Assessment of Seismic Responses of CFT Composite Columns with Different Section Forms in Short-Height and Moderate-Height Moment Frames

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\textbf{Abstract}
This study is regarding assessment of behaviour of moment frames with CFT composite columns under seismic loadings and knowing their behaviour. For this purpose, structures with this type of composite columns with three different section types with different quantity of stories (4, 8 and 12 stories) and with 5 spans are considered. Variables are span's length and structure height. These structures are analysed using Opensees software and applying of dead, live and earthquake loading by nonlinear analysis methods and results of structure analysis are presented considering 7 different earthquake records. Finally, average values and highest displacement response and structure rotation with different quantity of stories and under applied loads with consideration of different earthquake records are assessed and compared.

\section{1. Introduction}
One of important decisions in design and building of structure is selection of type of consuming materials in structure (concrete, steel and or building materials). Selection of material type in building of structure depends on different issues such as structure type, location of building of structure, access to materials, architectural considerations, economic issues and also experience of structure designer. This is to design a safe structure with proper performance and at the same time economic. Use of steel only in building of columns in structures especially high structures is not economic. Moreover, high structures that are built just with steel columns often has relatively large lateral deformations. Also these structures are highly vulnerable against firing. Use of concrete only in columns of high buildings leads to occupation of so many spaces especially in low stories too and weight of structure increases and resulted structure has lower ductility due to fragility of concrete and structure strength will reduce against seismic loadings. Therefore, taking advantage of both concrete and steel leads to coverage of weak points of each one and performance improvement of structures. Combination of these two materials with each other results in formation of composite systems. Nowadays, composite systems are used in columns, beams, slabs with medium and large spans in buildings and also in bridge's base and beams. Composite columns based on location of steel and concrete are categorized into three general groups that includes: 1- Concrete Filled Steel Tube (CFT): these are columns that have advantages of concrete and steel, both. These columns include circular, rectangular and or polygon hollow steel section that are filled with concrete, 2- Steel section encased in concrete section and or Steel-Reinforced Concrete Section (SRC): in this group, section includes rolled or composite steel section that a reinforced concrete is encased inside section, 3- Embedded partial composite sections: in this sections, concrete and steel do not fully embed each other. CFT composite columns have multiple advantages: 1- in CFT columns, steel section is like a form for concrete and this issue leads to reduction of human costs, 2- Building speed of structure with CFT composite columns is higher especially in high buildings, 3- Experiences of building of structure with CFT columns show that cost of building of structure reduces by increase of story quantity comparing steel moment frame. But in contrast with very appropriate behavior that CFT columns in different loadings especially seismic loading show from themselves, they have some weak points too. Some of them are as following: 1- sensible reduction of strength

