A New Round of Updation of Seismic Design Code of China

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ABSTRACT

A new round of updation of seismic design code of China named GB50011 has taken since the second half of 2006. The conception of the performance based seismic design has been presented in terms of Three Earthquake Defence Lines and Seismic Objectives. Basic requirements for conception design, design earthquake strong motion parameters and response spectra, methodologies for site classification, requirements on input earthquake acceleration records for time history analysis of structures, the minimum required shear force of base and stories, two phases of seismic design : the elastic analysis for the section design to minor earthquake actions and the elasto-plastic analysis for displacement response of structures to major earthquake actions and corresponding drift limits of structures, etc. are summarized. Lesions learned from damages of the 512 Wenchuan Earthquake, 2008 are introduced. provision for new types of structures, such as steel structure, building with base isolators and energy dissipation devices, spacious structures and underground buildings are also involved in the code.

Keywords: *Design code, Performance-based seismic design, Conception design*

1. INTRODUCTION

Section headings are to be in 11pt bold and full caps. Number headings consecutively. Leave two blank lines before Section Heading and one blank line between the heading and the first line of text. Between paragraphs of text leave one line gap. Paragraphs are not to have any indents. Text should be single spaced, left and right justified, providing 20mm left margin and 15mm right margin. Leave a 30mm margin at top and a 25mm margin at bottom.

2. A Brief History of Seismic Design Code Development in China

The first officially issued seismic design code was " The Code for the Seismic Design of Civil and Industrial Buildings TJ11-74 " (1974) which was revised as TJ11-78 version in 1978. A updated version named as " The Code for Seismic Design of Buildings GBJ11-89 " was edited and issued in 1989 by China Academy of Building Research. A series of seismic design codes and regulations for infrastructure engineering and industrial buildings related to facilities of water supply, gas supply and heating outdoor, railway, highway, nuclear power plant, electrical installations, bridge, mechanical installations, chemistry, petroleum, communication system and so on, were issued afterwards. Essentially, they follow the GBJ11-89 Code in regulations concerning the earthquake design level, fundamental principle of design, earthquake force, site classification, design for base and foundation, seismic calculation, detailing, etc. [1].

3. Main Features of the Previous GBJ 11-89 Code

The main features of GBJ11-89 Code can be summarized as following [2]:

a. seismic design objectives related to three earthquake force levels in terms of "no damages to minor earthquakes", "repairable damages to moderate earthquakes", and "collapse-forbidden to major earthquakes " and two phases of seismic design in terms of the elastic analysis at the minor earthquake level and the elasto-plastic analysis at the major earthquake level.
b. seismic requirements for buildings in regions of low seismicity (below 6 degree of intensity).
c. defence intensity for seismic design of buildings determined based on the zoning intensity and the importance category of buildings.
d. site classification based on the thickness and the rigidity of the soil profile.
e. the design response spectrum featured with the near-field and far-field effects.
f. the assessment of liquefaction potential and land slide hazard for a specified site.
g. requirements of time history analysis.
h. calculation of rotation and vertical response to earthquake actions.
i. seismic adjustment coefficient applied to replace the general safety factor and structural factor for the section strength design.
j. requirements of elasto-plastic response calculation and drift limits.

4. Performance-Based Seismic Design in Chinese Codes

The international community of civil engineering highlights the performance-based earthquake engineering (**PBEE**) that is related to the full procedures of design and construction.[3] The target of **PBEE** is to guarantee the building expected functions in the future earthquake events. It requires that a group of earthquake design levels and rational performance levels for buildings, as well as a group of earthquake design objectives be determined in seismic design codes [4] [5].

A general principle of three levels of design earthquake and two phases of seismic design has been adopted by the Code for Seismic Design of Buildings GBJ11-89 [6] that is compatible with the national standard named Uniform Code for Building Structure Design GBJ68-84. [7] The reliability of structure is defined by Code GBJ68-84 as the probability of realizing the target function of a building exposed to the specified gravity (dead load, live load), environmental (wind, seismic, or snow) or man-made (blast or shock) loads in a certain service period. It is seen that the conception of performance-based seismic design has been involved implicitly by Code GBJ11-89.

4.1. Three earthquake force level

Compatible with the probability-theory-based structural reliability specified by Code GBJ68-84, the seismic design for buildings can possess three earthquake design levels as following:
a. The minor earthquake design level (63 % exceeding probability in 50-year service life, or the return period of 50-year).
b. The moderate earthquake design level(10 % exceeding probability in 50-year service life, or the return period of 475-year).
c. The major earthquake designs level (2-3 % exceeding probability in 50-year service life, or the return period of 2000-year).

