PRELIMINARY DESIGN AND ANALYSIS OF COST PARAMETERS OF A HIGH-RISE BUILDING: BRACED SHEAR WALL CORE SYSTEM

T. Chrysanidis
Civil Engineering Department, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece

V. Panoskaltsis
Civil Engineering Department, Democritus University of Thrace, 67100, Xanthi, Greece

I. Tegos
Civil Engineering Department, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece

ABSTRACT

In the framework of the current work, a design proposal for a high-rise building is investigated. This design proposal for the structural system of the high-rise building is the type of a braced shear wall core system. First, a preliminary design for the design proposal in question takes place. Afterwards, a parametrical cost analysis of the building’s structural system takes place based on the member sections derived from the final detailed design of the building. Finally, based on the aforementioned preliminary design and the parametrical cost analysis, several conclusions are stated concerning the usefulness of the preliminary design and the huge number of parameters affecting the cost estimation of a building.

Key words: High-rise, Shear Wall, Parameters, Cost.


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1. INTRODUCTION

High-rise buildings and high-rise construction is an extremely demanding and challenging process both from an engineer’s point of view and from a financial point of view. Certain technical and engineering limits need to be satisfied but at the same time there are also financial limits which should not be exceeded. Modern international Codes [1-10] whether there are seismic codes, or concrete codes, or codes for steel and composite buildings have certain provisions which ought to be satisfied during the design process. It is well-known worldwide that the horizontal loads play a crucial role when designing these buildings, whether it is seismic loads or wind loads [11-14]. Thus, the structural system must satisfy both vertical and horizontal loads. At the same time displacements, especially the horizontal ones need to stay below certain limits for engineer and for psychological purposes concerning the inhabitants of such buildings and their need to feel safe and secure inside it. Ductility requirements and buckling phenomena in many cases, especially in seismic regions, play an important role [15-23] for the consultant engineer who makes the
choice for the proper structural system and its correct design. At the same time, consultant engineer has to meet some financial criteria. Cost is extreme in size compared to a usual building, due to the vast size of high-rise buildings. Thus, it is easily comprehensible that the choice for the suitable structural system is one of the most critical choices when designing high-rise or ultra high-rise buildings. A very useful tool that helps engineers to make the correct choice and propose the correct solution is the tool of preliminary design. Nowadays, usually, engineers forget to use this tool due to the extent use worldwide of personal computers and appropriate software for static and dynamic analyses and design of buildings. However, when it comes to high-rise construction because of the numerous parameters that need to be taken into account and the time that is needed for a correct final design, even for a high-end personal computer, correct preliminary design can untie the hands of the engineer and offer a fast and useful method for choosing the right structural system for the final design of the structure. Although, preliminary design plays such an important role, the bibliography for such a design is very scarce and proper preliminary design methods and methodologies are difficult to be found. Moreover, when and if they are found, they are not properly explained.

In the framework of the present work, a structural system is proposed for a high-rise building with certain technical and geometrical characteristics. The system in question is a braced shear wall core system. A preliminary design for this design proposal takes place and is explained thoroughly step by step, in order to help engineers follow the same procedure. Finally, a cost estimation of the building in question takes place based on the sections resulted from the detailed and final design, in order for the cost estimation to be more realistic and better depicting true conditions. An analysis of the parameters which affect the cost of the structural system takes place and useful comments on the type of members and their contribution to the final cost of the structural system are given.

2. GENERAL CHARACTERISTICS

2.1. Introduction

A structural arrangement of a braced shear wall core system has been chosen. The structural system is described thoroughly later in the present work. It is common for usual and high-rise buildings to have an increased storey height for the ground floor. So, according to these specifications and keeping in mind that in the framework of the present study, a choice has been taken that the building should not be less than 200 meters and higher than 220 meters, the following choices are made.

2.2. Elevation Characteristics

The bottom storey usually has a bigger height than the other storeys. Thus, the following storey heights are chosen:

- Storey “0”: 6m height
- Storeys “1” - “48”: 4.45m height

Thus, bearing in mind that an upper limit for the height has been set equal to 220m, the total height of the building would be:

\[
\text{TOTAL HEIGHT} = 6 + 48 \times 4.45 = 219.60 \text{ m}
\]

2.3. Plan Characteristics

In the framework of the present case study, an upper limit for the volume of the building has been set equal to 400,000 m³. Thus, in order to satisfy the aforementioned volume limit, the area of the building would be:

\[
\begin{align*}
\text{Volume} & \leq 400,000 \text{ m}^3 \\
\text{Volume} = \text{Height} \times \text{Area} \\
\Rightarrow & 219.6 \times \text{Area} \leq 400000 \\
\Rightarrow & \text{Area} \leq 1821 \text{ m}^2
\end{align*}
\]
We choose a plan area of 42×42 m:
A = 42×42 = 1764 m² ≤ 1821 m² → OK

