The Japanese Experience in Design and Application of Seismic Grade Rebar

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0 Introduction

Japan is an earthquake-prone country in the world, therefore, has sustained serious damage due to earthquakes throughout its long history. The great Kanto Earthquake (1923) caused simultaneous outbreaks of fire in many places in Tokyo with approximately 450,000 buildings being destroyed by fire, and some 143,000 persons dead or missing. In the Great Hanshin-Awaji Earthquake (1995), 104,906 buildings collapsed, and causing 6,433 deaths. It is estimated that 80% of the deaths were due to falling building or furniture.

Therefore, it has been one of the main concerns in building design to withstand earthquakes. The Japanese Building Code has been requiring structural calculation in considering seismic force since 1924. This is the earliest in the world.

1 Outline of building standard law in Japan

The building standard law was enacted in 1950, and since then has been subjected to many revision, in accordance with advances in technology and incidents of building disasters that have occurred. The purpose of the building standard law is to protect the lives and property of the public from disasters, such as earthquakes, typhoons and fires, and also to maintain public health by ensuring environmental sanitation.

The building standard law is a law that applies to all buildings throughout Japan. However, the standards that it provides for are not uniform throughout the country because additional standards are determined in accordance with regional conditions. The building standard law is enforced through administrative procedure, and all buildings must confirm to requirements determined by the building standard law and the documents under the law.

The building standard law is the main law relating to the building codes. But there are some other law relating to the fields of the building codes. But there are some other laws relating to the fields of the building codes and related fields as shown in Table 1.

2 Building code for structural safety

In the building standard law, the basic idea concerning structural safety is that structures must be safe against loads and external forces, such snow loads, wind pressure, and seismic forces. This is to ensure that:

Table 1 Japanese building standard law and related laws.

<table>
<tr><th rowspan="3"></th><th colspan="6">Fields of building codes and related fields</th></tr>
<tr><th colspan="2">Fire safety</th><th rowspan="2">Structural safety</th><th rowspan="2">Hygienic safety</th><th rowspan="2">Accessibility</th><th rowspan="2">Energy saving</th></tr>
<tr><th>Fire extinguishing equipment, etc.</th><th>Fire-resistance, evacuation, etc.</th></tr>
<tr><td>Restrictive laws</td><td>Fire Service Law</td><td colspan="3">Building Standard Law</td><td rowspan="2">Barrier-free Law</td><td></td></tr>
<tr><td>Promotional laws</td><td></td><td></td><td>Seismic Retrofitting Law</td><td>Building Management Law</td><td>Energy Saving Law</td></tr>
</table>

(a)Structures remain undamaged during and after normally predictable phenomena, such as snowfall in cold regions and small-magnitude earthquakes; and

(b)They are not destroyed, even in big earthquakes, typhoons and other disasters.

As for safety from earthquakes, the building standard law requires buildings to satisfy both performances, as shown in table 2.

Table 2 Required performances against earth quakes.

	Assumed earthquakes	Required performances
(1)	Small seismic forces, which might occur several times during the life of the building	Building structure remains undamaged during and after an earthquake.
(2)	Large seismic forces, which might occur on very rare occasions during the life of the building	Building structures is not destroyed and will not endanger people's lives.

When building materials designated by the Minister of Land, Infrastructure, Transportation and Tourism (such as concrete, steel and seismic isolation devices) are used for major building parts (such as foundations, columns, bearing walls, and fire doors).

(1)These materials must conform to either Japanese Industrial Standard (JIS) or Japanese Agricultural Standard (JAS), as specified by the Minister;

(2)Otherwise they must be approved by the Minister.

In case of (2), before application for ministerial approval, it is mandatory to have performance evaluations conducted by Designated Evaluation Bodies based on the technical criteria concerning the respective materials, which are provided by the Ministry of Land, Infrastructure, Transportation and Tourism Notification.

3 Structural calculation

The Enforcement Order prescribes the loads, external force, allowable unit stresses, and material strength, which are necessary for structural calculation. It also prescribes various structural calculation methods in accordance with the height and structure of buildings.

Loads and external forces as factors for structural calculation vary, depending upon the location of the building and its use. Of these forces, at least five must be checked. They are permanent load (dead load), imposed load (live load), snow load, wind pressure, and seismic force. Depending upon the condition, check must also be performed for other external forces such as ground pressure, water pressure, vibration, and shock.Values of allowable unit stress are available for common materials, such as timber, steel, concrete, etc. These values are specified for both sustained loads and temporary loads (see Table 3). Values of material strength are available for use in horizontal load carrying capacity calculation (see (d) in Table 4).

