A Comparative Study on Seismic Provisions Made in UBC-1997 and Saudi Building Code for RC Buildings

S. Nazar, M. A. Ismaeil

***Abstract*—**This paper presents a comparative study of static analysis procedure for seismic performance based on UBC-1997 and *SBC-301-2007(Saudi Arabia).* These building codes define different ductility classes and corresponding response reduction factors based on material, configuration and detailing of reinforcements. Codes differ significantly in specifying the procedures to estimate base shear, drift and effective stiffness of structural members. One of the major improvements made in new SBC (based on IBC-2003) is ground motion parameters used for seismic design. In old SBC (based on UBC) maps have been based on seismic zones. However new SBC provide contour maps giving spectral response quantities. In this approach, a case study of RC frame building located in two different cities and with different ductility classes has been performed. Moreover, equivalent static method based on SBC-301 and UBC-1997 is used to explore the variation in results based on two codes, particularly design base shear, lateral loads and story drifts.

***Keywords*—**Ductility Classes, Equivalent Static method, RC Frames, SBC-301-2007, Story drifts, UBC-1997.

I. Introduction

An earthquake is caused by movement of tectonic plates in earth crust results in severe ground shaking. In the past thirty years moderate to severe earthquakes have occurred in world at intervals of 5 to 10 years caused severe damages and suffering to humans by collapsing the structure, tsunamis, floods, landslides in loose slopes and liquefaction of sandy soils. Socio-economic losses have been increased significantly in the world due to establishment of new cities in earthquake prone areas. In the past these developments in construction have not been followed by guidelines of seismic codes. The effect of horizontal loads like wind loads, earthquake forces and blast forces etc. are attaining increasing importance and almost every designer is faced with the problem of providing adequate strength and stability against horizontal loads. However, structural engineers face major challenges to minimize these damages by proper designing of structure.

By using state-of-the-art design and construction techniques in earthquake engineering may reduce life threats and damages to reinforced concrete buildings. Various types of damages have been found after each disastrous earthquake. Through investigation these damages leaded towards the improvement in the design and construction practices. The intensity of damages depends upon the magnitude of earthquake, its focus & distance from epicenter and soil strata on which structure stands [1].

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Reinforced concrete is being used as major construction material for the construction of multistory buildings since 19th century. Large number of residential and commercial buildings in Middle East has been constructed with parking at basement and first story. These stories are called soft stories having less than 80% stiffness than the story above. As a result, soft stories become more vulnerable to earthquake as in [2]. Reinforced concrete moment frame structure is most common type of construction to resist earthquake. Beam and columns in frame structure are properly proportioned and detailed to resist flexural, axial and shearing actions produced during strong earthquake ground shaking. Various seismic design codes define these frame structures in different ductility classes with specific response reduction factor based on proportioning and detailing of structure. This factor governs the seismic performance of code-designed buildings In addition to; control of drift is an important factor in design and expected seismic performance of building. All codes define procedures to estimate drift and allowable limits of drift, however difference is found due to effective stiffness of structural members as in [3]. Previously zoning for earthquake areas for Kingdom was made on the basis of UBC-91, Later on with the development of seismic codes in world; seismic maps in Kingdom were modified based on IBC 2003. According to the seismic map, most of the Kingdom regions fall in the zone of no and low risk level. Areas along the western coast, especially in the northwest and southwest are considered to be of moderate risk level [4]. In this approach, earthquake response of eight story frame structure building with different ductility and site classes has been studied. Moreover, building response has been compared for two cities i.e. Yanbu with minimum earthquake risk level (seismic zone factor Z= 0.075) and Jazan with maximum earthquake risk level (seismic zone factor Z = 0.2).

II. Seismic Resistant Design of Buildings

The ground motion due to earthquake is characterized by displacement, velocities and accelerations that are erratic in direction, magnitude, duration and sequence. As these ground accelerations are imposed on every unit of mass, resulting earth quake forces are body forces proportional to the mass of building. The layout of lateral force resisting system should be appropriate to ensure that a building responds as a unit when subjected to ground motion. Exact determination of the earth quake forces is almost impossible. As a best approximation, we can assume earth quake forces as a one dimensional body force system and most of the building codes assume this simplification. According to the codes, the resulting earth quake forces are distributed along the height of the building, being zero as at the ground level and maximum at the top. There are two design procedures for incorporation the effect of earth quake forces as given below.

i. Quasi-Static Approach: In this procedure, earth quake forces are treated as static horizontal forces
ii. Dynamic Approach: In this procedure, the building is idealized as a system of spring, dashpots, and mass units inter-connected systematically.

