Assessment of reinforced concrete structures under wind and earthquake using different design methods

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ABSTRACT

The effect of wind and earthquake on the structures can be specified briefly by the effect of horizontal forces acting on structures varying in their value and direction depending on the location and the distance from the sea in case of wind load and the seismic activity of the region in case of an earthquake. These horizontal forces conflict in concept with the structural stability of the structure. Most of the designer engineers adopted the vertical forces only in design calculations and neglected the horizontal forces based on the opinion that the horizontal forces are not effective. This design concept is wrong; thus, it is necessary to take into consideration the effect of these horizontal forces on structures; especially there are a number of earthquakes that took placed in different places of Iraq. So, it is necessary to deal seriously with design calculations according to local and international common codes. This investigation presents a review for the design procedures of different codes, solved design examples according to different local and international codes, the difference in design between the horizontal and vertical forces, and the methods to minimize the effect of wind and earthquake on structures. Data of a 12-floor symmetrical building were adopted in seismic and wind analysis. The results of SAP2000 were compared with international common codes such as European, American, Brazilian, Italian, and Romanian codes. The results of calculations revealed that there are some variations in the analysis of different codes. Romanian code is more conservative in calculating the lateral displacement and forces, while Italian code was low conservative.

Keywords: Assessment, earthquake, international codes, wave, wind.

INTRODUCTION

During robust ground motions or severe windstorms, many constructed reinforced concrete structures are severely damaged and collapsing or causing the loss of economy and lives. Collapse or damage of reinforced concrete structures after these acts of nature compels us to revise our information about the structural wind and earthquake analyses of these constructions.

In modern high-rise constructions, lateral loads induced by earthquake or wind often resisted by a system of coupled shear walls. But when the construction increases in height, the stiffness of the structure becomes more paramount, and the introduction of outrigger beams between the shear walls and external columns is usually utilized to supply sufficient lateral stiffness to the structure (Nanduri et al. 2013).

Fur et al. (1996) observed that the actively controlled base-isolation method with velocity feedback has better performance than that with either displacement or acceleration feedback. A comparative study of the wind and seismic dynamic responses of base-isolated buildings was presented by Vulcano (1998). He found that a different demeanor of the test structures is subjected to wind or seismic when assuming different grades of deformability of the isolators within a wide range of variation. The aim is to design more efficient constructions, less susceptible to natural hazards, particularly strong wind forces or earthquakes, and to reach the utmost security grade for both human lives and buildings. The resulting control systems fall within three categories: active control systems, passive control systems, and semiactive control systems (Fisco and Adeli, 2011). Türkeli et al. (2014) indicated that the analyses findings found from seismic time history analysis should be utilized in the structural design of reinforced concrete minarets and that additional care should be taken in those constructions where there is a reduction in cross section, and door opening took place.

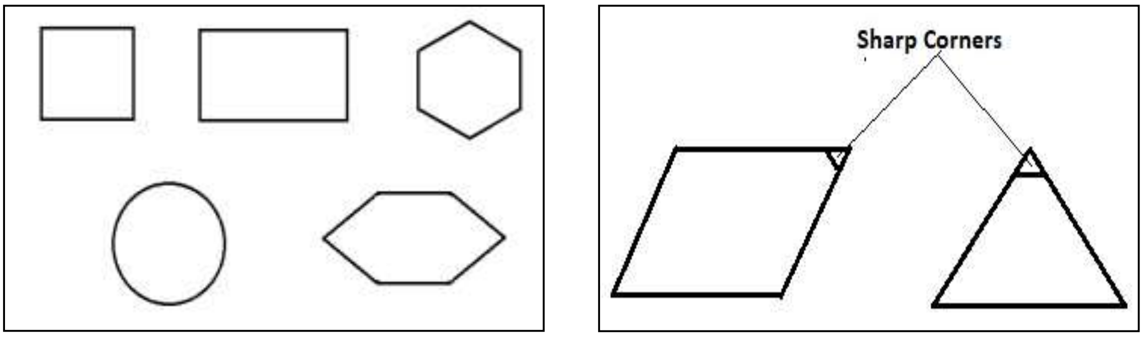
Pant and Wijeyewickrema (2012) conducted numerical analyses on the reinforced concrete building under the seismic pounding. They reported that the performance of the base-isolated construction is basically influenced by pounding. A postearthquake questionnaire indicated that damage in reinforced concrete constructions in urban regions was predominately due to the low concrete strength, poor construction quality, nonseismic detailing in the beam-column joints, and local site effects (Sharma et al. 2016). Hosseinpour and Abdelnaby (2017) pointed out that earthquake direction (in the irregular construction), the vertical earthquake component, and structure irregularity can have a considerable influence on the response of constructions subjected to multiple earthquakes.

