SEISMIC ANALYSIS OF BUILDING USING DIFFERENT COUNTRY CODES: A REVIEW

[1]Ankush R. Kene,[2]Dr. Ashok R. Mundhada
[1]PG Student, [2] Professor
[1]Civil Department,
[1] PRMIT&R, Badnera, Amravati, India

Abstract*— Seismic codes are very important in the designing of multistoried buildings. In order to design an earthquake resistant building, structural engineers must have the good knowledge of the various seismic codes. In this study, 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 reviewed. American seismic design code was first to be introduced in the world in 1927, after the California earthquake. Great advances in the building standards in different countries make it possible for their comparison. Factors like Importance factor, response reduction factor, seismic zones, soil profile, Fundamental time period, base shear will be compared. Prima facie, after the study performed it looks like the Japanese code is the most advanced code in the world. Indian and American codes are quite similar, while there is a huge difference in the Japanese and rest of the codes.

***Keywords* — Base Shear, Fundamental Time Period, Importance Factor, Response Reduction Factor.**

I. INTRODUCTION

Natural calamities such as earthquakes, tsunamis, landslides, floods etc. cause severe damage and suffering to human beings by collapsing many structures, trapping or killing persons, cutting off transport systems, blocking of navigation systems, animal deaths etc. Such natural disasters are big challenges to the progress of development. However, civil engineers play a major role in minimizing the damages by properly designing the structures or by proper material selection or proper construction procedure and taking other appropriate decisions. This includes understanding the earthquakes, behavior of the materials of construction and structures and the extent to which structural engineers make use of the knowledge in taking proper decisions in designing the structures made of reinforced concrete.

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.

As a part of research, the international standards and their provisions were critically studied. For this purpose following codes were considered:

- IS 1893-2002 (Part-1),
- AIJ (Japan)
- UBC 1997 (USA)
- Canadian (NRC 2005)
- IBC 2009 (USA)

II. LITRETURE REVIEW

Nimita Gautam, Tejas Patil, Bhavesh Panker [1]

This paper 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.

Anoop Singh, Vikas Srivastava, N.N.Harry [2]

In this study, the seismic response of the structures is investigated under earthquake excitation expressed in the form of member forces, joint displacement, support reaction and story drift. The response is investigated for g+10 building structures by using STAAD PRO designing software. We observed the response reduction of cases ordinary moment resisting frame. In this case we have taken earthquake zone 2, response factor 3 for ordinary moment resisting frame and importance factor 1.

Dr. S.V. Itti, Prof. Abhishek Pathade et al. [3]

This study focuses on the comparison of the Indian Code (IS) and International Building Codes (IBC) in relation to the seismic design and analysis of ordinary RC moment resisting frame (OMRF), Intermediate RC moment-resisting frame (IMRF) and Special RC moment-resting frame (SMRF). The analytical results of the model buildings are then compared and analyzed taking note of any significant differences. This study explores variations in the results obtained using the two codes, particularly design base shear, lateral loads, drifts and area of steel for structural members for all RC buildings in both the codes.

The discussion in this study is confined to monolithically cast reinforced concrete buildings. Specific provisions for design of seismic resistant reinforced members are presented in detail. Provisions of Indian and International Buildings Codes are identified.

This work aims at the comparison of various provisions for earthquake analysis as given in building codes of India and International Building Codes.

P. R. Bose, R. Dubey & M. A. Yazdi [4]

This 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. The empirical formula for time period is based on number of stories in IS and NBCC while it is based on total height of building in BSLJ and UBC.

All the five codes include the effect of seismic risk, spectral content, structural behavior and soil foundation effect. The importance of building is included in all the codes except in BSLJ, because BSLJ stipulate minimum standards applicable to all building.

