

# Investigation on the Impact of the Design of R.C Buildings in KSA According to Different Building Codes on the Level of Safety and Cost

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**Abstract**— The construction industry is a highly competitive sector in the Kingdom of Saudi Arabia. In the absence of obligatory local building codes, the construction industry in KSA was adopting standards and codes of practice from several other countries. As a result, a variety of the constructed buildings suffered different features of failure. So, the national building code of the KSA (SBC) was issued in 2007. The present study intends to deeply investigate the impact of using the professions of different international codes used in the KSA on the level of safety and cost of RC buildings. It should be stated that every design code stipulates factors of safety adequate for the local conditions. Over-designing beyond these limits is a waste of materials and hence harming the environmental conditions. Otherwise, neglecting the differences in loads between different cities in the KSA leads to incorrect designs of buildings which may lack the required level of safety. In this study, two types of common buildings are investigated which are moment resisting frames (MRF) and shear wall - moment resisting frames (SW-MRF). The buildings are designed according to different international building codes which are SBC, Eurocode-8, UBC 97 and NBCC. The case of study buildings have different heights ranging between 3 and 17 floors. A comparative analysis between the resulted normalized total base shear and concrete quantities according to the designs relying on these codes is carried out.

**Keywords:** RC structures - Building codes - safety factors - cost.

## 1 INTRODUCTION

The Kingdom of Saudi Arabia is a developing country that has been growing significantly over the past few decades. According to the Central Department of Statistics-Demographic [1], it is estimated that the total population is about 28,376,355 residents live in Saudi Kingdom in 2011. The total land space of the Kingdom of Saudi Arabia is about 1,960,582 sq. km. (climate-zone). The total owned houses are about 1,526,678 and the total of leased houses is about 1,520,693 (Central Department of Statistics-Demographic 2003). According to the UNICEF, 82% of the population is urbanized [2]. The urbanization rate of Saudi Arabia is growing very high, thus the country faces significant urban challenges today in the field of construction in general and in housing especially [3].

During the last few decades, Kingdom of Saudi Arabia has witnessed great deal of advancement in different fields. Of particular is the construction of modern, huge and challenging structures which were mainly made of reinforced concrete elements. Unfortunately, significant parts of the structures were built in the absence of stringent and unified local building codes. Thus, a sizable part of structures in KSA were constructed in the absence of minimum safety provision assurance, absence of qualified supervision, lack of unified reference for error free design and lack of qualified building inspectors and clear inspection process. Therefore, many of the existing structures are now suffering from different types of deteriorations and may not be adequate for the actual service life and environmental conditions [4]. In the absence of local building codes, the construction industry in Saudi Arabia was adopting standards and codes of practice from several other countries for the design and construction of the infrastructure.

The adopted codes, usually, depended on the country of origin of the contractor/consultant. Such a practice is currently causing a great burden on national community. The only practical way to push back such a problem is to stop its progress. Because of that the National Building Committee was formed to establish the complete Saudi Building Code (SBC) [5].

A Saudi Building Code National Committee (SBCNC) was formed by the Royal Decree No. 7/B/3230 dated June 12th, 2000. One of the strategic goals of SBCNC is to propose regulations that obligate public and private sectors to implement the code requirements and standards for designing buildings to resist earthquakes in the Kingdom. The SBCNC reviewed a number of the regional and international references and codes in addition to studying the standards, building systems and plans of the governmental departments and authorities including the International Code Council (ICC) issued in USA [6], the European Code [7] and Arab Codes [8]. It has also been acquainted with the experiences of some countries - such as Canada - when preparing the Canadian Building Code (CBC) [9] by the assistance of the American Codes as a basis. SBCNC has also discussed the recommendations benefiting from the codes of ICC as a main reference for the Saudi Building Code with a stress on benefiting from the local and international expertise in the field of preparing and approving the Code. ACI 318 [10], being the most widely used standard for concrete structures, was selected to be part of the SBC. However, suitable modifications were made to this document to suit to the environmental conditions of Saudi Arabia.

National building codes and their provisions always gain a

specific concern from researchers especially with the continuous development in these codes. Many clear research examples can be mentioned as the tremendous number of researches carried out on the new edition of the National Building Code of Canada NBCC [9] as in [11] and [12]. Comparative studies between national seismic provisions and international ones as Turkish earthquake code and UBC as [13], Eurocode-8 and Japanese one as [14] and comparison between set of different international codes as [15] were also reported. Related to the Arab countries, many investigations related to the successive evolutions of the Egyptian Code of Loads were addressed as [16-20]. The newly released Saudi Building Code also gained attention from researchers to review and assess its different regulations and rules as [3], [4].

