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COMPARISON OF OMAN SEISMIC CODE FOR BUILDINGS WITH INTERNATIONAL COUNTERPARTS

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Abstract

The paper presents a comparison of the recently developed Oman Seismic Code (OSC) for buildings with Uniform Building Code 1997 (UBC) and International Building Code 2006 (IBC). OSC utilizes the seismic hazard assessment of the country and is applicable to building heights up to 60 m. OSC categorizes Sultanate of Oman into two zones; a high seismic zone (Zone-1) and a low seismic zone (Zone-2). Muscat the capital of the country falls in Zone-1. According to UBC, Muscat falls in Zone-2A, this definition was used as the reference for zonal equivalence. The paper compares base shear and lateral force distribution obtained from the three seismic codes using equivalent static load method. 4-, 10- and 14- storey buildings having heights of 17 m, 41 m and 57 m, respectively were considered. The buildings were modeled as reinforced concrete having normal occupancy conditions, resting on soil class “C” defined as very dense soil or soft rock. Both zones of OSC were used for comparison. For all building heights and seismic zones, the international codes (UBC & IBC) provided base shear values that were multiple times higher than OSC. For the high seismic zone, values of base shear obtained by using UBC were 7.6, 4.1 and 3.2 times higher and those from IBC were 6.3, 3.3 and 2.6 times higher than those from OSC for the 4-, 10- and 14- storey buildings, respectively. For the low seismic zone, UBC provided 7.8, 4.2 and 3.3 times higher and IBC gave 5.8, 3.1 and 2.4 times more than those obtained from OSC for the 4-, 10- and 14- storey buildings, respectively. Lateral force distribution had the same scale factor as base shear while OSC distribution followed the same distribution pattern as UBC with a slightly smaller allowance for additional force at the top storey. These numbers indicate that the both UBC and IBC provide highly conservative seismic loads on buildings compared with OSC. Therefore, it is essential that the national seismic code be implemented, to make the seismic design more realistic and economical.

Keywords: Oman Seismic Code; Equivalent Static Load Analysis; Seismic Code Comparison; IBC; UBC

1 Introduction

Ground motion resulting from earthquake presents a unique challenge to the design of buildings that are principally designed to carry gravity loads. Earthquakes induce forces that are large in magnitude, act over a short period and must be resisted by the structure without collapse. Further it is essential that structure should be able to handle minor excitation with no or minor damage to minimize maintenance costs. The lateral forces due to earthquakes have a major effect on structural integrity; experience from past earthquakes and research has provided technical solutions that can minimize loss of life and damage to property associated with earthquakes. To ensure desired behavior, seismic codes provide guidelines that laydown essential requirements and procedures for structural design. Due to a wide spectrum of civil infrastructure, specialized regulations are available for each individual category. Among all categories, the most emphasis is laid on seismic design of buildings to avoid loss of life. Many international and national guidelines are developed and enforced to ensure life safety and minimization of damage in general building design. Seismic design is very sensitive to regional seismicity and geography but in absence of any national code, designers need to rely on international guidelines. Therefore, once a national seismic design code is developed, a comparative study with international guidelines is essential. Many countries have established their seismic specification and compared their guidelines with International counterparts to investigate and quantity the differences [1-5].

The Sultanate of Oman is part of the Arabian plate, which comprises of the continent of Arabia as well as oceanic regions of the Red Sea, Arabian Sea, Oman Sea and the Gulf of Aden. No major earthquakes have ever been instrumentally recorded in Oman. The global database, however, lists an earthquake of magnitude 5.1 (Richter scale) in AI-Kamil area in 1971 [6]. Further, there are numerous reports of felt earthquakes [6]. Most of these reports are related to strong earthquakes occurring in regions at distance of more than 1000 kilometers. In 1985, the Ministry of Petroleum and Minerals adopted a written survey form for felt earthquakes. But no quantification was done. As knowledge of seismic risk and its assessment are important socioeconomic concern for any country, an extensive seismic hazard assessment for the major regions of the country was carried out [7-9] to improve and optimize the infrastructure design in the country. These studies were utilized to develop the seismic code for design of buildings in Oman [10] that shall help to achieve optimized design, safety and performance of buildings. The code [10] provides specific seismic design requirements for reinforced concrete, steel, composite and masonry structures that are in compliance with the respective eurocodes [11, 12, 13, 14].

