Seismic Analysis and Design of a 10 Storey Existing Reinforced Concrete Building in Khartoum, The Sudan

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Abstract—The aim of this paper is the evaluation of an existing RC multistory building if exposed to seismic loads. The building studied is a ten storey residential building in the city of Khartoum, Sudan. It is constructed from reinforced concrete and designed for gravity loads only according to the British standard Codes BSI 1997. It is well known that the Sudan has no regulations for the seismic design of buildings. Therefore, in the present paper earthquake loads are calculated following the Equivalent static method which is given in the Regulations for earthquake resistant design of buildings in Egypt, (ESEE, 1988) [1]. These regulations have been prepared by the Egyptian Society for Earthquake Engineering (ESEE). The results from the analysis due to seismic and gravity loads are compared in order to evaluate the straining actions in selected beams and columns. The bending moment and shear forces can be obtained from SAP2000 v.14 [2], which is usually used to perform the linear and nonlinear analysis. The results showed there is no effect for seismic loads in the X direction. So that the paper studied the effect of seismic loads in the Y direction. Bending moments in beams and columns due to seismic excitation showed much larger values compared to that due to gravity loads. The results obtained, show the need for additional reinforcements and increase of cross sections of the original concrete frame, in order to improve its seismic behavior.

Keywords—Sudan, Seismic Analysis, Equivalent static Method, SAP2000, Assessment.

I. INTRODUCTION

A major problem in the Sudan is the fact that the majority of existing buildings are designed for gravity loads only. The Sudan is not free from earthquakes. It has experienced many earthquakes during the recent history, and the previous studies in this field demonstrated this argument [3]. Sudan is generally considered a country of low seismic activity [3]. However; recent seismic activities in different regions within the Sudan warrant seismic hazard assessment of the Sudan. The country and its vicinity experienced one of the largest earthquake in recent history: The May 20,1999, 7.4 earthquake and its aftershocks that hit Southern Sudan is the one of the largest in continental Africa in the instrumental era of earthquake recording[3]. In additional to the Southern Sudan, major portions in Central Sudan also experienced earthquakes recently (e.g., earthquakes stroke Kordofan State in August 1, 1993 with a magnitude of 5.5 and in November 15, 1993 with a magnitude of 4.3). Central Khartoum is affected by all seismic sources in Sudan and its vicinity though some sources, e.g. Kordofan State sources, are more sensible than Central Khartoum (Mohamedzein et al [4]).

II. DESCRIPTION OF THE BUILDING

The building considered is a traditional residential ten-storey regular reinforced concrete frame building. It consists of the ground floor and nine stores. The main dimensions in plan are 20 meters in X direction and 12 meters in Y direction. The four figures (1, 2, 3 and 4) below show the buildings plan view along their dimensions. The vertical support system of the building consists of columns and it has symmetry. The building has ten levels over the ground. Each level has a standard height of 3.00 m while the height of the ground floor is 3.5 m. Figure 5 presents the section of the building at y direction along the height of each storey. The structure system is a moment resisting RC frame with solid slab, 130mm thickness, situated in zone one. The cross-sections of columns and beams of the frame are shown in Table 1. One selected frame (at the center) was analyzed using SAP 2000 program [2]. Some members of the frame building were selected for the purposes of the analysis. The selected members, which are shown in Figure 5, were:

Columns: C02, C20, C24, and C13 from ground floor to tenth floor.
Beams: B01, B09, B13, B23 and B30 from ground floor to tenth floor.

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Numerical models for the case has been prepared using SAP2000 version 14 (Computers and Structures) [2]. Beams and columns are modeled as frame elements while walls and slabs are modeled as shell elements. In this paper the seismic performance of the considered residential building will be evaluated using the linear static analysis procedure. Figure 6 shows the model of the studied building.

### 2.2 Load combinations

The load combinations used in the analysis of the RC building follow the Egyptian Code for Design and Construction of RC Structures [6]. The sustained live load associated with lateral load combinations is 25% of the total live load. These load combinations are:

#### 2.2.1 Case 1: Gravity loads

\[ 1-1.4D+1.6L \]  

#### 2.2.2 Case 2: Gravity and seismic loads in the X direction

\[ 1-0.8 \times (1.4D+1.6L+1.6EQX) \]  
\[ 2-0.9D+1.3EQX \]
2.2.3 Case 3: Gravity and seismic loads in the Y direction

\[ 1-0.8 \times (1.4D+1.6L+1.6EQY) \] (4)

\[ 2-U5=0.9D+1.3EGY \] (5)

Where D is the dead load, L is the live load, and EQ is the seismic load.

