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Effect of Wind Environment on the Response of Buildings in Oman

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تأثير الرياح على المباني في سلطنة عُمان

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خلاصة : هذا البحث يتعلق بدراسة تأثير عناصر الرياح على مختلف الأبنية . البحث تناول دراسة ستة أبنية موزعة في صحار ، ثمريت وسيق في سلطنة عُمان . استعملت في هذا البحث معلومات مناسبة لهذه المناطق . إحدى النتائج المستنتجة في أن تأثير الرياح على الأبنية الموجودة في المناطق المفتوحة أكثر منها على الأبنية الموجودة في المدن . انه من المستحسن أن تجمع معلومات عن الرياح في مختلف المناطق من سلطنة عُمان عندما تصمم أبنية معرضة لتأثير الرياح .

ABSTRACT: An investigation has been carried out to study the effect of the wind parameters on the response of multistory buildings subjected to wind induced forces. This study is concerned with the wind response of the buildings located at six building sites in Sohar, Thumrait and Saiq regions of Oman. A typical plan of multistory-framed building has been chosen for the present investigation. The wind and the other related data appropriate to these regions have been used in the analysis. It turns out from the present study that the response of the building located at a site in a country terrain of a region has higher values than the response obtained for the same building if constructed in a town terrain of the same region with other parameter combinations remaining invariant. It is recommended that a database for the wind parameters, based on the available wind and other related data for different regions of Oman, should be developed for the design of buildings subjected to wind induced forces.

Many countries in the world face the problem of wind destroying buildings from time to time. The damage to buildings due to wind depends on the wind environment and also on their dynamic characteristics. The size, shape and natural frequency of the first few modes of vibration of buildings are the principal parameters that affect their performance due to wind forces. The wind response is also much dependent on the wind environment. The altitude of the site, the seasonal exposure, the terrain and the topography of the whole region, in which a building is located, are some of the important factors which affect the wind response of buildings. Therefore, it is very difficult to predict the extent of damage to buildings in the event of a disaster due to high wind speed because of too many factors and parameters involved in their analysis and design.

The performance of structures subject to wind forces should be adequate during their anticipated life from the standpoints of both the structural safety and serviceability. A designer needs information regarding (1) the wind environment, (2) the relation between the wind environment and forces it induces on the structures, and (3) the behavior of the structures under the action of these forces. Structural design has been based on the climatological, meteorological, and aerodynamic considerations taking into account the along-wind forces alone until recently. But, the mechanical properties of the structure, that is, mass distribution, flexibility and damping were not considered in the design (Scalan, 1985). These parameters must be considered in the design because the natural frequencies of vibration may be in the same range as the average frequencies of occurrence of powerful gusts. The structure would also be subjected to torsion moments in the case of an eccentricity between the elastic center of the structure and the aerodynamic center. Accordingly, the structure may be designed to resist whatever anticipated moments and forces may significantly occur.

This paper presents an investigation of the effect of the wind environment on the response of multistory buildings in Oman. The essential and basic wind environment data needed in this investigation are procured from the Department of Meteorology (1993). To determine the topography of the three regions, topographic maps were used (prepared by the National Surveying Organization, Oman). The methodology employed to assess the wind forces on the buildings are based on the British Standard BS 6399: Part 2 (1995). The

TABLE 1

Building Parameters.(L for Longitudinal, T** for Transverse)*

Building	Number of Stories	Actual Height	Effective Height	Diagonal Length for Wind Direction L*	Diagonal Length for Wind Direction T**
B10	10	40	28	75.5	53.8
B15	15	60	48	87.7	70.0
B20	20	80	68	102.4	87.7
B25	25	100	88	118.7	106.3

investigation has been made for ten, fifteen, twenty and twenty-five story buildings with the same building plan in each story. The response study has been performed for wind acting in the transverse direction of the buildings for most of the cases. The wind direction along the longitudinal axis of the building has also been taken into account for few cases. The study has been made for the building sites located in the country and town terrain.

Method of Analysis

A knowledge of the complex interaction among meteorological, aerodynamic and structural aspects is required for the assessment of wind induced forces for design and analysis of building structures. Turbulence characteristics of the general wind flow vary over a wide range depending on the roughness of the ground surface. Depending on the influence of upstream, there is a convection causing mixing of the air masses and a mechanical stirring caused by the friction of the air in contact with the ground (Cook, 1985). The following steps are employed to derive wind induced forces on the structures.

