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Dynamic Response Analysis of Reinforced Concrete Buildings According to Egyptian code (EC-2011) and National Building Code of Canada (NBCC-2005)

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Abstract: **This paper compares the induced dynamic responses of reinforced concrete shear buildings in accordance with the seismic building code of Egypt (EC-201) and the national building code of Canada (NBCC-2005). Code provisions regarding the design response spectrum analysis are compared and their effect on the dynamic responses viz storey displacements, drifts, shear forces and overturning moments are studied. A real reinforced concrete building with shear walls located in Cairo and composes of 13 storeys is used in the analysis. The well-known structural package ETABS (Extended 3D Analysis of Building Systems) is used to develop the building model and to perform the dynamic analysis in X and Y directions separately. In order to scale the dynamic base shear following the requirements of the applied codes, the equivalent static lateral force procedure is utilized as well. The obtained seismic responses of the building following guiltiness of the EC show substantial differences with those obtained following the stated guidelines in the NBCC-2005. Based on the analysis, The Provisions for design response spectrum of the NBCC-2005 has been found to be conservative compared with the EC.**

Keywords: **reinforced concrete buildings, Egyptian Code, Canadian Code, Response Spectrum.**

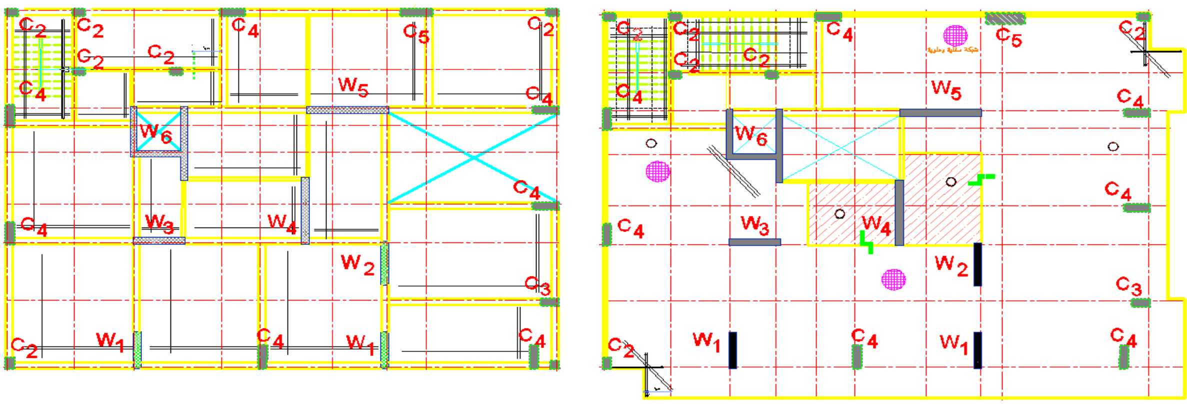
I. INTRODUCTION

Current seismic design code for buildings in Egypt needs to be continuously improved to be suitable for seismic design. Complex and irregular geometries and mass distributions of building structures are critical parameters that may result in variety of dynamic characteristics that significantly affect the dynamic behavior of the structure. The use of current design provisions to such buildings is challenging for structural and design engineers where it requires continuous adaptation of design rules and may result in inadequate designs [1]. Since the occurrence of the ground shaking in Egypt in 1992, the Housing and Building National Research Centre considers the improvement of the existing Egyptian Code for loads to be efficient in simulating the expected ground motions and to provide the seismic loads required for earthquake resistant design of structures as a crucial issue [2-5]. The first edition of the Egyptian code only included the equivalent static force method to represent the applied earthquake load. However this method has many limitations in terms of structures heights, regularity and irregularity in plan and elevation and seismic intensity of the location. Several improvements have been introduced to the implemented seismic code of design in order to overcome the shortage of the introduced static method of analysis. The nest editions of the Egyptian codes included the dynamic response spectrum analysis method to accurately capture the induced seismic responses. The dynamic time-history analysis has also been included in the edited versions. Static and dynamic analysis of structures following the requirements of the Canadian code and other codes have been carried out [6-9]. In order to study the effect of the effect of building height on the induced seismic responses employing the static and dynamic analysis methods, Khan [10] conducted a comparative study considering two building structure of height 200 ft and 400 ft. Mahmoud and Abdallah [11] performed a detailed comparative study between the equivalent static and dynamic response spectrum methods of analysis stated in the Egyptian code for loads using reinforced concrete building with shear walls to resist the applied seismic loads. Raheem [12] utilized the static, dynamic response spectrum and dynamic time-history analysis methods to evaluate the seismic performance of reinforced concrete framed building according to the Egyptian code provisions for seismic loads.

