Assessment of Reinforced Concrete Structures under Wind and Earthquake Using Different Design Methods

DOI : 10.36909/jer.10411

Maha Al-Soudani*, Aamer Najim Abbas* and Hesham A. Numan*

*Civil Engineering Department, College of Engineering, Mustansiriyah University, Iraq.
*Email: amir_najim@uomustansiriyah.edu.iq; Corresponding Author.

ABSTRACT

The effect of wind and earthquake on the structures can be specified briefly by the effect of horizontal forces act on structures varied in its 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 neglecting 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 took placed in different places of Iraq. So, it is necessary for dealing 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 12 floors 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.

Key words: Assessment, earthquake, international codes, wave, wind.
INTRODUCTION

During robust ground motions or severe wind storms, many constructed reinforced concrete structures are severely damaged collapsing or causing the loss of economy and lives. Collapses or damages of reinforced concrete structures after these acts of nature compel 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 are 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 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. (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 (Vulcano, 1998). He found that a different demeanor of the test structures 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 semi-active control systems (Fisco and Adeli, 2011). Türkeli et al. (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 reduce in cross section and door opening take places.
Pant and Wijeyewickrema (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 post-earthquake questionnaire indicated that damages in reinforced concrete constructions in urban regions were predominately due to the low concrete strength, poor construction quality, non-seismic detailing in the beam-column joints and local site effects (Sharma, et al. 2016). Hosseinpour and Abdelnaby (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 (Lombardo, 2012) and De Gaetano et al. (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. (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 (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. (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 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 non-identical building, the joint must be used. See Figure 1 (Miguel et al. 2018).

![Preferable and Rejected Architectural Design](image)

**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).
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 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 REQUIREMENTS FOR WIND AND SEISMIC LOADS**

Below 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. Adopting shear walls distributed on different locations of the building (Chen and
3. Adopting 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 building (Bayülke, 2001).

5. Including special detailing of reinforcement (Arnold and Reitherman, 2002).

**INTERNATIONAL CODES OF REINFORCEMENT METHODS FOR SEISMIC REQUIREMENTS**

The reinforced concrete frames in seismic zones shall satisfy most common international codes 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 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 Detail of 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 inch (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).
Walls and diaphragms

Walls and diaphragms are the most important structural members in lateral loads such as seismic and wind loads. It is 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 $2.5 \times 10^{-3}$ (Astaneh-Asl, 2003) with a maximum spacing between bars 18 inch (450 mm). The wall must be reinforced with closely spaced hoops at which the compression force becomes less than $0.15 f_{c'} A_g$. 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.
In different international codes, the beam-column connection must be given careful attention. Accurate drawings 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, that lead to increase the joint strength for lateral loads (Astaneh-Asl, 2003). The effective width of joint in most codes should not exceed the smaller of:

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:

$$av = \frac{fy}{f_{yi}} \left[ 1 + \frac{h_1^2}{h_2} \right] \left( \frac{A_{s1}}{n} \right) \ldots \ldots \ldots \ldots (1)$$

Where:

\(f_{yi}\) : yield strength of radial steel with n legs.

\(fy\) : yield strength of main steel.

\(h_1\) and \(h_2\) : 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)

**Proposed building**

The proposed data were brought from the model suggested by Gosh and Fanella (Gosh and Fanella, 2003), it is 12 floors 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 below:

**NUMERICAL EXAMPLE**
- 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](image)
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 in the United State of America. A record of 475 years seismic data was available, the design ground acceleration for soil conditions in this location can be taken as $ag = 0.15g$. This relatively small level of seismicity closed to seismic data of Iraq. The seismic history of this location is shown in Figure 10. The current wind map for North Carolina appeared the wind speed 7mph, which adopted in the inputs 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: 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) mode 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