The building standard law provides requirements on structural methods and various structural calculation methods (see A to F in Table 4). Every building must be confirmed its structural safety though one of the combinations. Any types of combinations can be used for small buildings, but for all other buildings, the possible combinations are limited based on the structural type, height, and size of the building (see Table 5). There are six combinations (A through F). The order of sophistication of the combinations is from F (the highest), down to A.

Table 3 Sustained loads and temporary loads

Load type	Possible conditions	Loads and external forces, which must be included
Sustained loads	Normal time	G+P
Temporary loads	Snow	G+P+S
	Storm	G+P+W
	Earthquake	G+P+K

In this table, *G*, *P*, *S*, *W* and *K* represent the following loads and forces:

G: Permanent load
P: Imposed load
S: Snow load
W: Wind load
K: Seismic force

<Exception> Buildings in heavy snow areas designated by the *Designated Administrative Agency*

Table 4 Structural calculation methods

Remarks: The methods indicated by "○" are included in the combination of methods.

Structural calculation methods, etc.	Combinations of methods					
	A	**B**	**C**	**D**	**E**	**F**
(a) Requirements on structural methods Requirements on structural methods are general regulations stipulating details of structural methods according to the structural type.	○	○	○	○ *1	○ *2	○ *2
(b) *Allowable stress calculation* + *Structural calculation for roofing material, etc.*		○	○	○		
(c-1) *Calculation for story-drift angle*			○	○		
(c-2) *Calculation for stiffness ratio* + *Calculation for eccentricity ratio* + *Aspect ratio*, etc.			○			
(d) *Horizontal load-carrying capacity calculation*				○		
(e) *Response and Limit capacity calculation* or structural calculations methods stipulated by the Minister					○	
(f) *Time-series analysis*						○

*1 Some requirements on structural methods are not applied to the building solutions for which structural safety is confirmed through combination **D** of structural calculation methods.

*2 Only provisions concerning durability, etc. are applied to the building solutions of which structural safety is confirmed through the combinations **E** or **F** of structural calculation methods.

Table 5 Possible combinations of structural calculation methods

Structure, height, and size of building		Possible combinations of **Table 10**
(I) Small buildings	Wooden buildings that conform to the following criteria: - number of stories ≦2; - total floor area ≦500 m^2; - building height ≦13m; - eave height ≦9 m. Others - single-story buildings with floor area ≦200 m^2	**A** to **F**
(II) Medium-sized buildings	Buildings other than (I), (III) and (IV)	**B** to **F**
(III) Large-sized buildings	Any of the buildings below, unless they are more than 60m in height: - Wooden buildings that are more than 13m in height and that have eaves of more than 9m in height; - S buildings with 4 or more stories (excluding basement); - RC or SRC buildings of 20m or more in height.	**C** to **F**
	Building height ＞ 31m	**D** to **F**
(IV) High-rise buildings	Building height ＞ 60m	**F**

4 Ultra high strength steel rebar and concrete

In the first half of 1990s, steel rebar with 390 N/mm^2 of tensile yield strength and concrete with 42 N/mm^2 of compression standard strength have been used for high rise reinforced concrete buildings in Japan. Japanese Industrial Standard (JIS) prescribes the quality requirement of rebar as shown in Table 6.

Ultra high strength steel bars have recently been developed for super high-rise reinforced concrete buildings such as sixty stories and/or about 200m of height. The rebars have mechanical properties exceeding those conventionally required by JIS. The New RC Project was started by the Ministry of Land, Infrastructure, Transportation and Tourism in 1988. Fifteen construction companies in Japan joined this project and settled on the guideline of the ultra high strength materials. Schematic stress-strain curve on quality requirements of rebars in New RC Project is shown in Figure 1 and the quality requirement of rebars in New RC Project is listed in Table 7. Figure 2 indicates the relation among tensile yield strength of steel bar, diameter of the bar and compression standard strength of concrete used for high-rise reinforced concrete buildings in Japan.