In the current study, the seismic response of reinforced concrete building is examined using the dynamic response spectrum method following the provisions stated in two different seismic codes namely; Egyptian and Canadian codes. The proposed analysis method in the two codes is used to compute storey displacements, moments, shear forces and drifts for an existing building located in Cairo. The predicted responses using the proposed spectrum method in the Egyptian code are compared to those predicted utilizing the dynamic spectrum method proposed in the Canadian code. The dynamic response spectrum method is applied in X and Y directions.

II. BUILDING MODEL

The considered herein reinforced concrete building is a real one for residential use and located in Cairo with a bedroom, a ground floor and 11 typical storeys. The bedroom floor has been designed so as to have solid slab system carried by main and secondary beams. The remaining other floors have been designed as flat slab system supported on columns directly. The plan dimensions of the building at the bedroom level are 19.83 m x 14.66 m. The typical floor has the same dimensions with an added cantilever slab of about 1.00 as can be seen in Figure 1. The considered floor height is of about 3.00 m. The designed solid slab thickness for bedroom is 14 cm. the designed thickness for the flat slab system is 20 cm for all storeys. Different cross-sections have been assigned for the columns and shear walls to resist both gravitational and lateral loads applied to the building. A designed elevator core with reinforcements of 53Φ12 has also been added to resist the seismic forces. The chosen cross-sections for columns and shear walls are presented in Table 1. Reinforced concrete with characteristic compressive strength f_{cu} = 25 MPa and steel reinforcement with yield strength f_y = 360 MPa have been utilized in the design process.



(a) **(b)**

Fig 1: Rresidential building (a) ground floor plan (b) typical floor plan

TABLE 1: Columns and shear walls models, dimensions and bar reinforcements

Column models	Dimensions (cm)	Reinforcement	Wall models	Dimensions (cm)	Reinforcement
C1	30x30	4Φ18	W1	30x150	12Φ12
C2	30x45	8Φ16	W2	30x180	15Φ12
C3	30x65	10Φ16	W3	30x190	16Φ12
C4	30x95	16Φ16	W4	30x275	22Φ12
C5	30x110	16Φ16	W5	30x300	24Φ12

The cross-sections and reinforcement details of the designed horizontal elements in terms of beams and slabs have been used to build the three-dimensional (3-D) model shown in Figure 2 using ETABS software package. Similarly the designed vertical elements in terms of columns and walls have also been used to develop the reinforcement concrete building model in 3-D. in order to ensure transferring the slab mass to the supporting beam, column and wall elements element they were modelled as shell elements. Such modelling also ensure providing stiffness in all directions of analysis as well. Semi-rigid diaphragms have been assigned at the ground and typical floor levels. The modal damping effect has been considered through employing the complete quadratic combination technique (CQC) for modal combination.

Appropriate restraints are chosen for defining the supports and connections of the developed reinforced concrete building model. ETABS enables the user to carry out the seismic analysis using static and dynamic procedures defined according to the seismic design codes in both X and Y directions. The used structural package also enables the user to define the mass source required to calculate the building weight and hence the shear at base. Employing either the Eigen mode or Ritz mode methods are also available through defining the modal cases in both X and Y directions.