The objectives of this investigation can be summarized as:

1. Present one from the first studies which attempts to examine the impact of design practices on the level of safety and cost of residential buildings in the KSA.
2. Investigate the levels of safety for buildings designed prior to the obligatory usage of the Saudi Building Code.
3. Try to form a basis for a large scale endeavor leading to the required development of the newly released Saudi Building Code depending on the findings of the present study.

## 2 CASE OF STUDY BUILDINGS

Two types of typical buildings are used. These buildings are moment resisting frames (MRF) and shear wall - moment resisting frames (SW-MRF). Fig. 1 depicts example of SW-MRF Building. The MRF building has same plan features while replacing the shear walls with columns. The buildings are square with typical bay dimension of 5.0 m. Different building heights represented by the number of floors are considered, 3, 6, 9, 12, 15 and 17 floor buildings are analyzed. The height of the first floor above foundation is always equal to 4.5 m, while the height of the typical remaining floors are 3.0 m. The column sections are varying according to the height of building.

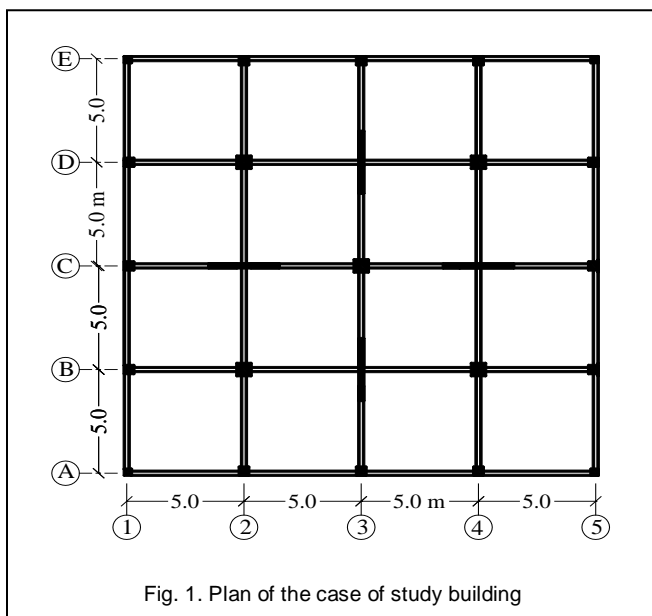


Fig. 1. Plan of the case of study building

The effective total lengths of shear walls in the first story in each orthogonal direction ( $L_w$ ) is seismically designed. This ratio ( $L_w / H$ ) is considered initially as 0.20 for each orthogonal direction, SW thickness is 0.2 m.

The compressive strength of used concrete is 25.0 MPa while the used steel is high tensile with yield strength of 400.0 MPa. The analysis is carried out using two software packages, ETABS [21] and SAP 2000 [22].

## 3 METHODS OF APPLYING LATERAL LOADS

To verify the seismic protection level provided by the SBC versus the results obtained from some different international codes, three seismic codes are selected. These codes include Eurocode-8, the famous UBC 97 and finally the renewed National Building Code of Canada NBCC.

For the sake of carrying out a rational comparison between these codes versus the recently edited SBC, results obtained for buildings to be constructed in Alsharaf city, located in the north of the KSA, using soil type "D" are compared with those for same building types found on same soil conditions and located in cities with seismicity similar to this city. Doing so, a city with zone factor  $Z = 0.15$  is selected to represent UBC 97 code while Kamloops city which is remarked by  $PGA = 0.14 g$  is selected to represent the NBCC. Typical conditions to Alsharaf city are available in the Eurocode-8.

According to the properties of Alsharaf city and the selected soil (soil type D) only methods 3 (Equivalent Lateral Force Procedure) and method 4 (Modal Analysis Procedure) of calculating the lateral earthquake loads presented by the Saudi Building Code of loads (SBC 301) are applicable. A brief description about each method is as follows:

### Equivalent Lateral Force Procedure:

**Seismic Base Shear:** The seismic base shear ( $V$ ) in a given direction shall be determined in accordance with the following equation :

$$V = C_s W$$

Where

$C_s$  = the seismic response coefficient.