In high-rise buildings, wind-induced vibrations could cause nuisance to the occupants (particularly in the upper floors), constructional damage, or impaired function of the devices (Aly et al., 2011). Based on the studies conducted by Lombardo (2012) and De Gaetano et al. (2014) confirmed that the wind loads that control constructional design in most areas of the continental Europe and USA are due to wind events. For the New Marina Casablanca Tower in Casablanca, Masera et al. (2015) presented a study based on the computational fluid dynamics findings to show how the wind loads are calculated and applied in the design. Roy and Bairagi (2016) highlighted the effect of wind directions on the stepped tall structure at different geometrical shape placed on above to each other. For super-tall buildings under different configurations, Tamura et al. (2017) studied the dynamic wind response, also awarded pedestrian-level and aerodynamic wind properties. Wind loads play an important role in structural design, particularly for light or tall structures (Miguel et al. 2018).

ARCHITECTURAL DESIGN REQUIREMENTS FOR WIND AND SEISMIC LOADS

Below are the architectural requirements for design buildings exposed to high wind and seismic loads:

1. The shape of the plane of a building must be chosen to be identical and must avoid the sharp corners in the design of a building. In the case of a nonidentical building, the joint must be used. See Figure 1 (Miguel et al. 2018).



a) Preferable b) Rejected

Figure 1. Preferable and rejected architectural design of a building exposed to wind and seismic.

2. The building units must be distributed symmetrically to achieve a uniform distribution of load (Architectural Institute of Japan, 1970).
3. Bearing element (walls and columns) must be uniformly and symmetrically distributed (Gonencen, 2000).
4. It is preferable to locate the center of gravity at area center of building plane; see Figure 2 (Gülay and Çalım, 2003).

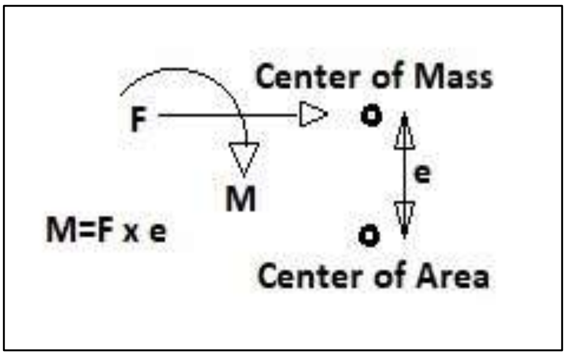


Figure 2. Effect of the center of gravity location on building.

5. The walls must be located in the same location and orientation of different floors (Mezzi, Parducci and Verducci, 2004).
6. Avoid the cantilever slabs and other members exposed to falling down during the earthquake (Ersoy, 1999).
7. The forces must be transformed directly to the foundations to avoid concentric load on beams and slabs of buildings (Lindeburg and Baradar, 2001).
8. The opening must be symmetrically and identically distributed in building plane (Livaoğlu and Doğangün, 2003).
9. The air conditioning system, gas system, ventilation system, and electrical system must be automatically switched off when the building is exposed to high wind pressure and seismic load (Lagorio, 1990).
10. The position of stairs must be located at interior panels of building plane (Zacek, 2005).

STRUCTURAL DESIGN REQUIRMENTS FOR WIND AND SEISMIC LOADS

Below are the structural requirements for design building exposed to high wind and seismic loads:

1. In the case of high-rise buildings, it is necessary to increase the stiffness of structural elements to increase its resistance to high wind pressure and seismic load (Naeim, 2001).
2. Adopt shear walls distributed on different locations of the building (Chen and Scawthorn, 2002).
3. Adopt a concrete core for stress and elevators (Bayülke, 2001).
4. It is preferable to choose the location of the concrete core at the center of gravity of the building (Bayülke, 2001).
5. Include the special detailing of reinforcement (Arnold and Reitherman, 2002).

INTERNATIONAL CODES OF REINFORCEMENT METHODS FOR SEISMIC REQUIRMENTS

The reinforced concrete frames in seismic zones shall satisfy the most common international codes and provisions such as Euro code 8 (ECS, 2004), ASCE-7/10 (ASCE, 2010), NBR15421 Brazilian (ABNT, 2006), Italian (IMI, 2008) and Romanian (RMTCT, 2007) codes from chapter one to chapter eighteen in every detail of reinforced concrete structures. Below are the most important requirements of structural members according to most common code provisions:

Beams

A longitudinal reinforcement for beams must be extended through columns; at least two of tension and compression bars extend to minimum twice beam depth through column; see Figure 3. At shear zone, hooks must be placed to increase the shear capacity of the section, and the shear legs must be rotated around longitudinal reinforcement as shown in Figure 4 (Do, 2005).

