TECH-CHRONICLE
AN INTERNATIONAL E-JOURNAL ON
EMERGING TRENDS IN SCIENCE, TECHNOLOGY AND MANAGEMENT

Critical Study and Comparison of Earthquake Standards and Specifications of Important Countries

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Abstract*- Most seismic codes require that structures be designed to resist specified static lateral forces related to the structure and the seismicity of the region. Based on an estimate of the fundamental natural period of the structure, formulas are specified for the base shear and the distribution of lateral forces over height of the buildings. These seismic design provisions in five building codes, IS 1893-2002 (Part-1), Japan (AIJ), 1997 USA (UBC), Canadian (NRC 2005) and 2009 USA (IBC) and their similarities and differences are presented in the paper. This document focuses on a few specific parameters of different countries and compares it with the Indian seismic codes. At first, the codes and their backgrounds are introduced and the design procedures in these three are described. Then for calculating the seismic load in each code the base shear coefficient, seismic zoning, spectral content, fundamental period, structural behavior coefficient, importance factor, effect of soil profile and foundation, and effect of the weight of buildings are precisely discussed and the differences have been mentioned. After calculating the seismic force, the distribution methods over the height of the building and the base shear coefficients are compared. Although these five codes differ in details, they have a lot of common features which can be compared. This comparison shows that the Indian seismic code is very similar to the Americans but the Japanese code is considerably different from the other two codes.

***Keywords*— Earthquake, standards and specifications, codal provision, Base shear, storey shear.**

I. INTRODUCTION

With rapid strides in earthquake engineering in the last several decades, the seismic codes are becoming increasingly sophisticated. The code provides two performance objectives: life safety and damage limitation of a building at two corresponding levels of earthquake motions. The first code was elaborated in 1927 in the USA for the Californian earthquakes. Following this code, the effort to elaborate codes was extended to all the world's seismic zones. For these codes, the current set of seismic design factors found in national standards is based on a measured combination of history of seismic events, state-of-the-art of research works and engineering judgments, very different in each country as a function of its experience of construction in seismic areas, coming from the nature and characteristics of ground motions, traditions and jurisdictions. Therefore, it is very important to analyze the evolution of seismic codes in the world's main seismic areas, in the context of the above-mentioned factors. Earthquakes all over the world have affected the seismic resistant design in different countries and made a revision necessary in many areas. Great improvements during last 50 years in Japan and USA make a comparison between their codes and other countries' inevitable. The Building Standard Law in Japan (AIJ) has been in force since 1950 (after World War II) to safeguard the lives, health and property of people, and to increase the public safety. The current seismic design method comprises the revised enforcement order, notifications and related regulations in force since 1981 under the Building Standard Law. The regulations were issued after a five-year national research project to develop new seismic design methods and a three-year review. The aim of this project is to focus on a few specific parameters of different countries and compare it with the Indian seismic codes which are very important in order to know how concepts and provisions of one code could be used for the development of other codes, without making important errors. Some of the important steps in this context are Variation of codal provisions in different countries; Relating Indian seismic codes with seismic codes of other countries.

II. BRIEF LITERATURE REVIEW

A. *Comparison of Seismic Codes*

Marjan FAIZIAN and Yuji ISHIYAMA as in [4] in their paper states most seismic codes require that structures be designed to resist specified static lateral forces related to the structure and the seismicity of the region. Based on an estimate of the fundamental natural period of the structure, formulas are specified for the base shear and the distribution of lateral forces over height of the buildings. These seismic design provisions in three building codes, 1981 Japan (BSLJ), 2000 USA (IBC) and 1999 Iran (2800), and their similarities and differences are presented in the paper. Although these three codes differ in details, they have a lot of common features which can be compared.

Adeel Zafar as in [1] in his paper stated, the primary objective of this study is to evaluate R factor for typical reinforced concrete (RC) moment resisting frames

(MRFs) which exist in Pakistan, using nonlinear analytical tools, and compare the calculated R factor with the values given in seismic code of practice. Incremental dynamic analysis (IDA) was utilized in this study to find the response modification factor for RC-MRF in Pakistan using a suite of ground motion records representative of the region. Another objective of this thesis is to conduct a parametric study to evaluate the effect of variation of material and geometric properties of RC-MRFs on R factor.