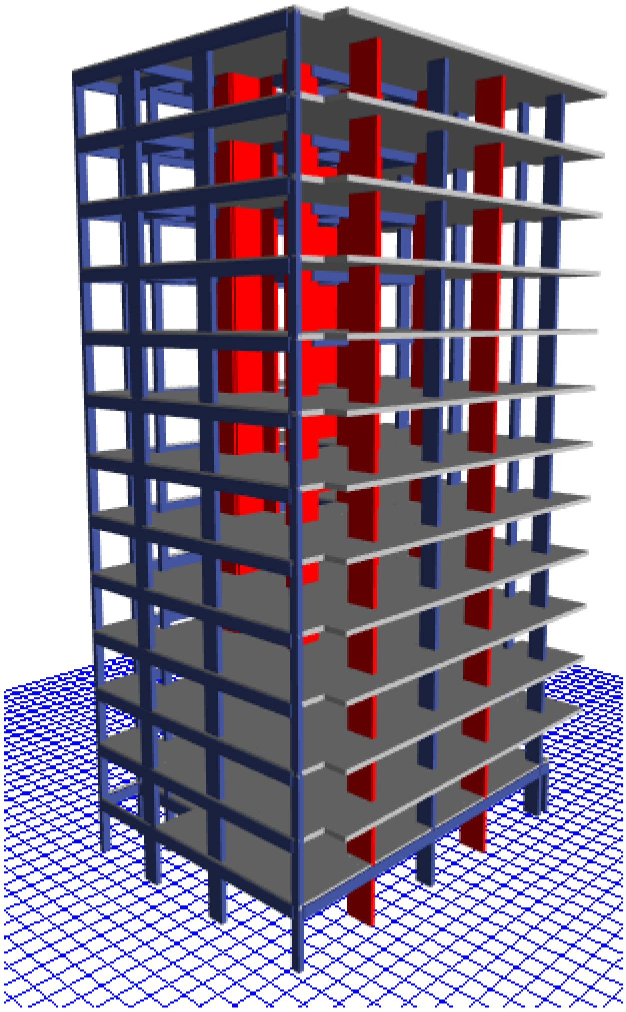


Fig 2: Three-dimensional building model

III. RESPONSE SPECTRUM ANALYSIS METHOD

The methods of earthquake analysis divided into static and dynamic analysis methods. However, the dynamic analysis can be considered as the general method used in performing earthquake resistant design of structures. The equivalent static force method can only be utilized for limited cases related to the building configurations in terms of regularity in plan and elevation as well as the height of the building. The seismic zone is one of the parameters control the use of the static method of analysis. The dynamic analysis is performed either using the response spectrum method or the time-history analysis method. In the time-history analysis, the ground acceleration records is used to describe the seismic action which incrementally affects the structure at specified time-intervals [13, 14]. This method is highly recommended for structures with high degree of importunacy. On the other hand, the response spectrum analysis is most commonly used method for performing the dynamic analysis of structures. This method mainly depends on deriving the response spectrum curves for peak displacement, peak velocity or peak acceleration versus the natural period of the assumed single degree of freedom building system subjected to an earthquake excitation. The application of response spectrum analysis requires definition of specified parameters. The seismic intensity of the considered location and the supporting soil type are key parameters used in performing the response spectrum procedure. Modifying the response spectrum curve in order to account for the ductility demand and over strength according to the used earthquake resistant system is another key parameter for performing the dynamic response spectrum analysis. The used modal combination method in terms of The Square Root

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of Some of Squares (SRSS) of the maximum modal values, the absolute of the modal response values (ABS) and the CQC are also used for peak response computation is key parameter as well. The number of requested modes for completing the analysis can be confirmed through achieving a mass participation ratio of no less than 90% of the total effective mass in the relatively high structures. However, for low and mid-rise building structures, considering the first three modes can be considered as sufficient in capturing accurate structural response where the contributions from the higher modes are relatively small as compared the first three modes. It is worth noting that the use of response spectrum analysis requires the use of equivalent static force method in order to compare the obtained design base shear forces using the two methods. The dynamic base shear should be no less than the static one. Rescaling the design base shear in accordance with the ones obtained with the ESF analysis is another important parameter. The regularity and irregularity of structures mainly govern the scaling factor of the design base shear. The design building codes in seismic regions uses the obtained design spectral acceleration values $S_d(T)$ as basis for calculating the forces that a structure must be designed to resist. The Egyptian design code for loads defines specific equations for each range of the spectrum curve for four different soil types and damping ratio as:

$$S_d(T) = a_g \gamma_I S \left[\frac{2}{3} + \frac{T}{T_B}\left(\frac{2.5}{R} - \frac{2}{3}\right)\right] \qquad \text{for } 0 \leq T \leq T_B$$

$$S_d(T) = a_g \gamma_I S \frac{2.5}{R} \qquad \text{for } T_B \leq T \leq T_C$$

$$S_d(T) = a_g \gamma_I S \frac{2.5}{R}\left[\frac{T_C}{T}\right] \geq [0.2]\, a_g \gamma_I \qquad \text{for } T_C \leq T \leq T_D$$

$$S_d(T) = a_g \gamma_I S \frac{2.5}{R}\left[\frac{T_C T_D}{T^2}\right] \geq [0.2]\, a_g \gamma_I \qquad \text{for } T_D \leq T \leq 4$$

