Optimization in the Selection of Structural Systems for the Design of Reinforced Concrete High-rise Buildings in Resisting Seismic Forces

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Abstract

In this paper the application of a solution the issue of optimization in the selection of structural systems for design of reinforced concrete (RC) high-rise residential buildings is studied through the study and design of three models of RC high-rise structure buildings consisting of (10-15-20) storeys, where the genetic algorithm (GA) was based on to find designing models to facilitate access to the optimum solutions, as the technical Analysis-Design Cycle was applied to determine the optimum cross-sectional dimensions of all reinforced concrete elements of high-rise structure building, thus determining the best structural system, which ensures the economic dimensions that achieve the saving in concrete and steel amounts thus achieve lower cost.

1. Introduction

The economic cost for engineering projects is the most important factor in the design of structures after the achievement of those structures for the safety factors and design requirements in accordance with international codes. Reinforced concrete (RC) high-rise buildings designed to resist vertical loads in general, and checked on the seismic loads, in particular, adopted structural systems in the design to resist the forces of earthquakes consist of [1] :
- Shear Walls System.
- Moment - Resisting Frame System.
- Dual System is the system that contains together frames and shear walls.

In couple system, shear walls were presented as central reinforced concrete core of the stairs and lifts, which were favourite to resist the shear forces in general in the regular structures and private due to its symmetry and placed in the centre of the structure, and if the shear walls were insufficient to resist the shear forces caused by earthquakes, the additional shear walls are added to give structural system appropriate stiffness to resist the horizontal forces in both directions [2,3].
There are many types of structural systems, resistance to the forces of earthquakes, and structural systems which previous referred to it considered more systems used in the design of public and private structures, but in the design of RC high-rise buildings, can we adopt certain structural system without the other and generalization use in the design of RC high-rise buildings whatever the number of storeys, type of foundation soil and regardless of whether this system achieve the economic cost of the building required designing it, and what if one of these systems achieve economic cost of the multi-storey building without the other, whether those buildings are similar to or different from each other in the number of storeys, type of foundation soil. To answer these questions and study the problem at hand the following models of RC high-rise buildings was imposed, as shown in Fig 1:

- Structural models for RC high-rise building consisting of 10-storey, structural systems in it are:
  - Frames system (F).
  - Shear Walls system (SW).
  - Couple system (C).

- Structural models for RC high-rise building consisting of 15-storey, structural systems in it are also F & SW & C systems.

- Structural models for RC high-rise building consisting of 20-storey, structural systems in it are also F & SW & C systems.

Fig 1: some of supposed structural models for three structural systems (F-SW-C)
2. **Aims of Research:**

- Optimization in the selection of structural system that suits the RC high-rise structure buildings specified number of storeys and the type of foundation soil.
- Study affection of three types of structural systems (F-SW-C) with prices change of two materials of concrete and steel, where there are three cases of prices change: medial prices-concrete is expensive and steel is cheap-concrete is cheap and steel is expensive, and seeing which of these structural systems achieve the economic cost.

3. **Steps of the Research**

The research adopt on the following steps:

1. Adoption of several models of RC high-rise structure buildings consisting of (10-15-20) storey and for the three types of structural systems in resisting earthquakes forces (F-SW-C) and for two type of foundation soil SA and SB. The designing models adopt walls of the central core of the stairs and lifts as essential shear walls to resist shear forces in addition to surrounding shear walls in both directions. The thickness for shear walls and cross-sections dimensions of reinforced concrete elements are identified and inferred based on GA after the process of analysis and design using technical Analysis-Design Cycle for imposed designing models and make sure to achieve the Syrian code conditions in structures design to resist earthquakes about dimensions and ratio of reinforcement for each structural element [1,5], wherein the Syrian code is agreeing to UBC 97 code conditions in this range, then after that, study the conclusion models again after modification to the dimensions of cross-sections of some or all structural elements (beams - columns - shear walls), then the processes of analysis, design is made and new models are concluded and so on until reaching to the final models that all its structural elements achieve design code conditions as well as to achieve lower cost.

2. Adoption of structural analysis program ETABS.v9 [4] in analysis and structural design models of RC high-rise structure buildings and extraction the results of the design for the three types of structural systems (F-SW-C) and calculation amounts of concrete and steel for whole structure building and all models using Excel program and then calculation the total cost of construction and then making a comparison between the models.

