Comparison of Seismic and Wind Actions on Medium to High-Rise Buildings in Muscat, Oman

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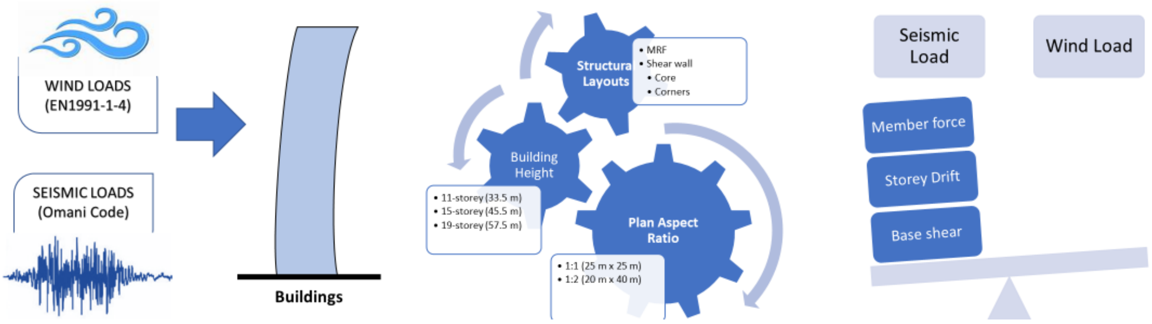

ABSTRACT: This study is a comparison of wind and seismic loads on medium and high-rise buildings in Muscat, Oman. It uses the proposed Omani Seismic Code and Eurocode EN1991 for seismic and wind calculations, respectively. Muscat falls under Zone-1 in the Omani seismic code and experience basic wind speed of 30 m/sec. The research investigates buildings with varying aspect ratios (1:1 and 1:2), heights (11, 15, and 19 stories), and structural layouts (frame only, core shear wall, and corner shear wall), using ETABS for structural analysis. The findings reveal that seismic actions are generally more significant than wind actions for buildings in Muscat. In frame-only structures, wind-induced base shear ranges from 16%-33% for 1:1 aspect ratio and 21%-43% in the x-direction and 10%-20% in the y-direction for 1:2 aspect ratio, when compared to seismic actions. This difference decreases with increasing building height. Incorporating shear walls notably reduces the maximum lateral displacement across all scenarios, with core-located walls being most effective, leading to a 49% reduction in lateral displacement. Shear walls also substantially mitigate first-story column shear forces and bending moments. The study concludes that seismic actions are more critical than wind actions in Muscat for simple moment-resisting frame systems. Additionally, using shear walls in these buildings is highly beneficial for controlling lateral displacements and reducing member forces.

الملخص: إن الهدف من هذه الدراسة هو مقارنة الأحمال الناجمة عن قوى الزلازل والرياح على المباني متوسطة وعالية الارتفاع في مسقط بسلطنة عُمان، تم استخدام الكود العماني المقترح والكود الأوروبي لحساب تأثير قوى الزلازل والرياح. تقع مسقط ضمن المنطقة-1 حسب الكود الزلزالي العماني وسرعة رياح تصميمية تبلغ 30 م/ث. تم تحليل مباني ذات نسب أبعاد مختلفة (1:1 و1:2) وارتفاعات (11، 15، و19 طابقًا) وتصاميم هيكلية متنوعة (إطار فقط، جدار قص مركزي، وجدار قص زاوية)، باستخدام برنامج ETABS للنمذجة والتحليل الهيكلي. أظهرت النتائج أن أحمال الزلازل هي أكثر أهمية من الأحمال الناجمة عن الرياح في هياكل المباني ذات الإطار فقط، وقد تراوحت قوة القص الناتجة عن الرياح بين 16%-33% لنسبة الأبعاد 1:1، وبين 21%-43% في الاتجاه x و10%-20% في الاتجاه y لنسبة الأبعاد 1:2 مقارنة بأحمال الزلازل. مع العلم بأن هذه الفروقات تقل مع زيادة ارتفاع المبنى. كما أن استخدام جدران القص تقلل بشكل ملحوظ من الازاحات الجانبية الكبيرة في جميع اشكال المباني تحت الدراسة، وتكون الجدران الموجودة في المركز أكثر فعالية، مما يؤدي إلى تقليل الازاحات الجانبية الكلية بنسبة 49%. بالإضافة إلى ذلك، تعمل جدران القص على الحد بشكل كبير من قوى القص وعزوم الانحناء في أعمدة الطابق الأول. وقد خلصت الدراسة إلى أن الأحمال الناجمة عن الزلازل تُعد أكثر خطورة من أحمال الرياح بالنسبة لأنظمة الإطار المقاوم للعزوم البسيطة في مسقط، وأن استخدام جدران القص في هذه المباني يعد حلاً فعالاً للغاية في التحكم في الازاحات الجانبية وتقليل قوى الأجزاء المختلفة للمبنى.

Keywords: Medium- and High-Rise Buildings, Seismic Actions, Wind Actions, Oman Seismic Design Code, Eurocode, Shear Wall.

الكلمات المفتاحية: المباني متوسطة وعالية الارتفاع؛ الأعمال الزلزالية؛ أعمال الرياح؛ قانون تصميم الزلازل العماني؛ الكود الأوروبي؛ الجدار القصي.

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NOMENCLATURE

A_c	Total area of shear wall on the first floor (m^2)
A_j	Area of the 'jth' shear wall on the first floor (m^2)
c_o	Orography factor
c_r	Roughness factor
c_e	Exposure factor
$c_{pe,w}$	Coefficient of external pressure for the windward face.
$c_{pe,l}$	Coefficient of external pressure for the leeward face.
c_sc_d	The structural factor for calculation of wind pressure
C_t	Coefficient for calculation of natural period 'T'
d	Dimension of the Building in the direction of the wind.
F_t	Additional force at the top storey to account for higher modes (kN)
h	Height of the Building facing the wind (m)
h_i	Height of the ith-storey above ground (m)
h_n	Total building height (m)
I	Importance factor
I_v	Turbulence intensity
kr	Terrain factor for wind profile
l_{wj}	Plan length of the 'jth' shear wall on the first floor (m)
N	Number of storeys in the building
q	Behavior factor
$q_R(T)$	Seismic load reduction factor for period 'T'
q_p	Peak velocity pressure (Pa)
S_{1D}	1.0 second elastic spectral acceleration (g)
S_{AE}	Elastic spectral acceleration (g)
S_{AR}	Design (reduced) spectral acceleration (g)
S_{SD}	Short period elastic spectral acceleration (g)
T	Prominent natural period of the building (sec)
T_0	Initial Spectral period (sec)
T_L	Long spectral period (sec)
T_S	Short spectral period (sec)
v_b	Basic design wind speed (m/sec)
v_i	Shear force at the ith-storey (kN)
V	Base shear (kN)
w_e	Wind pressure (Pa)
w_i	Weight of the ith-storey (kN)
W	Total seismic weight of the structure (kN)
ΔF_N	Additional force at the top storey to account for higher modes (kN)
z	Height above the ground level for wind profile (m)
z_0	Minimum wind profile elevation (m)
$z_{0,II}$	Minimum wind profile elevation for terrain category -II (m)
z_{min}	Minimum wind profile elevation for use in wind speed profile equation
ρ	density of air (kg/m^3)