This research provides a comparison of the Oman Seismic Code (OSC) [10] with the international counterparts, the International Building Code 2006 (IBC) [15] and the Unified Building Code 1997 (UBC) [16]. These international standards are the ones currently employed for seismic design of buildings in the country. The study shall compare the base shear and lateral force distribution along the building height using the equivalent static load method. Three building heights of 17m, 41 m and 57 m are considered having 4-, 10- and 14- stories, respectively.

2 Oman Seismic Code for Buildings

In OSC [10], the Sultanate of Oman has been divided into two seismic zones. Zone 1 is the high seismic hazard zone that covers the region including Muscat, Sohar, Diba and Khasab. Zone 2 is the low seismic hazard zone addressing areas that include cities of Nizwa, Sur and Salalah. The code [10] defines elastic spectral accelerations for the two zones depending on the type of soil as shown in Table 1. These values are the basis for estimation of seismic action in the code using elastic response spectrum that is similar fashion as done in EC-8 [17]. OSC [10] provides detailed procedures for seismic design of buildings based on Equivalent Seismic Load Method, Multi-mode Response Spectrum Analysis Method and Response History Analysis Method specified for low-rise, medium-rise and high-rise buildings. In OSC, Low-rise buildings are defined as buildings with a total height not exceeding 20 m. Mid-rise buildings are defined as buildings with a total height between 20 m to 40 m and high-rise buildings are defined as buildings with a total height more than 40 m but not exceeding 60 m. Building heights are to be measured from ground floor level. The code further provides guidelines for detailing and design of reinforced concrete, steel and masonry structures that compliments the respective eurocodes [11, 12, 13, 14].

Table 1 – Elastic spectral accelerations & seismic zonation [10]

Local Soil Class	Oman Seismic Zone			
	Zone – 1 (Muscat, Sohar, Diba, Khasab)		Zone – 2 (Nizwa, Sur, Salalah)	
	S_{SD} (g)	S_{1D} (g)	S_{SD} (g)	S_{1D} (g)
A	0.16	0.064	0.08	0.032
B	0.20	0.080	0.10	0.040
C	0.24	0.136	0.12	0.068
D	0.32	0.192	0.16	0.096
E	0.50	0.280	0.25	0.140
F	Site-specific geotechnical investigation and dynamic site response analysis required			
S_{SD} - Short period elastic spectral acceleration S_{1D} - One second elastic spectral acceleration				

3 Methodology

The study considers zone equivalence among the codes based on seismic zone tabulation of UBC [16] for regions outside USA. Muscat is defined as zone 2A by this zone tabulation which in turn makes Muscat zone-II in IBC [15]. Since Muscat belongs to Zone-1 in OSC [10], the low seismic zone of OSC (Zone-2) is therefore equivalent to Zone-1 of UBC and Zone-I of IBC. The study considers a simple reinforced concrete moment resisting frame buildings with normal occupancy conditions with varying heights. All buildings are assumed to be situated on very dense soil or soft rock, which is classified as type "C" in the three codes.

3.1 Structural System

A simplified building layout with a foot print of 25 m x 25 m is considered with a grid spacing of 5m x 5m. Fig. 1 shows the typical structural plan used for all buildings in the study. The first story is considered to have a height of 5m and all subsequent storeys have a constant height of 4m. The buildings are subjected to typical values of permanent and variable actions in addition to the seismic action calculated using equivalent static method (to be discussed in the next sub-section) for the respective seismic code. The following three building heights are considered in this study:

- 4-Storey Building: G + 3 floors, total height = 17 m.
- 10-Storey Building: G + 9 floors, total height = 41 m.
- 14-Storey Building: G + 13 floors, total height = 57 m.

