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Comparison of Japanese and Other Codes on Serviceability Limit States

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Abstract: Provisions corresponding to the serviceability limit state from Japanese structural design codes were examined in this paper. Most of them were specifications, although the correspondence with the serviceability limit was not clear. For example, the relationship between beam span '*l*' and beam depth '*D*' was determined from the viewpoint of ensuring the rigidity of the beam, but the relationship between them and the resulting deflection and vibration level was determined empirically. In this paper, detailed specifications are reviewed and compared with specifications given in other international codes. The necessity for future developments in Japan is also discussed.

Keywords: Serviceability limit state, Specifications, Rigidity, Deflection.

1. Introduction

In Japan, the first building code was established in 1919 and its enforcement regulations were enforced in 1920. At that time, only the dead load and live load for ordinally conditions were listed and these loads formed the basis of structural design. In 1923, the Great Kanto Earthquake occurred and in 1924, the enforcement regulations were revised to introduce a horizontal seismic coefficient C_0 = 0.1 for allowable stress that was 1/3 of the destruction strength level for concrete. Since then, the basic skeleton of serviceability level structural design in Japan has not changed. The only change was that the allowable stress level for emergency level has become 2/3 of the destruction strength level and C_0 has become 0.2 from 1948. The Building Standard Law, which was established in 1950, inherited these values.

In this paper, detailed specifications are reviewed and compared with specifications given in other international codes. In addition, the necessity for future developments in Japan is also discussed.

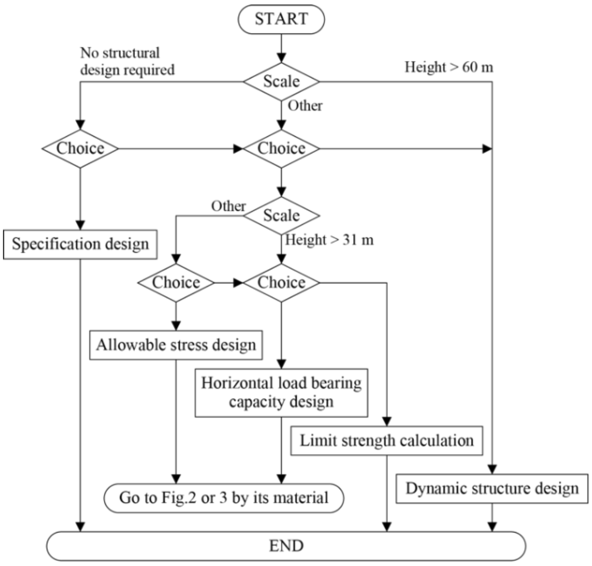

Figure 1. Selection of design procedure in Japan.

2. Structural Design Flow in Japan

In Japan, a two-step seismic structural design was introduced in 1981 and horizontal seismic coefficient C_0 = 0.2 was adopted for serviceability level and C_0 = 1.0 was introduced for ultimate level. However, the definition of serviceability was not clear. The former level is still considered as ultimate for small and middle size buildings. The ambiguities of this condition are shown in Figures 1, 2 and 3. Figure 1 shows the selection flow of structural design procedure in Japan. We can choose upper level of design procedure based solely on our design judgement.