A. Equivalent Static Force Analysis

Equivalent static force procedure is approximation (often gross approximations) of reality which is used for the vast majority of buildings because of the great difficulties associated with realistic dynamic analysis. All loading and design standards and codes for buildings permit equivalent static force analysis for a greater or lesser range of structures. They all start from the simple basis of:
Force = Mass multiplied by Acceleration, which for earth quake is: (Horizontal base shear) = (fixed mass of the building) x (seismic horizontal acceleration) or

$$V = m\ a$$

Earthquake ground motion is three-dimensional (one vertical and two horizontal), Generally, the inertia forces generated by the horizontal components are more critical for seismic design since adequate resistance to vertical seismic loads is usually provided by the member capacities required for gravity load design. These inertia forces are represented by equivalent static forces in the equivalent static procedure. The refinements are made to approach the results obtained from realistic dynamic analyses. The first and common refinement is made by providing rules to distribute the total base shear vertically over the entire building height. UBC gives usually a triangular distribution with an additional point load at the top of the building. While Saudi building code (SBC) gives:

a. A triangular distribution for buildings having a fundamental period not exceeding 0.5 seconds.
b. A parabolic distribution for building having an elastic fundamental period in excess of 2.5 seconds.
c. A linear interpolation between linear and parabolic distribution for buildings with periods between 0.5 and 2.5 seconds [5].

The configuration, structural system and site characteristics are considered while determining these forces. The equivalent static force analysis then takes these distributed forces and determines the resulting moments, shears, etc. by any conventional means. The analysis is done to satisfy the structural performance and acceptable deformation levels prescribed in designed codes. Moreover, the structural members are appropriately detailed to possess the necessary characteristics to dissipate energy by inelastic deformations as in [6].

B. Equivalent Static Method as per UBC-1997

The total design base shear along any principal direction can be calculated by following equation.

$$V = \frac{Cv\,I}{R\,T}.W \tag{1}$$

The total base shear need not to be exceed the following

$$V = \frac{2.5\,Ca\,I}{R}.\,W \tag{2}$$

The total base shear shall not be less than the following

$$V = 0.11\ I\ C_a\ W \tag{3}$$

The approximate fundamental period (T), in seconds, is determined from the following equation:

$$T = C_t\,.\,h_n^{3/4} \tag{4}$$

whereas: C_a and C_v are acceleration and velocity based seismic co-efficients respectively. 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.

The base shear shall be distributed over the height of the structure, including Level *n*, according to the following formula:

$$Fx = \frac{(V-Ft)\ wx\,.hx}{\sum_{i=1}^{n} wi.hi} \tag{5}$$

whereas:

$F_t = 0.07\ T\ V < 0.25\ V$; when $T \le 0.7$ sec.

C. Equivalent Static Method as per SBC-303-2007

According to SBC total base shear (V) can be calculated in accordance with the following equation:

$$V = C_s\ W \tag{6}$$

C_s = the seismic response coefficient
W = total seismic weight of the building

$$C_S = \frac{S_{DS}}{R/I} \tag{7}$$

S_{DS} = the design spectral response acceleration in the short period range as determined from Section 9.4.4 (SBC-301)
R = the response modification factor in Table II.
I = the occupancy importance factor

The value of the seismic response coefficient, (Cs), need not be greater than the following equation:

$$C_S = \frac{S_{D1}}{TR/I} \tag{8}$$

But shall not be taken less than

$$C_s = 0.044\ S_{DS}\ I \tag{9}$$

S_{D1} = the design spectral response acceleration at a period of 1.0 sec, in units of g-sec, as determined from Section 9.4.4
T = the fundamental period of the structure (sec)

The approximate fundamental period (Ta), in seconds, is determined from the following equation:

$$T_a = C_t \, . \, h_n^x \qquad (10)$$

where, h_n is the height in (m).