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during the time due to concrete creep which in large buildings leads to form many secondary stresses in joint areas. Consequently, there is a possibility of separation between two materials in load that are lower than the capacity of the column. Jacobson and Gardner [2] made some studies on CFT columns under axial loading and compared the results with ACI and NBC codes and also other studies. These columns were loaded by cyclic loadings and an axial load was also placed on them. Their results show that CFT columns have very high ductility and softness. Varma et al. [4], in a research designed and evaluated seismic behavior of concrete filled columns and beams experimentally. Effect of width to thickness ratio of column, yield stress of steel section on columns and composite beams behavior and axial bearing, stiffness, strength and their energy absorption level was studied. Abedi et al. [5] evaluated the behavior of a kind of CFT composite column with a new section shape and compared it with common sections of these columns. They evaluated 9 models of column with different shapes of section including square, circular, circular with reinforced concrete, suggested circular section and octagonal section with longitudinal stiffeners by finite element analysis using ANSYS software. Han et al. [6], assessed behavior of composite frame with composite column and steel beam by finite elements method and experimentally. They placed 6 frame specimens under lateral cyclic load in the lab and compared results by modeling of frames in Abaqus software. Their results showed that lateral bearing capacity, ductility and energy waste in frames reduced by increase of axial loading on columns. Lee et al. [7] investigated the behavior of circular CFT composite columns with applying of eccentric loading using experimental investigations and fiber element analysis. 11 specimens of column which were fabricated by steel and reinforced concrete were tested and the effect of applying of eccentric loading on the level of bearing, ductility and failure of composite columns were evaluated. They showed that in specimens where eccentric loading was equal to half of column's diameter, axial stiffness and torsional stiffness of columns decreases. Gan et al. [8], evaluated seismic behavior of composite sections. They applied seismic loading on 6 built specimens that two specimens have circular section and four other specimens have square section. Results of this research showed that circular sections has much higher bending strength than other sections with constant ratio of steel level and same axial loading. On the other side, regarding nonlinear analyses in different structures, In 2018, Shayanfar et al. [9] evaluated the behavior of concrete beam-column connections reinforced with FRP rebar. In their study, ultimate strength of connections and energy absorption was evaluated. Ghanoonibagha et al. [10] did the pushover analysis of steel frames with steel shear wall under different lateral loading patterns. They compared nonlinear static analysis results with the results of nonlinear dynamic analysis. Shayanfar et al. [11] compared the seismic performance of steel frame in regular plane and in irregular elevation. Xiong et al. [12], assessed the strength of CFT columns against fire using Matlab software. They estimated the strength time of these columns against fire by M-N interaction curves. Kheiroldin et al. [13], assessed the encasement effect of concrete affected by steel in steel-concrete circular composite columns. In this research meanwhile of introduction of some of concrete encasement correlations, it was concluded that assumptions related to two parameters of encasement pressure and steel peripheral stress results in difference in this correlation. Fan et al. [14], assessed capacity of shear joints by 3D modeling between CFT columns and steel beam and compared their results with 2D modeling. Wang et al. [15], Assessed hysteretic behavior of square CFT columns using binding bars. Their results in this research showed that CFT columns with binding bar has higher stiffness and higher ultimate deformation capacity relative to CFT columns without binding bar. Besides above researches, some researches also have been done on an endeavor to apply and evaluate different methods of dynamic and static nonlinear analysis that is also used in this research. In this regards, in 2019 Ghanoonibagha et al. [16] assessed the seismic performance of corroded reinforced concrete frames affected by corrosion of bars using pushover static analysis and dynamic IDA methods which showed reduction of seismic performance level due to corrosion of bars. Also Ghanoonibagha et al. in 2016 and 2017 [17, 18] assessed the effect of corrosion of longitudinal bars of corroded reinforced concrete sections on compressive strength using nonlinear analyses and reliability behavior of corroded reinforced beams under different modes. Zabih Samani and Ghanoomi-Bagha in 2017 [19, 20] presented a logical control solution for improvement of control trend of structures using MR dampers. In this study, the behavior of designed moment frames with CFT composite columns with different shapes of column section (square, circular and polygon) is evaluated. Get knowledge on seismic behavior of these types of frames and determining of their behavioral different parameters is one of purposes of this study. OPENSEES software [21] is used to model this type of building system. This software has high accuracy in calculations and nonlinear analyses and has been used by many researchers. The analysis method is time-history nonlinear dynamic analysis and all models are compared with each other.
2. Evaluated models specifications

The evaluated structures in this study include three structures with 4, 8, and 12 stories and each one has five 4m span. These structures are analyzed with three sections including square, circular, and polygon. The model with square sections called model A, the model with circular sections called model B and the model with polygon sections called model C. The models that are created in OPENSEES software are shown in figure 1. To increase accuracy of modeling in models, beam-column elements are divided into 4 sections and the results for each one of elements are considered per each earthquake separately. For modeling of frames with polygon section is considered as figure 1-D.

![Model Diagrams]

3. Modeling

Gravity loading of frames is considered based on 6th article of Iran national building code [22] and their lateral loading is considered based on Iran 2800 earthquake code [23]. The modeled frames are analyzed using nonlinear dynamic time-history analysis method which is most accurate method of nonlinear analysis. In this method, by applying a specific earthquake record to the structure, the structural behavior due to this earthquake record is assessed. For this purpose, 7 standard earthquake accelerated based on Iran earthquake code for analysis of structures is considered. Also based on categorization of 2800 code, the soil type of the area is assumed as type 3 and its risk of seismicity is assumed in high level of risk. The gravity loading on the frame is also considered equal to 20601 N/m.

3.1. Material behavior

The materials with elastic behavior are the materials with linear behavior that the possibility of their usage in above software is provided. Figure 2 shows stress-strain relation for this mode of materials.
Elastoplastic behavior is second type of materials that is possible to be modeled and defined in solution solving in OPENSEES software. Figure 3 shows stress-strain curve of this behavior type.

The material properties for steel and concrete that are used in this investigation is indicated in table 1. Moreover, the compressive strength of concrete and yield stress of bars are considered equal to 280Kgf/cm² and 4000Kgf/cm² respectively and poisson coefficient of concrete is also assumed equal to 0.15. If concrete with mineral additives is used the change in material properties should be considered separately [24, 25].