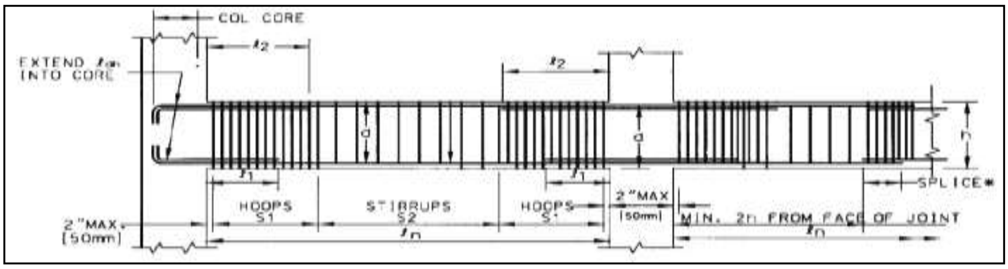


Figure 3. Details of beam at joint (Do, 2005).

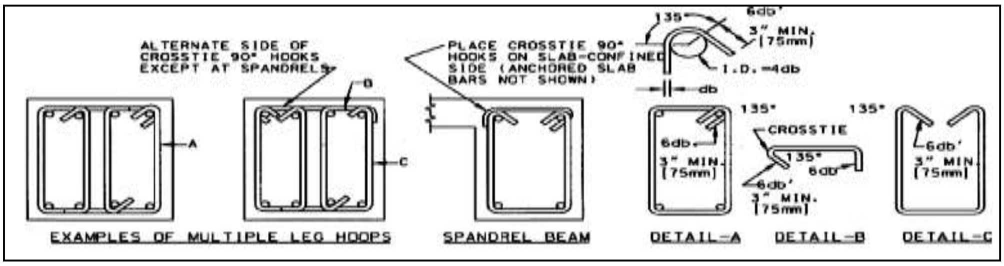


Figure 4. Details of cross section in beam at joint (Do, 2005).

Columns

The spacing between stirrups at the top and bottom ends of columns shall not be larger than the smaller of the following:

- 8 dsb.
- 24 dsb.
- 1/2 smaller dimensions column cross section.
- 12 inches (300 mm); the stirrups extend until 1/6 clear height of column at top and bottom, maximum dimension of cross section or 18 inch (450 mm); see Figure 5 (Do, 2005).

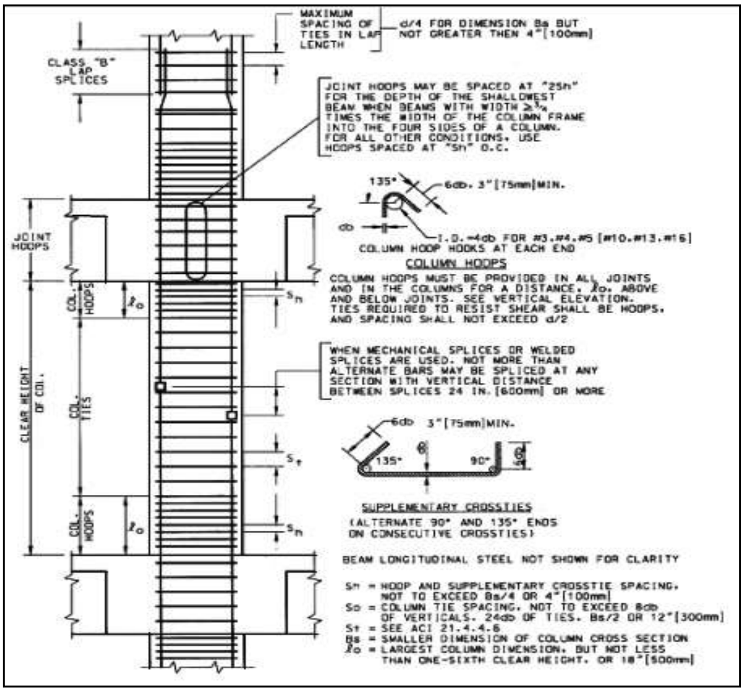


Figure 5. Details of column (Do, 2005)

Walls and diaphragms

Walls and diaphragms are the most important structural members in lateral loads such as seismic and wind loads. They are stiffer than beams, columns, and slabs. A longitudinal and a transverse reinforcement of walls shall be in two layers. The reinforcement ratio in longitudinal and transverse directions must be greater than 2.5×10^{-3} (Astaneh-Asl, 2003) with a maximum spacing between bars 18 inches (450 mm). The wall must be reinforced with closely spaced hoops at which the compression force becomes less than 0.15fc′Ag. Boundary elements must be placed at wall edge to increase the stiffness of wall; the boundary element reinforcement like column has longitudinal and transverse reinforcements; see Figure 6 (Astaneh-Asl, 2003).