P. R. Bose, R. Dubey & M. A. Yazdi as in [10] in their paper compares the seismic provisions for multistoried framed buildings of various countries. The provisions compared are Building Standard Law of Japan (BSLJ) 1981, Criteria for Earthquake Resistant Design of Structures IS: 1893-1984(IS) National Building Code of Canada 1985 (NBC), New Zealand Standard (NZS) 4203:1984 and Uniform Building Code-1988 (UBC). In general the provisions of five countries can be related to one another in terms of component. The study presents and compares the distribution of seismic shear along the height of building according to these five codes and the distribution pattern obtained by dynamic analysis.

III. FINDINGS OF THE STUDY

A. Seismic Load

1) IS 1893-2002 (Part 1):

As per this code, Seismic wt is calculated as,

$W = DL+25\% \ LL$; for $LL \leq 3KN/m^2$

$= DL+50\% \ LL$; for $LL > 3KN/m^2$

The imposed load on roof need not be considered [5].

2) IBC 2009 & ASCE 7-05 , UBC 1997, NRC 2005:

In these codes, the effective seismic weight of the structure, including the total dead load and other loads are: First, in areas used for storage, a minimum of 25 percent of the reduced floor live load. Second, where an allowance for partition load is included in the floor load design, the actual partition weight or a minimum weight of 0.48 KN/m^2, whichever is greater. Third, total weight of permanent operating equipments and at last, 20 percent of flat roof snow loads where flat snow load exceeds 1.44 KN/m^2.

3) AIJ:

AIJ specifies that the weight of the building shall be the sum of dead load and the applicable portion of live load. In heavy snow districts, the effect of snow load shall be considered. The applicable portion is 0.6 KN/m^2 for residential rooms and 0.5 KN/m^2 for offices, which correspond to about one-third of the design live load for floor slabs as in [4].

B. Base Shear Coefficient

1) IS 1893-2002 (Part 1):

Horizontal seismic coefficient

$A_h = Z/2*I/R*Sa/g$

Where Z = Zone factor

I = Importance factor

R= Response reduction factor

Sa/g= Average response acceleration coefficient

2) IBC 2009:

The seismic response coefficient shall be determined as,

$Cs = S_{DS}/(R/I)$

Where, I is the occupancy importance factor,

R is the response modification factor and

S_{DS} is the design spectral response acceleration at short period.

The maximum considered earthquake spectral response acceleration as in [3] for short periods, SMs, and at 1-secondperiod, SM1, adjusted for site class effects shall be determined by

$S_{MS} = F_a*S_s$

$S_{M1} = F_v*S_1$

F_a, F_v = Site coefficient defined in [7].

S_s = the mapped spectral accelerations for short periods

S_1 = the mapped spectral accelerations for a 1-second period.

Design spectral response acceleration parameters.

Five-percent damped design spectral response acceleration at short periods, S_{DS}, and at 1-second period, S_{D1}, shall be determined as:

$S_{DS} = (2/3)\ S_{MS}$

$S_{D1} = (2/3) S_{M1}$

The value of Cs computed need not exceed the following:

$Cs = SD1/T*(R/I)$ for $T \leq TL$

$Cs = SD1.TL/T\ 2(R/I)$ for $T > TL$

Cs shall not be less than 0.01

In addition, for structures located where S1 is equal to or greater than 0.6g, Cs shall not be less than 0.5S1/(R/I). SD1 is the design spectral acceleration at 1-second period; T is the fundamental period of the building.