4.2. Two phases of seismic design

a. The first phase: section design of structural members and deformation check by elastic analyses at the minor earthquake level.
b. The second phase: structural deformation check by elasto-plastic analyses at the major earthquake level.

4.3. Three seismic performance objectives

Corresponding to the three earthquake design levels, three earthquake performance objectives are determined according to the importance and occupancy of a building as follows:

a. The operational objective: the building and facilities remain operational and serviceable without damage or with slight damage at the minor earthquake design level.

b. The repairable objective: the building suffers limited structural and severe non-structural damages which can be repaired at the moderate earthquake design level.

c. The life-safety objective: the building suffers hazardous but controlled structural damages at the major earthquake design level.

Earthquake design levels and objectives are both determined based on the seismic intensity I (in terms of 6, 7, 8, 9 degree) and the category of building importance (in terms of A, B, C, D). The criterion of the structural and nonstructural damages, as well as the relationship between the performance objective and the limit state of the structural response to a given earthquake design level can be established by using the elastic and the elasto-plastic drift of story. A seismic intensity-related category in terms of 1-4 is specified for the section design and detailing of R.C. members. Both of general requirements and conception configurations of the seismic design for a building are also related to the seismic intensity *I.*

5. Major Modifications in the New Seismic Design Code GB50011-2001[8]

A new round updating on the Code for Seismic Design of Buildings GBJ11-89 was completed in 2001[9]. Dozens of researchers and engineers from nationwide are involved in this program. The code revision mainly focuses on the earthquake design force and the related seismic requirements can be summarized as follows:

5.1. The seismic intensity *I* is replaced by the peak acceleration A_g. A new generation of Seismic Ground Motion Parameter Zoning Map of China (2001) featuring by A_g and characteristic period T_g has been published and used since August 2001[10], instead of the previous Seismic Intensity Zoning Map (1990). Zones 6, 7 (a, b), 8 (a, b) and 9 in the new Zoning Map (2001) are corresponding respectively to the Intensity 6, 7, 8 and 9 degree in the Seismic Intensity Zoning Map (1990). The correspondence between the seismic intensity I and the peak acceleration A_g is shown in Table 1.

TABLE 1

THE CORRESPONDING OF SEISMIC INTENSITY AND PEAK ACCELERATION

(Code GB50011-2001)

Seismic intensity *I* degree	6	7		8		9
Earthquake zone	6	7_a	7_b	8_a	8_b	9
peak acceleration A_g (g)	0.05	0.10	0.15	0.20	0.30	0.40

5.2 The site is classed based on the thickness of overlay above the hard soil layer or bed-rock and the rigidity of the soil profile in terms of the equivalent velocity of shear wave. Table 2 shows the category of sites.

TABLE 2 SITE CLASSIFICATION
(Code GB50011-2001)

Equivalent velocity υ_{se}	Site class			
	I	II	III	IV
υ_{se}>500	0m			
500≥υ_{se}>250	< 5m	> 5m		
500≥υ_{se}>140	< 3m	3～50m	> 50m	
υ_{se}≤140	< 3m	3～15m	15～80m	> 80m

5.3. The site-dependent characteristic period T_g of the response spectra adopted in the Code GBJ11-89 is a parameter identified as either the near-field or the far-field that is in consideration of both of the earthquake magnitude and epicenter distance. It is shown in Table 3. In Code 50011-2001, the effects of earthquake source mechanism and wave propagation path on the shape of the design response spectrum has been considered in the Zoning Map (2001). The characteristic periods T_g of the response spectrum for different site classes in Seismic Effective Zone A, B, C are shown in Table 4.

TABLE 3
CARACTRERISTIC PERIODS OF RESPONSE SPECTRA (s)
(Code GBJ11-89)

Earthquake field	Site class			
	I	II	III	IV
Near field	0.20	0.30	0.40	0.65
Far field	0.25	0.40	0.55	0.85

TABLE 4
CHARACTRERISTIC PERIODS OF RESPONSE SPECTRA (s)
(Code GB50011-2001)

Site class		I	II	III	IV
Seismic effective zone	A	0.25	0.35	0.45	0.65
	B	0.30	0.40	0.55	0.75
	C	0.35	0.45	0.65	0.90

5.4. The response spectrum with the longest period of 6 seconds and different damping ratios adopted by Code GB50011-2001 is shown in Figure 1 :