Table 2 – Gravity loads acting on the building

Description	Typical Floor	Roof
Permanent action		
Self-weight of 150 mm thick Slab = 0.15 x 25 (kN/m^2)	3.75	3.75
Finishes and services (kN/m^2)	2.50	3.60
Total (kN/m^2)	6.25	7.35
Wall / parapet load along periphery (kN/m)	20.4	4.8
Variable Action (kN/m^2)	3.00	3.00

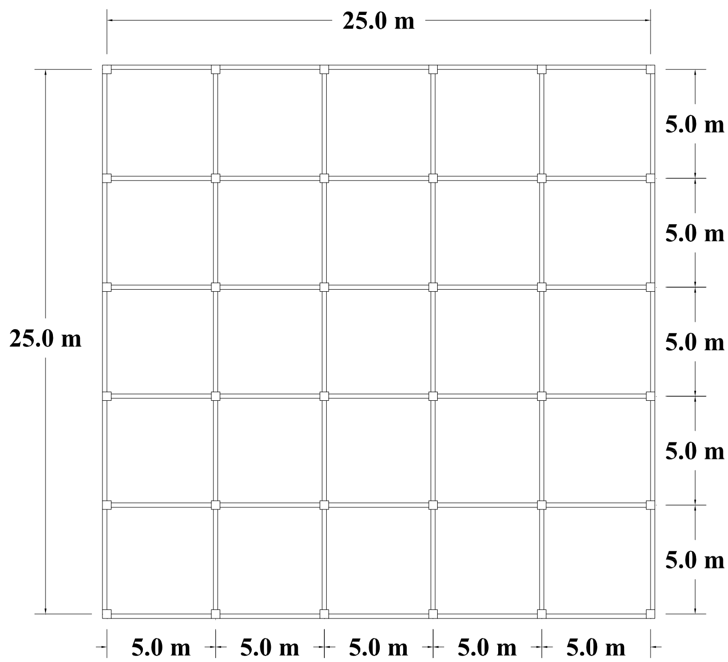

Fig. 1 – Typical plan at each floor level for all building heights

All beams in the building are considered to have dimensions of 600 mm x 200 mm while all columns are considered to be 400 mm x 400 mm. Compressive strength of 35 MPa is used for concrete and reinforcement has yield strength of 460 MPa. These dimensions and parameters are based on the norms in the construction industry in Oman. The gravity loads considered to act on the building are summarized in Table 2. ETABS [18] software package was used for the numerical modeling of the buildings. The software automatically calculates the storey weight and total structural weight using these loading and member details.

3.2 Equivalent Static Method

OSC [10], IBC2006 [15] and the UBC97 [16], each has its own set of specifications for calculation of base shear 'V' and distribution of the lateral force along the building height. This section shall briefly review the equations for the equivalent static method from each code. The values adopted for the different seismic parameters in this study have been indicated in their context.

3.2.1 Omani Seismic Code (OSC)

Total equivalent seismic load (base shear) in the direction of earthquake shall be calculated by Eq. (1);

$$V = {W_t}/{g}\, S_{AR}(T) \geq 0.11\, {W_t}/{g}\, S_{SD} I \tag{1}$$

Where 'W_t' is the total seismic weight of the structure, 'S_{AR}' represents design (reduced) spectral acceleration calculated as:

$$S_{AR}(T) = \frac{S_{AE}(T)}{q_R(T)} \tag{2}$$

'$q_R(T)$' is the seismic load reduction factor calculated as:

$$q_R(T) = 1 + \left(\frac{q}{I} - 1\right)\frac{T}{T_S} \qquad (T \le T_S)$$
$$q_R(T) = \frac{q}{I} \qquad (T > T_S) \tag{3}$$

Where 'q' is the behavior factor that has a value of 3.5 for concrete buildings with moment resisting frame system. The occupancy importance factor 'I' is taken as 1 for normal occupancy. The code suggests using Rayleigh quotient method for estimation of prominent period. 'S_{AE}' is the elastic spectral acceleration based on the prominent natural period 'T' that is calculated as follow in OSC:

$$S_{AE}(T) = \begin{cases} 0.4S_{SD} + 0.6\frac{S_{SD}}{T_0}T & T < T_0 \\ S_{SD} & T_0 < T < T_S \\ S_{1D}/T & T_S < T < T_L \\ S_{1D}T_L/T^2 & T_L < T \end{cases} \tag{4}$$