2.3 Calculation of base shear

The total design seismic base shear force is estimated using the static equivalent force procedure (ESEE, 19880) [1]. The resulting seismic coefficient, \( C_s \), was determined to be 0.0624 and the corresponding base shear was approximately 2245 KN from equation (6):

\[ V = C_s \times W_t \] (6)

2.3.1 Distribution of horizontal seismic force

The period of the building is the same in both directions. Hence, the load in the E-W direction are the same as those for the N-S direction. For our case study, distribution of the lateral seismic loads is shown in Table 2 for both directions. The total weight is given by equation (7):

\[ W_i = D + \rho L \] (7)

Where, \( \rho \) is the incidence factor and is equal to \( \rho = 0.25 \).

\[ F_i = \frac{h_i W_i}{\sum W_i h_i} \left( V - F_t \right) \] (8)

\( F_i = 0.0 \) for (H/d) less than 3.0 m.

Table 2: Lateral load distribution with height.

<table>
<thead>
<tr>
<th>Storey level</th>
<th>Wi (KN)</th>
<th>hi (m)</th>
<th>Wihi</th>
<th>Wihi/sum</th>
<th>V (KN)</th>
<th>Lateral Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3598.5</td>
<td>30.5</td>
<td>109754.3</td>
<td>0.18</td>
<td>2245</td>
<td>402.78  402.78</td>
</tr>
<tr>
<td>9</td>
<td>3598.5</td>
<td>27.5</td>
<td>98958.75</td>
<td>0.16</td>
<td>2245</td>
<td>363.16  363.16</td>
</tr>
<tr>
<td>8</td>
<td>3598.5</td>
<td>24.5</td>
<td>88163.25</td>
<td>0.14</td>
<td>2245</td>
<td>323.54  323.54</td>
</tr>
<tr>
<td>7</td>
<td>3598.5</td>
<td>21.5</td>
<td>77367.75</td>
<td>0.13</td>
<td>2245</td>
<td>283.93  283.93</td>
</tr>
<tr>
<td>6</td>
<td>3598.5</td>
<td>18.5</td>
<td>66572.25</td>
<td>0.11</td>
<td>2245</td>
<td>244.31  244.31</td>
</tr>
<tr>
<td>5</td>
<td>3598.5</td>
<td>15.5</td>
<td>55776.75</td>
<td>0.09</td>
<td>2245</td>
<td>204.69  204.69</td>
</tr>
<tr>
<td>4</td>
<td>3598.5</td>
<td>12.5</td>
<td>44981.25</td>
<td>0.07</td>
<td>2245</td>
<td>165.07  165.07</td>
</tr>
<tr>
<td>3</td>
<td>3598.5</td>
<td>9.5</td>
<td>34185.75</td>
<td>0.06</td>
<td>2245</td>
<td>125.46  125.46</td>
</tr>
<tr>
<td>2</td>
<td>3598.5</td>
<td>6.5</td>
<td>23390.25</td>
<td>0.04</td>
<td>2245</td>
<td>85.84   85.84</td>
</tr>
<tr>
<td>1</td>
<td>3598.5</td>
<td>3.5</td>
<td>12594.75</td>
<td>0.02</td>
<td>2245</td>
<td>46.22   46.22</td>
</tr>
<tr>
<td>SUM</td>
<td>35985</td>
<td>611745</td>
<td>611745</td>
<td>2245.00</td>
<td>2245.00</td>
<td></td>
</tr>
</tbody>
</table>

III. ANALYSIS OF BUILDING

The paper studied four columns for the evaluation. The internal forces obtained from the computer analysis program SAP2000 [2]. The moments and shear forces obtained from earthquake and Gravity loads are shown in Tables 3 and 4, graphically in figures 7 and 8.

Table 3: The maximum bending moments in some selected columns due to three cases of loading.

