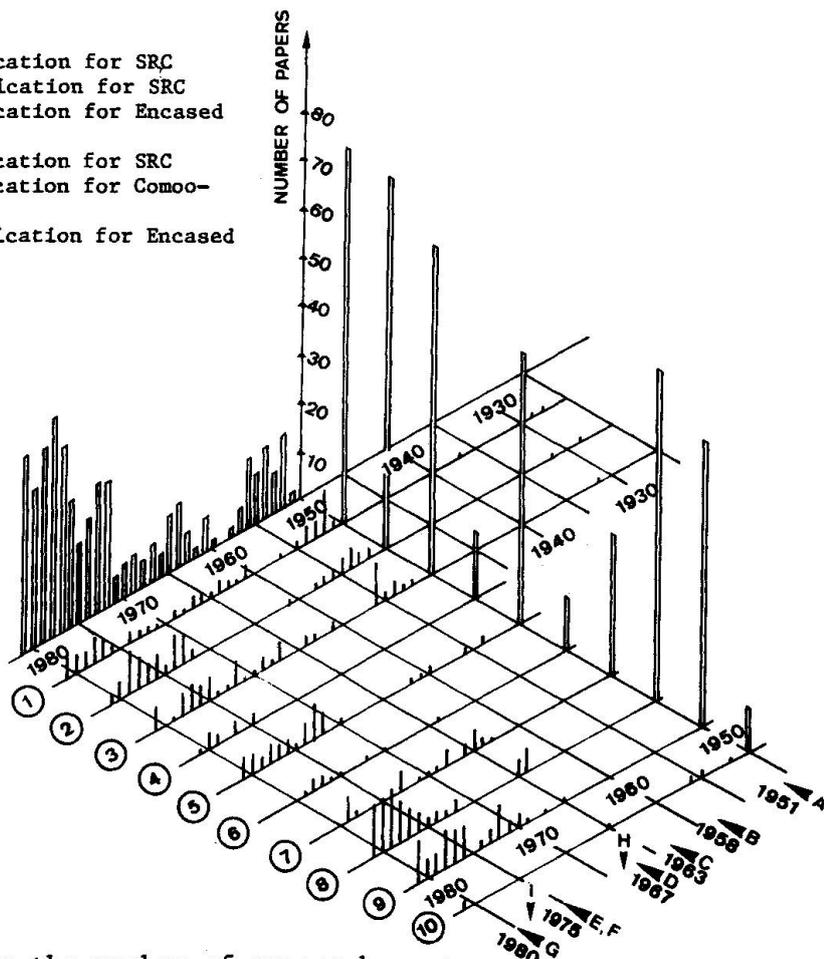


Fig. 4 Increase in the number of research papers classified according to the subject

subjects. In the 1950's, most research dealt with the behavior of SRC members with open-web steel composed of angles under compression, bending or shear, and SRC beam-to-column connections under shear. The number of papers decreased for a while in the 1960's because of the publication of the design standards. In the 1970's, the number of papers has again increased and the research objectives have broadened: not only the SRC system but also general composite systems have recently been studied. New methods of construction have also been proposed.

5. CONCLUDING REMARKS

The SRC system has been very widely used in Japan. For the future success of this system there is a need for rationalisation of the system to make the best use of the mechanical, economic and constructional advantages. Such rationalisation also needs to be incorporated into the design standards.

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