3) UBC 1997:

(Cv I/R T)

Where, Cv = seismic coefficient depending on soil profile type,

I= importance factor,

R= Force reduction coefficient,

T= Fundamental period

4) NRC 2005:

S(Ta)*Mv*Ie/Rd*Ro

Where, S(Ta) is the design-spectral-response acceleration at the fundamental period of vibration. S(Ta) is the design spectral acceleration and is determined as follows, using linear interpolation for intermediate values of Ta:

$S(Ta) = Fa*Sa(0.2)$ for $Ta \leq 0.2s$

$= Fv*Sa(0.5)$ or $FaSa(0.2)$,

whichever is smaller for $Ta = 0.5s$

$= Fv*Sa(1.0)$ for $Ta = 1.0s$

$= Fv*Sa(2.0)$ for $Ta = 2.0s$

$= Fv*Sa(2.0)/2$ for $Ta \geq 4.0s$

Ta is the fundamental lateral period,

Mv is the factor to account for higher mode effect on base shear,

Ie = importance factor,

Rd is the ductility-related force modification factor,

Ro is the over strength related force modification factor.

5) AIJ:

In AIJ, the lateral seismic shear coefficient for moderate earthquake motions is determined as,

$Ci = Z*Rt*Ai*Co$

Where, Z is the seismic zoning coefficient,

Rt is the design spectral coefficient,

Ai is the lateral shear distribution factor and

Co is the standard shear coefficient.

In AIJ, the lateral seismic shear coefficient given for each story is calculated by multiplying the base shear coefficient and the lateral shear distribution factor Ai that is given by

$$A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \alpha_i\right) \cdot \frac{2T}{1+3T}$$

α_i = ratio of weights at different floor

C. *Seismic Zoning*

1) IS 1893-2002(part-1): Four zones are classified as II, III, IV, V and their factors are, Z= 0.10, 0.16, 0.24, and 0.36.

2) IBC 2009 & ASCE 7: Zones are divided based on the design spectral accelerations Ss, S1 and zip codes.

3*) UBC 1997:* Zones are classified as 1, 2A, 2B, 3, 4 and factors are, Z= 0.075, 0.15, 0.2, 0.3, 0.4

4) NRC 2005: Zones are classified on the basis of spectral accelerations i.e. S (0.2), S (0.5), S (1.0), S (2.0)

5) AIJ: The AIJ seismic zoning map as shown only indicates the relative seismicity, dividing Japan into three zones. The seismic zoning coefficient Z is 1.0, 0.9, 0.8 and 0.7for Okinawa.

D. *Importance Factors*

1) Japanese (AIJ):

Co = standard shear coefficient,

$Co \geq 0.2$ for allowable stress design against moderate earthquake,

$Co \geq 1.0$ for ultimate lateral shear capacity design against severe earthquake.

TABLE I. IMPORTANCE FACTORS

Codes	**IS 1893 - 2002 (Part 1)**	**IBC 2009 & ASCE 7**	**UBC 1997**	**Canadian (NRC 2005)**	**AIJ**
Importance factors (I)	1 1.5	1 1.25 1.5	1 1.25	0.8 1.0 1.3 1.5	-----

E. *Response Reduction Factor*

1) Japanese (AIJ): In AIJ, the design spectral factor coefficient, Rt, is determined as, where T is the fundamental natural period of the building and Tc is critical period, which is equal to 0.4, 0.6 and 0.8 for soil profiles type I, II and III. Thus it depends on design fundamental period of vibration of the building, T, and the type of the ground.

$T < TC$	$Rt = 1$
$TC \leq T \leq 2\,TC$	$Rt = 1-0.2(T/Tc -1)$
$2TC < T$	$Rt = 1.6Tc/T$

TABLE II. RESPONSE REDUCTION FACTORS

Codes	**IS 1893 - 2002 (Part 1)**	**IBC 2009 & ASCE 7**	**UBC 1997**	**Canadian (NRC 2005)**	**AIJ**
OMRF	3	3	3.5	Ductility related Rd = 1.5 Overstrength related Ro = 1.3	-----
SMRF	5	8	8.5		

F. *Soil Profile*

1) IS1893-2002 (PART 1), AIJ: Soil types are hard soil, soft soil, medium soil

2) UBC 1997, Canadian (NRC 2005), IBC 2009 & ASCE 7: Soil types are Sa: Hard rock, Sb: Rock, Sc: Very dense soil and soft rock, Sd: Stiff soil, Se: Soft soil, Sf: Soils requiring site-specific evaluations.