INTRODUCTION

The rapid urbanization of Muscat has started to change the urban landscape with a surge in tall apartment buildings. Lateral loading due to strong wind or an earthquake plays a key role in the design of medium and high-rise buildings. These may govern the design of such buildings in some cases. The Sultanate of Oman is situated in the southeastern part of the Arabian plate, surrounded by active tectonic zones. The Oman Seismic Network, over the period of 2003-2017, recorded, on average, 1292 earthquakes every year. This included 398 (ave.) regional events, with 66 (ave.) having epicentres in the Oman Mountains or the Gulf of Oman. On the other hand, Oman has a 3,165 km long coastline that exposes it to strong tropical winds. In 2007, cyclone Gonu and in 2022 cyclone Shaheen caused widespread damage to property and also led to loss of life (El Rafy, M. and Hafez, Y. 2008; Shaheen 2021).

In Oman, building design is principally based on gravity loads and lateral loading is generally ignored. This may not be serious for low-rise residential buildings, but the design of medium and high-rise buildings should consider lateral loading due to wind and earthquakes. Since these types of Buildings are becoming more common, it is essential to account for these lateral loads in design. The nature and characteristics of these two types of loads are very different. However, the way these loads are considered in the analysis and their effect on a building are very similar.

Many structural parameters play a role in the behaviour of a building under wind and seismic loading. The most significant is the building height, where an increase in building height causes an increase in the magnitude of base shear and lateral displacement (Badami & Suresh 2014, Hirde & Magadum 2014, Tidke & Katti 2015, Waris et al. 2017, Waris et al. 2022 Chandradhara & Vikram 2016, Sadh & Pendharkar 2016, Getachew et al. 2020). The aspect ratio of the building is found to have a significant on wind loads as it directly affects the exposed area of the building, leading to an increase in the base shear and member forces (Sadh & Pendharkar, 2016; Chandradhara & Vikram, 2016, Haritha & Srivalli 2013, Venkanna & Avinash 2016). The presence and location of the shear wall have a more significant effect on seismic loads due to the change in stiffness and natural period of the building. The magnitude of wind actions is unaffected; however, the response is changed due to a change in stiffness (Badami & Suresh 2014, Biswas et al. 2013, Harne 2014, Hiremath & Hussain 2012, Lakshmi et al. 2014, Raju & Balaji 2015, Suresh & Yadav 2015, Suresh & Yadav 2015, Seo et al. 2015).

The external factors affecting wind load include the maximum wind speed, the topography, and the built environment around the structure. On the other hand, seismic loads are affected by seismology and the soil characteristics at the site. Since both wind and seismic loads depend upon the local geographical, topological, and seismological characteristics, several regional studies have been carried out to identify the critical type of lateral for the particular location. Since the nature of the two types of loads is unique, most research focuses on either wind loads (Chandradhara & Vikram, 2016; Haritha & Srivalli, 2013; Venkanna and Avinash, 2016) that considers the effect of aspect ratio as the primary parameter along with terrain categories. Others considered seismic loads only to investigate the effect of shear walls (Badami & Suresh 2014, Harne 2014, Hiremath & Hussain 2012, Lakshmi et al. 2014, Raju & Balaji 2015, Suresh & Yadav 2015) and the building height (Sadh & Pendharkar 2016, Waris et al. 2017, Getachew et al. 2020, Waris et al. 2022). Some of these studies also compared the method of seismic load estimation using equivalent static or response spectrum analysis (Lakshmi et al. 2014; Waris et al. 2022).

Studies available on the comparison of the two types of loads on buildings did not consider all the parameters that affect both the seismic and wind loads. Some considered the effect of shearwall (Biswas et al. 2013, Suresh & Yadav 2015), some focused on building height (Hirde & Magadum 2014, Tidke & Katti 2015, Getachew et al. 2020), while others discussed case studies for real buildings (Heiza & Tayel 2012, Suresh & Yadav 2015, Raju et al. 2013, Adnan & Suradi 2008, Zeris & Repapis 2018).

Heiza and Tayel (2012) compared the wind and seismic loads as per Egyptian code and found that seismic loads were more critical. Adnan and Suradi (2008) made a similar conclusion for Malaysia. Biswas et al. (2013) concluded that wind loading is more critical in Bangladesh. For India, it is observed that either wind or earthquake loads can be critical depending upon the terrain category and seismic zonation (Hirde & Magadum 2014, Suresh & Yadav 2015, Raju et al. 2013, Reddy & Tupat 2014, Tidke & Katti 2015). Some researchers have reported building height is found to play an important role, where seismic load governs smaller heights while the wind is critical for taller buildings (Heiza & Tayel 2012, Tidke & Katti 2015).

Since the wind and seismic loads are regional in nature, this study will consider a comprehensive comparison of the seismic and wind loads in context to Muscat, focusing on medium to high-rise buildings. Further, it is observed that a single study covering all the parameters that affect wind and seismic loads is missing in the literature. Therefore, this comparison will focus on the significance of these two types of loads in context to Muscat while considering aspect ratio, building height, and presence or location of the shear wall. The study will consider the Omani Seismic Code for the estimation of seismic forces, while the Eurocode-1 will be used to estimate the wind loads based on the wind design speeds reported by Al-Nuaimi et al. (2014).

METHODOLOGY

The study will use an ordinary reinforced concrete building with normal occupancy to compare the seismic and wind loads for buildings in Muscat, Oman. Three key parameters are considered:

- Building aspect ratio: two building aspect ratios of C1- 25m x 25m (1:1) and C2-20m x 40m (1:2) are considered.
- Building height: three building heights, 33.5m, 45.5m and 57.5 m, with 11-,15- and 19-storeys, respectively, are employed.
- Shear wall and its location: three scenarios considering a bare frame, core shear wall and corner shear wall are considered.

The plan dimensions are selected to keep the area of the two aspect ratios comparable while also allowing for the symmetric placement of shear walls. The building heights are selected to cover the range of medium-rise (20m – 40m) and high-rise (40m – 60m) buildings as per the Omani Seismic Code (OSC, 2013). The 11-storey building is, therefore, a medium-rise building, while the other two are high-rise buildings. These buildings' heights are considered to cover the range of building heights, while smaller heights have been ignored as lateral loads are reported to be critical for heights more than 30 m (Hirde & Magadum 2014, Tidke & Katti 2015). The details of the structural system and calculation of seismic and wind loads will now be discussed in respective sections.