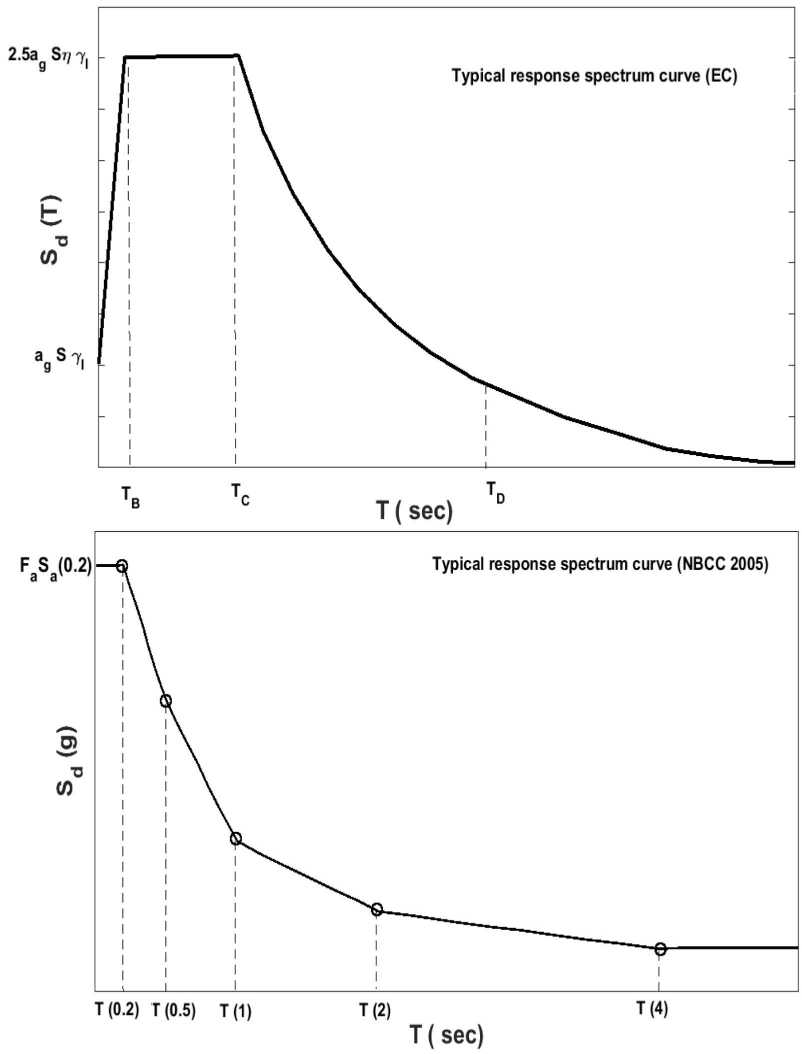

Fig 3: Typical response spectrum curve according to the Egyptian code and the Canadian code

Where a_g , γ_I , and S respectively represent the designed peak ground acceleration, the important factor for the structure, and soil factor. R is a factor accounts for the ductility and over strength of the structural system. T_B , T_C , T_D are values for the periods describing the shape of the elastic response spectrum and depend on the ground type. On the other hand, the 2005 Canadian code for loads uses the design spectral acceleration (Sd (T)) values to define the response spectrum curve as:

$S_d(T) = F_a S_a(0.2)$ for T ≤ 0.2 sec

$S_d(T) = F_v S_a(0.5)$ or $F_a S_a(0.2)$ whichever is smaller for T = 0.5 sec

$S_d(T) = F_v S_a(1)$ for T = 1 sec

$S_d(T) = F_v S_a(2)$ for T = 2 sec

$S_d(T) = F_v S_a(2)/2$ for T ≫ 4 sec

Where F_a and F_v are the acceleration-based and velocity-based site coefficients respectively. S_a is the spectral response acceleration at specified time periods of 0.2 sec, 0.5 sec, 1 sec and 2 sec.