The lateral seismic force (Fx) (kN) induced at any level shall be determined from the following equations:

$$F_x = C_{vx} V \qquad (11)$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \qquad (12)$$

k = an exponent related to the structure period as follows: For structures having a period of 0.5 sec or less, k = 1, having a period of 2.5 sec or more, k = 2 and for structures having a period between 0.5 and 2.5 seconds, k shall be 2 or shall be determined by linear interpolation between 1 and 2 as in [5].

III. Seismic Design Category

In the 1997 UBC, the permissible structural system, limitations on height and irregularity, type of lateral force analysis, detailing of reinforcements of structural members and joints is determined by seismic zone in which structure is located. While SBC uses the seismic design category (SDC) based on S_{D1} and S_{DS} values, define all these purposes. For a structure SDC needs to be determined twice for SD1 and SDS, the more severe category governs. Table I shows approximate equivalency between UBC-1997 seismic zones and SBC-301 seismic design categories.

TABLE I
Approximate Equivalency between UBC Seismic Zones and SBC Seismic Design Categories

1997 UBC Seismic zones	0, 1	2A, 2 B	3, 4
SBC Seismic Design Category	A, B	C	D, E ,F

IV. Building Ductility Classification and Response Reduction Factors

Ductility is the capacity of materials or structures to absorb energy by deforming into inelastic range. All seismic codes take the effect of inelastic energy dissipation by reducing the design seismic force by a response reduction factor. These codes provide constant response reduction factors for a particular ductility class and construction type [6]. UBC-1997 and SBC-301 classifies RC frame buildings into three ductility classes: Ordinary Moment Resisting Frame (OMRF), Intermediate Moment Resisting Frames (IMRF) and Special Moment Resisting Frames (SMRF) as in [2]-[5]. Value of R is directly related to performance of the building. Therefore SMRF with value of R greater than OMRF and IMRF performs better during earthquake. Table II shows the values for R.

TABLE II
Value of R for UBC and SBC

	UBC	SBC
Response modification factor	R	R
SMRF	8.5	6.5
IMRF	5.5	4
OMRF	3.5	2.5

V. Description and Model of the Building

An eight-story residential building with plan and elevations as shown in Figs. 1 and 2 are considered for study. The building is composed of moment resisting RC frame with solid slab, 150mm thickness, situated in zone 3. The structure members are made of in-situ reinforced concrete. The overall plan of building is rectangular with dimensions 17.5x28m as shown in Fig. 1. Height of the building is 25.6 m and story height for each floor is 3.2m. Columns and beams sizes are 500×400mm. The building is symmetric in both directions. The 3D model of the building is developed in ETABS 13 [7] as shown in Fig. 2. Beams and columns have been modeled as frame elements while in-plane rigidity of the slab is simulated using rigid diaphragm action. The columns are assumed to be fixed at the base. The building is analyzed as per seismic provisions provided by UBC-1997 and SBC-301-2007 respectively. The seismic load according to the relevant codes has been estimated and the building is analyzed for combined effect of gravity and seismic loads as shown in Table III, considering all the design load combinations specified in each code. Analysis results are considered for both cities of Yanbu and Jazan.

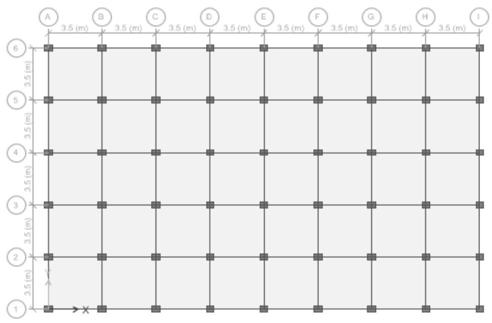

Fig. 1 Plan of building

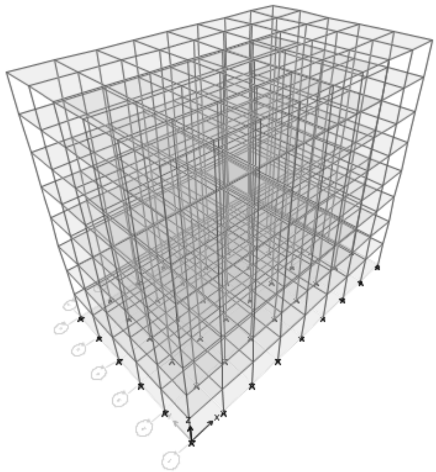

Fig. 2 3-D view of building

TABLE III
GRAVITY LOADS ON BUILDING

Dead Loads	
Water proofing	2.5 KN/m^2
Super Imposed load on roof	1 KN/m^2
Floor Finish	1 KN/m^2
Partitions	3 KN/m^2
Live Loads	
On roof	1 KN/m^2
On floors	3 KN/m^2