2.1 Structural System

A simplified building layout with a grid spacing of 5m in either direction is used. Fig-1 shows the typical structural plan for the two aspect ratios considered. The selection of a simplified layout would eliminate structural irregularities that have a significant effect on seismic loads and the consideration of methods for their analysis. This will also provide uncoupled behaviour for the lateral directions of the building. The aspect ratios are labelled as C1 for 1:1 and C2 for 1:2. Fig.2 shows the location of the shear walls at the core and the corner for the case of C1 and C2. The grid layout ensured a symmetric arrangement of shear walls for both scenarios. The shear wall ratios for the two cases are 0.80 % and 1.25% for C1 and C2, respectively. The first storey is considered to have a height of 3.5 m, and all subsequent stories have a height of 3.0 m. All beams had dimensions of 600mm x 300mm, while all columns were 500mm x 500mm. The slab thickness is 200 mm, and a constant shear wall thickness of 250 mm is considered. Concrete compressive strength and reinforcement yield strength is considered 35 MPa and 460 MPa, respectively. These dimensions and strength parameters are based on the norms in the construction industry in Oman. The structural elements are considered uncracked in all cases. An additional dead load of 1.8 kN/m^2 is considered in addition to the self-weight, and a live load of 3.0 kN/m^2 is considered on all floors. The beam and columns are modelled as frame elements, while the slab and shear wall are modelled as shell elements. ETABS 18 (CSI) software is used for the numerical modelling of buildings. The floors are modelled as rigid diaphragms, and the P-δ effects are considered in the analysis.

2.2 Seismic Actions

The elastic response spectrum in OSC is defined based on 'S_{SD}' *and* 'S_{1D}', *which are the elastic spectral accelerations associated with short-period* 'T_S' *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*. According to the Omani Seismic Code (OSC), Muscat is defined as Zone-1. This study considered that the building rests on Soil-C, the most commonly found soil type in Muscat (El-Hussain et al. 2013). Therefore, according to OSC, $S_{SD} = 0.24g$ *and* $S_{1D} = 0.136g$ *are used in this study.* For the equivalent static load method of OSC, the total equivalent seismic load 'V' (base shear) in the direction of the earthquake is calculated by Eq-1 (OSC-Eq 3.2).

$$V = M_t S_{AR}(T) \geq 0.11 M_t S_{SD} I \qquad (1)$$

Where 'M_t' is the total seismic mass of the structure, 'g' is the acceleration due to gravity, and 'I' is the importance factor based on the occupancy of the building. '$S_{AR}(T)$' given in Eq-2 (OSC-Eq 1.7) is the design (reduced) spectral acceleration, which is based on the natural period 'T' of the Building and the characteristics of the structural system.

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

$q_R(T)$ is the seismic load reduction factor estimated using Eq-3 (OSC-Eq 1.8). Where 'q' is the behaviour factor that depends upon the ductility class and the type of structural system used for the reinforced concrete building. The importance factor 'I' is taken as 1.0 for normal occupancy. 'S_{AE}' is the elastic spectral acceleration based on the prominent natural period 'T' is calculated using Eq-4 (OSC-Eq 1.1), with the limits for 'T' as listed in Eq-5 (OSC-Eq 1.2):

$$q_R(T) = \begin{cases} 1 + (q/I - 1)\,T/T_s & 0 < T < T_s \\ q/I & T \geq T_s \end{cases} \quad (3)$$

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

$$T_S = \frac{S_{1D}}{S_{SD}}; T_0 = 0.20T_S; T_L = 8.0\,sec \quad (5)$$

The code provides Eq-6 (OSC-Eq 3.7) for the calculation of the dominant period, where 'C_t' is 0.075 for buildings with moment resisting frames *as the base shear calculation is directly related to the natural period of the building. It is essential to consider the effect of shear walls on the natural period of a building. Therefore, OSC suggests an expression for the estimation of* 'C_t' as given in Eq-7 (OSC-Eq 3.8), where 'A_c' is the total area of the shear wall on the first floor of the building based on Eq-8 (OSC-Eq 3.9). 'A_j' and 'l_{wj}' is the area and the length of the j^th^ wall on the first floor and.'H_N' is the overall building height. OSC further recommends verification of the natural period calculated using Eq-6 using the Rayleigh quotient method as the limit for the natural period for seismic load calculation.

The lateral force 'v_i' on the i^{th}-storey is calculated using Eq-9 *(OSC-Eq 3.5)*. '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 and above that level. An additional seismic force 'ΔF_N' should be considered to act at the top floor (roof level) of the building to account for the contribution of the higher vibration modes. 'ΔF_N' is estimated using *Eq-10 (OSC-Eq 3.4)* and is based on the total number of stories in the building 'N' and the total base shear 'V'.