IV. DYNAMIC ANALYSIS RESULTS

In order to develop the reinforced concrete building model considered herein, the structural software package ETABS is employed. It is worth noting that the several seismic design codes are defined in the software package and can be used to define the earthquake load either as static or dynamic load according to the seismic intensity of the considered location. The developed model for analysis consists of a bedroom, ground floor and typical eleven storeys of height 3.0m for each. The designed concrete dimensions of the horizontal elements in terms of slabs and beams has been found to be of 14cm for solid slab and 20 cm thickness for flat slab systems and 25x50cm for beams. Designed columns with different dimensions vary from 30x30 to 30x110cm have been obtained to resist the applied gravitational and seismic loads. The shear walls as the main lateral force resisting system have also been designed and found to have a thickness of 30 cm. the used raft foundation to carry the building storeys is of 1.3m thickness. The location of the considered building is Cairo which is located in seismic zone 3. The defined static and dynamic functions are calculated according to the Egyptian and Canadian codes for loads separately. Cairo seismic zone is of about 0.15g and has a soil profile type classified as stiff. The coefficients and factors related to the response modification and ductility ae chosen according to the lateral system used to resist seismic loads following the considered two codes of seismic design. In order to study the seismic performance of the building model in two orthogonal directions, the static and dynamic earthquake loads are applied in X and Y directions separately. Following the design codes requirements, the dynamic base shear is scaled with obtained static one in the considered two directions of analysis.

The induced storey shear forces, displacements, drifts and overturning moments in the considered X and Y directions are presented in Fig. 4, 5, 6 and 7 respectively.

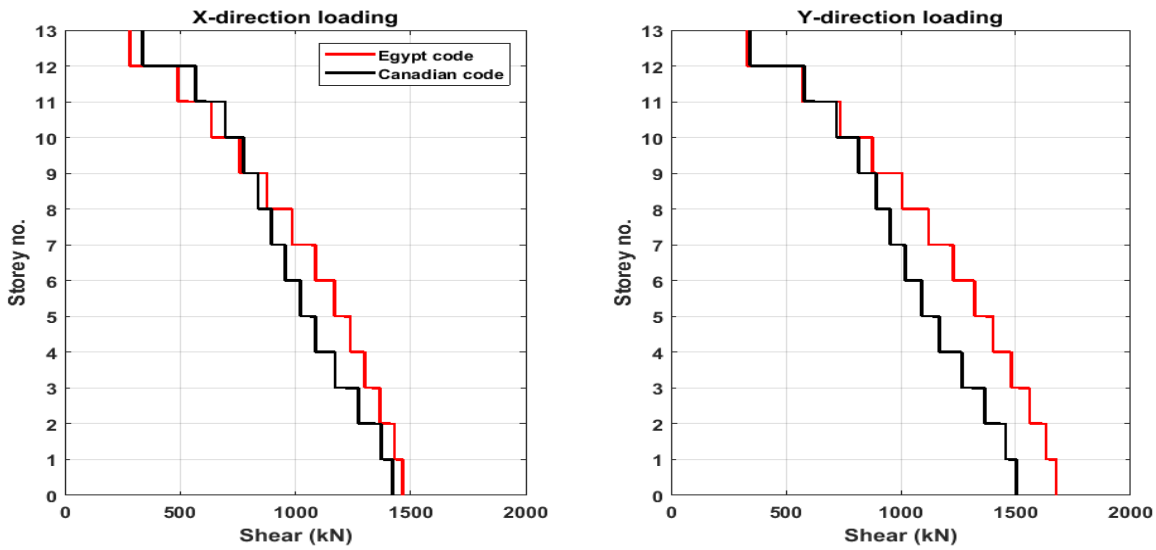

Fig 4: Scaled dynamic storey shear forces following the requirements of EC and NBCC-2005 under applied load in X and Y directions