<table>
<thead>
<tr>
<th>Floor no.</th>
<th>Direction of vibration</th>
<th>Period</th>
<th>Longitudinal %</th>
<th>Transverse %</th>
<th>Vertical %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>¼ wave longitudinal</td>
<td>1.5142</td>
<td>0.86214</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>¼ wave transverse</td>
<td>1.07771</td>
<td>0.86214</td>
<td>0.7401</td>
<td>2E-18</td>
</tr>
<tr>
<td>3</td>
<td>torsion</td>
<td>0.93766</td>
<td>0.86214</td>
<td>0.7401</td>
<td>4.1E-18</td>
</tr>
<tr>
<td>4</td>
<td>¾ wave longitudinal</td>
<td>0.49877</td>
<td>0.95355</td>
<td>0.7401</td>
<td>1.3E-17</td>
</tr>
<tr>
<td>5</td>
<td>¾ wave transverse</td>
<td>0.29882</td>
<td>0.95355</td>
<td>0.89957</td>
<td>5E-16</td>
</tr>
<tr>
<td>6</td>
<td>5/4 wave longitudinal</td>
<td>0.28973</td>
<td>0.97921</td>
<td>0.89957</td>
<td>8E-16</td>
</tr>
<tr>
<td>7</td>
<td>Longitudinal and transverse coupling</td>
<td>0.26476</td>
<td>0.97921</td>
<td>0.89957</td>
<td>1.3E-15</td>
</tr>
<tr>
<td>8</td>
<td>7/4 wave longitudinal</td>
<td>0.20231</td>
<td>0.98923</td>
<td>0.89957</td>
<td>5.7E-15</td>
</tr>
<tr>
<td>9</td>
<td>2/4 wave vertical and central</td>
<td>0.19205</td>
<td>0.98923</td>
<td>0.89957</td>
<td>0.47732</td>
</tr>
<tr>
<td>10</td>
<td>4/4 wave vertical</td>
<td>0.16242</td>
<td>0.98923</td>
<td>0.89957</td>
<td>0.47732</td>
</tr>
<tr>
<td>11</td>
<td>9/4 wave longitudinal</td>
<td>0.15431</td>
<td>0.9937</td>
<td>0.89957</td>
<td>0.47732</td>
</tr>
<tr>
<td>12</td>
<td>Transverse and vertical coupling</td>
<td>0.15355</td>
<td>0.9937</td>
<td>0.9076</td>
<td>0.47732</td>
</tr>
<tr>
<td>13</td>
<td>Transverse and vertical coupling</td>
<td>0.14668</td>
<td>0.9937</td>
<td>0.95412</td>
<td>0.47732</td>
</tr>
</tbody>
</table>

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 that obtained from other codes, while Romanian code recorded maximum lateral displacement.
Figure 1 Obtained displacements, longitudinal direction (X) @ the top of structure

Figure 2 Obtained displacements, transversal direction (Y) @ the top of structure

Figures 13 and 14 indicated 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 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 collapses 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, it was recommended using of suitable reinforcement methods for structural members and joints to ensure high resistance to repeated loads on the structure, and that the shear walls are constructed in different places of concrete installations. The adoption of international standards in the design of concrete structures is very 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. Romanian code is highly conservative in calculating the lateral displacement and forces, while Italian code was low conservative. Therefore, the 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 Italian, European, Brazilian and American codes in term of horizontal forces, but the difference is increased with respect to Romanian Code.

ACKNOLEGEMENT

The authors would like to express their gratitude and thanks to Mustansiriyah University for providing a good environment and all facilities to achieve this work.
REFERENCES


American Society of Civil Engineers (ASCE). 2010. Minimum design loads for buildings and other structures (ASCE/SEI 7-10), Washington, D.C, USA.


Ersoy, U. 1999. Binaların mimarisinin ve taşıyıcı sisteminin deprem dayanımına etkisi (The effects of architectural design and structural system of buildings on earthquake


**Italian Ministry of Infrastructures. 2008.** Italian ministerial decree of 14/01/08: Norme tecniche per le costruzioni (technical standard for the constructions).