GENERAL: The dynamic behavior of the structure subjected to wind forces is determined to assess whether the structure can be treated as static or mildly dynamic. Also, the relevant dynamic modification factor would be determined. The site wind speed, which is dependent on the altitude of the structure, direction of wind and the seasonal exposure of the structure, should be estimated. Depending on the terrain of the site and using the appropriate gust size of the site wind speed; the reference wind speed can be determined which may further be modified for the effect of site topography. Finally, the wind induced forces on the structure are determined employing the reference wind speed, the dynamic magnification factor and the pressure coefficient (Cook, 1990).

BUILDING PARAMETERS: Mildly dynamic structures can be analyzed statically using the dynamic modification factor. The appropriate gust can be determined from the gust peak factor that is dependent on the height and relevant diagonal dimension of the loaded area of the structure. The dynamic modification factor is a function of the gust peak factor, fetch factor, turbulence factor, topography factor, damping factor, building frequency parameter and basic mean hourly wind speed.

WIND PARAMETERS: The hourly mean site wind speed, V_{SITE}, is a variant involving the basic wind speed, altitude factor of the site, direction factor and seasonal factor. The meteorological station records the hourly mean wind speed and maximum hourly gust speed. The direction factor is a function of the wind direction only from the point that no significant variation of extreme wind with location occurs. The highest wind speed comes from the prevailing wind direction.

The reference wind speed, V_{REF}, at any height of the building is a function of the site wind speed and terrain and building factor, S_{TB}. The wind speed and its turbulent characteristics depend on the roughness of the ground surface. The gradual deceleration of the mean speed is accounted for by defining the site by its distance downwind if it is in a country terrain. If it is in a town terrain, its distance is measured from the edge of the town.

A set of fetch factors has been defined (Cook, 1990) to account for the effect of country terrain on the mean wind speed. The fetch factor, S_{SC}, modifies the site wind speed at any height above the ground with respect to various distances from the sea. The turbulence factor, S_{TSC}, depends on the fetch factor, the effective height of the building and the site terrain. An adjustment fetch factor, S_{CT}, is used to account for the deceleration of mean wind speed for a site in a town. Similarly, to account for increased turbulence over rougher town terrain, an adjustment turbulence factor, S_{TCT}, is employed. These factors are related to the distance of the site from the edge of the town and the effective height of the building. The topography deals with the assessment of wind speed over topographic features such as hill, ridge, escarpment and cliff. The effect of the topography can be quantified by speed increment coefficient that depends on the position of a site from the crest and the height above the ground.

Building Data

A typical plan (64m x 36m) of a multistory framed building (Al- Mammari, 1994) has been chosen for the present study. Seven building frames, located parallel to the longitudinal direction (direction L) of the building, are provided at 6m center to center. Nine frames parallel to the transverse direction of the building (direction T) are located at 8m center to center. The building has the same height of 4m in all the stories. The wind response study has been carried out for the buildings with the number of stories as ten, fifteen, twenty and twenty-five employing the typical building plan as invariant. Table 1 shows the designation of these buildings and their important data (dimensions in meters) to be used in the response computation. In rough terrain, the wind tends to skip over the buildings leaving sheltered regions below. The effective height of any building in such terrain is the actual height less the height of the sheltered zone (Cook, 1990). The height of the sheltered zone is considered here as 0.8 times the height of the obstruction. The height of the obstruction is 15m where buildings are at least three stories high. The diagonal length (b) of the building is given as:

$$b = \sqrt{[(\text{actual height})^2 + (\text{width})^2]}$$

Three regions of Oman, with six building sites in each region, have been selected in the present investigation. Therefore, there are eighteen building sites and the response computation has been made for four multistory buildings at each site. These regions are Sohar, Thumrait and Saiq. Sohar is situated at a distance of 1 km from the sea at an altitude of 3.6m. Thumrait is located at 70 km from the sea at an altitude of 467m. Saiq is situated at an altitude of 1775m and distant 80 km from the sea.