$$T_S = \frac{S_{1D}}{S_{SD}} \quad ; \quad T_0 = 0.2T_S \tag{5}$$

Where 'S_{SD}' and 'S_{1D}' are seismic coefficients associated with short period and one second elastic spectral acceleration respectively. 'S_{SD}' and 'S_{1D}' are based on the geographic location of the structure (seismic zone) and soil conditions at the site as shown in Table 1. 'T_L' is the transition limit of response spectrum to long-period range taken as 8 sec in OSC. 'T_0' defines the start of the acceleration plateau and 'T_S' defines its end calculated using Eq. (5) based on the zone and soil type. The elastic spectrum can been graphically summarized as shown in Fig. 2.

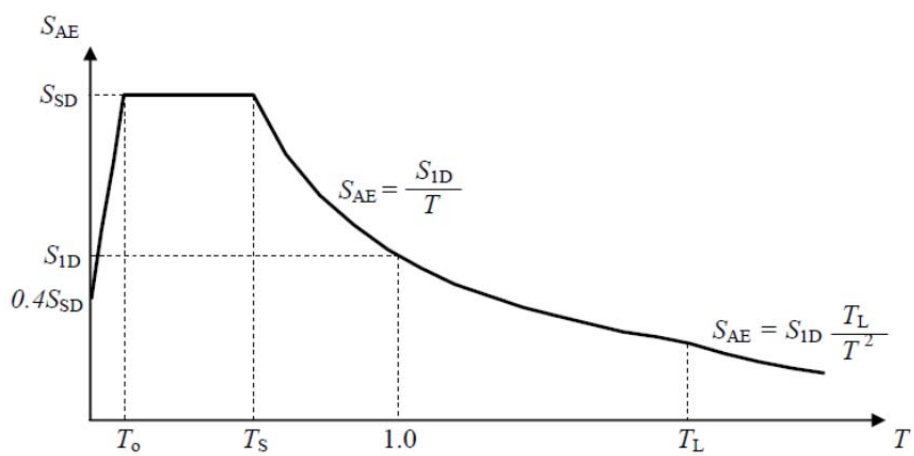

Fig. 2 – Elastic Response Spectrum from OSC [10]

The lateral force 'v_i' for the 'i^{th}' storey is calculated using the following formula:

$$v_i = (V - \Delta F_N)\frac{w_i h_i}{\sum_{i=1}^{N} w_i h_i} \tag{6}$$

'w_i, h_i' are the seismic weight and overall height of the 'i^{th}' storey, respectively. The seismic mass typically includes the total weight of the floor or ceiling/roof system at the level, plus half the weight of the vertical elements (walls; columns) located immediately below that level and half the weight of the vertical elements located immediately above that level. An additional seismic force 'ΔF_N' should be considered to act at the top floor (roof) of the building to account for contribution of higher vibration modes. It is based on the total number of stories in the building 'N' and base shear 'V' as given by Eq. (7).

$$\Delta F_N = 0.0075NV \tag{7}$$

3.2.2 International Building Code 2006 (IBC)

In IBC [15], the base shear is calculated based on the natural period of the structure 'T' and is given as:

$$V = C_s W \tag{8}$$

If $T < T_L$:

$$C_s = \min\left(\frac{S_{DS}}{\left(R/I\right)}, \frac{S_{D1}}{\left(R/I\right)T}\right) \tag{9}$$

If $T > T_L$:

$$C_s = \frac{S_{D1}T_L}{\left(R/I\right)T^2} \tag{10}$$

But for all periods:

$$C_s \geq 0.044\left(2/3\right)S_{DS}I \tag{11}$$

Where 'W' is the structure's seismic weight. 'S_{DS}' and 'S_{D1}' are design spectral response accelerations for short (0.2 second) periods of vibration and for longer (1.0 second) periods of vibration, respectively. These are based on the maximum spectral response accelerations 'S_S' and 'S_1' associated with the geographic location of the structure and soil conditions at the site using Eq.(12) and Eq.(13).