Siluveri Shivaji, A. Sravan & P. Rama Krishna [5]

This project discusses the analysis procedure adopted for the evaluation of symmetric high rise multi-storey building (G+15) under the effect of Earthquake (EQ) forces. Earthquake occurred in multistoried building shows that if the structures are not well designed and constructed with and adequate strength it leads to the complete collapse of the structures. To ensure safety against seismic forces of multistoried building hence, there is need to study of seismic analysis to design earthquake resistance structures. In seismic analysis the response reduction was considered for two cases both ordinary moment resisting frame and special moment resisting frame. The main objective of this report is to study the seismic analysis of structures for static and dynamic analysis in ordinary moment resisting frame and special moment resisting frame. Equivalent static analysis and response spectrum analysis are the methods used in structural seismic analysis. We considered the residential building of G+ 15 storied structures for the seismic analysis and it is located in zone II. The total structure was analyzed by computer with using STAAD.PRO software. We observed the response reduction of cases ordinary moment resisting frame and special moment resisting frame values with deflection diagrams in static and dynamic analysis. The special moment of resisting frame structured is good in resisting the seismic loads.

K. Ramakrishna Reddy, Dr. S. V. Mohan Rao [6]

Many high-rise buildings are designed with basement. In general, we assume that a building is fixed at the ground level. Therefore, the basement of the building is not included in the analysis and only gravity loads are considered in designing the basement. However, the basement may introduce flexibility to the structure resulting in larger lateral displacements and longer vibration periods. The seismic loads applied to a building structure will affect the member forces in the basement. Thus, it is recommended to include the basement in the analysis of high-rise building structures. The effect of the basement is investigated based on the seismic response of high-rise buildings and an efficient analysis method to account for the effect of the basement was proposed in this study. Most of the degrees of freedom in the basement are eliminated by the matrix condensation procedure using a rigid diaphragm for each floor in the basement in part or in full. When a 20-story building structure was subjected to static lateral loads, the displacements of the roof were 13.8cm and 12.7cm for the cases with and without the basement. And the period of the building with the basement was about 10% longer than that of the building without the basement. Therefore, it is recommended to use the proposed method to get more accurate results in the analysis of building structures with basement.

M. A. Noor, M.A. Ansary and S.M. Seraj [7]

The main objective of this study is to critically evaluate and compare some sections of the current seismic design provision, which deals with the specification of seismic design forces on buildings. The code provisions reviewed and compared are Uniform Building Code (UBC), 1994 editions. The criteria for earthquake resistant design standards institutes (IS),1984 editions, The national building code of Canada(NBC),1995 editions, the building standard law of japan(BSLJ),1987 edition. Different parameters such as zone factors, importance factor, structural system factor, site geology and soil characteristics, time period etc. which calculates the base shear has been compared and critically evaluated. For the purpose of analysis, moment resisting concrete and steel buildings have been taken into considerations. In case of concrete building special, Intermediate and ordinary moment resisting frame building have been analysed. Limited numerical study has been done with STRAND6 software, to complete code listed time period, base distribution with that of model analysis using UBC (1994) SPECTRA. It has been found that for calculating base shear in the equivalent static methods almost all code of practices adopts similar definitions for the numerical coefficient of base shear formula. It appears that further improvement in the equation pertaining to the calculation of time period of the buildings may not be rewarding

III. FINDINGS OF THE STUDY

Seismic Load

IS 1893-2002 (Part 1):

As per this code, Seismic wt. is calculated as,

W = DL+25% LL; for LL ≤ 3KN/m2

= DL+50% LL; for LL > 3KN/m2

The imposed load on roof need not be considered.

IBC 2009, 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 0.48KN/m2, whichever is greater.

Third, total weight of permanent operating equipment’s and at last, 20 percent of flat roof snow loads where flat snow load exceeds 1.44 KN/m^2.

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 slab.

LOAD COMBINATIONS

IS-1893-2002:

As per IS 1893 (Part 1): 2002 Clause no. 6.3.1.2, the following load cases have to be considered for analysis.

1.5 (DL + IL)

1.2 (DL + IL ± EL)

1.5 (DL ± EL)

0.9 DL ± 1.5 EL

IBC 2009, UBC 1997, NRC 2005:

As per 2009 IBC Section 2.3.2, the following load cases have to be considered for analysis.