2.4. Core Dimensions
Typical core plan dimension for a modern high-rise building is that the core occupies 20% of the total plan area. This space for the core is considered to be enough, in order for the core to include staircases, toilet facilities, lifts, etc. and at the same time not to reduce the total usable plan area for other activities like office activities, dance activities, residential purposes, etc. So, the core has a plan area equal to:

\[ A_{\text{core}} = 18\times18 \text{ m} = 324 \text{ m}^2 \quad \text{20\%}\times A = 0.20\times(42\times42) = 352.8 \text{ m}^2 \]

3. 3D MODEL

3.1. General
The building was modeled by using the structural analysis program SAP 2000 and the 3D model is shown in figures 1, 2, 3 and 4. Figure 1 shows the 3D model of the whole building. Figure 2 shows only the 3D model of the shear wall concrete core. Figure 3 shows a typical plan of the building with its frame elements (beams, etc.). Finally, Figure 4 shows the same typical plan like figure 3 but with elements being extruded this time.

Figure 1 3D Model of the whole building

Figure 2 3D Model of the shear wall concrete core
4. STRUCTURAL SYSTEM

4.1. General
The structural system is basically a core-supported structure and its structural members are the beams, columns and the shear wall core.

4.2. Columns
For the purpose of the preliminary design of the case study of the present work, the columns are chosen to be concrete-filled Circular Hollow Section (CHS) members. The concrete is normal weight concrete of grade C50/60.

4.3. Beams
In the framework of the present work, the beams are chosen to be typical composite beams with steel section of the type of Universal Beam (UB) section.

4.4. Core
The core is designed as a reinforced concrete core with high-strength concrete of grade C90/105.

4.5. Load Transfer Path

4.5.1. Dead and Imposed Loads
The vertical (dead and imposed) loads from the floor will be transferred to the secondary beams and from there, the loads will be transferred to the primary beams (if the secondary beams are connected to the primary beams) or straight to the columns or the reinforced concrete shear wall, according to where the secondary beams are connected to.

From the columns and the shear wall, the forces will be transmitted to the supports of the columns and the shear wall respectively and from there to the ground.

4.5.2. Wind Loads
With the high rigidity which they possess, it makes sense to exploit concrete shear walls in improving the building’s rigidity. Reinforced concrete shear walls, with their high resistance to shear stress, are highly
suitable for assuming the shear forces that arise through lateral loads. It is more than obvious, of course, that the stiffness of the central core overwhelms the stiffness of the other vertical elements. The cladding, floors and roof are designed suitably in order to be able to transfer the horizontal wind loads to the concrete core. Thus, the floors and roof behave as horizontal girders [24]. Since all the lateral loads are carried from the central reinforced concrete shear wall core, the vertical columns at the perimeter of the building are used only to carry the vertical loads or better a part of the total vertical loads since the other part of them is carried by the shear wall, as it was stated previously.

5. PRELIMINARY HAND CALCULATIONS

5.1. Natural Period and Natural Frequency
There are 3 different formulas which can be used in order to make a preliminary estimation of the natural period and natural frequency of structure.

• 1\textsuperscript{st} Method
According to this method an approximate formula for the estimation of the period of the building is (This formula is for general use) [25]:

\[ f = \frac{46}{H} \]  \hspace{1cm} (1)

where:
1. \( H \) is the total height above foundations

Having a total height of 219.6m we find that:

\begin{align*}
(1) \Rightarrow f &= \frac{46}{219.6} = 0.2095 \Rightarrow T = 4.77 \text{ sec}
\end{align*}

• 2\textsuperscript{nd} Method
According to this method an approximate formula for the estimation of the period of the building is (This formula is for frame buildings) [25]:

\[ f = \frac{10}{N_h} \]  \hspace{1cm} (2)

where:
1. \( N_h \) is the number of storeys of height \( h \)

Assuming that all 49 storeys have the same height \( h = 4.45 \text{m} \) we find that:

\begin{align*}
(2) \Rightarrow f &= \frac{10}{49} = 0.2041 \Rightarrow T = 4.90 \text{ sec}
\end{align*}

• 3\textsuperscript{rd} Method
According to this method an approximate formula for the estimation of the period of the building is (This formula is for shear wall buildings) [25]:

\[ f = \frac{9 \cdot \sqrt{D}}{H \cdot \sqrt{1 + 2 \cdot \frac{D}{H}}} \]  \hspace{1cm} (3)

where:
1. \( D \) is the building depth
2. H is the total height above foundations

\[
T = \frac{9 \cdot \sqrt{42}}{219.6 \cdot \sqrt{1+2\cdot \frac{42}{219.6}}} \cdot 0.2259 = 4.43 \text{ sec}
\]