<table>
<thead>
<tr>
<th>Table 1. Material properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Density (Kg/m³)</td>
</tr>
<tr>
<td>Specific weight (Kgf/m³)</td>
</tr>
<tr>
<td>Elasticity module (Kgf/m³)</td>
</tr>
</tbody>
</table>

The dimensions of square and circular sections in 4, 8 and 12 story structures are shown in table 2. Based on figure 1-D, used polygon columns are created by placing of two semi-circular in both ends of square section.
Table 2. Dimensions of structures columns

<table>
<thead>
<tr>
<th>Structure</th>
<th>Circular section diameter (cm)</th>
<th>Square section dimensions (cm)</th>
<th>Stories</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-story</td>
<td>50</td>
<td>40×40</td>
<td>1 to 4</td>
</tr>
<tr>
<td>8-story</td>
<td>60</td>
<td>50×50</td>
<td>1 to 4</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>40×40</td>
<td>5 to 8</td>
</tr>
<tr>
<td>12-story</td>
<td>80</td>
<td>60×60</td>
<td>1 to 4</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>50×50</td>
<td>5 to 8</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>40×40</td>
<td>9 to 12</td>
</tr>
</tbody>
</table>

3.2. Types of element in modeling

Fiber element is used to define specification of CFT column and the other sections. The fiber element is used to define the sections that composes of multiple types of material, the materials with abnormal geometric shape or a combination of multiple geometric shapes. Using this element, it is possible to define and analyze the sections that are a combination of different materials. In fiber sections, section is being meshed. Each section of fibers is analyzed with consideration of the properties of its composing materials and its behavior is assessed in combination with the other fibers. Final result of element is reported by summation of stress-strain curves of fibers. The modeling of elements is done as Dis Beam Column that in this method, the beams and columns are meshed.

3.3. Selection of accelerated for time-history analysis

The used analysis method in this study, is nonlinear dynamic time-history analysis method. For this purpose, 7 different earthquake records are selected. The obtained accelerated become balance with each other using the software of seismo signal based on the standard range of Iran 2800 (type 3 of soil type, high risk area). Earthquake records that are applied to the structure are shown in figure 4.
3.4. Scaling method of earthquake records

There are different algorithms to scale the considered seismic intensity which the proper algorithm should be selected based on structure type and the earthquake properties such as their frequency content, time, maximum acceleration and the other factors in order to optimize the scaling quantity per each record and in addition to achieve sufficient accuracy and speed up to the end of scaling that is obtaining of dynamic instability level of structure. In this study, many steps for scaling of each record are used in order to obtain high analysis accuracy. The pair of selected accelerated are scaled based on Iran 2800 code [23].

3.5. The assumptions of frame modeling in software

For 2D modeling of frames, the degrees of freedom of movement of all elements is considered in X, Z plane and rotational freedom just around Y axis is assumed. The compact sections are used in modeling of moment frame and the ends of beams are fixed in all degrees of freedom. Loads that are applied on planes are calculated in 3D model and are applied on beam elements as an equivalent distributed loading. Dead load, live load and wall load are considered for loading. Applied loads are considered based on the application type of floor (residential, roof and parking area). In moment frames, joints are considered at two ends of the beam in 0.05 distance of column and in braced frames they are considered in the middle of the beams. Displacement responses and created rotation in beams in different stories are evaluated by dynamic time-history analysis under concerned earthquakes.

4. Structural modeling results

4.1. Displacement response

4.1.1. Displacement response of 4-story building

Displacement response results from analysis of 4-story models under 7 assessed earthquake records are presented that are shown in figure 5.
Maximum value of displacement response of 4-story structure with circular section

The average of displacement responses in 4-story structures

Maximum value of displacement response of 4-story structure with square section

Maximum value of displacement response of 4-story structure with polygon section

Figure 5. Displacement response of 4-story structure

Obtained results from displacement responses in three evaluated 4-story structures show that structure with square sections has most critical condition that is possible so that value of maximum displacement is recorded in this model. The average value of displacement in structure with square and polygon sections are obtained almost close to each other. Considering geometrical specification of considered sections, circular section has better responses. Maximum displacement value in model A is obtained equal to 20 cm and average displacement value in model A is obtained equal to 9.7 cm. while average of this parameter for circular section is equal to 7.9 and in polygon section is equal to 8.5 cm. it is notable that 2D analysis is done for evaluated sections in this study and sections behavior are assessed in one direction.