<table>
<thead>
<tr>
<th>Column No</th>
<th>Case1</th>
<th>Case2</th>
<th>Case3</th>
</tr>
</thead>
<tbody>
<tr>
<td>C02</td>
<td>9.87</td>
<td>9.87</td>
<td>215.07</td>
</tr>
<tr>
<td>C13</td>
<td>-9.87</td>
<td>-9.87</td>
<td>205.07</td>
</tr>
<tr>
<td>C24</td>
<td>0.54</td>
<td>0.54</td>
<td>235.98</td>
</tr>
<tr>
<td>C20</td>
<td>-0.54</td>
<td>-0.54</td>
<td>235.45</td>
</tr>
</tbody>
</table>

Fig.7: The maximum bending moments in some selected columns due to three cases of loading.

Table 4: The maximum axial forces in some selected columns due to three cases of loading.

<table>
<thead>
<tr>
<th>Column No</th>
<th>Case1</th>
<th>Case2</th>
<th>Case3</th>
</tr>
</thead>
<tbody>
<tr>
<td>C02</td>
<td>2110.72</td>
<td>2110.72</td>
<td>2437.89</td>
</tr>
<tr>
<td>C13</td>
<td>2110.72</td>
<td>2110.72</td>
<td>2110.72</td>
</tr>
<tr>
<td>C24</td>
<td>3159.74</td>
<td>3159.74</td>
<td>3159.74</td>
</tr>
<tr>
<td>C20</td>
<td>3159.74</td>
<td>3159.74</td>
<td>3159.74</td>
</tr>
</tbody>
</table>

Fig.8: The maximum axial forces in some selected columns due to three cases of loading.

IV. RESULTS OF THE ANALYSIS

4.1 The internal forces in the selected columns (S.F and B.M)

4.1.1 Shear forces:

Figures 9-12 show the shearing forces in the selected columns C02, C20, C24 and C13, respectively.
4.1.2 Bending moments

Figures 13-16 show the bending moments in the selected columns C02, C20, C24, and C13, respectively.
4.2 The internal forces in the selected beams

4.2.1 Axial Forces

Figure 17 shows the axial forces in the selected beams.

4.2.2 Shear Forces

Figure 18 shows the shearing forces in the selected beams.

4.2.3 Bending moments

Figure 19 shows the bending moments in the selected beams.

4.3 Design of selected columns

Figures 20-23 show the internal forces in C20 and C24 at the ground floor and Table 9 shows the results of the design.

4.3.1 Column No C20-GF
4.3.2 Column No C24

Table 5: Design of columns before and after adding seismic loads in direction (y)

<table>
<thead>
<tr>
<th>Column No.</th>
<th>Original design</th>
<th>Including seismic loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dimensions</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>C20</td>
<td>500 X 300</td>
<td>10 Φ 16</td>
</tr>
<tr>
<td>C24</td>
<td>500 X 300</td>
<td>10 Φ 16</td>
</tr>
</tbody>
</table>

V. DISCUSSION

The results of the analysis indicated that the shear forces and bending moments increased in columns and beams due to seismic loads shown graphically in Figures 9-16. It can be observed that the shear forces due to case 3 increased in the interior column C20 and C24 than the exterior column C02 and C13 and decreased in the upper levels shown in Figures 9-12. Also, the bending moments and shear forces in upper floor columns showed lesser values as shown in Figures 7-14.

The values of shear forces and bending moments due to case 3 in the selected columns were found to be about more than approximately 10 times the values due to case 1 as in Figures 7 and 8, respectively.

Table 5 and figures 22 and 23 show the design of columns before and after adding seismic loads. Therefore, the building needs additional reinforcements and increase cross sections to the original to withstand earthquake loads.

VI. CONCLUSION

The results obtained from the analysis of the 10 storey reinforced concrete building in Khartoum city, lead to the following conclusions:

1. There is no effect for seismic loads in direction X. So that the paper studied the effect of seismic loads in direction Y.
2. Bending moments in beams and columns due to seismic excitation showed much larger values compared to that due to gravity loads.
3. The values of shear forces and bending moments due to case 3 in beams B01, B09, B13, B23 and B30 were found to be about more than 2 times the values due to case 1.
4. The values of axial forces due to gravity and seismic loads in the selected beams are approximately equal.
5. The values of shear forces due to seismic loads in columns C02, C20, C24, and C13 were about more than 5 times the shear forces due to gravity loads.
6. Also the results obtained, clearly, show the need for additional reinforcements and increase in cross sections to the original concrete frame, in order to improve its seismic behavior.

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