5.2. Loads

In order to perform the preliminary design of the different elements of the building, first the dead and imposed loads need to be defined. Of course, the loads corresponding to a typical floor are chosen because they are more onerous than the loads which correspond to a typical roof. These loads are presented in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Loads for Preliminary Design.</th>
</tr>
</thead>
<tbody>
<tr>
<td>**DEAD LOADS (kN/m}^2)</td>
<td></td>
</tr>
<tr>
<td>Steelwork Self weight</td>
<td>Ignored for preliminary design</td>
</tr>
<tr>
<td>Concrete slab self weight</td>
<td>2.16</td>
</tr>
<tr>
<td>Tiles</td>
<td>0.70</td>
</tr>
<tr>
<td>Partitions</td>
<td>1.00</td>
</tr>
<tr>
<td>Services</td>
<td>0.50</td>
</tr>
<tr>
<td>Ceiling</td>
<td>0.25</td>
</tr>
<tr>
<td>Profile self weight</td>
<td>0.13</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4.74</td>
</tr>
<tr>
<td>**IMPOSED LOADS (kN/m}^2)</td>
<td></td>
</tr>
<tr>
<td>Imposed loads (Given)</td>
<td>5.00</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5.00</td>
</tr>
</tbody>
</table>

The concrete slab self weight is calculated by assuming lightweight concrete grade 40/50 of density 1800 kgr/m\(^3\) =18 kN/m\(^3\) and a profile with height of ribs equal to \(h_p = 60\) mm. Moreover, it is assumed that the slab has a total height equal to 150 mm. Thus, we find that:

Self weight of concrete slab = 18 \cdot (0.090 + 0.060/2) = 2.16 kN/m\(^2\)

6. PRELIMINARY DESIGN OF SECONDARY BEAM

6.1. Loads

For the purpose of the preliminary design, an internal secondary floor beam is chosen which has a width of loading region equal to 3m. It has to be noted the fact that this beam is simply supported and the preliminary design will take place for the loading case 1.35G+1.50Q, which is, by inspection, the most onerous case for the design of beams, even in the case of a detailed design. Moreover, the composite action of the beam is neglected for the purpose of the preliminary design.
Thus, we have:

\[ p = 1.35 \cdot 4.74 + 1.50 \cdot 5.00 \Rightarrow p = 13.90 \text{ kN/m}^2 \]

For loading region with width of 3.0m:

\[ p = 13.90 \cdot 3.00 \Rightarrow p = 41.70 \text{ kN/m} \]

6.2. Forces at Secondary Beam

- **Force**
  
  The beam is loaded by a uniform load to its whole span.

- **Bending moment**
  
  \[ M_{\text{max}} = \frac{q \cdot l^2}{8} = \frac{41.70 \cdot 12^2}{8} \Rightarrow M_{\text{max}} = 750.60 \text{ kNm} \]

6.3. Choosing a Secondary Beam Section

A section is chosen by doing a bending check:

\[ M_{\text{pl,Rd}} = W_{\text{pl,y}} \cdot \frac{fy}{\gamma_{fa}} > M_{\text{ad}} \Rightarrow W_{\text{pl,y}} > \frac{750.60 \cdot 10^6 \cdot 1.1 \cdot 10^{-3}}{355} \Rightarrow W_{\text{pl,y}} > 2326 \text{ cm}^3 \rightarrow \]

\[ \text{UB533x210x92 (} W_{\text{pl,y}} = 2360 \text{ cm}^3 \) \]

7. PRELIMINARY DESIGN OF PRIMARY BEAM

7.1. Loads

For the purpose of the preliminary design, an internal primary floor beam has been chosen which supports 3 secondary floor beams and has a span of 12m. In addition, the beam is loaded from the uniform load of the floor, from a loading region which has width of 1.50m. It has to be noted the fact that this beam is simply supported and the preliminary design will take place for the loading case 1.35G+1.50Q, which is the most onerous case for the design of beams, even in the case of a detailed design. Moreover, the composite action of the beam is neglected for the purpose of the preliminary design.

Thus, we have:

\[ p = 1.35 \cdot 4.74 + 1.50 \cdot 5.00 \Rightarrow p = 13.90 \text{ kN/m}^2 \]

For loading region with width of 1.50m:

\[ p = 13.90 \cdot 1.50 \Rightarrow p = 20.85 \text{ kN/m} \]

The point loads from the secondary beams are equal to:

\[ P = 41.70 \cdot (12/2) \Rightarrow P = 250.2 \text{ kN} \]

7.2. Forces at Primary Beam

- **Forces**
  
  The beam is loaded from a uniform load to its whole span and from 3 point loads because it supports 3 secondary beams.