VI. LOAD COMBINATIONS AS PER UBC-1997:

According to UBC-1997, following combinations must be used when analysis and design is done by using Load and Resistance Factor Design (Strength Design)

$$1.4D \quad (13)$$
$$1.2D + 1.6L + 0.5\,(Lr) \quad (14)$$
$$1.2D + 1.6\,(Lr) + (f1L) \quad (15)$$
$$1.2D + f1L + 0.5\,(Lr) \quad (16)$$
$$1.2D + 1.0E + (f1L) \quad (17)$$
$$0.9D \pm (1.0E) \quad (18)$$

whereas:

$$E = \rho E_h + E_v \quad (19)$$
$$E = \rho E_h + 0.5CaID \quad (20)$$
$$1.0 \leq \rho \leq 1.5$$

$f1$ = 1.0 for floors in places of public assembly, for live loads in excess of 100 psf (4.9 KN/m^2), and for garage live load.
$f1$ = 0.5 for other live loads.
$f2$ = 0.7 for roof configurations (such as saw tooth) that do not shed snow off the structure.
$f2$ = 0.2 for other roof configurations

VII. LOAD COMBINATIONS AS PER SBC-303-2007:

As per SBC-301 section 2.3, following load combinations should be considered for design of structures, components, and foundations.

$$1.4\,(D + F) \quad (21)$$
$$1.2\,(D + F + T) + 1.6\,(L + H) + 0.5\,(L_r \text{ or } R) \quad (22)$$
$$1.2\,D + 1.6\,(L_r) + (f_1L) \quad (23)$$
$$1.2D + f1L + 0.5\,(L_r) \quad (24)$$
$$1.2D + 1.0\,E + f_1L \quad (25)$$
$$0.9D \pm 1.0E \quad (26)$$

where:

$$E = \rho Q_E + 0.2S_{DS}D \quad (27)$$
$$1.0 \leq \rho \leq 1.5$$

f_1 = 1.0 for areas occupied as places of public assembly, for live loads in excess of 5.0 kN/m2, and for parking garage live load.
f_1 = 0.5 for other live loads.
S_{DS} = the design spectral response acceleration in the short period range as determined from Section.
Q_E = the effect of horizontal seismic (earthquake-induced) forces.

Table V shows the design parameters taken from both codes for analysis of building.

VIII. RESULTS AND DISCUSSION

While comparing the results of both codes, the most significant improvement in seismic design provisions has been found in SBC-301over the UBC-1997 is due to the ground motion parameters used for seismic design. UBC-97 classifies the areas based on seismic zones, although near source factor has been implemented in UBC-97 maps to show the increased ground motion for areas in close proximity with major faults but later was found that all areas in same zone don't have same peak ground acceleration. While in SBC contour maps have been provided to give the spectral response quantities instead of seismic zones. These mapped quantities represent the maximum consider earthquake (MCE) spectral response acceleration, S_s (at short period) and S_1 (1-second period) for site class B.

According to UBC-1997 the structure is to be designed with 10 % probability of being exceeded in 50 years (commonly referred to as 475 year earthquake) therefore it doesn't provide adequate protection for infrequent very large seismic events. While SBC-301 considers this effect of collapse prevention with 2% probability of being exceeded in 50 years (commonly referred to as the 2500 year earthquake) [2]-[5]. The results calculate for both cities are shown below.

A. Base Shear

The building is analyzed to calculate the base shear for Yanbu and Jazan. UBC gives higher values of base shear as compared to SBC. Moreover, base shear also increases as site class changes from hard rock to soft soil and ductility class changes from SMRF to OMRF. Due to low values of Ss and S1, Yanbu has low base shear values as compared to Jazan having maximum risk level as shown in Figs. 3 & 4.