$$T = C_t(h_n)^{3/4} \quad (6)$$

$$C_t = \frac{0.075}{\sqrt{A_c}} \quad (7)$$

$$A_c = \sum_j \left[A_j\left(0.20 + {l_{wj}}/{H_N}\right)^2\right] \quad (8)$$

$$v_i = (V - \Delta F_N)\frac{w_i h_i}{\sum_{i=1}^{N} w_i h_i} \quad (9)$$

$$\Delta F_N = 0.0075NV \quad (10)$$

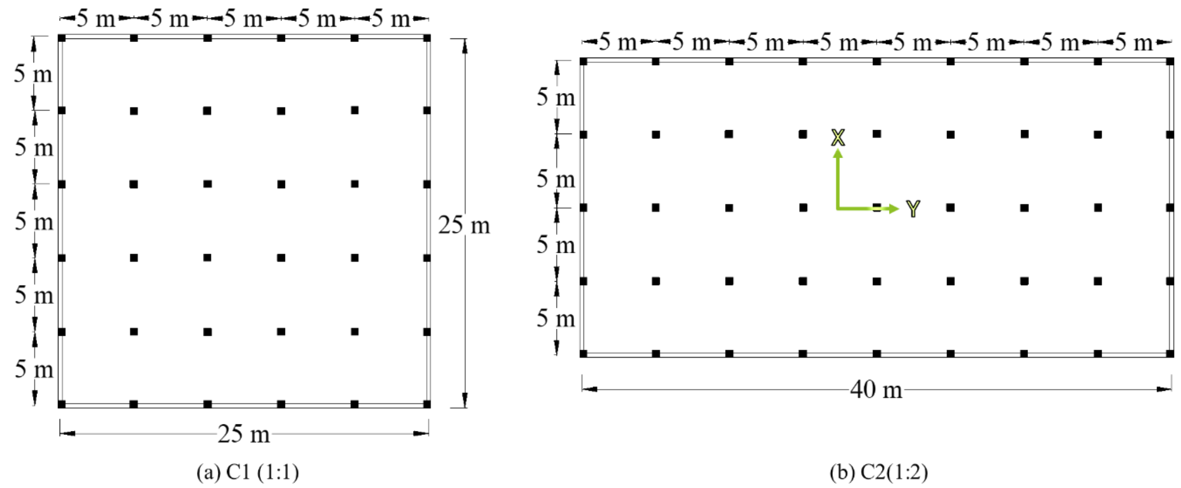


Figure 1. Typical floor plan for the two aspect ratios for all building heights

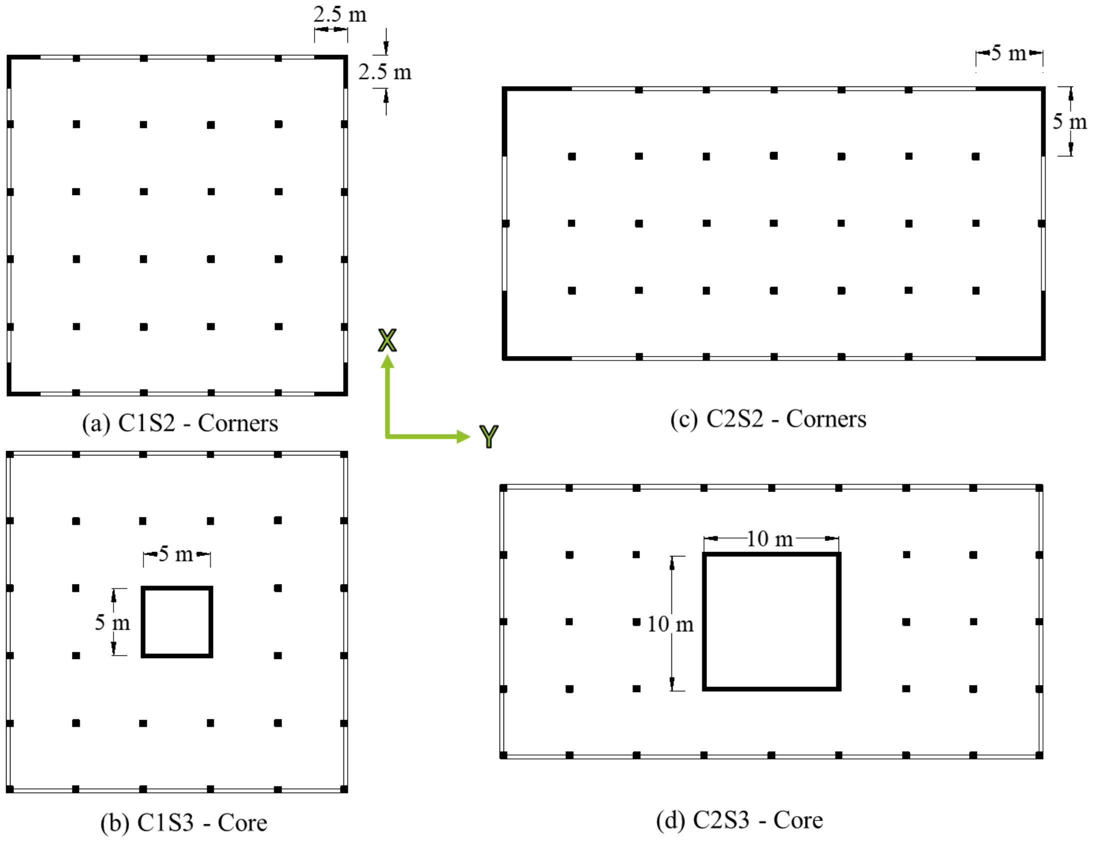


Figure 2. Shear wall layout at corners and core in C1 (a & b) and C2 (c & d) aspect ratio

2.3 Wind Actions

Al-Nuaimi et al. (2014) developed the design of a wind map for Oman. This study considered a wind speed of 30 m/sec and wind exposure category IV, defined as an area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m. The peak velocity pressure '$q_p(z)$' at any height 'z' on the vertical projected surface is estimated using the EN 1991-1-4 (EC1-4) as given in Eq. 11 (EC1-4 Eq 4.8). Where,'v_b' is the basic design wind speed, 'ρ' is air density. '$I_v(z)$','$c_r(z)$', and '$c_o(z)$' is the turbulent intensity (Eq. 12, EC1-4 Eq 4.7), roughness factor (Eq. 13, EC1-4 Eq 4.4 & 4.5) and orography factors at height 'z', respectively. A simplified representation of $q_p(z)$ as given in Eq. 14 (EC1-4 Eq 4.8), is more commonly used based on the exposure factor.'$c_e(z)$'. The exposure factor accounts for all the factors of Eq. 11 as a single parameter varying all the heights'z'. In this study, $z_0 = 1.0\, m$ and $z_{min} = 10\, m$ for terrain category-IV. The orography factor $c_o(z)$ has been considered as 1.0, '$z_{0,II}$' is the 'z_0' for terrain category II and is equal to 0.05 m in this study.

$$q_p(z) = \frac{1}{2}\rho[1 + 7I_v(z)][c_r(z)c_o(z)v_b]^2 \qquad (11)$$

$$I_v(z) = \frac{1}{c_o(z).\ln(z/z_0)} \leq I_v(z_{min}) \qquad (12)$$

$$c_r(z) = k_r ln\left[\frac{z}{z_0}\right] \geq c_r(z_{min}) \qquad (13)$$

$$k_r = 0.19\left[\frac{z_0}{z_{0,II}}\right]^{0.07}$$

$$q_p(z) = c_e(z).\frac{1}{2}\rho v_b^2 \qquad (14)$$

Fig-3 shows the variation of the exposure factor with height above the ground. The factor maintains a constant value of 2.18 up to $z_{min} = 10\, m$ and then varies logarithmically to a maximum of 2.60 for $z_{max} = 60\, m$. Since the maximum building height in this study is 57.5 m, the value of the factor beyond this range is not relevant.

The wind pressure 'w_e' acting on the external surfaces is expressed using Eq. 15 (EC1-4 Eq 5.1), where '$c_{pe,w}$' and '$c_{pe,l}$' are the coefficient of external pressure for the windward face and leeward face of the building, respectively. It depends upon the surface area (in m^2) and the 'h/d' of the building, where 'h' is the height and 'd' is the width of the building in the direction of the wind. For exposure area larger than 10 m^2 and h/d for this study, the windward positive pressure coefficient is 0.80, and the leeward negative pressure coefficient varied between 0.45 – 0.60 depending upon the 'h/d', $c_s c_d$ is the structural factor and the recommended value of 1.0 are used in this study.

$$w_e = c_s c_d(c_{pe,w} + c_{pe,l}).q_p(z) \qquad (15)$$

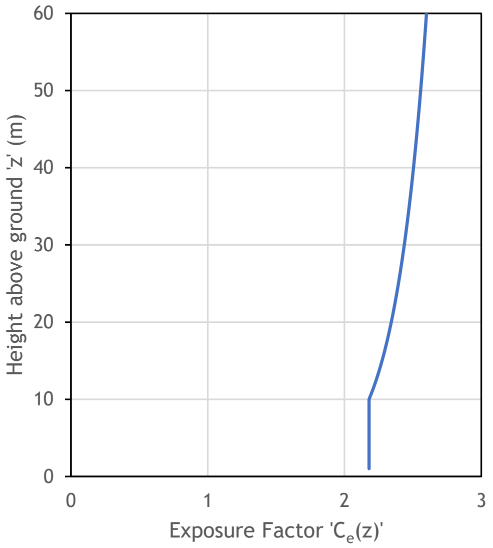


Figure 3. Variation of exposure factor 'c_e' above ground.