From the structural designer's point of view, the induced shear force at building base is an important parameter in performing the design process. Fig. 4 presents the dynamic storey shear forces in X and Y directions employing the Egyptian and Canadian codes for seismic loads after performing scaling process with the static one. As it can be seen from the figure, regardless the direction of the applied dynamic load, the obtained storey shear values using the Egyptian code exceed the values obtained using the Canadian code. The higher the storeys the lower the induced shear forces in the considered two orthogonal directions. In addition, at higher storeys, the induced shear forces using the two codes of design show insignificant differences in X direction and seems to be identical in Y direction. The application of seismic load in Y direction compared to X direction clearly identify the difference between the values obtained using the two codes especially at base. The increase in dynamic storey shear at the base employing Egyptian code with respect to Canadian code is of about 11.7% in Y direction and of about 3% in X direction

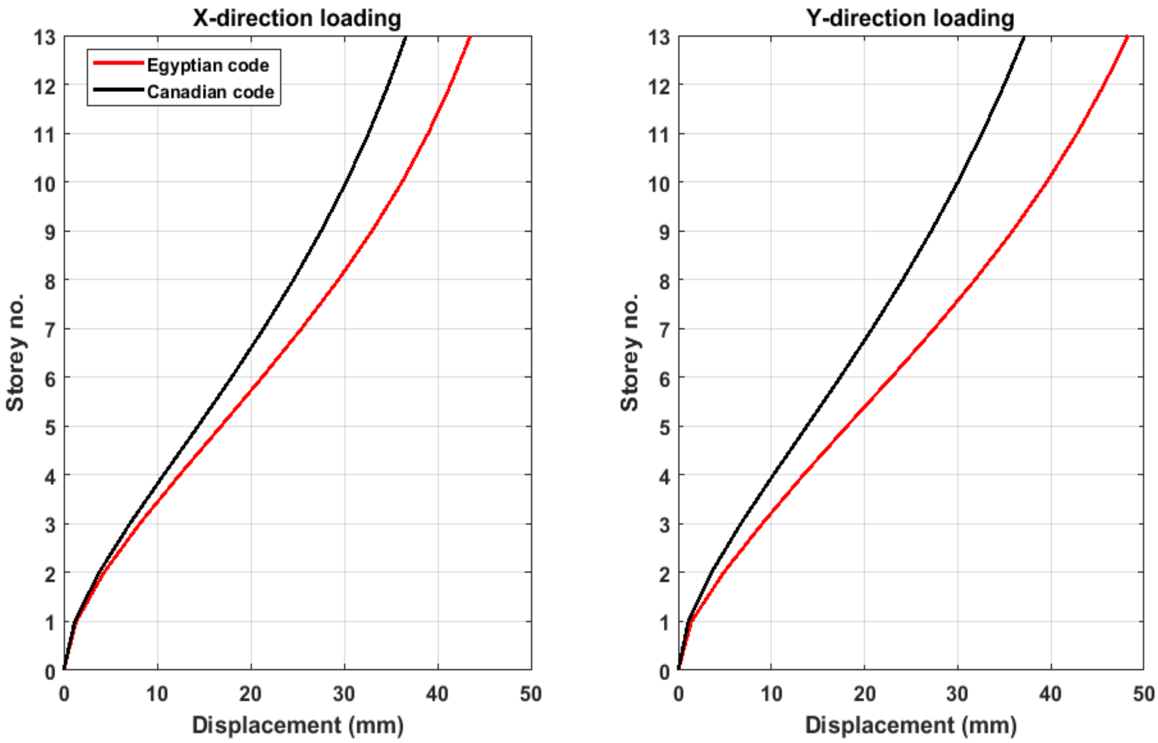

Fig 5: Dynamic storey displacements following the requirements of EC and NBCC-2005 under applied load in X and Y directions

The induced storey displacement at each storey level due to the application of seismic load in X and Y directions following the requirements of Egyptian and Canadian codes are presented in Figure 5. The figure shows that the obtained storey displacements following the EC requirements are of higher values as compared to those obtained following the requirements of the NBCC-2005 in both X and Y directions of loading. Contrary to the obtained storey shear forces, the higher the storey level the higher the captured storey displacements. The variation in the induced storey displacement responses is more pronounced at higher storey for the considered two directions of loading. However, the obtained displacements in Y direction show significant differences between the two codes compared to the obtained values due to the application of load in X direction. The computed percentage of increase of the displacement values obtained following the Egyptian code as compared to the displacement values obtained using the Canadian code has been found to be of 30% during applying the seismic load in Y direction. The percentage value of increase in X direction between the values from EC-201 and the corresponding values from NBCC-2005 has been found to be of about 19%. Computations of the percentages show significant increase between the Egyptian and Canadian codes especially during the application of load in Y direction. The reason behind the increase in storey displacement in Y direction compared to X direction values can be due to the change in the overall global stiffness matrix in X and Y directions.