B. Lateral Loads

The results for lateral loads have been compared for only site class-D for both cities. Values of lateral load based on

UBC were found more than the values based on SBC. Also these values increase with change in ductility class from SMRF to OMRF as shown in Figs. 5 & 6. Therefore SMRF provides more resistance to lateral forces on building. Moreover, UBC provides sudden change in slope between top two stories due to additional load on top.

C. Story Displacement

Story displacement has been calculated for site class-D in short and long direction for both cities. The building analyzed by UBC shows more displacement than SBC. Similarly displacement increases as ductility class changes from SMRF to OMRF. Due to maximum lateral forces, top storey shows higher displacement. Moreover, building is more critical in long direction with respect to displacement values. Jazan being located in moderate earthquake zone shows more critical values of displacements and lateral loads as shown in Figs. 7 to 10. For simplicity, all the results for lateral loads, displacement and drift have been calculated for site class D.

IX. Drift (Δ_A)

Drift is generally defined as lateral displacement of one story relative to story below. Drift control is necessary to limit damage to interior partitions, elevator and stair enclosures, glass, and cladding systems. Drift, $\Delta_x = \delta_x - \delta_{x-1}$ (as shown in Fig. 15 and Table IV) where, Drift has been calculated for both cities in short and long direction. These values increase with change in ductility class from SMRF to OMRF. Based on UBC provisions for seismic analysis, drift calculated has been found more than calculated by SBC. Percentage difference in drift by both codes has been calculated as shown in Figs. 11 to 14. 60–70% difference has been found in values of drift for OMRF. While for IMRF and SMRF, drift values by UBC have been observed 20-40% more than by SBC.

TABLE IV
Drift Calculations

UBC	SBC
(Max. inelastic disp.) $\delta_x = 0.7\,R\,\delta_{xe}$	(Max. inelastic disp.) $\delta_x = C_d\,\delta_{xe}/\,I_E$
$\Delta_a = 0.020h_{sx}$ ($T \geq 0.7$ Sec)	$\Delta_a = 0.020h_{sx}$

Where h_{sx} is height below level x.

TABLE V
Design Values for UBC and SBC

SBC	UBC
1. Occupancy Category = II. i.e. I=1	1. Occupancy Category = II. i.e. I=1
2. Mapped Acceleration Co efficient a) Ss = 0.192g , S1 = 0.055g b) Ss = 0.435g, S1 = 0.128g	2. Seismic Zoning , 1 and 2B a) Z = 0.075 b) Z = 0.20
3. Site Class , S_D	3. Site Class , S_D
4. Design spectral response acceleration at short periods and at 1-sec period a) SDS = 0.21 , SD1 = 0.09 b) SDS = 043 , SD1 = 0.199	
5. Seismic Design Category ,(SDC) a) due to SDS = B , due to SD1 = B b) due to SDS = C , due to SD1 = C	
6. Basic Seismic resisting force system a) Special RC moment resisting frame b) Intermediate RC moment resisting frame c) Ordinary RC moment resisting frame	4. Basic Seismic resisting force system a) Special RC moment resisting frame b) Intermediate RC moment resisting frame c) Ordinary RC moment resisting frame
7. Time Period, T = 0.8 sec	5. Time Period, T = 0.832 sec
8. Analysis Procedure : Equivalent Static Force Method	6. Analysis Procedure : Equivalent Static Force Method