Wind Data

The basic wind environment data needed in the investigation is procured from the Department of Meteorology (1993). The basic wind speed used in the response computation of the buildings in Sohar, Thumrait and Saiq regions are 21.3, 20.6 and 20.0 m/s, respectively. The wind parameters, which are dependent on the direction of wind and seasonal exposure of the structure, have been evaluated for each region. The altitude factor is computed for each site of the three regions and hence V_{SITE} values have been determined (Al-Mammari, 1994). A set of fetch and turbulence factors and their respective adjustment factors have been evaluated employing different relations (Cook, 1990). The gust peak factor and terrain and building factor are also determined depending upon various parameters for different sites of the three regions for the wind response computation.

Wind response Computation

Employing different building and wind data, the wind response of the buildings located at different sites in the country and town terrain of the three regions has been obtained by the equivalent static method (Cook, 1990). In all of these cases, the analysis has been made when the wind acts in the transverse direction of the buildings. Response computation for the buildings subjected to the wind acting in their longitudinal direction has also been done for few sites located in Thumrait region only, because in such cases the wind response would be less than the corresponding values of the response when the wind acts in their transverse direction as established in other studies (Qamaruddin et al., 1995).

Discussion of Results

In general, the results obtained by the wind response investigation of seventy-two multistory buildings show similar trend. In view of this, the results are discussed in the following paragraphs through representative typical figures and tables of forty-two building cases for different building parameters, regions and terrain.

TERRAIN AND BUILDING FACTOR (S_{TB}) VARIATION: Typical values of gust peak factor (g_{GUST}) and terrain and building factor (S_{TB}) are shown in Tables 2 through 8 for buildings B10, B15, B20 and B25 located in the building sites of Sohar, Thumrait and Saiq regions for the country and town terrain. In all of these tables, the buildings are subject to the wind force acting along their transverse axis with the exception of Table 6 which shows the values of the wind parameters for buildings of the Thumrait region when the wind force acts in the longitudinal direction of the structures. Topography factor (S_{TOP}) values are zero for all the building sites in the three selected regions except for one of the building sites in the Saiq region where $S_{TOP} = 0.19$.

BUILDING SITES IN THE SOHAR REGION: Table 2 shows that the value of S_{TB} decreases slightly as the distance of sites 1, 2 and 3 increases from the sea. It is seen from Table 3 that for the building B10 in the town terrain, the value of S_{TB} decreases sharply as the distance of the site increases from the sea unlike the case of country terrain. Therefore, it turns out that S_{TB} depends mainly on the building height irrespective of the site altitude. But, the site distance from

TABLE 2

S_{TB} for Building in Country Terrain of Sohar Region.

Site Number	Distance from Sea (km)	Type of Building	V_{SITE}	S_{SC}	S_{TSC}	g_{GUST}	S_{TB}
1	2	B10	18.81	1.294	0.147	2.332	1.739
		B15		1.409	0.127	2.305	1.822
		B20		1.474	0.116	2.258	1.860
		B25		1.534	0.106	2.214	1.894
2	6	B10	18.81	1.280	0.152	2.328	1.733
		B15		1.394	0.132	2.300	1.817
		B20		1.459	0.121	2.255	1.857
		B25		1.519	0.111	2.209	1.892
3	26	B10	20.70	1.250	0.159	2.358	1.720
		B15		1.356	0.145	2.329	1.812
		B20		1.420	0.134	2.284	1.855
		B25		1.480	0.124	2.239	1.891

TABLE 3

S_{TB} for Building B10 in Town Terrain of Sohar Region.

Site Number	Distance of Site from Sea (km)	S_{CT}	S_{TCT}	g_{GUST}	S_{TB}
1	2	0.909	1.270	2.290	1.681
2	6	0.866	1.404	2.267	1.640

TABLE 4

S_{TB} for Building in Country Terrain of Thumrait Region.

Site Number	Distance from Sea (km)	Type of Building	V_{SITE}	S_{SC}	S_{TSC}	g_{GUST}	S_{TB}
1	50	B10	25.20	1.240	0.160	2.437	1.724
		B15		1.344	0.147	2.408	1.820
		B20		1.407	0.137	2.362	1.863
		B25		1.466	0.127	2.317	1.900
2	60	B10	25.20	1.237	0.160	2.436	1.720
		B15		1.341	0.147	2.407	1.817
		B20		1.404	0.137	2.361	1.860
		B25		1.462	0.128	2.316	1.896
3	100	B10	28.80	1.226	0.160	2.489	1.717
		B15		1.330	0.148	2.460	1.815
		B20		1.390	0.139	2.413	1.860
		B25		1.446	0.131	2.368	1.900

the sea has significant effect on S_{TB} in the town terrain than the country one.