3. Study the effect of prices change of concrete and steel on the total cost of RC high-rise structure building for three cases of prices change and for the three types of structural systems (F-SW-C) and for SA and SB.

4. Drawing relations between the total cost and three cases of prices change for each type of structural systems (F-SW-C) and for SA and SB.

5. Determination the best and the appropriate of structural systems for the different RC high-rise buildings in the number of stories, type of foundation soil, and determination the percentage of saving achieved by foundation soil.

4. **Characterization of the Problem**

Two architectural plans of the structure of RC high-rise buildings are supposed for SA and SB. The first dose not contain shear walls, as shown in Fig 2, for F system and for 10-15-20 storey. The second contains walls of the central core in addition to surrounding shear walls for SW and C systems and for 10-15-20 storey, as shown in Fig 3, wherein its number and length, thicknesses are adopted after a series of studies, analysis and design has been done for multiple models to access the adoption models that achieve the conditions of the Syrian Arab code in this range.

4.1. **Geometric characteristic of the Problem**

- Structure regular RC high-rise building is supposed (the architectural plan is symmetrical for axes x and y).
- The structure floor area is 30x30m² for 10-15-20 storey.
- Height of storey is 3.5m.
- The thickness of floor slab is 15cm.
- The structural systems are: F-SW-C.
- Seismic zone 2C and therefore the seismic zone factor is \( Z = 0.25 \).
- The importance factor of construction is \( I = 1 \).
- Overstrength Factor \( R \), so we have: frames system, \( R = 8 \) and shear walls system, \( R = 4.5 \) and In couple system, \( R \) is determined according to the frames contribution percentage in bearing base shear forces.
- Yield strength of steel for longitudinal reinforcement \( f_y = 4000 \text{kgf/cm}^2 \).
- Yield strength of steel for cross-sectional reinforcement \( f_y = 3000 \text{kgf/cm}^2 \) for shear walls and \( f_y = 2400 \text{kgf/cm}^2 \) for stirrups in beams and columns.
- Characteristic compressive strength of concrete \( f'_c = 200 \text{kgf/cm}^2 \) (the amount of cement is \( 350 \text{kgf/m}^3 \) in control concrete case and \( 400 \text{kgf/m}^3 \) in non-control concrete case).
- To simplify the problem, it is assumed that all columns have square cross-section with initial dimensions begin from \( 50 \times 50 \text{cm} \) and fixed dimensions \( 40 \times 60 \text{cm} \) and \( 50 \times 60 \text{cm} \) for beams.
- Dead load on all slabs is assumed \( 300 \text{kgf/cm}^2 \) and live load \( 300 \text{kgf/cm}^2 \).

During the study, the case of reinforcing all RC high-rise building columns with minimum reinforcing ratio 1% and its effect on total cost was studied.

Prices change of concrete and steel according to the local workable prices in Syria come in three cases:

- First case: medial prices.
- Second case: expensive concrete and cheap steel.
- Third case: cheap concrete and expensive steel.

In order to study the effect of prices change according to the three cases on total cost and for each structural system and draw relations, and to simplify the problem, prices were imposed to concrete and steel materials, as shown in the table 1, this prices are put according to the local workable prices in Syria.

Table 1: a table shows the prices change according to the workable prices in Syria

<table>
<thead>
<tr>
<th>cost of materials</th>
<th>Three Cases of Prices Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>medial prices</td>
</tr>
<tr>
<td>cost of 1m³ concrete (Syrian Pound)</td>
<td>3000 SP</td>
</tr>
<tr>
<td>cost of 1t steel (Syrian Pound)</td>
<td>24000 SP</td>
</tr>
</tbody>
</table>
5. Results

Fig. 4 shows the values of total cost for multi-storeys RC high-rise buildings and for F system, three cases of prices change, and for SA and SB, so Fig. 5 shows the values of total cost for multi-storeys RC high-rise buildings and for SW system, three cases of prices change, and for SA and SB, and also Fig. 6 but for C system.

Fig. 4. Structure cost of multi-storeys RC high-rise buildings by use F system for SA and SB.