1.4DL

1.2DL + 1.6LL

0.9DL ± 1.0EQX

0.9DL ± 1.0EQY

1.2DL + 1.0LL ± 1.0EQX

1.2DL + 1.0LL ± 1.0EQY

Base Shear Coefficient

IS 1893-2002(Part1):

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

IBC 2009:

The seismic response coefficient shall be determined as, Cs = SDS/(R/I)

Where,

I is the occupancy importance factor,

R is the response modification factor and

SDS 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- second period, SM1, adjusted for site class effects shall be determined by,

SMS = Fa*Ss

SM1 =Fv*S1

Where,

Fa, Fv = Site coefficient defined in [7].

Ss = the mapped spectral accelerations for short periods

S1 = the mapped spectral accelerations for a 1-second period.

Design spectral response acceleration parameters.

Five-percent damped design spectral response acceleration at short periods, SDS, and at 1-second

SDS = (2/3) S_{MS}

SD1 = (2/3) SM1

The value of Cs computed need not exceed the following:

Cs = SD1/T*(R/I) for T ≤ 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.

UBC 1997:

$V = \frac{Cv*I}{R*T}$

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

I= importance factor,

R= Force reduction coefficient,

T= Fundamental period

NRC 2005:

V = (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:

$S(T_a) = F_a * S_a(0.2)$ for $T_a \leq 0.2s$

$= F_v * S_a(0.5)$ or $F_a S_a(0.2)$,

whichever is smaller for $T_a = 0.5s$

$= F_v * S_a(1.0)$ for $T_a = 1.0s$

$= F_v * S_a(2.0)$ for $T_a = 2.0s$

$= F_v * S_a(2.0)/2$ for $T_a \geq 4.0s$

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.

AIJ:

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

$C_i = Z * R_t * A_i * C_o$

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,

α_i = ratio of weights at different floor

Seismic Zoning:

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.

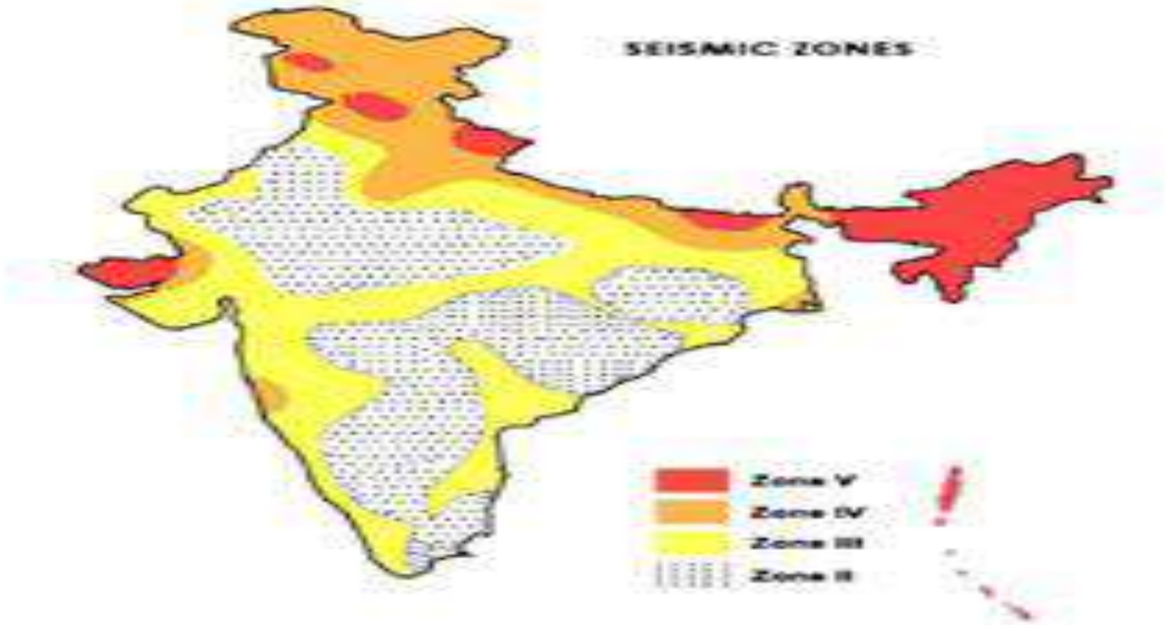

Fig.2. Sketch Of Seismic Zone Map Of India: Sketch Based On The Seismic Zone Of India Map Given In IS: 1893 (Part 1) - 2007.