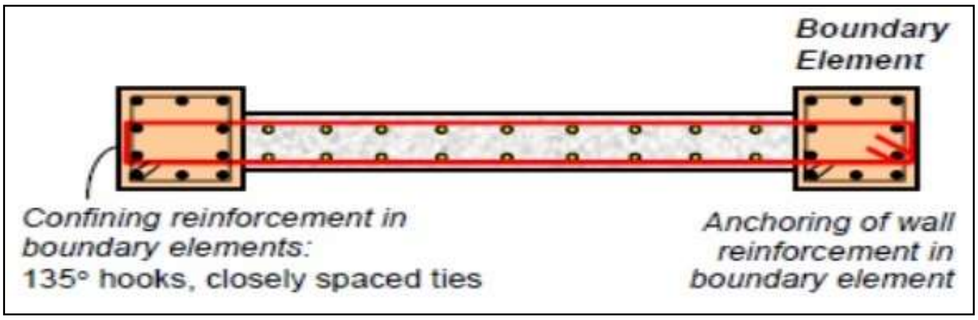


Figure 6. Details of wall (Astaneh-Asl, 2003).

Beam-column connection

In different international codes, the beam-column connection must be given careful attention. Accurate drawing details should be prepared to supply enough information before construction. Figures 7 and 8 illustrate commonly used methods for connection reinforcement. It is represented by special hooks, in addition to extending the beam flexural bars to the column core. The flexural bars extend from each side to another in interior beam-column connection, which lead to an increase in the joint strength for lateral loads (Astaneh-Asl, 2003). The effective width of joint in most codes should not exceed the smaller of the following:

1. Beam width plus the joint depth.
2. Twice the smaller perpendicular distance from the longitudinal axis of the beam to the column side.

Hoops may be included in corners; the area of radial hoops required is approximately given by the following equation:

$$av = \left[\frac{fy}{fyi}\sqrt{1+\frac{h1^2}{h2}}\right]\left(\frac{As1}{n}\right) \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{1})$$

where

fyi: yield strength of radial steel with n legs.

fy: yield strength of main steel.

h1 and h2: beam depth and column width, respectively.

As1: the area of tension steel in the beam.

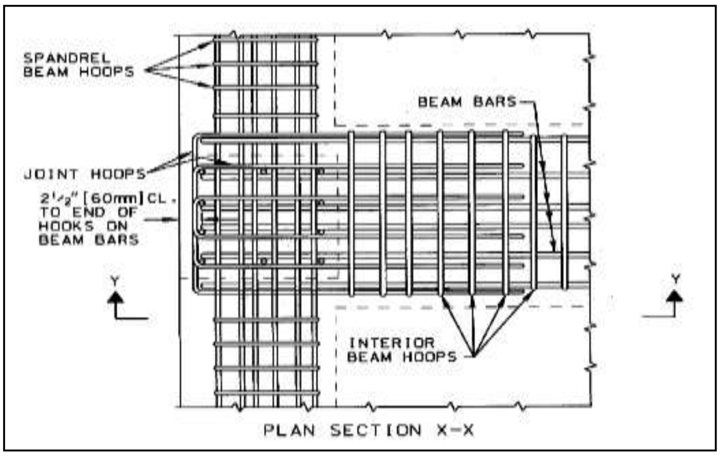


Figure 7. Details of joint (Astaneh-Asl, 2003).