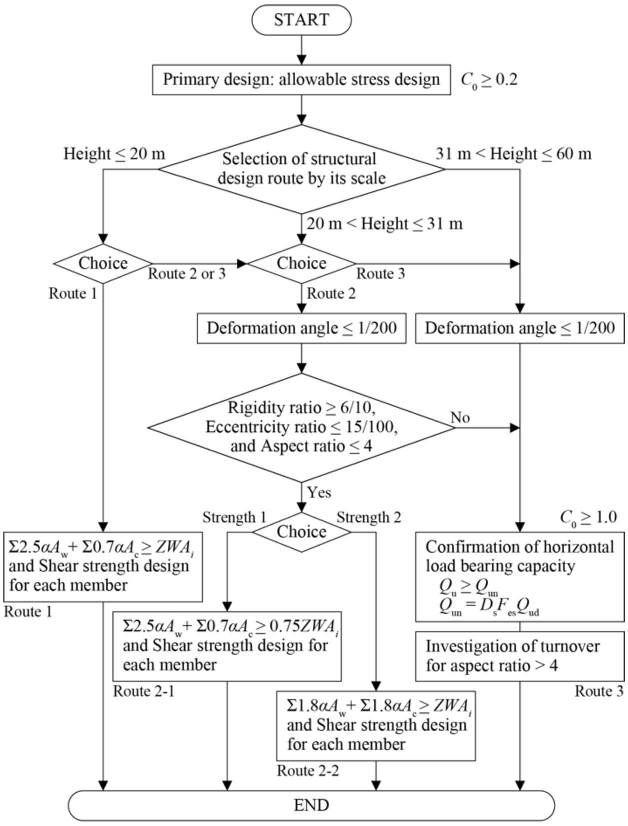

Figure 2. Structural design flowchart for RC buildings in Japan.

Figure 2 shows the design procedure for RC buildings. α is the surcharge factor that depends on the concrete strength. A_w is the horizontal area of shear wall [mm^2]. A_c is the horizontal area of columns [mm^2]. Z is the location coefficient of the ground motion. W is the upper weight of the building [kN]. A_i is the distribution coefficient of seismic base shear force coefficient. Q_n is the horizontal load bearing capacity [kN]. Q_{un} is the required horizontal load bearing capacity [kN]. D_s is the structural characteristic coefficient. F_{es} is shape coefficient. Q_{ud} is the horizontal force generated on each floor by seismic force [kN].

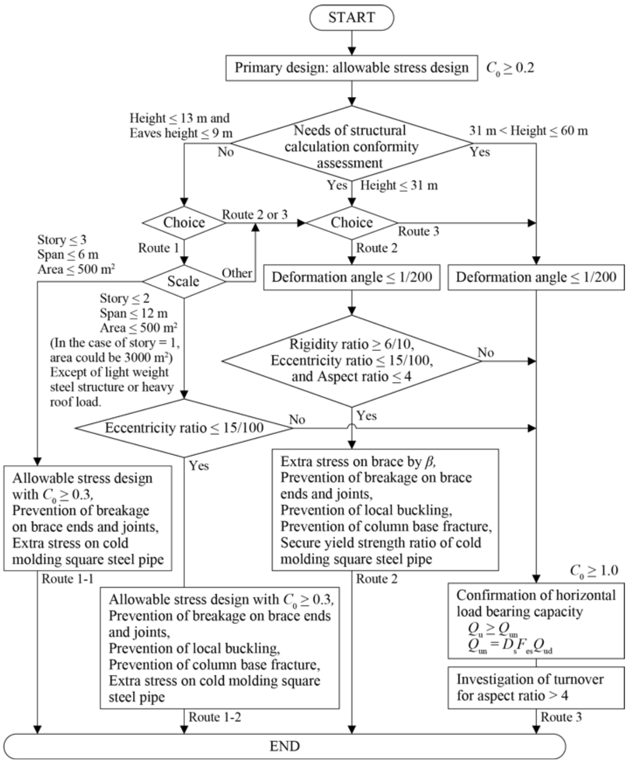

Figure 3. Structural design flowchart for steel buildings in Japan.

Figure 3 shows the structural design flow for steel buildings. β is the horizontal force sharing ratio of bracing.

As you can see in Figures 2 and 3, except for route 3, primary design, i.e. allowable stress design for the following situations, are dominant. For ordinarily actions, Eq. (1) for general area and Eq. (2) for snowy area, ordinarily allowable stress are used:

$$G + P \tag{1}$$

$$G + P + 0.7S \tag{2}$$

For emergency actions, Eq. (3) for heavy snow, Eq. (4) for strong wind on general area, Eq. (5) for strong wind on snowy area, Eq. (6) for strong ground motion on general area and Eq. (7) for strong ground motion on snowy area, emergency allowable stress are used:

$$G + P + S \tag{3}$$

$$G + P + W \tag{4}$$

$$G + P + W, G + P + 0.35S + W \tag{5}$$

$$G + P + K \tag{6}$$

$$G + P + 0.35S + K \tag{7}$$

For snow and wind, 50-year return period values, which were derived from AIJ (1996), were used in conjunction with the equation. For ground motion, $C_0 = 0.2$ may be assumed to be equivalent to the 50-year return period value at Tokyo (AIJ 2007).