G. *Fundamental Time Period*

1) IS1893-2002 (PART 1):

$T = 0.09h / d^{1/2}$, due to brick infill panels

Where, h = Height of building in m, and

d =Base dimension of the building at the plinth level, in m, along the considered direction of the lateral force.

The approximate natural period of vibration (T) in seconds of a moment resisting frame building without brick infill panels may be estimated by the empirical expression

$T = 0.075\ h^{0.75;}$ For R.C. Frame Building

$= 0.085\ h^{0.75;}$ For Steel Frame Building

2) IBC 2009 & ASCE 7:

$T_a = C_t.h_n^{3/4}$

For moment resisting frame buildings not exceeding 12 stories and having a minimum story height of 3m is also permitted. (N is the number of stories)

$Ta = 0.1\ N$

3) UBC 1997:

The value of *T* shall be determined from one of the following methods: For all buildings, the value *T* may be approximated from the following formula:

$T = C_t\ (h_n)^{3/4}$

Where, C_t = 0.035 (0.0853) for steel moment-resisting frames.

C_t = 0.030 (0.0731) for reinforced concrete moment-resisting frames and eccentrically braced frames.

C_t = 0.020 (0.0488) for all other buildings

Note: metric equivalent shown in brackets.

4) Canadian (NRC 2005): Ta is the fundamental lateral period in the direction under consideration and is determined as $0.085(h_n)^{3/4}$ for steel moment frames, $0.075(h_n)^{3/4}$ for concrete moment frames.

5) Japanese (AIJ): T= 0.02 H

Where H= height of the building.

H. *Calculation of Base Shear*

1) IS1893-2002 (PART 1): The Design base shear is calculated as,

$V_B = Ah\ .W$

Where, Ah= Horizontal seismic coefficient,

W = seismic weight of the structure

2) IBC 2009 & ASCE 7: The base shear is determined as,

$V = Cs.W$

Where, Cs = the seismic response coefficient

W = the effective seismic weight

3) UBC 1997: The base shear is calculated as,

$V = (Cv\ I/R\ T)*W$

The total design base shear need not exceed the following:

$V \leq (2.5\ Ca\ I/R)*W$

The total design base shear shall not be less than the following:

$V = (0.11\ Ca\ I)*\ W$

In addition, for Seismic Zone 4, the total base shear shall also not be less than the following:

$V = (0.8\ Z.Nv\ I/R)*W$

Where, Ca, Cv = seismic coefficient depending on soil profile type,

I= importance factor,

R= Force reduction coefficient,

T= fundamental period,

W = seismic weight.

4) Canadian (NRC 2005): The minimum lateral earthquake design force, *V*, at the base of the structure (equivalent static force procedure), is

V = S (Ta).Mv.Ie.W/Rd.Ro

Except that V shall not be less than:

Vmin = S (2.0).Mv.Ie.W/Rd.Ro

And for Rd= 1.5, V need not be greater than

Vmax = 2S (0.2).Ie.W/3Rd.Ro

Where, S (Ta) is the design-spectral-response acceleration at the fundamental period of vibration,

Ta is the fundamental lateral period,

Mv is the factor to account for higher mode effect on base shear,

Ie = importance factor,

W= seismic wt of structure,

Rd is the ductility-related force modification factor,

Ro is the over strength-related force modification factor.

I. *Distribution Of Seismic Load*

1) IS1893-2002 (PART 1): The design base shear (Vb*)* computed shall be distributed along the height of the building as per the following expression:

$$Q_i = V_B.\ \frac{w_i.h_i^{\,2}}{\sum_{j=1}^{n} w_j.h_j^{\,2}}$$

Where, Qi = Design lateral force at floor *i*,

Wi = Seismic weight of floor i,

hi = Height of floor *i* measured from base, and

n =Number of storey's in the building is the number of levels at which the masses are located.