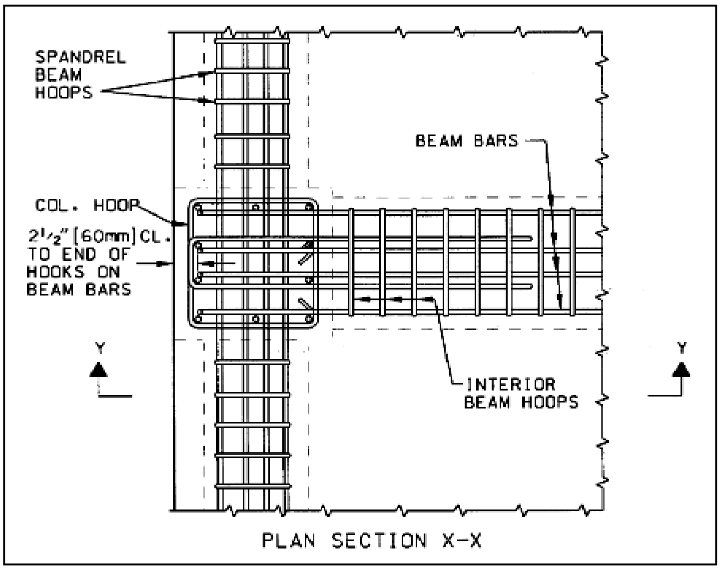


Figure 8. Details of joint (Astaneh-Asl, 2003).

NUMERICAL EXAMPLE

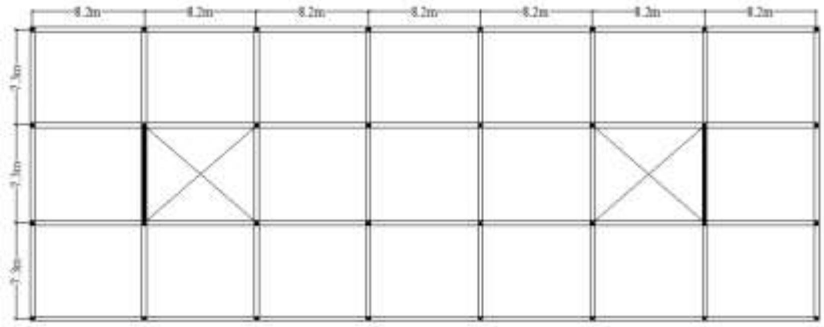
Proposed building

The proposed data were brought from the model suggested by Gosh and Fanella (Gosh and Fanella, 2003); it is a 12-floor symmetrical building. A seismic analysis was performed on this building by adopting different international common codes such as Euro code 8 (ECS, 2004), ASCE-7/10 (ASCE, 2010), NBR15421 Brazilian (ABNT, 2006), Italian (IMI, 2008), and Romanian (RMTCT, 2007) codes. The main information and data of this building are listed as follows:

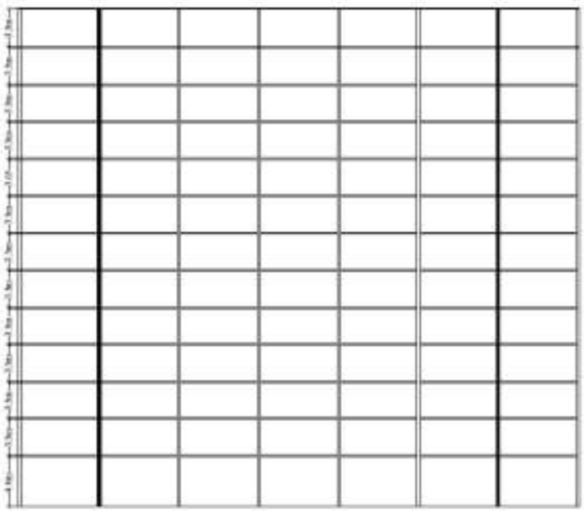
- Cube concrete compressive strength = 28 MPa.
- Modulus of elasticity of concrete = 32 GPa.
- Concrete density= 25 kN/m³.
- Weight of finishing all stories = 1.5 kN/m2.
- Weight of finishing of roof = 0.5 kN/m2.
- Dimensions of building: 21.9 m×85 m (c/c of columns).
- Overall building height: 49 m.
- Exterior columns sectional dimensions= 600 mm×600 mm.
- Interior columns sectional dimensions= 650 mm×650 mm.

- Beams sectional dimensions= 550 mm×900 mm.
- Thickness of the slabs: 200 mm.
- Shear-walls thickness= 300 mm.
- Total weight of the building= 171.3 ton.