$W$  = the total dead load and applicable portions of other loads.

**Calculation of Seismic Response Coefficient:** When the fundamental period of the structure is computed, the seismic design coefficient ( $C_s$ ) shall be determined in accordance with the following equation :

$$C_s = S_{DS} / (R/I)$$

Where

$S_{DS}$  = the design spectral response acceleration in the short period range.

$R$  = the response modification factor.

$I$  = the occupancy importance factor.

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

$$C_s = S_{D1} / (T(R/I))$$

but shall not be taken less than:

$$C_s = 0.044 S_{DS} I$$

Where

$S_{D1}$  = the design spectral response acceleration at a period of 1.0

sec, in units of g-sec.

$T$  = the fundamental period of the structure (sec).

For regular structures 5 stories or less in height and having a period,  $T$ , of 0.5 sec or less, the seismic response coefficient,  $C_s$  shall be permitted to be calculated using values of 1.5 g and 0.6 g, respectively, for the mapped maximum considered earthquake spectral response accelerations  $S_s$  and  $S_1$ .

**Approximate Fundamental Period:** The approximate fundamental period ( $T_a$ ), in seconds, shall be determined from the following equation:

$$T_a = C_t h_n^x$$

Where:  $h_n$  is the height in (m) above the base to the highest level of the structure and  $x$  is a factor presented in the code.

**Vertical Distribution of Seismic Forces:** The lateral seismic force ( $F_x$ ) (kN) induced at any level shall be determined from the following equations:

$$F_x = C_{vx} V$$

Where

$C_{vx}$  = vertical distribution factor.

$V$  = total design lateral force or shear at the base of the structure, (kN)

### MODAL ANALYSIS PROCEDURE

**Modal Base Shear:** The portion of the base shear contributed by the  $m^{\text{th}}$  mode ( $V_m$ ) shall be determined from the following equation:

$$V_m = C_{sm} W_m$$

Where

$C_{sm}$  = the modal seismic design coefficient.

$W_m$  = the effective modal gravity load.

The modal seismic design coefficient ( $C_{sm}$ ) shall be determined in accordance with the following equation:

$$C_{sm} = S_{am} / (R/I)$$

Where

$S_{am}$  = the design spectral response acceleration at period  $T_m$ .

$T_m$  = the modal period of vibration (in seconds) of the  $m^{\text{th}}$  mode of the Structure.

The elastic response spectrum, which is constructed in regardless of the over strength factor, for the selected cities are illustrated in Fig. 2.

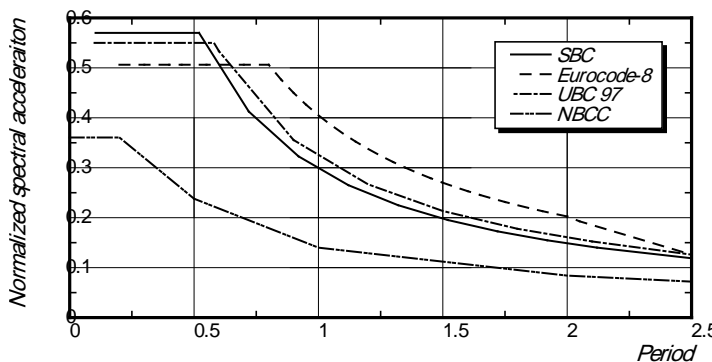


Fig. 2. Normalized spectral acceleration for specified cities according to different considered codes

Some notes could be highlighted for this figure. These notes include the high proximity in the values of maximum spectrum acceleration between SBC, Eurocode-8 and UBC 97. Also the maximum spectrum acceleration specified by the NBCC is much less than all other code spectrum.

To get the design response spectrum from the elastic response one, all ordinates of spectral accelerations are divided by a factor used to incorporate for the inelastic response expected for the structure to the design earthquake. This factor is called response modification factor (R) in SBC, behavior factor in Eurocode-8 (q), structural system coefficient (R) in UBC 97 and over strength and force modification factors ( $R_o$ ,  $R_d$ ) in NBCC. This factor depends mainly on the structural force resisting system (SFRS) and the proposed degree of ductility assumed for the building. Summary of values for response modification factor for MRF and SW-MRF buildings is shown in Table 1.

Table 1: Summary of response modification factor for MRF and SW-MRF buildings.