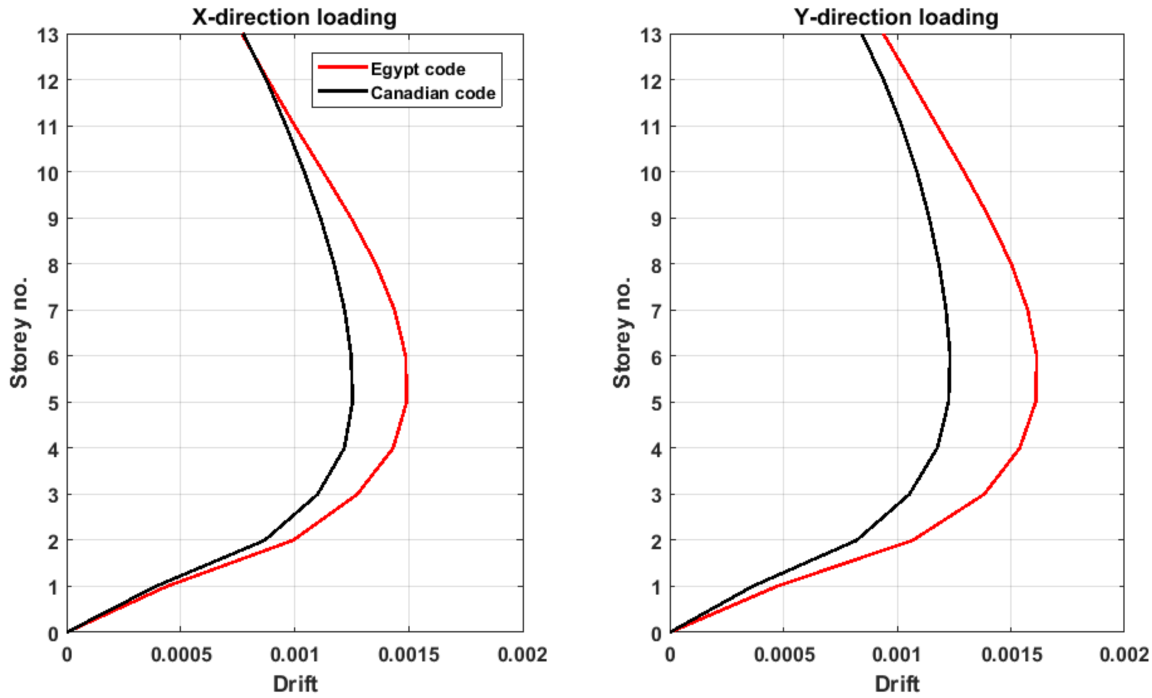

Fig 6: Dynamic storey drifts following the requirements of EC and NBCC-2005 under applied load in X and Y directions

From seismic design point of view, the storey drift values can significantly affect the structural and non-structural elements of building structures. The plotted curves for the obtained storey drifts employing the requirements of Egyptian and Canadian codes under applied seismic load in two orthogonal directions are shown in Figure 6. The plotted values of storey drift ratios demonstrate the differences between the Egyptian and Canadian codes for seismic design regardless the direction of loading. As it can be seen from the figure, the increase in drift ratios induced by the Egyptian code as compared to those obtained using the Canadian code is more pronounced in Y direction with respect to values induced by applying the seismic load in X direction. The percentage of increase in Y direction has been found to be of about 29%. However, the corresponding values in X direction show percentage increase of about 18%. These obtained values seem to be identical to the percentage increase values obtained for the displacement responses in X and Y directions respectively.