3. Regulations Related to Serviceability in Japanese Building Standard Law

There is a regulation in the Japanese Building Standard Law Enforcement Order: "In case of specified by the Minister, it shall be confirmed by the method specified by the Minister, that any deformation or vibration of structural members constituting elements required for structural resistance will not have adverse effects on the use of the building concerned" (BSL Enforcement Order 82-4).

3.1 Vertical deflection - method 1

Method 1 is specified by the Minister for confirmation of obstruction to the use (Ministry of Construction 2000a) as follows:

Table 1. Regulations in beams and slabs.

Part of building		Conditional expression
Wooden structure	Beam (limited to those used in floor frame: the same in the remainder of this table)	$\frac{D}{l} > \frac{1}{12}$
Steel structure	Deck plate (limited to parts considered to be floor slabs which conform to the provisions of MLIT Notification No. 326 of 2002; the same hereinafter)	$\frac{t}{l_x} > \frac{1}{25}$
	Beam	$\frac{D}{l} > \frac{1}{15}$
Reinforced concrete (RC) structure	Floor slab (excluding cantilever)	$\frac{t}{l_x} > \frac{1}{30}$
	Floor slab (cantilever)	$\frac{t}{l_x} > \frac{1}{10}$
	Beam	$\frac{D}{l} > \frac{1}{10}$
Steel-core RC structure	Beam	$\frac{D}{l} > \frac{1}{12}$
Aluminum alloy structure	Beam	$\frac{D}{l} > \frac{1}{10}$
Autoclaved lightweight aerated concrete panel structure	Floor slab	$\frac{t}{l_x} > \frac{1}{25}$

In this table, t, l_x, D and l represent the following values respectively.
t: thickness of floor slab [mm]
l_x: effective length of the short side of the floor slab (In the case of deck plate or autoclaved lightweight aerated concrete panels, distance between support points) [mm]
D: depth of the beam [mm]
l: effective length of the beam [mm]

This regulation stipulates the thickness of floor slabs or size of beams directly with engineering judgement that is corresponding to serviceability metaphorically.

3.2 Vertical deflection - method 2

Except for the case with method 1, the maximum value of deflection generated in beams or floor slabs by the dead load and live load according to the state of the said building shall be calculated. To account for the increase of deformation caused by sustained loading, a deformation increase coefficient α can be applied to the maximum value of the deflection obtained in the preceding calculation. Suggested deformation increase coefficients are presented in Table 2 according to the form and material of the structure. As a check, the final design value can be confirmed by dividing the result by the effective length of the said member, and the ratio should be 1/250 or less. Alternatively, an appropriate deformation increase coefficient α can be determined by loading test.

Table 2. Deformation increase coefficient.

Structure type		Deformation increase coefficient α
Wooden structure		2
Steel structure	Deck plate slab	1.5
	Beam	1
RC structure	Floor slab	16
	Beam	8
Steel-core RC structure		4
Aluminum alloy structure		1
Autoclaved lightweight aerated concrete panel structure		1.6

The values for RC and wooden structure account for the effect of creep deformation of each structure.

3.3 Story drift ratio

Story drift should be checked for a mid-size earthquake, horizontal seismic coefficient $C_0 \geq 0.2$, the horizontal deformation in each floor (cross-section) is within the scope wherein no external components become detached and fall from the building (in principle, within 1/200, or 1/120 in cases where there is no fear of significant damage). In the other notification, it is said that building wall with a height of more than 31m that faces the outside should not fall off due to a 1/150 interlayer displacement (Ministry of Construction 1971).