Typical plans and elevations of the Model Building are presented in Figure 9.



a) Typical floor plan



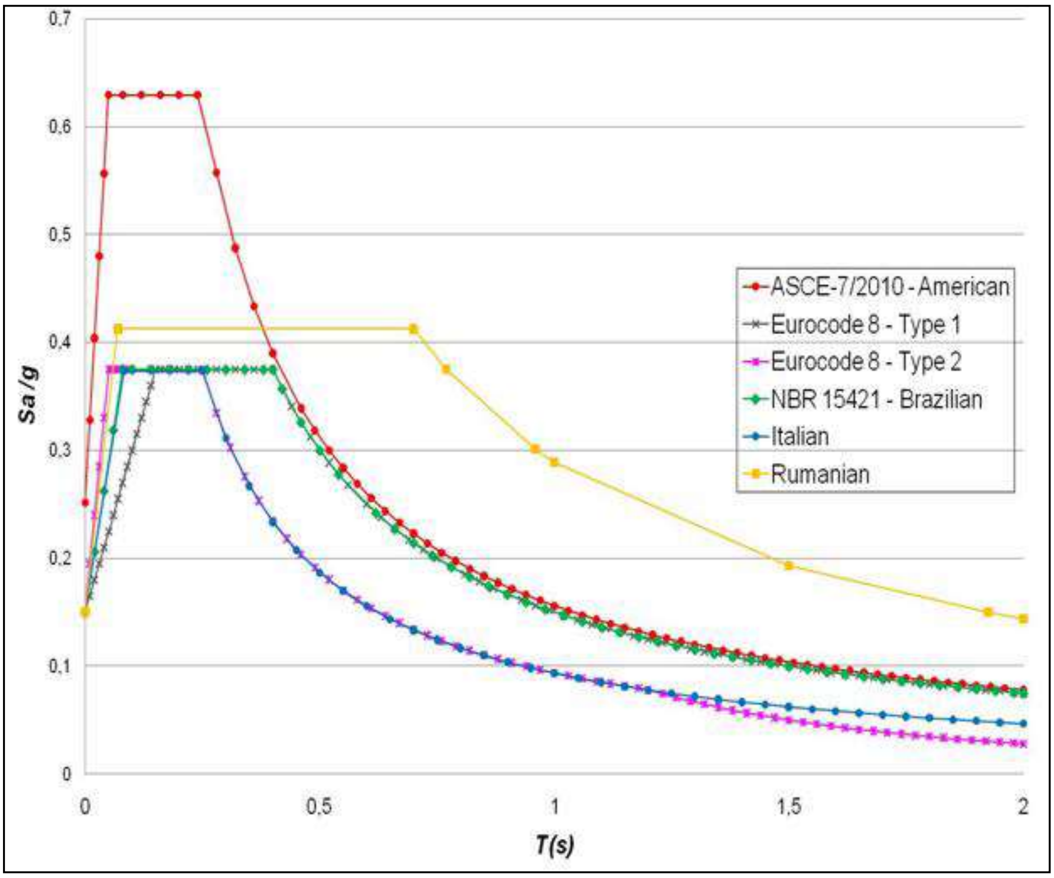
b) Elevation Plan

Figure 9. Plans for Model Building.

Considered seismic and wind data

To make a comparison of different international codes, a location of the proposed building was chosen in Reevesville, South Carolina, United States of America. A record of 475-year seismic data was available, and the design ground acceleration for soil conditions in this location can be taken as ag = 0.15g. This relatively small level of seismicity is close to that of the seismic data of Iraq. The seismic history of this location is shown in Figure 10. The current wind map for North Carolina showed wind speed of 7mph, which was adopted in the input of SAP2000 software and calculations in international codes.

The seismic collected data for this zone was recorded as the higher accelerations are concentrated in the 0.1s–0.25s periods range, and all the presented spectra consider the same seismicity (ag = 0.15g).



***Note**: The ASCE/SEI 7/2010 considers the recurrence period of 2475 years.*

Figure 10. Elastic response spectra according to different standards.

Analysis results

To make a comparison between different codes, the analysis of building structure was performed by using SAP2000 software program for the elastic response of spectra data of different standards codes. The codes used were as follows: Euro code 8 (ECS, 2004), ASCE-7/10 (ASCE, 2010), NBR15421 Brazilian (ABNT, 2006), Italian (IMI, 2008), and Romanian (RMTCT, 2007) codes. The first mode (T1=1.51s) indicates the elastic state of the structure. The bending vibration is typical and parallel to the long span of the structure. Table 1 shows the data representation of the first mode shapes extracted by SAP2000. The second mode (T2=1.08s) appears in the transversal direction (Y).

Table 1. Period and modal participation mass ratios.