System	MRF			SW-MRF		
	L	M	H	L	M	H
Ductility level						
SBC	2.5	4	6.5	5.5	-	6.5
Eurocode-8	-	3.3-3.9	4.95-5.85	-	1.8-3.6	2.7-5.4
UBC 97	3.5	5.5	8.5	-	6.5	8.5
NBCC	1.95	3.5	6.8	1.95	2.8	5.6

Where: L, M and H refer to low, medium and high ductility.

As they need high attention in design, practically constructed in KSA and to save space, the results obtained for structures with first lower degree of ductility are investigated and discussed. Results for any other degree of ductility can be easily obtained by scaling the results to the required degree of ductility.

## 4 ANALYSIS OF BUILDINGS

The lateral analysis of the MRF buildings is carried out using the different considered seismic codes. The results of the normalized base shear of the considered buildings with different heights using the equivalent lateral force procedures are shown in Fig. 3. The corresponding results obtained using the computer base modal analysis are shown in Fig. 4. From the carried out analysis, many observations can be stated. The first one is that the order of the obtained results of normalized base shear using the different considered codes of loads is the same using either of the two methods of analysis. The obtained results can be arranged, from the highest to the lowest one, according to the following codes: SBC, UBC 97, NBCC and at last, the Eurocode-8. It is also clear that the obtained results of normalized base shear using the equivalent lateral force procedures are higher than those obtained

using the computer base modal analysis. The measured differences between the results range between 76% and 2% for SBC, 67% and 28% for UBC 97, 60% and 27% for NBCC. The results obtained for the Eurocode-8 are very close using either of the two applied methods of calculating the normalized base shear. Carrying out a comparison between the obtained results of different codes and those obtained from the SBC yields that for this type of buildings the SBC results in values of normalized base shear higher than those obtained from the different considered codes. The percentage increase in the values using the equivalent lateral force procedures range between 28% and 16% for UBC, between 38% and 21% for the NBCC and between 83% and 75% for Eurocode-8. Similar observations are also obtained when calculating the normalized base shear using the computer base modal analysis but with different values. The measured differences range between 33% and 25% for UBC, between 37% and 30% for the NBCC and between 66% and 50% for Eurocode-8.

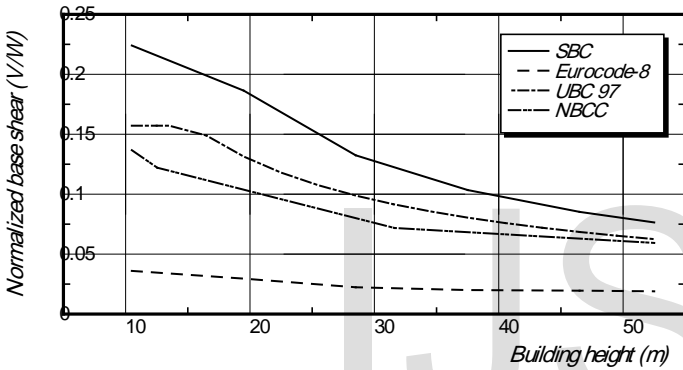


Fig. 3. Normalized base shear according to different codes (MRF building) using equivalent lateral force procedures

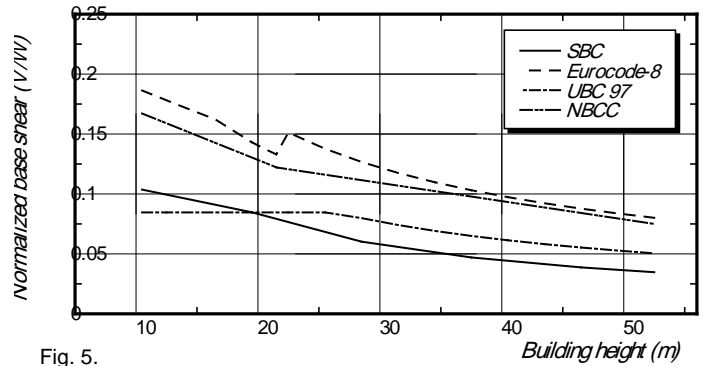


Fig. 5. Normalized base shear according to different codes (SW- MRF building) using equivalent lateral force procedures