$$S_{DS} = 2/3\, F_a S_S \tag{12}$$

$$S_{D1} = 2/3\, F_v S_1 \tag{13}$$

'F_v' and 'F_a' are based on the type of soil and seismic zonation. For this study, as per IBC [15], $S_S = 0.25$, $S_1 = 0.10$ for Zone-I and $S_S = 0.50$, $S_1 = 0.20$ for Zone-II. This leads to a value of $F_a = 1.2$ for both zones and $F_v = 1.7$ and 1.6 for Zone-I and Zone-II, respectively. In IBC, the natural period of the structure can be estimated by:

$$T = C_t\left(h_n\right)^x \tag{14}$$

Where $C_t = 0.044$ and x=0.90 for moment resisting concrete structure, 'h_n' represents the total height of the structure. In this study, response modification factor $R = 3$ and occupancy importance factor $I = 1$ is used. The lateral force 'v_i' for the 'i^{th}' storey is determined from the following formula:

$$v_i = \frac{V \times w_i h_i^k}{\sum_{i=1}^{n} w_i h_i^k} \tag{15}$$

'w_i, h_i' are the seismic weight and overall height of the 'i^{th}' storey, In Eq. (15), the superscript 'k' has a value of 1 for structures with a fundamental period 'T' less than or equal to 0.5 sec, and has a value of 2 for structures with a fundamental period greater than or equal to 2.5 sec. For structures having a period between 0.5 and 2.5 sec, 'k' shall be 2 or can be determined by linear interpolation between 1 and 2.

3.2.3 Uniform Building Code 1997 (UBC)

UBC specifies the following formula for calculating base shear ‘V’ on the structure while defining the upper and lower bounds for its values:

$$V = \frac{C_v IW}{RT} \quad ; \quad \frac{0.11 C_a IW}{R} \leq V \leq \frac{2.5 C_a IW}{R} \tag{16}$$

Where ‘W’ is the seismic weight of the structure, ‘I’ is the Importance factor that depends on occupancy and usage of the building, ‘R’ is ductility and over strength factor that depends on the basic structural system and lateral-force resisting system of the building. ‘C_v’ and ‘C_a’ are seismic coefficients associated with structure’s sensitivity to the velocity and acceleration of seismic ground motion, respectively. These are based on the geographic location of the structure (seismic zone) and soil conditions at the site. $C_v = 0.13$, $C_a = 0.09$ are used for Zone-1 and $C_v = 0.25$, $C_a = 0.18$ are adopted for Zone-2A. The over strength factor R= 4.5, the Importance factor I=1 for this study. In Eq (16), the upper bound for base shear tends to govern for stiff structures while lower bound tends to govern for flexible structures. In UBC, the prominent natural period of a building with height ‘h_n’can be calculated as:

$$T = C_t \left(h_n\right)^{3/4} \tag{17}$$

$C_t = 0.0731$ is used to reinforced concrete moment-resisting frames. The lateral force ‘v_i’ for the ‘i^{th}’ storey of the building is estimated from the following formula:

$$v_i = \left(V - F_t\right) \frac{w_i h_i}{\sum_{i=1}^{n} w_i h_i} \tag{18}$$

‘w_i, h_i’ are the seismic weight and overall height of the ‘i^{th}’ storey, respectively. ‘F_t’ is an additional lateral force assumed to act at the top of the structure. This force is intended to approximate the effect of higher modes of vibration. The magnitude of ‘F_t’ is determined based on the natural period of building ‘T’ and base shear ‘V’, as given in Eq. (19).

$$F_t = \begin{cases} 0 & T < 0.70\,\text{sec} \\ 0.07TV & 0.70\,\text{sec} < T < 3.6\,\text{sec} \\ 0.25V & T > 3.6\,\text{sec} \end{cases} \tag{19}$$

4 Results and Discussion

4.1 Prominent Natural Period

Table 3 gives the prominent natural period of the three buildings. Rayleigh’s quotient method in ETABS was used for OSC, while Eq.(14) and Eq. (17) were used for IBC and UBC, respectively. A clear discrepancy between empirical values (Eq.(14) and Eq. (17)) and calculated value (Eq. (18)) is evident from the comparison. This difference is due to the absence of shear walls in the buildings considered in this study that render the structure flexible. Further, this study has ignored the contribution of infill walls to lateral force resistance that results in reduced lateral stiffness. Since the prominent period directly effects base shear calculations, program calculated value of prominent period is used to calculate the base shear in all three codes.