BUILDING SITES IN THE THUMRAIT REGION: There is an insignificant variation in S_{TB} values (Table 4) for B10, B15, B20 and B25 buildings located at the sites 1, 2 and 3 in the country terrain. It is also observed from the figure that S_{TB} decreases or increases slightly as the distance of the building sites from the sea increases. But, Table 5 shows that this observation is not true for the buildings located at different sites in the town terrain. Tables 5 and 6 show that the S_{TB} values decrease significantly for

TABLE 5

S_{TB} for Building B20 in Town Terrain of Thumrait Region.

Site Number	Distance of Site from Sea (km)	S_{CT}	S_{TCT}	g_{GUST}	S_{TB}
1	80	0.894	1.344	2.341	1.793
2	100	0.872	1.406	2.355	1.771

TABLE 6

S_{TB} for Building in Country Terrain of Thumrait Region (Wind direction L).

Site Number	Distance from Sea (km)	Type of Building	V_{SITE}	S_{SC}	S_{TSC}	g_{GUST}	S_{TB}
1	50	B10	25.50	1.240	0.160	2.579	1.752
		B15		1.344	0.147	2.503	1.839
		B20		1.407	0.137	2.427	1.875
		B25		1.466	0.127	2.364	1.908
2	60	B10	25.20	1.237	0.160	2.578	1.748
		B15		1.341	0.147	2.502	1.835
		B20		1.404	0.137	2.426	1.872
		B25		1.462	0.128	2.363	1.905
3	100	B10	28.80	1.226	0.160	2.631	1.745
		B15		1.330	0.148	2.554	1.833
		B20		1.390	0.139	2.478	1.871
		B25		1.446	0.131	2.414	1.908

TABLE 7

S_{TB} for Building in Country Terrain of Saiq Region.

Site Number	Distance from Sea (km)	Type of Building	V_{SITE}	S_{SC}	S_{TSC}	g_{GUST}	S_{TB}
1	70	B10	40.43	1.235	0.160	2.634	1.755
		B15		1.339	0.147	2.605	1.853
		B20		1.400	0.138	2.559	1.895
		B25		1.458	0.129	2.514	1.931
2	80	B10	48.84	1.232	0.160	2.590	1.975
		B15		1.336	0.148	2.557	2.090
		B20		1.397	0.138	2.511	2.148
		B25		1.454	0.130	2.466	2.200
3	90	B10	50.53	1.229	0.160	2.730	1.765
		B15		1.333	0.148	2.697	1.865
		B20		1.394	0.139	2.650	1.907
		B25		1.450	0.130	2.605	1.943

different distances of the building sites from sea in the town and country terrain respectively.

BUILDING SITES IN THE SAIQ REGION: S_{TOP} (topography factor) is equal to 0.19 for one of the building sites in this region. It is seen from Table 7 that the values of S_{TB} for building site 2 are much higher than the corresponding values of S_{TB} for the buildings at site 1 and 3. This jump may be attributed to the higher value of S_{TOP}. Also, it is clear from Table 7 that as the building height increases, the value of S_{TB} also increases irrespective of the distance of the building sites from the sea. Table 8 shows that the S_{TB} value decreases as the distance of the building site from the sea increases in the case of the buildings in the town terrain. However, the value of S_{TB} is less in the town terrain compared to its corresponding value in the country terrain.

Variation of Reference Wind Speed

Figures 1 to 3 show the variation of reference wind speed with the distance of the building sites from sea in the country terrain of the three regions. The variation of the similar parameters for the town terrain has been studied with the help of typical Figures 4 and 5 for Sohar and Thumrait regions, respectively. It is observed from these figures that the variation of the reference wind speed among buildings B15, B20 and B25 is almost constant for all the three regions as well as for both the terrain. Contrary to this observation, the difference between V_{REF} values of buildings B10 and B15 is larger for all the parameter combinations.

TABLE 8

S_{TB} for Building B20 in Town Terrain of Saiq Region.