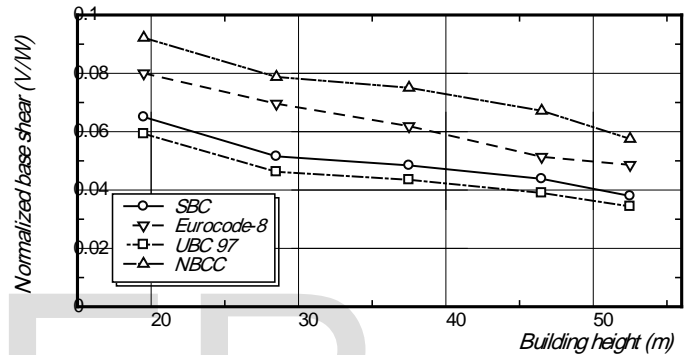


Fig. 6. Normalized base shear according to different codes (SW- MRF building) using modal analysis method

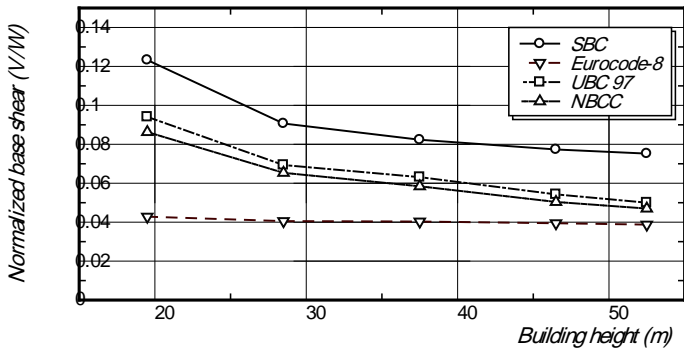


Fig. 4. Normalized base shear according to different codes (MRF building) using modal analysis method

The analysis of the SW-MRF frames is carried out under the lateral loads obtained from the different considered codes of practices. The results obtained using the equivalent lateral force procedures are shown in Fig. 5. The corresponding results obtained using the computer base modal analysis are shown in Fig. 6.

The order of the obtained normalized base shear is different using either of the considered method of analysis. Applying the equivalent lateral force procedures, the obtained results can be arranged, from the highest to the lowest one, according to the following codes: Eurocode-8, NBCC, UBC 97 and at last, the SBC. Using the computer base modal analysis, the previous order of results is changed to be NBCC, Eurocode-8, SBC and at last UBC 97. Exactly as previously observed for the MRF buildings, it is also clear that the obtained results of normalized base shear using the equivalent lateral force procedures are higher than those obtained using the computer base modal analysis. The measured differences between the results range between 61% and 2% for SBC, 44% and 27% for UBC 97, 80% and 27% for NBCC and finally 132% and 60% for Eurocode-8. A comparison between the obtained results of different codes and those obtained from the SBC is carried out. For this type of buildings the Eurocode-8 and the NBCC results in values of normalized base shear higher than those obtained from the SBC. The percentage increase in the values using the equivalent lateral force procedures range between 120% and 58% for NBCC and between 135% and 77% for the Eurocode-8. The results obtained from the UBC 97 code is higher than those obtained from the SBC by about 19%. Similar observations are also obtained when calculating the normalized base shear using the computer base modal analysis but with different values. The measured difference ranges between 55% and 42% for NBCC and between 32% and 23% for the Eurocode-8. The results obtained from the UBC code is higher than

those obtained from the SBC 97 by about 9%.

## 5 CONCRETE QUANTITY: ANALYSIS AND COMPARISON

A concrete quantity analysis is carried out for the deigned buildings with 6, 12 and 17 floors to identify the impact of using different codes in the analysis on the resulted concrete quantity and hence the final cost of the designed buildings. According to the variations in the effective lateral loads, the substructure elements are the main elements which are affected by such variation in designing lateral loads. So, in this study, only the quantity of concrete of columns in the case of MRF buildings is considered in the comparison analysis. For the case of SW-MRF, the variation in the concrete quantity for both supporting columns and shear walls are considered. A comparison between the percentage increase or decrease in the considered concrete quantity in the buildings designed according to different codes relative to those are designed according to the SBC is displayed in Fig. 7 for MRF building and in Fig. 8 for SW-MRF building.