Fig. 5. Structure cost of multi-storeys RC high-rise buildings by use SW system for SA and SB.
6. Discuss the Results

- When the concrete is cheap and steel is expensive, this situation has the highest cost in general and when the prices are an intermediate commensurate, this situation achieved less cost in general.
- In the models which all of its columns are reinforced by minimum reinforcing ratio 1%, the cost increase ratio is few and small compared with the models achieved less cost, rather some of these models were achieved the less cost, and we found that the highest of increase percentage in cost was about 5% and it can be considered neglected and it can be covered in other materials costs as long as we design the high-rise buildings.
- The adoption of minimum reinforcing ratio 1% for all columns of the reinforced concrete high-rise buildings is the beginning of the end to reach to optimized solution in the design of reinforced concrete high-rise buildings at minimum cost, but this does not mean we impose at the beginning of the design large concrete sections to the columns and consider it final sections because we would get great reinforcing area and therefore there is waste in both the amount of concrete and the amount of steel, as that, selecting the minimum dimensions does not always ensure minimum costs, so that the structural designer should find the structural cross-sections for the various structural elements which achieve the minimum use of both the concrete and the reinforcement under certain conditions and therefore, namely the optimal solution, as Senay Atabay and F.Gulten explain that [6].
- In the soil profile SA and SB, in the reinforced concrete high-rise building, consisting of 10-storey, we note that the couple system (C) achieved the highest saving in the cost than the other structural systems F and SW, where shear walls system (SW) achieved the highest construction cost and therefore the order of structural systems according to the best and best-as follows: C \(\Rightarrow\) F \(\Rightarrow\) SW.

And we note that the highest saving in the cost was 9.87 % when the concrete price is cheap and the steel price is expensive in profile soil SA, while it was 12.53 % when the concrete price is expensive and the steel price is cheap in soil profile SB.
- In the soil profile SA and SB, in the reinforced concrete high-rise buildings, consisting of 15-storey and 20-storey, we note that the couple system (C) achieved the highest saving in the cost than the other structural systems F and SW, where frames system (F) achieved the highest construction cost and therefore the order of structural systems according to the best and best-as follows: C \(\Rightarrow\) SW \(\Rightarrow\) F.

The highest saving in cost was 17.7 % and 21.35 % for RC high-rise buildings consisting of 15-storey and 20-storey, respectively, when the concrete price is cheap and the steel price is expensive in soil profile SA,
while it was 16.1 % and 22.34 % when the concrete price is cheap and the steel price is expensive in soil profile SB.

- Table 2 shows the percentage of saving in the cost which the reinforced concrete high-rise buildings achieved it when it founded on foundation soil SA off those the reinforced concrete high-rise buildings that founded on foundation soil SB.

Table 2: a table shows the saving in the cost which the founded RC high-rise buildings on SA achieved it.

<table>
<thead>
<tr>
<th>Cases of Prices Change</th>
<th>Storeys Number</th>
<th>F (%)</th>
<th>C (%)</th>
<th>SW (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial prices</td>
<td>10</td>
<td>3.78</td>
<td>3.16</td>
<td>2.85</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5.53</td>
<td>3.17</td>
<td>3.29</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>5.03</td>
<td>5.14</td>
<td>4.08</td>
</tr>
<tr>
<td>Expensive Concrete and Cheap Steel</td>
<td>10</td>
<td>4.07</td>
<td>1.51</td>
<td>2.62</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>6.80</td>
<td>1.69</td>
<td>4.02</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>3.70</td>
<td>2.63</td>
<td>4.12</td>
</tr>
<tr>
<td>Cheap Concrete and Expensive Steel</td>
<td>10</td>
<td>3.39</td>
<td>2.94</td>
<td>4.63</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5.07</td>
<td>5.06</td>
<td>3.30</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>6.01</td>
<td>5.37</td>
<td>4.28</td>
</tr>
</tbody>
</table>

7. Conclusion

- This paper presents economic cost of reinforced concrete high-rise buildings consist of 10-15-20 storey by studying three structural systems with prices change and determining the best structural system that achieves saving in the use of concrete and steel materials for two type of soil profile SA and SB.
- The couple structural system (C) achieved the best results in both soil profiles SA and SB, hence the optimization in design the reinforced concrete high-rise buildings.

References
[3] Engineers Association., 2008 - "lectures on the course code Syrian Arab developer code and extension number (2) to resist earthquakes". Damascus, Syria.