RESULTS AND DISCUSSION

Using the three building heights, two aspect ratios, and three scenarios for shear walls, 18 different building models are developed and used to compare the wind and seismic actions. For layout C2, as the exposed building area and the natural periods are different in the X and Y directions, these have been discussed separately. The study first compares the predominant natural period of the building based on layouts, heights, and shear wall location. The results for wind and seismic actions are discussed in terms of base shear and lateral force distribution for different building heights. The effect of the shear wall on storey displacement and column forces is discussed using storey lateral displacement for the 19-storey building.

3.1 Natural Period

As indicated in Eq-1, the seismic actions on the building are a direct function of its natural period. Therefore, it is essential to accurately estimate the natural period of the buildings. Eq-6 can be used to estimate the natural period, but OSC recommends using Rayleigh's quotient method to limit the estimated natural period. Table 1 shows the natural periods calculated based on Eq-6 considering the presence, size and number of shear walls as indicated in Eq-8. Since Eq-1 is based on the height of the building only without consideration for aspect ratio, it provides the same estimate for both aspect ratios (C1 and C2). Further, it can be observed that since Eq-8 is based on the length of the shear wall, the longer shear walls at the core result in a smaller period estimate. However, the prediction with the constant empirical constant of 0.075 meant for moment resisting frames provides the smallest natural period. This is unrealistic and indicates a clear shortcoming of Eq-7 (OSC-Eq 3.8) provided by OSC for the estimation of C_t. There should be a limit to the value of C_t based on Eq-7, as is available in the Turkish Earthquake Code (TEC, 1998), which only suggests the use of this equation for building heights less than 25 m. However, the limit imposed by OSC through Rayleigh's quotient estimate does make up for this limitation.

Tables 2 and 3 summarize the natural period estimated using Rayleigh's Quotient method for two aspect ratios, C1 and C2, respectively. The natural period for C1 is the same in the X and Y directions, while for C2, the values are slightly different, with the Y direction being slightly stiffer. The negligible variation in the natural period in the two directions is due to the symmetric building and shear wall layout, in addition to the use of square column sections that provide the same stiffness in both directions. The natural period for the S1 case for both aspect ratios has a nearly similar value to the natural period for all building heights. This allows a comparison in terms of the effect of different shear wall layouts and shear wall ratios.

The 0.80% ratio in C1 reduced the natural period to 50% in the core scenario (S2) and 64% in the corner scenario (S3) for the 11-storey building. The shear wall reduced the natural period to 58% and 64% in S2 and 70% and 74% in S3 for the 15th and 19th storey, respectively. The 1.25% ratio in C2 had a stronger effect, reducing the natural periods to 32%, 39% and 44% in S2 and 49%, 56% and 62% in S3 for the 11-, 15- and 19-storey, respectively. The increase in the shear wall ratio, therefore, leads to a drop in the natural period, while its effectiveness reduces with the increase in building height. Table 3 also shows that the natural period of buildings increases with building height, while the shear wall at the core provides the smallest natural period for a given building height.

Table 1 Natural Period (sec) of buildings as per OSC

No. of Storeys		11	15	19
Height (m)		33.5	45.5	57.5
No shearwall (S1) (C_t =0.075)		1.04	1.31	1.57
C1	Core (S2)	1.73	2.45	3.15
	Corner (S3)	2.20	2.98	3.71
C2	Core (S2)	0.86	1.28	1.71
	Corner (S3)	1.22	1.73	2.23

Table 2. Natural Period (sec) of the Square Aspect Ratio (C1) using Rayleigh's Quotient Method

No. of Storeys		11	15	19
No Shear wall (S1)		1.24	1.62	2.01
Shear wall	Core (S2)	0.62	0.94	1.28
	Corner (S3)	0.79	1.13	1.49

Table 3. Natural Period (sec) of the Rectangular Aspect Ratio (C2) using Rayleigh's Quotient Method

No. of Storeys			11	15	19
No Shear wall (S1)		X	1.26	1.66	2.07
		Y	1.22	1.60	2.00
Shear wall	Core (S2)	X	0.40	0.64	0.92
		Y	0.40	0.62	0.86
	Corner (S3)	X	0.61	0.93	1.28
		Y	0.60	0.90	1.23