Table 3 – Prominent natural period

Building Type	Total building height 'h_n' (m)	Prominent Period (sec)		
		OSC [18]	IBC Eq. (14)	UBC Eq. (17)
4 Storey	17	1.70	0.56	0.61
10 Storey	41	3.90	1.24	1.18
14 Storey	57	5.60	1.67	1.52

4.2 Base Shear

The results of base shear are summarized in Fig. 3 as low and high seismic zone definitions according to OSC. The low seismic zone represents Zone-2 of OSC, Zone-I of IBC and Zone-1 of UBC while the high seismic zone represents Zone-1 of OSC, Zone-II of IBC and Zone-2A of UBC. The values of base shear obtained using OSC are much less than those from either IBC and UBC, while UBC provides the highest among the three codes for all building heights and seismic zones. The base shear values for the high seismic zone are almost twice of the values for low seismic zone as it should be based on criterion for seismic zonation. Table 4 shows comparison of base shear obtained from IBC and UBC as a ratio of the values with respect to OSC. The ratio range between 2.4 to 6.3 for IBC while 3.2 – 7.8 for UBC for the three building types and two seismic zones. It can be observed in Table 4 that the ratio decreases with increases in number of storeys / building height for IBC as well as UBC. The principal reason for his discrepancy is higher spectral acceleration of the seismic zone defined by the international codes (IBC and UBC). Table 4 further shows the ratio of low to high seismic zone for all the buildings which is the same for all building heights for both the international codes. It indicates that IBC considers a larger amplification in base shear across the seismic zones compared to OSC while UBC considers a slightly lesser gain.

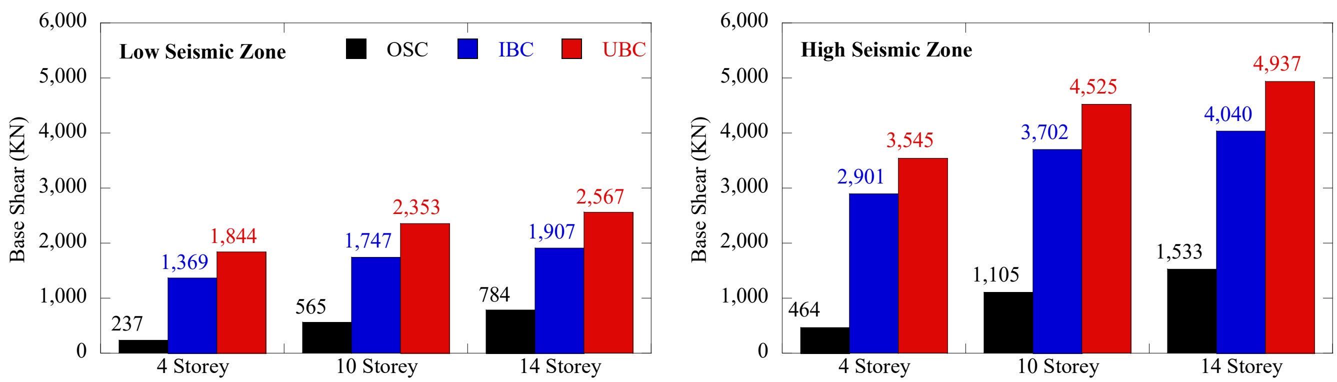

Fig. 3 – Comparison of base shear using the three codes for low (left) and high (right) seismic zones

Table 4 – Ratio of base shear w.r.t OSC

Building Type	IBC/OSC			UBC/OSC		
	Low	High	High/Low	Low	High	Low/High
4 Storey	5.8	6.3	108.4 %	7.8	7.6	101.6 %
10 Storey	3.1	3.3	108.4 %	4.2	4.1	101.6 %
14 Storey	2.4	2.6	108.4 %	3.3	3.2	101.6 %