Table 6 Quality requirements of rebar by Japanese Industrial Standard (JIS)

	Tensile strength/MPa	Yield point/MPa	Break elongation/%	Chemical component/%					
				C	Si	Mn	P	S	C+Mn/6
SD295A	440～600	≥295	≥18				≤0.050	≤0.050	
SD295B	≥440	295～390	≥18	≤0.27	≤0.55	≤1.50	≤0.040	≤0.040	
SD345	≥490	345～440	≥20	≤0.27	≤0.55	≤1.60	≤0.040	≤0.040	≤0.50
SD390	≥560	390～510	≥18	≤0.29	≤0.55	≤1.80	≤0.040	≤0.040	≤0.55
SD490	≥620	490～625	≥14	≤0.32	≤0.55	≤1.80	≤0.040	≤0.040	≤0.60

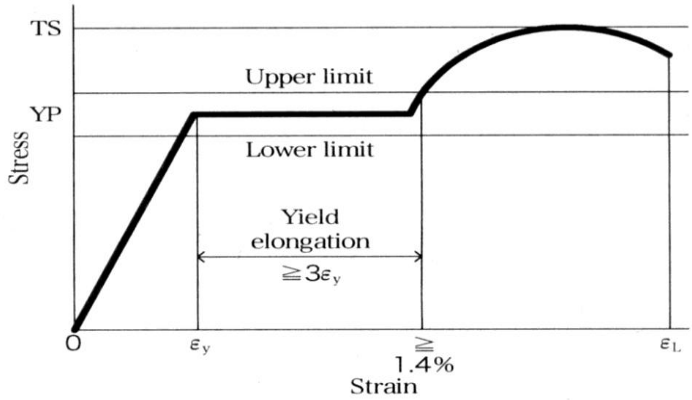

Figure 1 Schematic stress-strain curve on quality requirements of rebars in New RC Project

Table 7 Quality requirements of rebar by New RC Project

	Tensile strength/MPa	Yield point/MPa	Yield ratio YP/TS	Break elongation /%	Chemical component/%					
					C	Si	Mn	P	S	Cu
USD685A	⩾YP/0.85	685～785	⩽0.85	⩾10	⩽0.50	⩽1.50	⩽1.80	⩽0.030	⩽0.030	⩽0.050
USD685B	⩾YP/0.80	685～755	⩽0.80	⩾10	⩽0.50	⩽1.50	⩽1.80	⩽0.030	⩽0.030	⩽0.050
USD980	⩾YP/0.95	⩾980	⩽0.95	⩾7	⩽0.80	⩽1.20	⩽2.00	⩽0.030	⩽0.030	⩽0.050

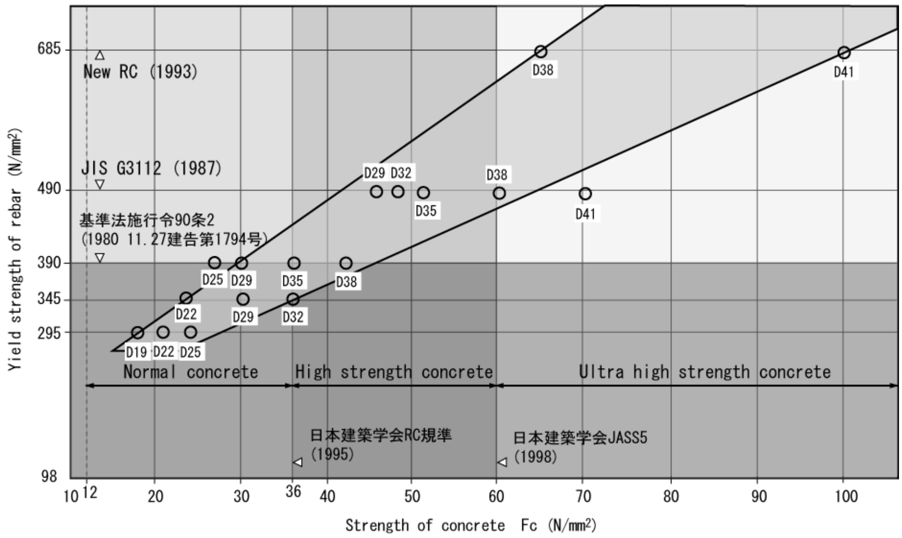

Figure 2 Example of the relation among tensile yield strength of steel bar,diameter of the bar and compression standard strength of concrete used for high-rise reinforced concrete buildings in Japan

Reference

Introduction to the Building Standard Law -Japanese Building Codes and Building Control System- (Ver. December 2009), Written by Mr. Hasegawa Tomohiro, Published by the Building Center of Japan (in English).