Floor no.	Direction of vibration	Period	Longitudinal %	Transverse %	Vertical %
1	¼ wave longitudinal	1.5142	0.86214	0	0
2	¼ wave transverse	1.07771	0.86214	0.7401	2E-18
3	torsion	0.93766	0.86214	0.7401	4.1E-18

4	¾ wave longitudinal	0.49877	0.95355	0.7401	1.3E-17
5	¾ wave transverse	0.29882	0.95355	0.89957	5E-16
6	5/4 wave longitudinal	0.28973	0.97921	0.89957	8E-16
7	Longitudinal and transverse coupling	0.26476	0.97921	0.89957	1.3E-15
8	7/4 wave longitudinal	0.20231	0.98923	0.89957	5.7E-15
9	2/4 wave vertical and central	0.19205	0.98923	0.89957	0.47732
10	4/4 wave vertical	0.16242	0.98923	0.89957	0.47732
11	9/4 wave longitudinal	0.15431	0.9937	0.89957	0.47732
12	Transverse and vertical coupling	0.15355	0.9937	0.9076	0.47732
13	Transverse and vertical coupling	0.14668	0.9937	0.95412	0.47732

The lateral displacements recorded at the top of the building frame are shown in Figures 11 and 12 for longitudinal (X) and transversal (Y) directions.

It can be noticed that, due to the consideration in the Eurocode 8, Type 2, and the Italian code spectrum, the lateral displacements and forces obtained from these codes are dramatically lower than those obtained from other codes, while the Romanian code recorded maximum lateral displacement.

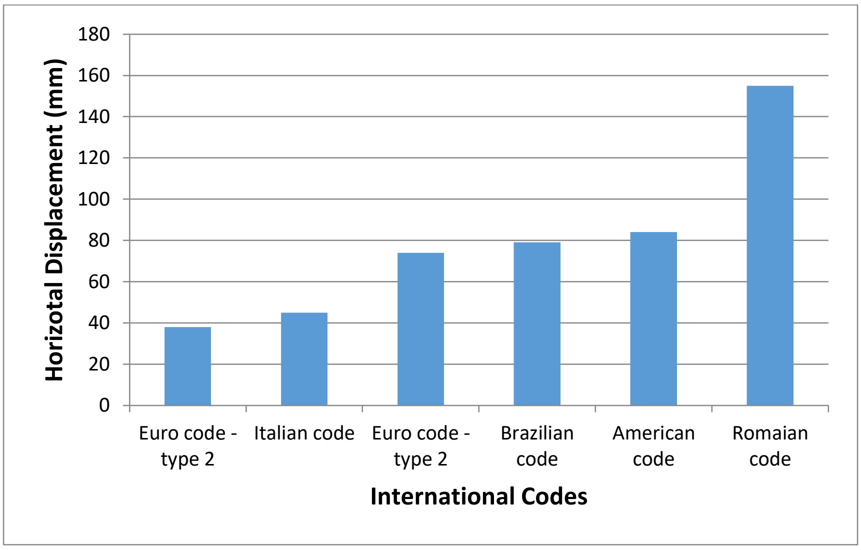


Figure 11. Obtained displacements, longitudinal direction (X) @ the top of structure.

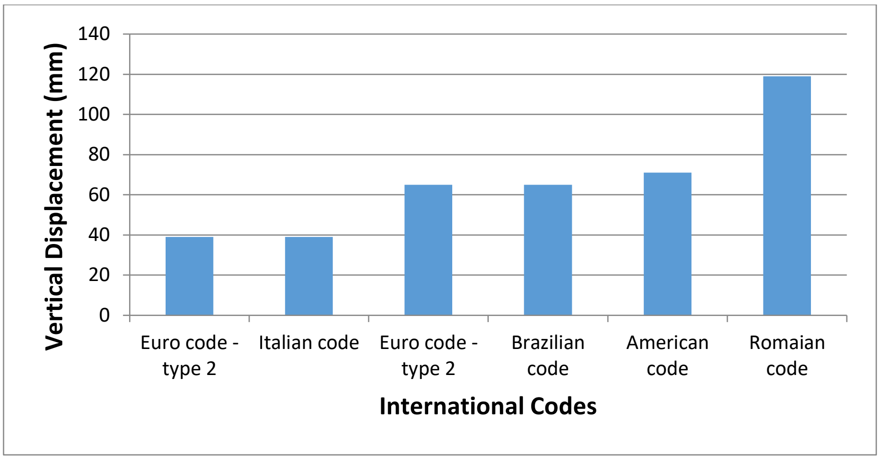


Figure 12. Obtained displacements, transversal direction (Y) @ the top of structure.

Figures 13 and 14 indicate the horizontal forces at the bottom of the structure as well as the static equivalent procedures analysis results of the structure. The Italian code recorded lower horizontal forces at the bottom while the Romanian code recorded maximum horizontal forces at frame base.