Site Number	Distance of Site from Sea (km)	S_{CT}	S_{TCT}	g_{GUST}	S_{TB}
1	90	0.139	1.894	2.600	1.851
2	100	0.139	1.883	2.590	1.837

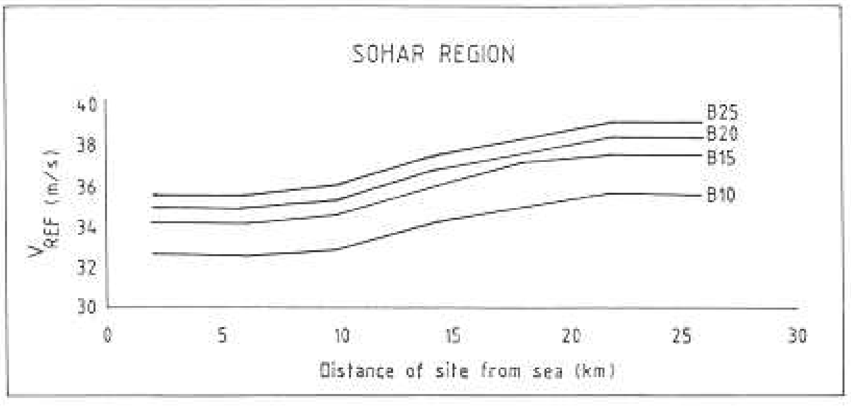

Figure 1. V_{REF} for different Sites and Buildings (Country Terrain).

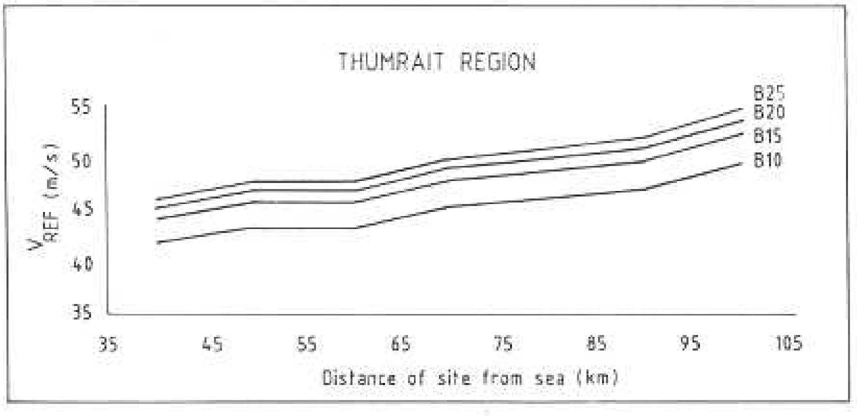

Figure 2. V_{REF} for different Sites and Buildings (Country Terrain).

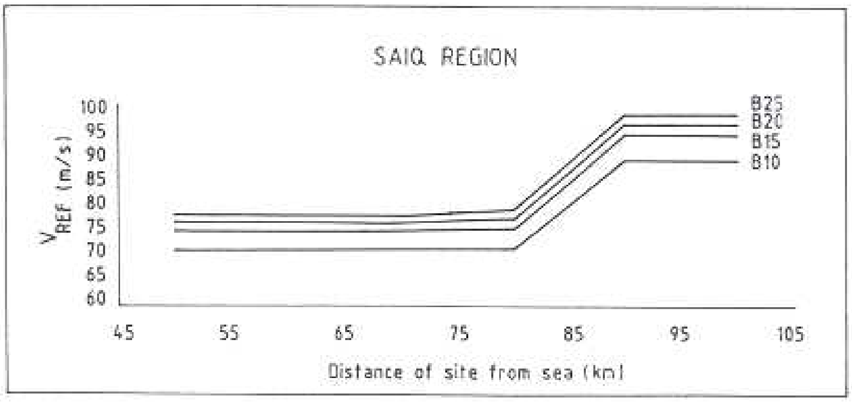

Figure 3. V_{REF} for Different Sites and Buildings (Country Terrain).

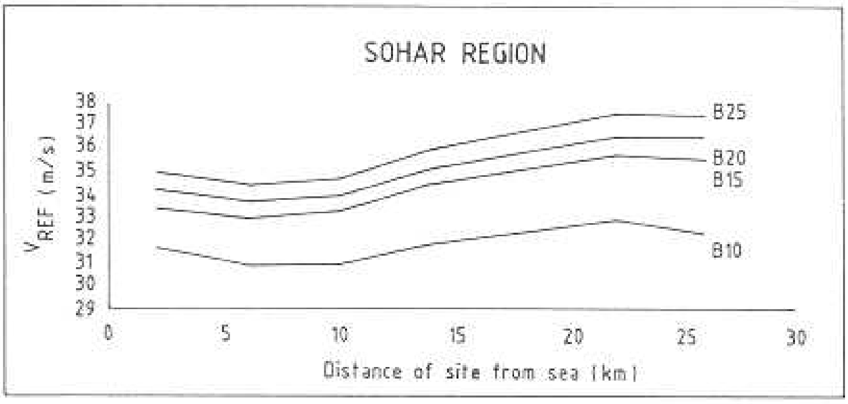

Figure 4. V_{REF} for Different Sites and Buildings (Town Terrain).