This regulation has not changed since the introduction of the two-step seismic design. Therefore, the limit state of horizontal seismic coefficient $C_0 \geq 0.2$ is not clear for each structure.

4. Serviceability Related Matters in each Structural System

4.1 Reinforced concrete (RC) structure

AIJ (2019b) "Standard for Structural Calculation of Reinforced Concrete Structures" prescribes that the minimum floor slab thickness for general and normal concrete shall be 80 mm. Long period deflection and elastic deflection limit value (considering long period deflection growth rate) is less than $\delta \leq l_x/250$, where l_x is the effective span length of short side.

4.2 Steel structure

AIJ (2017) "Design Standard for Steel Structure" prescribes that the deflection of general girder should be smaller than *l*/300. For girders supporting traveling crane, the girder deflection should be *l*/500 for small (speed of crane ≤ 60 m/min), *l*/800 ~ *l*/1000 for general (speed of crane ≤ 90 m/min), *l*/800 ~ *l*/1200 for speedy (speed of crane > 90 m/min) or steelmaking crane girders.

Story drift ratio limit in each floor for horizontal drift should be smaller than 1/200.

4.3 Timber structure

AIJ (2006) "Standard for Structural Design of Timber Structures 2006" prescribed that the primary maximum deflection shall be *l*/300 and there is no vibration disorder. For floor, tatami and joist, the primary maximum deflection shall be *l*/300 for floor, *l*/450 for tatami, and *l*/200 for main structure. Some details of members are tabulated in the Standard.

4.4 Building foundation

AIJ (2001) "Recommendations for Design of Building Foundations 2001" recommends limits for distortion angle and settlement for foundations as follows.

Table 3 Distortion angle and limit settlement for RC structure.

Soil	Limit state	Individual footing
Consolidation layer	Distortion angle [rad]	Lower: 0.7×10^{-3} Upper: 1.5×10^{-3}
	Relative settlement [cm]	Standard: 1.5 Maximum 3.0
	Absolute settlement [cm]	Standard: 3.0 Maximum 10
Sand layer	Distortion angle [rad]	Lower: 0.5×10^{-3} Upper: 1.0×10^{-3}
	Relative settlement [cm]	Standard: 1.5 Maximum 3.0
	Absolute settlement [cm]	Standard: 2.0 Maximum 3.5

4.5 Base isolated buildings

AIJ (2013) "Recommendations for the Design of Seismically Isolated Buildings 2013" recommends that clearance between adjacent building should be 1.5 times of its story drift.

Notification No.2009 (Ministry of Construction 2000b) describes that the story drift ratio of superstructure should be less than 1/300 for structures taller than 9 m, and for other structures, the ratio should be less than 1/200. Furthermore, the clearance between isolated building wall and side wall in isolated layer should be larger than 0.5 m. In addition, clearance values presented in Table 4 should be added for the clearance between the said building wall and adjacent buildings.

Table 4. Additional clearance around building.

Condition	Additional clearance
Dedicated to the passage of people	0.8 m
People can pass through	0.2 m
Other	0.1 m

5. Comparison with International Codes

Major international codes and standards, including ASCE 2017, CEN 2002, ISO 2015, ISO 2019, and AS/NZS 1170.2:2002, provide performance-based structural design and clear serviceability limit states for their design procedures. They constitute clear procedures for performance-based structural design.

On the other hand, Japanese structural design procedure is very complicated, and performance design and specification design stand side by side. Limit states of serviceability are not clear and sometimes they are defined solely by engineering judgement. Though AIJ Recommendations for Limit State Design of Buildings (AIJ 2002) was published, Japanese Building Code does not seems to take it into account. Recently, the Japanese Industrial Standard (JISC 2020) has adopted the principles recommended by ISO 2394, which may influence the future direction of the Building Code.

6. Conclusions

Japanese structural design procedures have been reviewed and compared with other international codes in this paper. Evidently, the Japanese structural design system can be regarded as an ad hoc patchwork collection. To introduce performance-based structural design procedure, they need to be reconfigured fundamentally.

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