2) IBC 2009: In IBC, the forces at each level shall be calculated as,

$F_x = C_{vx}.\ V$, &

$$C_{vx} = \frac{W_x\ .h_x^k}{\sum_{i=1}^{n} w_i.h_j^k}$$

Where, C_{vx}= vertical distribution factor,

V = total design lateral force or shear at the base of the structure (kip or KN)

Wi and Wx = the portion of the total effective seismic weight of the structure (W) located or assigned to Level i or x,

hi and hx = the height (ft or m) from the base to Level i or x

k = an exponent related to the structure period as follows:

For structures having a period of 0.5 s or less, k = 1

For structures having a period of 2.5 s or more, k = 2

For structures having a period between 0.5 and 2.5 s, k shall be 2 or shall be determined by linear interpolation between 1 and 2.

3) *UBC 1997:*The total force shall be distributed over the height of the structure in conformance as,

$$V = F_t + \sum_{i=1}^{n} F_i$$

The concentrated force Ft at the top, which is in addition to Fn, shall be determined from the formula:

Ft = 0.07 T V

The value of T used for the purpose of calculating Ft shall be the period that corresponds with the design base shear. Ft need not exceed 0.25V and may be considered as zero where T is 0.7 second or less. The remaining portion of the base shear shall be distributed over the height of the structure, including Level n, according to the following formula:

$$F_x = (V-F_t).\,\frac{W_x\,.h_x}{\sum_{i=1}^{n} W_i.h_i}$$

At each level designated as x, the force Fx shall be applied over the area of the building in accordance with the mass distribution at that level. Structural displacements and design seismic forces shall be calculated as the effect of forces Fx and Ft applied at the appropriate levels above the base.

4) *NRC 2005:* The total lateral seismic force, shall be distributed such that a portion, Ft shall be assumed to be concentrated at the top of the building, where Ft is equal to 0.07 Ta.V but need not exceed 0.25 V and may be considered as zero where the fundamental lateral period, Ta, does not exceed 0.7 s; the remainder, V-Ft shall be distributed along the height of the building, including the top level, in accordance with the following formula:

$$F_x = \frac{(V-F_t).\,W_x\,.h_x}{\sum_{i=1}^{n} W_i.h_j}$$

5) *Japanese (AIJ):* The storey shear is calculated as,

$Q_i = C_i.\,W_i$

Where, Ci= seismic shear force coefficient on the i-th story,

W = seismic weight of the structure.

IV. CONCLUDING REMARKS

The main factors, which constitute the seismic load provisions of IS 1893-2002(PART1), IBC 2009, UBC 1997, NRC 2005 and AIJ have been presented and compared. While the five codes differ in detail, they have essential common features and are comparable.

The IS 1893-2002(part1), UBC 1997, NRC 2005 is quite similar to IBC 2009, but there is difference between these four and Japanese codes. All of them include the effect of seismic risk, spectral contents, structural behavior and soil/foundation for seismic load but base shear is not calculated in Japanese (AIJ).

The importance of a building is included in rest of the codes but not in AIJ.

Indian code is relatively conservative in estimating seismic weight. In the example considered, seismic weight calculated by UBC 1997, NBCC 2005 and IBC 2009 is about 7% less than that calculated from Indian code.

Great amount of flexibility is available in Japanese (AIJ) code wherein standard shear coefficient can be between 0.2 to1 for allowable stress design against moderate earthquake. For severe earthquakes, it is more than or equal to 1. Thus, structure designed can be safe as well as economical.

Significant variation is observed in response reduction factor for frames with ductile detailing and without ductile detailing. For e.g. A ductile detailing RC frame by Indian standard reduces the base shear by 40%, while that by UBC 1997, this reduction is around 59% and by IBC 2009, it is around 62.5%. The methodologies adopted in NBCC 2005 and Japanese (AIJ) are significantly different. Extensive work on choosing appropriate response reduction factor and its inclusion in Indian code is essential to get appropriate base shear and related storey shears.

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