4.1.2. Displacement response of 8-story building

Figure 6 shows displacement response results from analysis of 8-story models with square, circular and polygon sections under 7 introduced earthquake records.
Displacement values that are obtained from analysis of 8-story structure with square, circular and polygon sections show that displacement response in model C is more desired than models A and B. Maximum displacement value in model A is equal to 53 cm, in model B is equal to 43 cm and in model C is equal to 37 cm. Average displacement value in model C in last story is equal to 25 cm and in model B is equal to 27 cm and in model A is equal to 31 cm. Displacement response curves in model A has a downward concavity in low stories but this concavity is upward in high stories. But in other models, displacement curves has a variable slope in height and relative displacement value in high stories is obtained higher than low stories. This slope change in structure with polygon section is seen less than structure with circular sections.

4.1.3 Displacement response of 12-story building

Figure 7 shows displacement response results of 12-story structure in three models A, B and C under 7 earthquake records.
The analysis results of 12-story structures show that maximum displacement response in 12-story structure in model C is obtained less than two other models which is equal to 84 cm and highest value of maximum displacement is created in model A that is equal to 115 cm. average of displacement values in model C is equal to 58 cm that is obtained less than other models, because average value of displacement values in models B and A are equal to 68 cm and 78 cm respectively.

### 4.2. Rotational response value of structure

#### 4.2.1. Rotational response value of 4-story structure

In figure 8, rotational response results of 4-story structure with square, circular and polygon sections under 7 concerned accelerated is shown.
Maximum value of rotational response of 4-story structure with circular section

Maximum value of rotational response of 4-story structure with square section

The average of rotational responses in 4-story structures

Maximum value of rotational response of 4-story structure with polygon section

Figure 8. Rotational response of 4-story structure

Highest rotation value that is created in structures, under 7 applied earthquake on structure, is occurred in model A that is in last story and is equal to 0.045 radian. Created rotation value in model B is less than model A. average value of created rotation in structure B under application of different earthquake records is also less than model A. the value of this parameter in model B is equal to 0.0142 radian and in model A is equal to 0.019 radian. In model C, average value of rotation in high stories is obtained less than two other models so that its value is equal to 0.0125 radian. It means that structure of model C showed a better behavior from itself.

4.2.2. Rotational response value of 8-story structure

Figure 9 shows analysis and comparison of results that are obtained from rotational response value in 8-story structure with consideration of 7 earthquake records.
Based on obtained results, maximum obtained rotation value from time-history analysis for model with square section is higher than other models but this parameter in model with polygon section is less. Average of rotation value in model with polygon section is equal to 0.029 radian that is less than square model with rotation equal to 0.036 radian and circular model with rotation equal to 0.0325 radian. Moreover, average of rotation value of model with square section is obtained higher than average rotational response of two other models.

4.2.3. Rotational response value of 12-story structure

Same as 4 and 8 story structures, figure 10 shows rotational response value of 12-story structure with square, circular and polygon sections under 7 earthquake records.
The maximum value of rotational response in structure with polygon section is less than two other models. So that response value of model with circular section (0.077 radian) is less than model with square section (0.12 radian). Also average value of response in model C (0.043 radian) in stories and roof is obtained less than two other models. Average value of rotational response in model A is obtained higher than all other models that is equal to 0.078 radian.

5. Conclusions

In this study behavior of steel structures with sections filled by concrete using time-history nonlinear dynamic analysis is assessed. Three square, circular and polygon sections for columns and three height for structures (4, 8 and 12 stories) are considered and obtained responses from dynamic analysis of structures are assessed. Time-history dynamic analysis was done using 7 scaled accelerated. Maximum value of time-history response of different earthquakes in structure's stories are derived and displacement value of structure and created rotation of members in stories are assessed and illustrated as curve. This process for all 3 evaluated structures is done. Below results are concluded based on made analyses:

- Obtained displacement results from analysis of structures show a better response of model with polygon section so that displacement increase trend in lower stories of structure with polygon section presents better responses and more desired behavior. Displacement value in 8 and 12 story structures in model with polygon section is less than other models. But in 4-story structures, model with circular section has lowest displacement value.
• Average displacement curves of structures has similar pattern. Average displacement value in 4, 8 and 12 story structures in model with square section is higher than other models. So that the value of this parameter in model with square section in 4, 8 and 12 story structures is obtained equal to 9.7, 31 and 78 cm respectively.

• Created rotation in all structures for models with polygon section is obtained less than other models. For instance, average of rotation in models with polygon section in 4, 8 and 12 story structures is equal to 0.0125, 0.029 and 0.043 radian respectively while value of this parameter for models with square sections is equal to 0.019, 0.036 and 0.078 radian respectively.

• In all structures, rotation value in models with square sections is obtained higher than other models. Moreover it is determined from analysis results that rotation value in high stories has more increase while in low stories shows a lower difference relative to other models.

References