4.3 Lateral Force Distribution

The distribution of the lateral force on individual storey level for the two seismic zones for the 4-, 10- and 14-storey buildings are shown in Fig. 4, Fig. 5 and Fig. 6, respectively. IBC and UBC provide much higher values of the storey force similar to what was discussed for the base shear. For the 4-storey building (Fig. 4), all the three codes have almost linear force distribution. This indicates that all the codes neglect the contribution of higher modes for this building height. The lateral force at each storey in both zones from UBC has a constant ratio with respect to OSC counterpart, which is the same as listed in Table 4 for base shear. This is because of the similar storey shear distribution model in OSC {Eq (6)} and UBC {Eq(18)}. Further, it indicates that for this storey height, the additional force at the top story is insignificant in both the codes. For IBC these ratios of individual storey shear increases with storey height reflecting the nonlinear distribution utilized in IBC {Eq. (15)} in contrast to the linear pattern of OSC and UBC.

For the 10-storey building (Fig. 5), an additional force on the top floor to account for higher modes is clearly observed in UBC and OSC, while the distribution for IBC gets a slight concave to account for higher modes. The ratio of intermediate storey force shows the same trend as 4-storey building and is same as listed in Table 4 (i.e. 4.2 for low seismic zone and 4.1 for high seismic zone). But, the ratio of top storey force for UBC has a 3% higher value compared to the ratio for base shear. For the 14-storey building trend continues to be similar as observed for the 10-storey but the ratio of the lateral force at the top storey from UBC is 4.0 % higher than the ratio in Table 4 for this case. This indicates that though both OSC and UBC account for the higher modes using a similar approach, OSC has a smaller allowance for the additional force [Eq. (7)] at the top storey compared to UBC [Eq. (19)]. The allowance in OSC further does not follow the same trend with increase in building height as UBC.