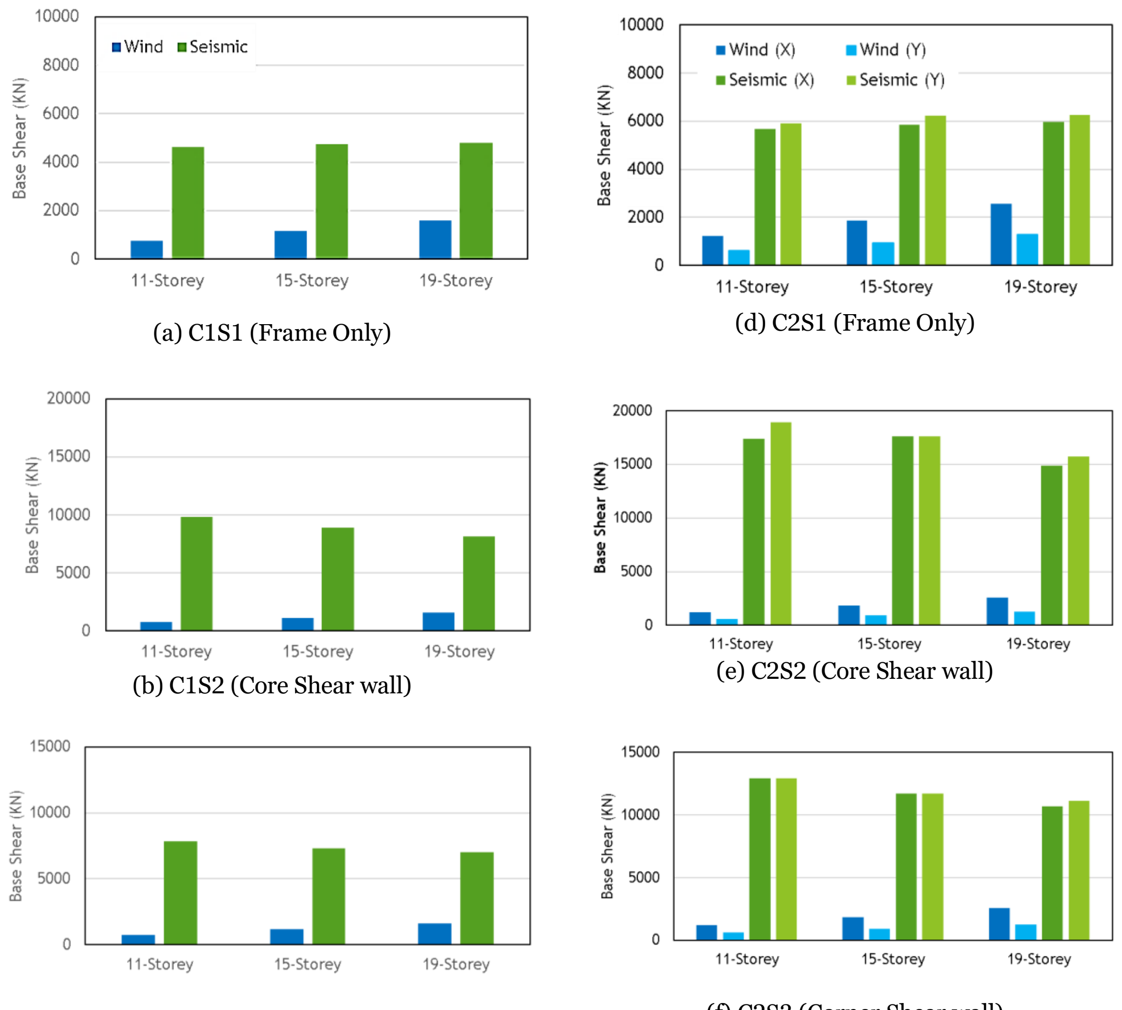
3.2 Base Shear

Base shear is a single quantitative measure for the magnitude of the lateral force that acts on the building. The study considered three-storey heights (11, 15, and 19), two aspect ratios (C1 and C2), and three structural layouts (S1, S2, and S3) to compare the wind and seismic loads. The comparison is presented using separate graphs in terms of the aspect ratio and shear wall layout. Fig-4 (a) – (c) presents the comparison of C1, while Fig-4 (d) – (f) show the results of C2 for the three shear wall scenarios.

The seismic base shear values increase due to the presence of shear walls in both aspect ratios due to the drop in the natural period. The case of core shear wall (S2), therefore, leads to the largest values of base shear. The base shear remains nearly the same for frame-only cases (S1). This is due to the increase in the natural period in height that causes a drop in design spectral acceleration; on the other hand, an increase in seismic mass due to the results of the additional floor in a near-constant base shear value. In the cases with shear walls (S2 and S3), there is a slight drop in the base shear values with height that indicates that the increase in natural period has a stronger influence compared to the increase in seismic mass. As the shear walls are moved to the corners, the building becomes slightly flexible, and the base shear drops for both aspect ratios C1 and C2.

As the wind load is a function of the exposed area only, the base shear due to wind load is the same for all structural layouts (S1, S2 and S3). However, it changes with plan dimension and building height. The base shear due to wind, therefore, shows a linear increase with the increase in building height, while the x-direction for C2 has the highest base shear for any building height.

In all the cases, base shear due to seismic load is much higher than that for wind action. The ratio of this base shear varies between 3.0-13.0 for the cases of C1 and between 2.3 – 31.2 for C2. For both aspect ratio, the least critical case is the 19-storey frame only Building, while the most adverse is the shortest 11-storey building with core shear wall (S2). The ratio of base shear for C2 is always higher in the Y-direction due to the small projected area. This comparison clearly indicates that for any building configuration in medium to high-rise buildings, from the most flexible (high-rise with frame only) to the most stiff (medium rise with shear wall at core), seismic load is going to be the critical lateral load. However, if building heights exceeding 60 m are considered wind load may lead to higher base shear values. Similar conclusions are also available in the literature (Tidke & Katti 2015, Heiza and Tayel 2012, Adnan & Suradi 2008).



(a) C1S1 (Frame Only)

(d) C2S1 (Frame Only)

(b) C1S2 (Core Shear wall)

(e) C2S2 (Core Shear wall)

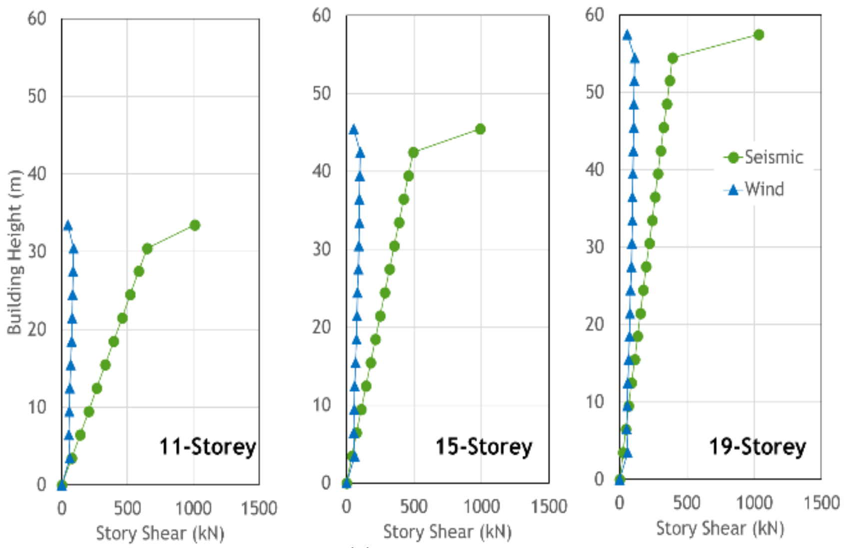
(c) C1S3 (Corner Shear wall)

(f) C2S3 (Corner Shear wall)

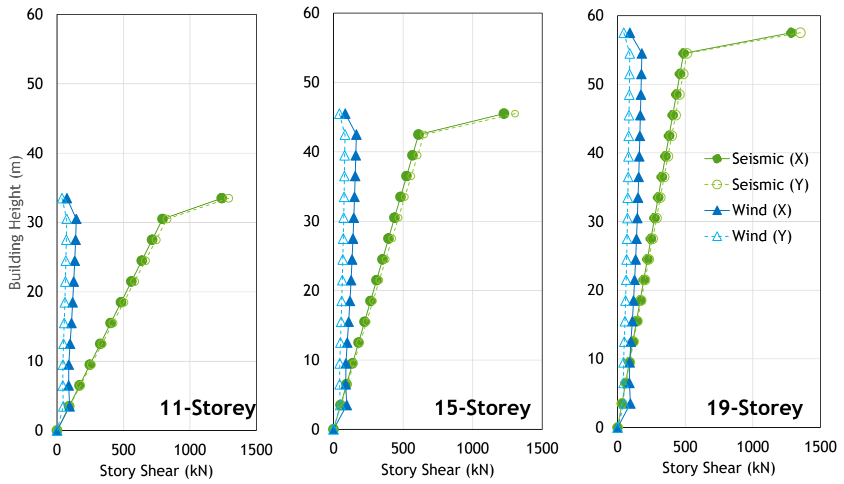
Figure 4. Comparison of Design Base Shear for Wind and Seismic loading for Aspect Ratio Layout C1 and C2.