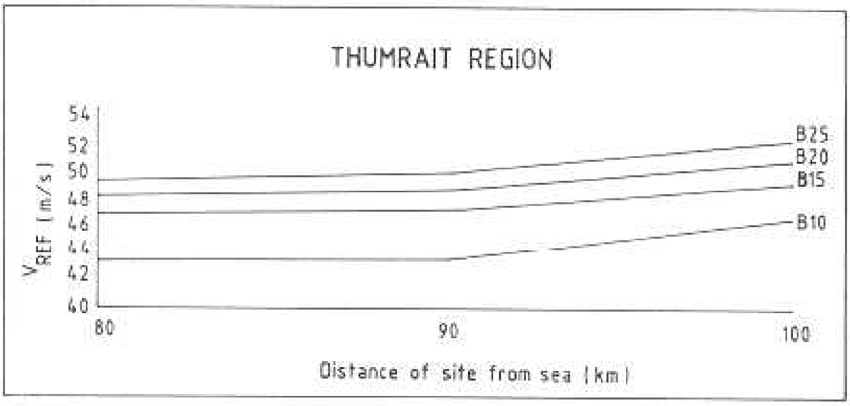

Figure 5. V_{REF} for Different Sites and Buildings (Town Terrain).

This may be attributed to the variation of the terrain and building factor whereas the value of V_{SITE} remains constant for each of the sites.

Effect of Wind and Building Site Parameters on Wind Response

The variation of story moment with respect to story number, for ten story buildings at different sites in the country and town terrain of Thumrait region, is shown in a representative Figure 6. As well established, the story moment decreases as the number of story increases. It is also observed from the figure that the wind response is higher for the buildings located at the sites in the country terrain as compared with that of those in the town terrain. This is mainly because the reference wind speed is higher in the case of country terrain and therefore this is a governing parameter for the development of higher response in such situations.

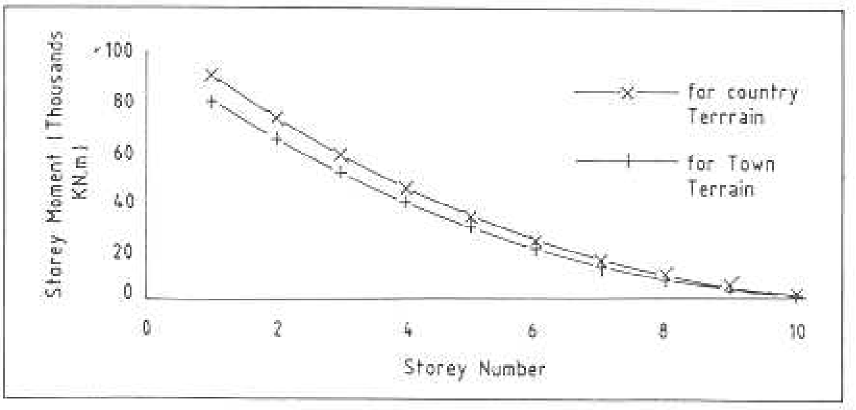

Figure 6. Comparison of Bending Moment for B10 (Thumrait Region).

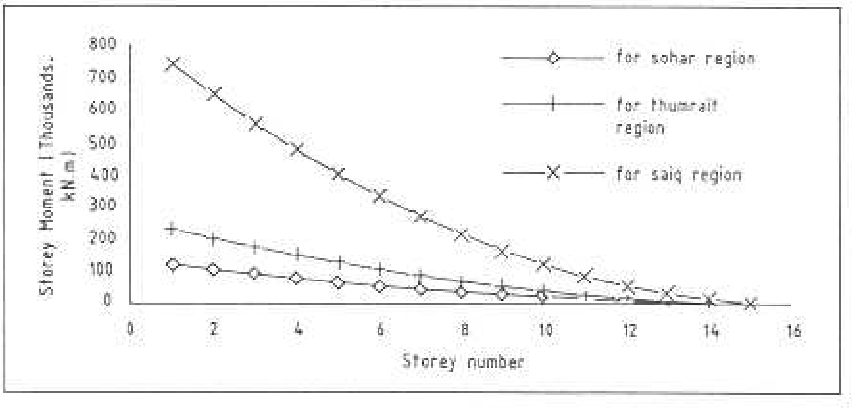

Figure 7. Comparison of Bending Moment for B15 (Country Terrain).