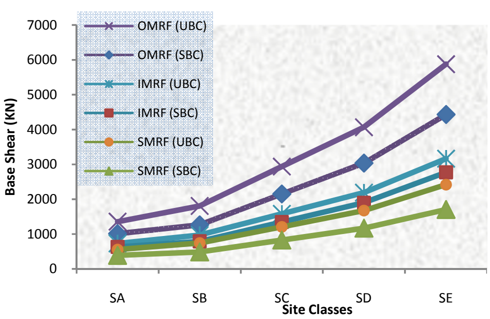

Fig. 3 Base Shear for Yanbu

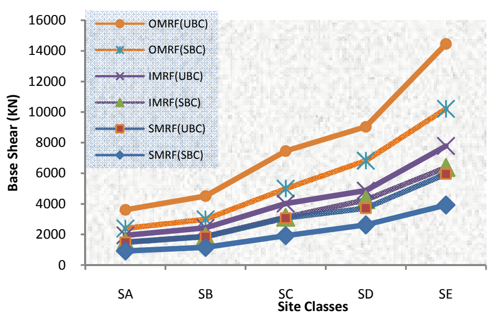

Fig. 4 Base Shear for Jazan

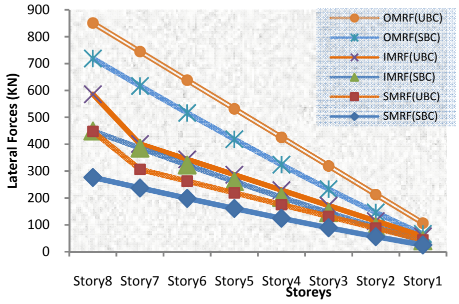

Fig. 5 Lateral Loads for Site Class D (Yanbu)

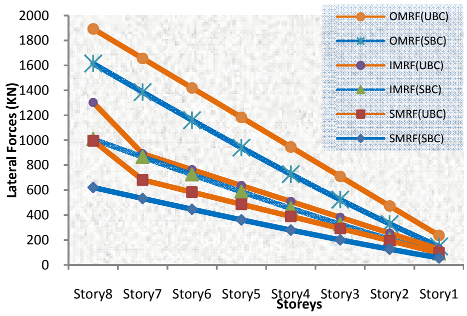

Fig. 6 Lateral Loads for Site Class D (Jazan)

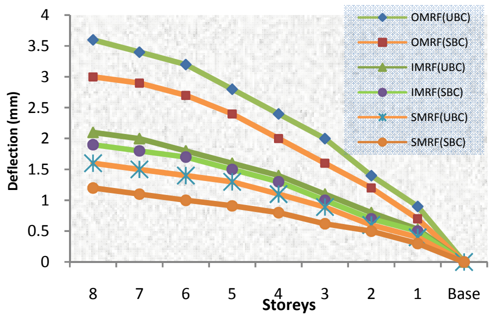

Fig. 7 Story displacement in short-dir for Yanbu

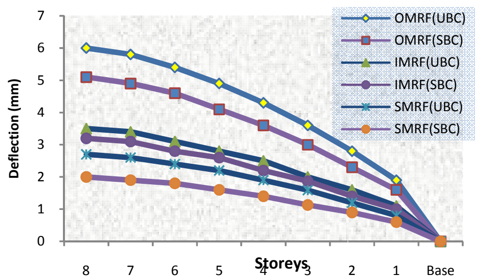

Fig. 8 Story displacement in long-dir for Yanbu

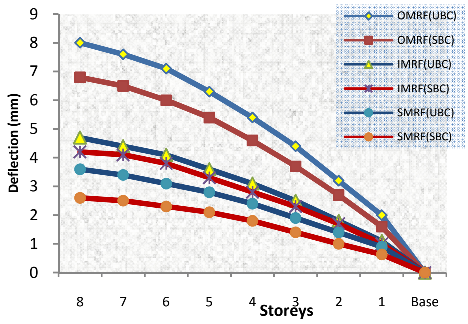

Fig. 9 Story displacement in short-dir for Jazan

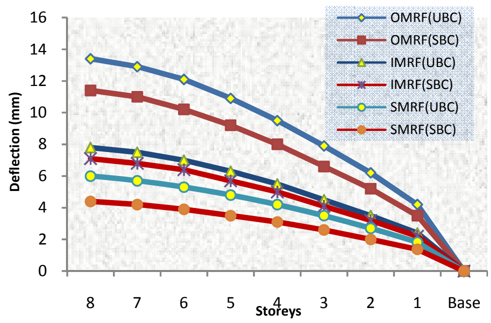

Fig. 10 Story displacement in long-dir for Jazan

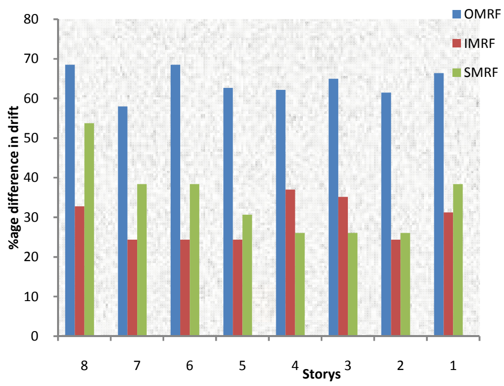

Fig. 11 % age difference in drift for Yanbu (short dir.)