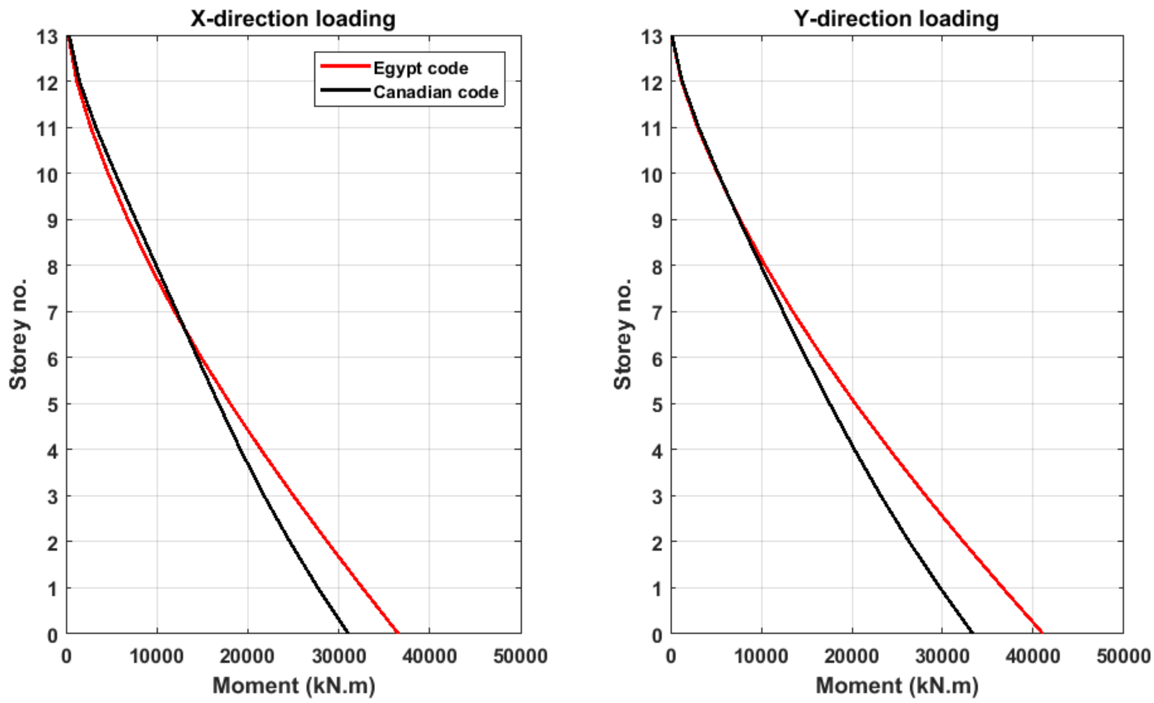

Fig 7: Dynamic storey moments following the requirements of EC and NBCC-2005 under applied load in X and Y directions

The obtained moment values at each storey according to the considered two different seismic codes are plotted in Figure 7 under applied seismic load in X and Y directions. Irrespective of the direction of loading, it can be noticed that, the lower the storey level the higher the induced storey moment under the earthquake load following the requirements of the two codes. Regarding the employed design code, applying the response spectrum load stated in the Egyptian code overestimates the obtained moment values as compared to the corresponding moment values employing the response spectrum curve suggested by the Canadian code. The percentage increase in the induced base moments by the Egyptian code compared to the Canadian code has been found to be of about 23% due to the application of seismic load in Y direction. On the other hand, an increase percentage value of about 18% has been computed due to the application of seismic load in X direction. The variation in moment values at higher storeys seems to be insignificant considering any of the two codes of design.

V. CONCLUSION

Dynamic response spectrum analysis of reinforced concrete building with shear walls as lateral load resisting system has been investigated according to two different seismic design codes and considering two orthogonal directions of loading. The considered two codes are the EC-201 and the NBCC-2005. The obtained storey seismic responses in X and Y directions and following the two design codes are computed and compared. It has been found from the analysis that the EC produces higher seismic response values as compared to the corresponding values obtained using the NBCC-2005 in both X and Y directions of loading. However, the higher storeys show slight and insignificant difference between computed storey shear forces using the EC-201 and the calculated values based on the NBCC-2005 in both directions of loading. Similar results has been obtained for the estimated storey moments in the considered two orthogonal directions and design codes. Contrary to the trend of storey shear forces and moments, the storey displacements show small differences between calculated results based on the two codes at lower storeys followed by significant differences between the obtained displacement values as the storeys get higher. The overall global stiffness of the considered building structure highly influenced the induced seismic responses in both X and Y directions where the computed values in Y direction are of higher values as compared to those computed in X direction.

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