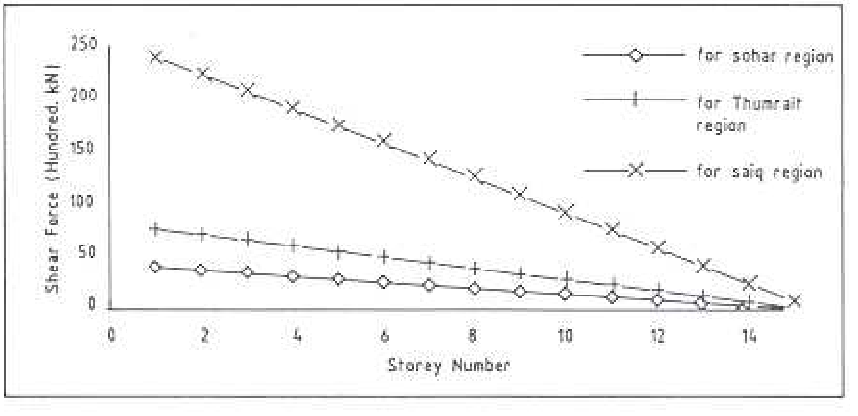

Figure 8. Comparison of Shear force for B15 (Country Terrain).

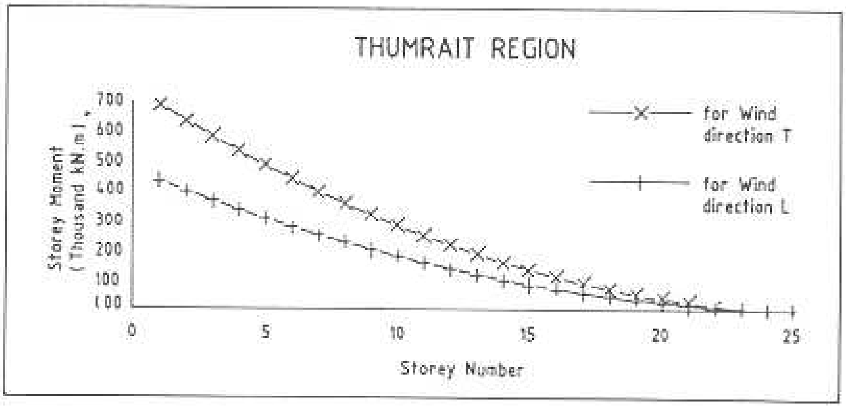

Figure 9. Comparison of Bending Moment for B25 (Country Terrain).

Comparison of Wind Response for Buildings Located in Different Regions

It can be observed from the representative Figures 7 and 8 that for the buildings, which have been analyzed for Saiq region, the wind develops more bending moment and shear force compared to the similar buildings of Sohar and Thumrait regions. Similar trend is noted between the response of the buildings located in Thumrait region as compared to those of Sohar region. These results are true for the building sites in the country and town terrain of these regions. The reference wind speed is the main cause for the development of higher response in such situations. Further, it is observed that the response values are significantly larger in the higher story buildings in comparison to the corresponding story-wise response values in the lower story buildings. It is seen from a typical Figure 9 that the response of the buildings subjected to wind acting in their transverse direction is higher than their corresponding values when the wind is acting in their longitudinal direction.

Conclusions

The following conclusions are drawn from the present study concerning the wind response of multistory framed buildings:

1. The reference wind speed of a building located in the country terrain has higher value than its corresponding value for the same building if constructed in the town terrain.

2. Wind response of the multistory buildings in Saiq region has higher values compared with the response of the similar buildings in Sohar and Thumrait regions for the same parameter combinations.

3. A detailed study is recommended for the development of the wind parameters based on the available wind environment and other related data for design of the buildings to be constructed in different regions of Oman.

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