3.3 Storey Shear Force Distribution

The storey shear force distribution is a direct function of wind pressure, as given by Eq. 15 for wind loads, while it is expressed using Eq. 9 for seismic loads. Furthermore, since the wind load is independent of the structural layouts, a comparison for one of the scenarios of the shear wall (S1, S2 or S3) would suffice for the qualitative comparison. Fig-5 shows the comparison of the storey shear force distribution of the frame-only case (S1). The layout is selected because the wind and seismic loads have the least difference for base shear in these cases. The storey shear due to seismic action is distributed as a linear function with an additional allowance at the top storey using Eq. 10. The allowance is proportional to the number of stories in the building. Therefore, its proportion in the total base shear increases with an increase in the number of stories. This increase is clear in all the curves in Fig. 5 for both aspect ratios. The storey shear due to wind is a function of the projected area and wind pressure profile; since the projected area is the same for all stories and the wind pressure does not have a significant variation, the storey shear forces are nearly the same. For aspect ratio C1, the storey shear for the first storey in all building heights is the same at 59.1 kN. The maximum storey shear is at the storey below the roof, with 90 kN, 102.7 kN and 112 kN for 11-, 15- and 19-storey buildings, respectively. The roof level has a reduced shear value due to a smaller contributory area. Comparing the two shear force distributions, the storey shear variation due to seismic loading increases linearly along the building with an additional force on the roof, while in the case of wind, the increase is very mild with a reduction at the roof level. This characteristic difference in the storey force distribution has a drastic effect on the resulting overturning moment due to these lateral force distributions, as presented in Fig. 6. The minimum ratio of the overturning moment for the wind to seismic action is 3.8 for C1 and 2.9 for C2 in case of the 19-storey building, which indicates that the lateral forces due to seismic actions will be more critical to ensure stability of the structure.

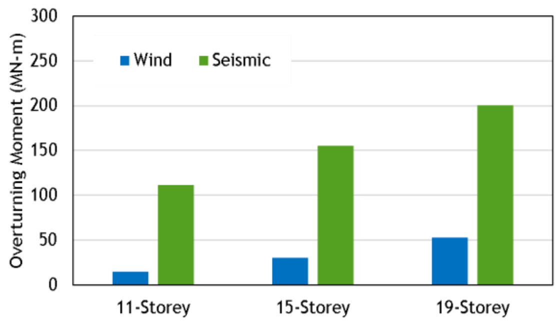


(a) C1 - Layout

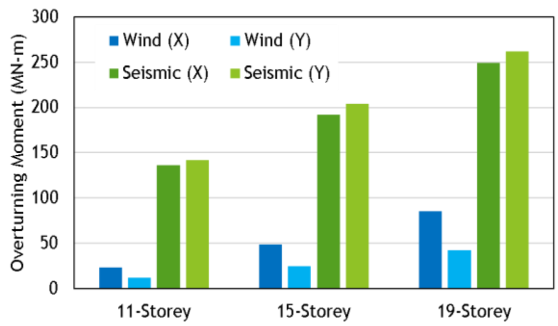


(b) C2 - Layout

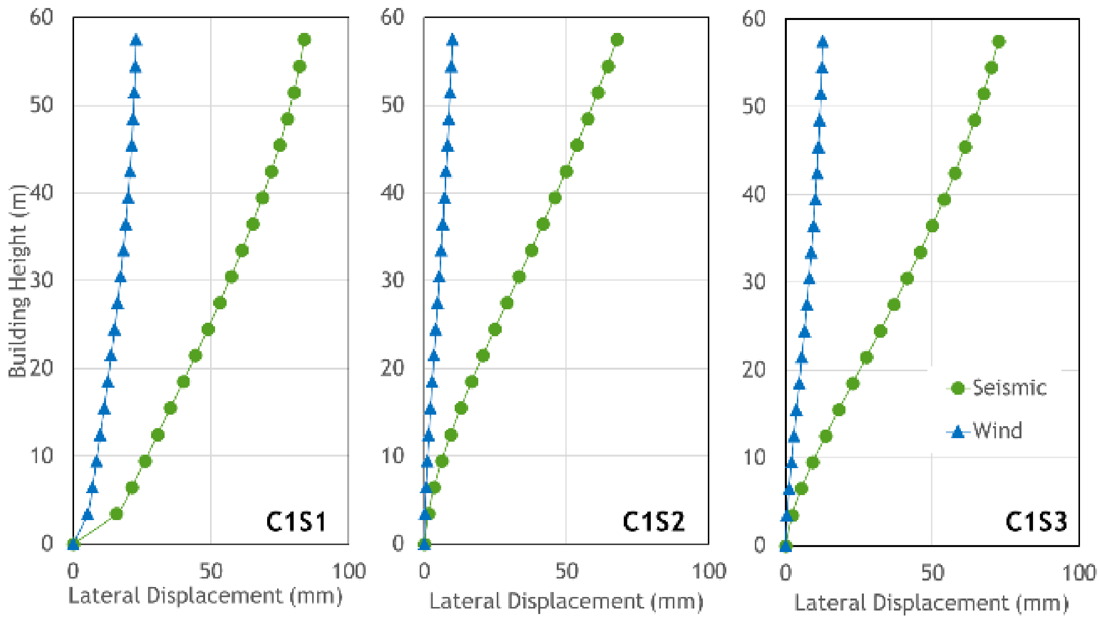
Figure 5. Storey Shear Force Distribution - Frame Only (S1)



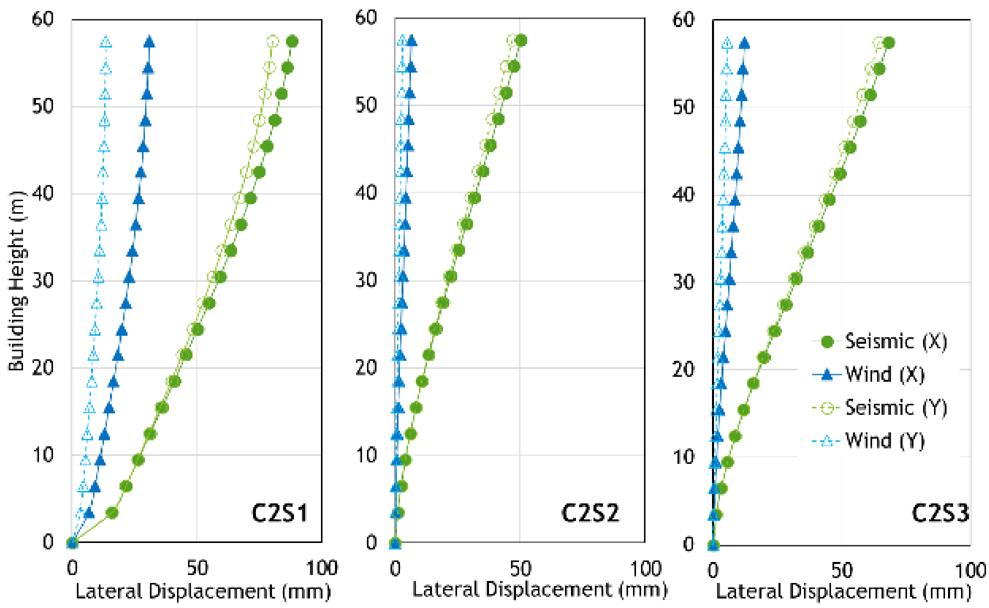
(a) C1 - Layout



(b) C2 - Layout



(a) C1 – Layout.



(b) C2 - Layout

Figure 7. Lateral Displacement profile for a 19-storey building.