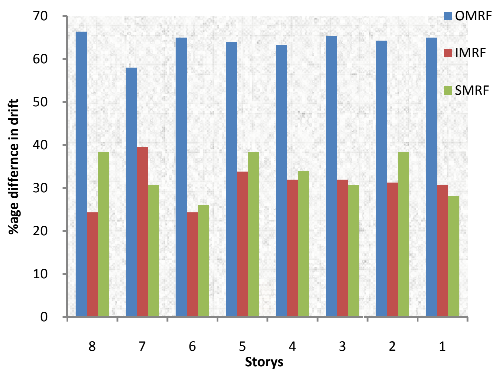

Fig. 12 %age difference in drift for Yanbu (long dir.)

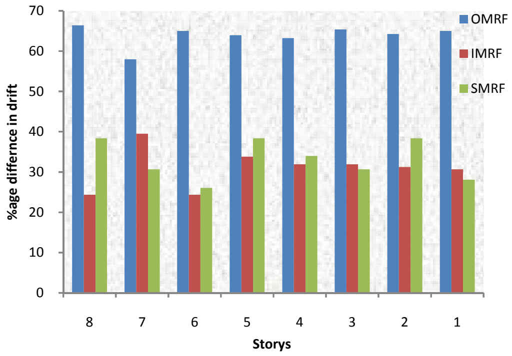

Fig. 13 %age difference in drift for Jazan (short dir.)

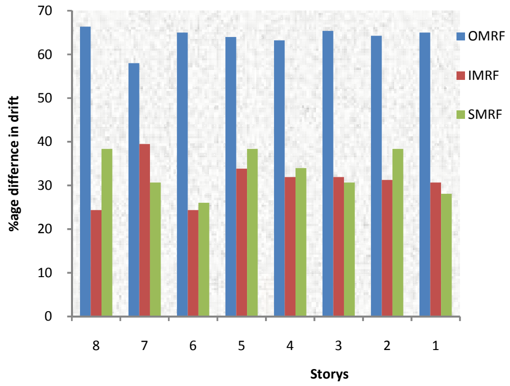

Fig. 14 %age difference in drift for Jazan (long dir.)

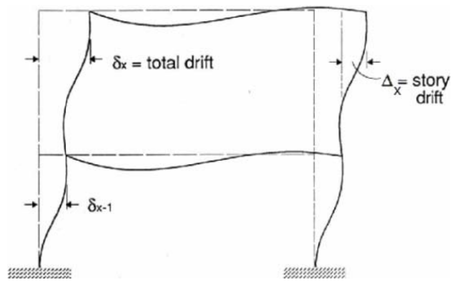

Fig. 15 Deflection of frame structure

X. Conclusions

A comparative study of seismic provisions between UBC and SBC has performed. Furthermore, seismic performance of an eight story RC frame building designed with UBC and SBC with different ductility classes has been compared. From this study following conclusions can be drawn.

1. SBC has been found more sophisticated giving more realistic values than UBC.
2. All areas in same zone doesn't have same ground peak acceleration, therefore in SBC seismic mapped coefficients S_1 and S_s have been introduced, while UBC is based on Seismic zoning Z.
3. In UBC structure height and irregularity, choice of analysis procedure as well as detailing all based on seismic zoning, while in SBC all of these are governed by Seismic Design Category (SDC).
4. Significant variation in strength capacity has been observed for the building design with two codes.
5. The variation in capacity curves may be attributed to differences in response reduction factor, design load combinations, load and material factors.
6. SMRF shows low values for base shear, displacement and drift, while IMRF and OMRF shows higher values because of low values for response reduction factor R.
7. SBC shows parabolic distribution of horizontal force with time period exceeding 2.5 sec, while UBC shows triangular distribution.
8. Drift is recognized as important control parameter by both codes; however they differ in procedures to estimate drift and allowable limits on drift.
9. More than 60% difference in drift has been observed in SMRF while 20-40 % difference in IMRF and OMRF calculated by both codes.

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