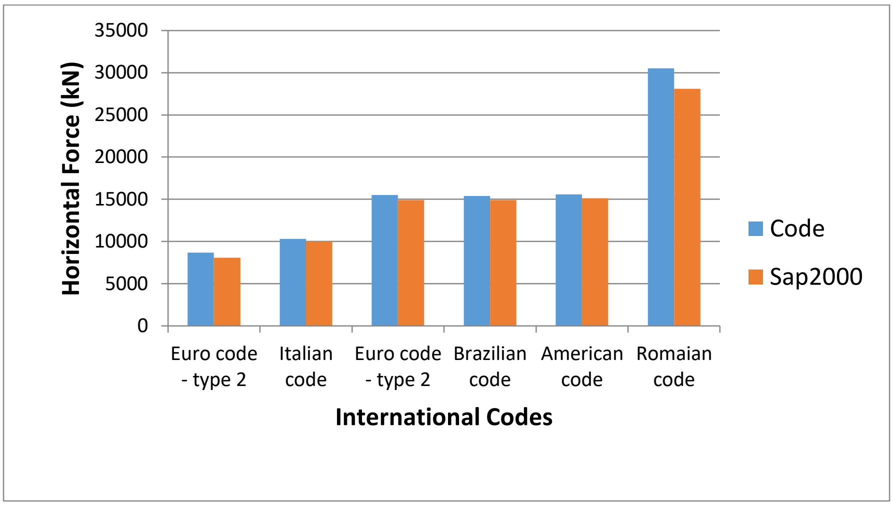


Figure 13. Codes and SAP2000 results of forces in longitudinal span @ the bottom of structure.

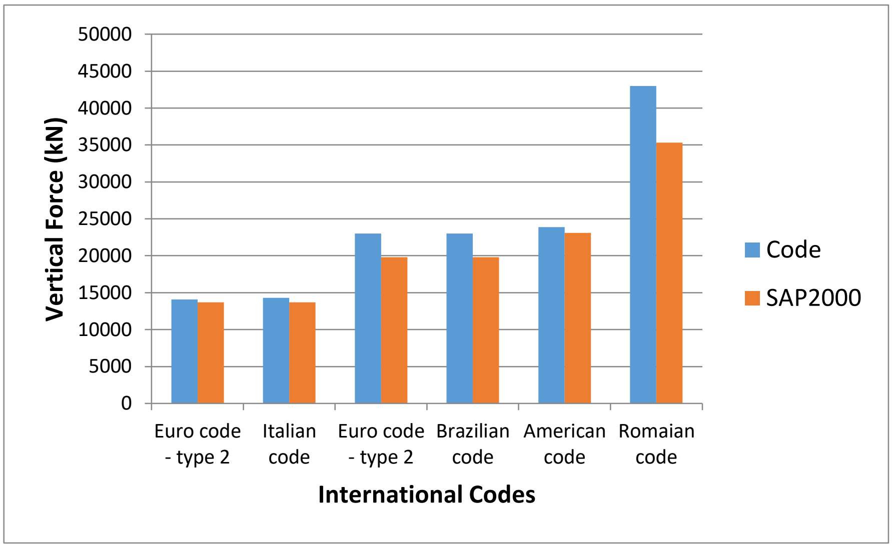


Figure 14. Codes and SAP2000 results of forces in transverse span @ the bottom of structure.

CONCLUSIONS

Earthquakes and winds can cause serious movements and collapse of buildings, bridges, and other concrete structures. The collapse may result from an increase in shear stresses or a weak shear resistance of structural elements. The occurrence of wind and seismic movements is accompanied by an increase in the load on the foundations on the one side and a decrease in the other. To overcome these stresses, designers must make an advanced structural analysis of facilities subject to frequency movements or make a model in the laboratory to represent these facilities. Therefore, using suitable reinforcement methods for structural members and joints was recommended to ensure high resistance to repeated loads on the structure, and the shear walls are constructed in different places of concrete installations. The adoption of international standards in the design of concrete structures is necessary, especially in areas exposed to earthquakes and strong winds. Therefore, in this paper, stresses in a specific building were calculated using different international codes.

A model of SAP2000 was developed to make a comparison between different international codes. As shown in the analysis, there are some differences in the analysis of results of different codes. The Romanian code is highly conservative in calculating the lateral displacement and forces, while the Italian code was less conservative. Therefore, in areas where the intensity of earthquakes and winds increase from time to time, it is preferable to use the Romanian specifications to calculate the forces and distortions that occur in concrete buildings. The calculations of SAP2000 software are close to the results brought from the Italian, European, Brazilian, and American codes in terms of horizontal forces, but the difference is increased with respect to the Romanian Code.

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