IBC 2009 & ASCE 7:

Zones are divided based on the design spectral accelerations Ss, S1 and zip codes.

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

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)

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.

Importance Factors

Japanese (AIJ):

Co = standard shear coefficient,
Co ≥ 0.2 for allowable stress design against
Moderate earthquake,
Co ≥ 1.0 for ultimate lateral shear capacity

Table 1: Importance Factors

Codes	IS 1893-2002 (PART1)	IBC 2009 &ASCE 7	UBC 1997	CAN-ADIA (NRC 2005)	AIJ
Importance Factor (I)	1 1.5	1 1.25 1.5	`1 1.25	0.8 1.0 1.3 1.5	---

Response Reduction Factor
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 2: Response Reduction Factors

Codes	IS 1893-2002 (PART1)	IBC 2009 &ASCE 7	UBC 1997	CANADIA N (NRC 2005)	AIJ
OMRF	3	3	3.5	Ductility Related Rd=1.5 over strength related Ro=1.3	---
SMRF	5	8	8.5		

Soil Profile

IS1893-2002 (PART 1), AIJ:

Soil types are hard soil, soft soil and medium soil

UBC 1997, Canadian (NRC 2005), IBC 2009 & ASCE7 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.

Fundamental Time Period

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 h0.75; For R.C. Frame Building
= 0.085 h0.75; For Steel Frame Building

IBC 2009 & ASCE 7:

$Ta = Ct.hn^{3/4}$

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

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:

$T = C_t (hn)^{3/4}$
Where,
Ct = 0.035 (0.0853) for steel moment-resisting frames.
Ct = 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.

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

Japanese (AIJ):
T= 0.02 H Where H= height of the building.

Calculation of Base Shear

IS1893-2002 (PART 1):
The Design base shear is calculated as,
$V_B = A_h .W$
Where, A_h= Horizontal seismic coefficient,
W = seismic weight of the structure

IBC 2009 & ASCE 7:
The base shear is determined as,
V= Cs.W
Where, Cs = the seismic response coefficient
W = the effective seismic weight

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.

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 weight of structure,
Rd is the ductility-related force modification factor, Ro is the over strength-related force modification factor.

Distribution of Seismic Load

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

$$Q_i = V_B . \frac{Wi.hi^2}{\sum_{j=1}^{n} W_j h_j^2}$$

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.

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

Fx = Cvx. V, &

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

Where,

Cvx = 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.

UBC 1997:

The total force shall be distributed over the height of the structure in conformance as, 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:

$F_x= (V-F_t).\frac{Wxhx}{\sum_{i=1}^{n} Wi.hi}$

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.

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:

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

Japanese (AIJ):

The storey shear is calculated as, Qi = Ci. Wi

Where, Ci= seismic shear force coefficient,

W = seismic weight of the structure.

Conclusion:

1. 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.
2. The IS 1893-2002(part1), UBC 1997, NRC 2005 are quite similar to IBC 2009, but there is difference between these four and Japanese codes.
3. The importance of a building is included in rest of the codes but not in AIJ.

REFERENCES:

[1] Nimita Gautam, T. P. (2017). Critical Study and Comparison of Earthquake. *International Journal of Research in Engineering, Science and Technologies , 03* (06), 15-21.

[2] Anoop Singh, V. S. (July 2016). Seismic Analysis and Design of Building. *International Journal of Innovative Research in Science, ,* 12105-12115.

[3] Dr. S.V. Itti, P. A. (n.d.). A Comparative Study on Seismic Provisions Made in Indian and International Building Code For RC Building.

[4] P.R.Bose, R. M. (1992). *Comparision of Codal Provisions Suggested by Various Countries.* University of Roorkee,India, Earthquake Engineering Department. Rotterdam: Earthquake Engineering, Tenth World Conference.*International Building Code 2009 (USA).*

[5] *CANADIAN (NRC 2005).*

[6] *IS 1893-2002- Indian Standard, Criteria for Earthquake Resistant Design Of Structures, Part 1 General Provisions And Buildings.*

[7] *Uniform Building Code 1997 (USA).*