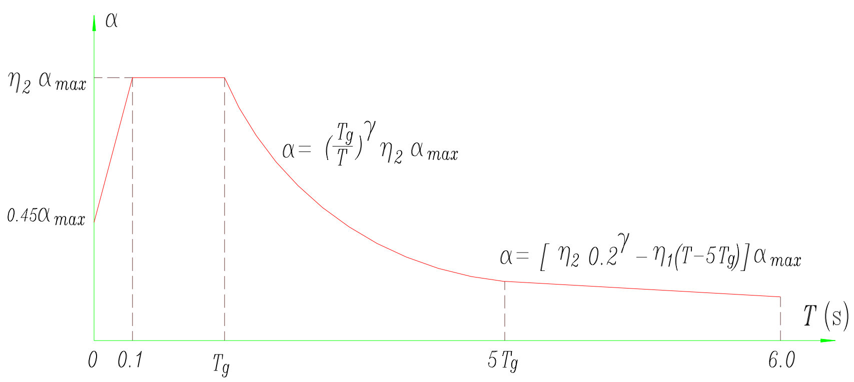

Figure 1 The response spectrum of GB50011-2001

Where γ is the factor that describes the descending ratio of the spectral curve between T_g and $5T_g$, η_1 is the factor for the segment of 5Tg to 6.0s, η_2 is the adjustment factor of damping ζ :

$$\gamma = 0.9 + \frac{0.05 - \zeta}{0.5 + 5\zeta} \tag{1}$$

$$\eta_1 = 0.02 + (0.05 - \zeta)/8 \tag{2}$$

$$\eta_2 = 1 + \frac{0.05 - \zeta}{0.06 + 1.7\zeta} \tag{3}$$

5.5. A group of acceleration records whose average spectrum is compatible with the design response spectrum is required for linear and non-linear time history analyses of structures. The base shear force calculated at average by the time history analyses is recommended no less than 80 % of the base shear force obtained by the spectral analysis method.

5.6. A minimum story shear force is requested by Equation (4):

$$Fi \; > \; \lambda \sum_{j=1}^{n} Gj \qquad j = i, i+1, \ldots n \tag{4}$$

Where *Fi* is the requested shear force of the i^{th} story, *Gj* is the gravity load of the j^{th} story, λ is the minimum coefficient of the story shear force, given by Table 5 as following:

TABLE 5

THE MINIMUM COEFFICIENTS OF THE STORY SHEAR FORCE λ

Seismic intensity zone	6	7_a	7_b	8_a	8_b	9
Structures with period T_1 < 3. 5s or obvious rotation response	—	0.016	0.024	0.032	0.048	0.064
Structures with period T_1 > 5. 0s	—	0.012	0.018	0.024	0.032	0.040

5.7. The elastic displacement responses of structures to the action of the minor earthquakes calculated by the base shear force method and spectrum method or time history approach are required to meet with the limits of the story drifts as Table 6 mentioned:

TABLE 6

LIMITS OF ELASTIC DRIFT OF DIFFERENT TYPE OF STRUCTURES

Structure type	Story drift
R.C. frame	1/550
R.C. frame-shear wall, slab-column-shear wall, frame-tube	1/800
R.C. shear wall, tube-tube	1/1000
R.C. shear wall-bottom frame	1/1000
Med-high rise steel building	1/300

5.8. The elasto-plastic displacement responses of structures to the major earthquake calculated by Push-over approach or time history analysis method are regulated to be under the limits of the story drift shown in Table 7:

TABLE 7

LIMITS OF ELASTO-PLASTIC DRIFT OF DIFFERENT TYPE OF STRUCTURES

Structure type	Story drift
One story bent with R.C. column	1/30
R.C. frame	1/50
R.C. frame-shear wall, slab-column-shear wall, frame-tube	1/100
R.C. shear wall, tube-tube	1/120
Masonry house with bottom R.C. frame	1/100
Med-high rise steel building	1/50

6. Major Revisions in GB50011 Code Based on Damage Data of Buildings learned from the 512 Wenchuan Earthquake, 2008

6.1 The importance of school and hospital buildings has been ranked one grade higher.

6.2 Multi-defence lines for seismic design of buildings have been stressed. RC frame structures are required to contain a certain number of braces or shear walls which can be treated as the first defence line to guarantee the frame structure from collapse.

6.3 Confined masonry structures are required to be with RC tie-columns and tie-beams to ensure the integration of buildings.

6.4 The seismic conception design for “strong column and weak beam” of RC frame structures should be realized by carefully determining proper size and detailing for column and beam in consideration of the rigidity and strength of floor slabs.

6.5 A special attention has been paid to the safety of the stair shaft of masonry buildings by taking account of the rigidity and strength of RC step beam and the slab.

6.6 More strict limits of height and stories for masonry school and hospital buildings have been regulated in the new code.

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