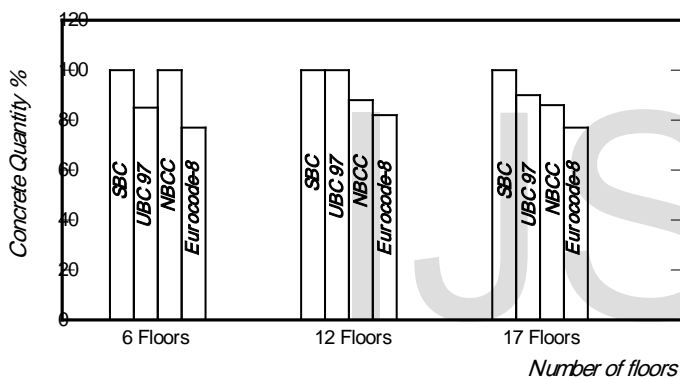


Fig. 7 Comparison between concrete quantity % for sub-base elements (MRF buildings)

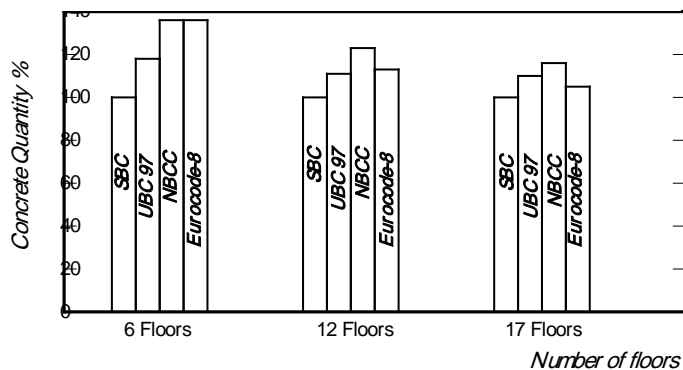


Fig. 8 Comparison between concrete quantity % for sub-base elements (SW-MRF buildings)

According to this comparison analysis, many findings can be drawn out which will be stated in this section. Regarding the MRF buildings, it is clear from the illustrated figure that for all buildings with considered heights that the maximum percent-

age of concrete amount is observed for buildings designed according to the SBC. The minimum amount of concrete quantity is observed for buildings designed according to the Eurocode-8 with percentage difference relative to the buildings designed according to the SBC by ratios ranging between 77% and 82% according to the building heights. Building designed according to NBCC and UBC 97 codes are with concrete quantities for substructure elements range between 85% and 100% relative to the buildings designed according to the SBC.

Carrying out a concrete quantity comparison analysis for the SW-MRF buildings, it is clear the calculated concrete quantity for buildings with different heights and designed according to the SBC is the least concrete amount relative to those designed according to all other considered design codes. The maximum variations in concrete quantity of buildings designed according to different codes are observed for buildings with minimum height which is 6 floors. For buildings with this height, the maximum difference in concrete quantity is 135% for buildings designed according either to Eurocode-8 or NBCC relative to SBC. As the height of building increases, the difference in concrete quantity decreases. The maximum percentage increase in concrete quantity does not exceed 115% of buildings designed according to the NBCC relative to the buildings designed according to the SBC.

## 6 CONCLUSIONS

Relying on the investigations and discussions presented in this study, the following conclusions may be drawn out.

- 1) For all studied buildings types under any considered code of practice it is clear that the obtained results of normalized base shear using the equivalent lateral force procedures are higher than those obtained using the computer base modal analysis.
- 2) The comparative analysis carried out on the MRF buildings results in that applying the SBC yields results of normalized base shear higher than all those resulted using the other considered codes of practices with ratios range between 16% and 66%.
- 3) The comparative analysis carried out on the SW-MRF buildings results in that applying the SBC yields results of normalized base shear less than all the considered codes, for buildings higher than 6 floors ranging between 135% and 58% when using the equivalent lateral load method. The results of normalized base shear using the computer base modal analysis yields that using the SBC results in values less that those obtained using the NBCC and UBC 97 by a range between 23% and 55%.
- 4) The comparative analysis which is carried out for the concrete quantity of sub-base structure for the MRF buildings, with 6, 12 and 17 floors, yields that the highest amounts is observed for buildings designed according to the SBC with differences up to 33% relative to buildings designed according to different considered codes. For the SW-MRF buildings, with same heights, the least concrete amounts are observed for buildings designed according to the SBC with variation ratios up to 15% relative to buildings designed according to different considered codes.

## Acknowledgment

This study is supported by Taif University under a (Grant No. 1-434-2823). The university is highly acknowledged for its financial support.

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