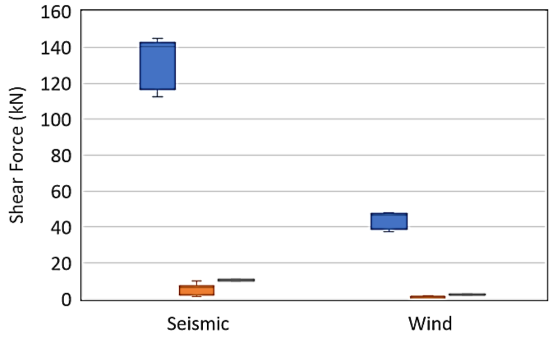
3.4 Effect of Shear wall on storey displacement and column forces

The lateral displacement of a building under seismic and wind loads is a critical serviceability concern for designers, and the use of shear walls is the primary tool to reduce this effect. Fig-7 shows the displacement profile for the two aspect ratios in the case of the 19-storey building. The discussion is only made for the 19-story as it has the largest values of lateral displacement observed among all cases. As discussed in section 3.1, building layouts with a core wall (S2) are stiffer than the one's corner wall (S3). Therefore, the displacements observed were the least for S2 for both the aspect ratios and the nature of loads. For wind action, using the core wall (S2) reduced the roof displacement to 44% and 21 % for C1 and C2, respectively. At the same time, the corner wall (S3) dropped the roof displacement to 56% and 40 % for C1 and C2, respectively. The higher reduction in the case of C2 is due to the higher shear wall ratio, while a symmetric structural layout leads to a nearly similar reduction in both directions. Since seismic loads are a function of the building stiffness, the base shear in cases S2 and S3 is much larger than S1 (frame only), as shown in Fig. 4. The core wall layout (S2) shows a roof displacement that is 81% and 57% for C1 and C2 aspect ratios, respectively. Corner wall layout (S3) gives values that are 87% and 78% for C1 and C2 aspect ratios, respectively. Though the presence of a shear wall led to the building attracting higher base shear, the overall displacement was reduced due to increased stiffness. Lateral loads govern the column forces in building design, principally affecting shear and bending moment. Figs. 8 and 9 show the shear and bending moment at the top of the ground floor columns. The column effects are summarized using a box plot for each type of structural system and the nature of loads. As expected, the values due to seismic action are higher than those due to wind action. Furthermore, it shows that the use of shear walls not only reduces the member forces but also reduces the variation in the member forces, which would simplify the design of these members. Tables -4 and 5 summarize the average shear force and bending moment at the top of ground floor columns. The values for wind are 33%, 20%, and 23% compared to seismic load for S1, S2 and S3, respectively, in the case of C1. For the aspect ratio C2, the values are 43%, 18%, 24% and 20%, 8%, and 11% in the X and Y directions for S1, S2 and S3, respectively. The comparison clearly indicates that the seismic loads will govern the design for lateral action in terms of member forces as well. However, it can be observed that the presence of a shear wall is critical to avoid overstressing the columns due to these lateral loads.

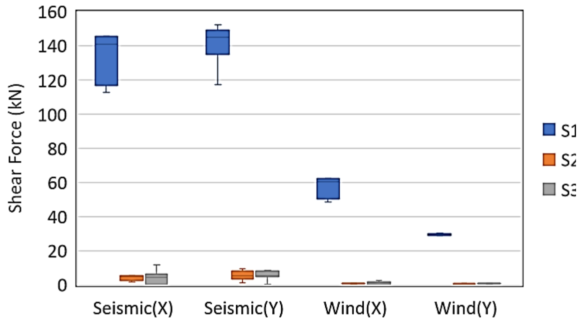
CONCLUSION

This study compared the seismic and wind actions with reference to Muscat to identify which of the two lateral loads govern the design of medium- to high-rise buildings in Oman. Considering different building heights, aspect ratios and structural layouts, the study was able to deduce the following:

- The seismic action resulted in higher base shear compared to wind actions. The ratio ranged between 4.7 - 31.2, 3.2 – 19 and 2.3 - 12.3 for 11-, 15- and 19-storey buildings, respectively.
- The base shear due to seismic loading is sensitive to the structural layout, while for wind loads, it is independent.
- The ratio of seismic-to-wind base shear ranged between 2.3 - 9.7, 4.9 - 31.2 and 4.2-21.3 for S1, S2 and S3 layouts, respectively.
- The storey shear force due to wind is nearly uniform with a dip at the roof level, while the profile for seismic actions is a linear function of the storey height with a spike at the roof level.
- The reduction in maximum roof displacement is proportional to the shear wall ratio and is more pronounced under wind loads compared to seismic loads.
- Seismic loading is critical for column shear and bending moments and is very high for frame-only cases.
- The presence of shear walls nearly eliminates the effect of lateral forces on the column's shear force and bending moments.
- For simple moment-resistance frame buildings in Muscat, the seismic load will clearly be the critical lateral load for medium- to high-rise buildings defined by the Omani Seismic Code.

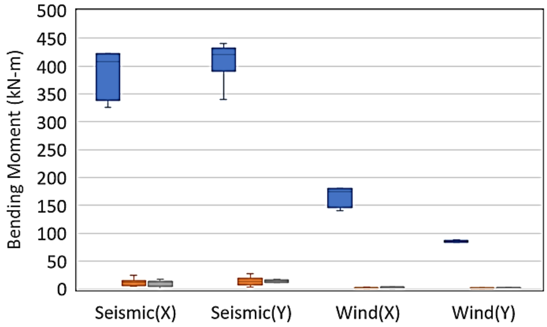


(a) C1 - Layout

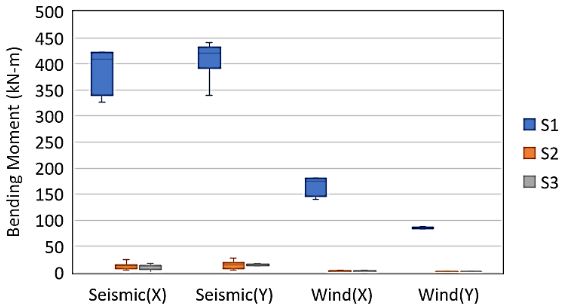


(b) C2 – Layout

Figure 8 Shear force at the top of first storey Column for the 19-storey Building



(a) C1 – Layout



(b) C2 - Layout

Figure 9 Bending moment at the top of first story column for the 19-storey building.

Table 4 Average shear force (kN) at the top of ground floor columns

	C1		C2			
	Seismic	Wind	Seismic (X)	Seismic (Y)	Wind (X)	Wind (Y)
S1	133.3	44.4	132.5	139.3	56.8	28.4
S2	13.0	2.6	14.2	16.3	2.6	1.4
S3	18.5	4.3	9.2	10.6	2.4	1.3

Table 5 Average bending moment (kN-m) at the top of ground floor columns

	C1		C2			
	Seismic	Wind	Seismic (X)	Seismic (Y)	Wind (X)	Wind (Y)
S1	386.5	128.6	384.4	404.1	164.6	82.3
S2	13.9	2.8	11.0	13.9	2.0	1.1
S3	27.5	6.3	10.5	13.4	2.5	1.5

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