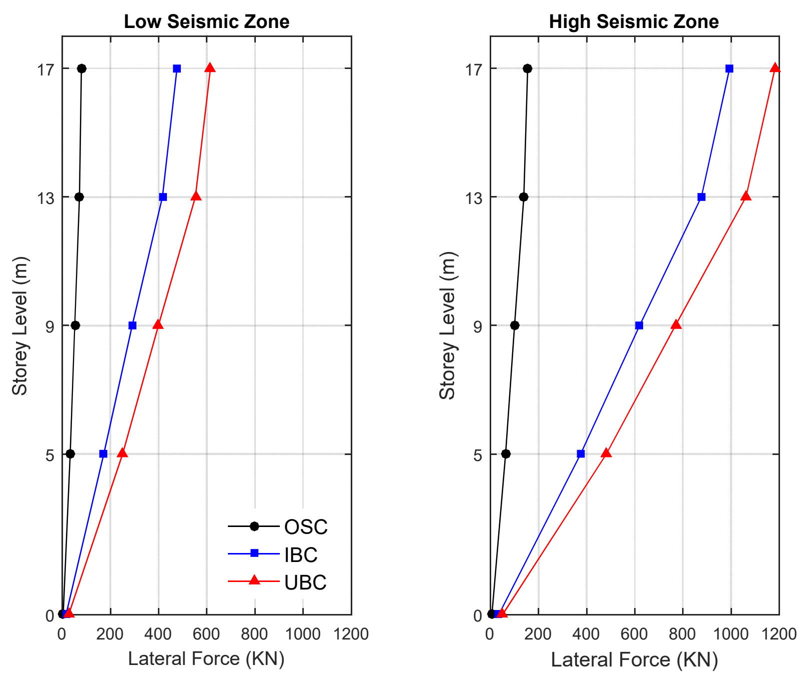

Fig. 4 – Comparison of lateral force distribution for 4 – storey building

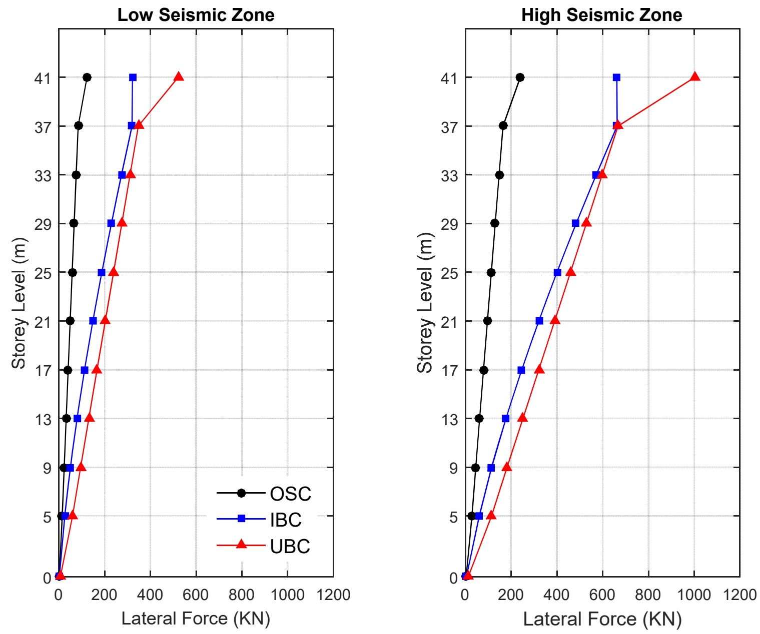

Fig. 5 – Comparison of lateral force distribution for 10 – storey building

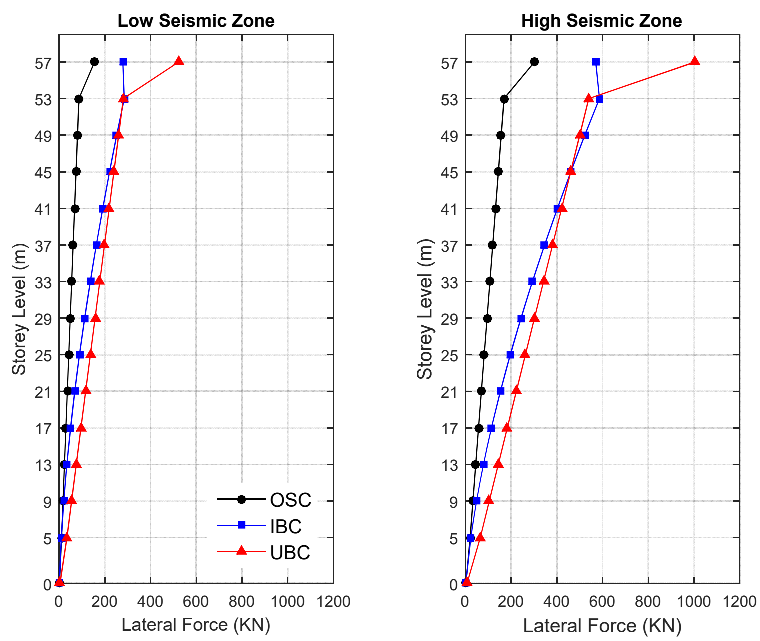

Fig. 6 – Comparison of lateral force distribution for 14 – storey building

5 Conclusions

The study presented a comparison of the Oman Seismic Code (OSC) with international codes UBC1997 and IBC2006. Magnitude of base shear and lateral force distribution using equivalent static method were compared. The two seismic zones of OSC (Zone-1 and Zone-2) were compared to equivalent seismic zones in UBC (Zone-2A and Zone-1) and IBC (Zone-II and Zone-I), respectively. Three building heights of 17 m, 41 m and 57 m were considered having 4-,10- and 14- storeys, respectively. OSC was found to provide much smaller value of base shear for both seismic zones and all building heights in comparison to UBC and IBC. For high seismic zone

(OSC: Zone-1), UBC provided base shear 3.2 - 7.6 times that of OSC, while IBC gave 2.6 - 6.3 times those from OSC. For low seismic zone (OSC: Zone-2), base shear using UBC and IBC were 3.3 - 7.8 times and 2.4 - 5.8 times higher than OSC, respectively. It is observed that the ratio reduced with building height for both international codes, while UBC gave relatively higher ratio for low seismic zone and IBC showed larger ratios for high seismic zone. For lateral force distribution, the ratio of individual storey force from IBC increased with respect to OSC with building height. For UBC, this was the same constant ratio as the base shear except slight difference for the top storey due to the additional force. This comparison indicates that the international seismic codes greatly overstate the seismic forces on buildings for Oman which is because of the conservative zone definition made by UBC. It is, therefore, essential to adopt OSC in design of building in the country to improve the economy of seismic design.

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