- **Bending Moment Diagram**
  
  For \( n=4 \), where \( \langle n \rangle \) is the number of spans in which the primary beam is divided from the point loads of the secondary beams, we find that \( \langle n_M=2 \rangle \) and so the maximum bending moment is [26]:
7.3. Choosing a Primary Beam Section

A section is chosen by doing a bending check:

\[
M_{pl,Rd} = W_{pl,y} \cdot \frac{f_y}{\gamma_a} > M_{pl} \Rightarrow W_{pl,y} > \frac{1876.50 \cdot 10^6 \cdot 1.1 \cdot 10^{-3}}{355} \Rightarrow W_{pl,y} > 5815 \text{ cm}^3 \rightarrow
\]

UB762×267×173 (W_{pl,y} = 6200 \text{ cm}^3)

8. PRELIMINARY DESIGN OF COLUMN

Again the estimation takes part for the loading case 1.35G+1.50Q. The tributary area of the worst loaded column is:

\[
A_{\text{tributary}} = 6 \cdot (6.00+4.50) = 6 \cdot 10.50 \Rightarrow \text{Area}=63.00 \text{ m}^2
\]

One Storey: \( F = p \cdot A = 13.90 \cdot 63.00 \Rightarrow F = 875.70 \text{ kN} \)

49 Storeys: \( F_{\text{tot}} = n \cdot F = 49 \cdot 875.70 \Rightarrow F_{\text{tot}} = 42909.30 \text{ kN} \)

Required area of the column section:

\[
F_{\text{tot}} \geq \frac{f_y \cdot A}{\gamma_a} \Rightarrow A \geq \frac{42909.30 \cdot 10^3 \cdot 1.1}{355} \Rightarrow A \geq 132958 \text{ mm}^2 \Rightarrow A \geq 1329.58 \text{ cm}^2
\]

Due to the simplified nature of the preliminary design, the contribution of bending moments and self weight of column have been ignored in the column design and that is the reason why the area of the column cross-section should be increased by 40%.

\( A_g = 1.40 \cdot A = 1.40 \cdot 1329.58 \Rightarrow A_g = 1861 \text{ cm}^2 \)

It can be seen from section tables that no section has such a big area. So, 2 things can be easily understood:

- Maybe the magnification factor of 1.40 is too conservative.
A composite column is probably going to be necessary.
A section is chosen by assuming a composite circular hollow section filled with concrete:
CHS508×20 (A = 2025.80 cm$^2$ assuming that the section is filled with concrete)
A = 2025.80 cm$^2$ > $A_g$ = 1861 cm$^2$ → OK

9. PRELIMINARY DESIGN OF SHEAR WALL

A first estimation of the shear wall size takes part by the use of the method described in Colaco (1971), for the preliminary design of shear walls. For the shear wall, high-strength concrete of grade C90/105 is used, which has modulus of elasticity equal to $E_{cm}$=44000 N/mm$^2$. The tributary area of this shear wall is shown in Figure 6.

The properties of this shear wall are found by using SAP2000:
Area: $A_w$ = 45.75 m$^2$
Moment of Inertia about minor axis: $I_{w,33}$ = 1533.30 m$^4$
Section modulus: $S_{w,33}$ = 214.41 m$^3$

Required Area of Shear Wall

If the gravity load is $W_u$ per floor and there are n floors in a tall building and $T_a$ is the tributary area of each wall and $B'$ is the width of the tributary area, for the case of wind loading in the direction where the wind comes from (Tributary area for wind loads is different to the tributary area for the gravity loads; here $B'$=B=42m), then the axial load and the overturning moment is equal to:
Preliminary Design and Analysis of Cost Parameters of a High-Rise Building: Braced Shear Wall Core System

\[ P_u = n \cdot T_a \cdot W_u \quad (4) \]

\[ M_w = \left( p \cdot B' \right) \cdot \frac{(n \cdot h)^2}{2} = \left( p \cdot B' \right) \cdot \frac{H^2}{2} \quad (5) \]

Thus, we find that:

(4) \Rightarrow P_u = 49 \cdot (30 \cdot 30) \cdot 13.90 \Rightarrow P_u = 612990 \text{ kN}

(5) \Rightarrow M_w = \left( 1.20 \cdot 42 \right) \cdot \frac{219.6^2}{2} \Rightarrow M_w = 1215249 \text{ kNm}

In equation (5), for preliminary purposes, it has been assumed a wind pressure equal to 1.20 kN/m\(^2\).

An approximate value of permissible axial stress in the wall, \( f_a \), can be assumed as \( 0.40 \cdot f_{ck} \). For full utilization of the wall under gravity loads, it has been assumed that the ultimate axial stress in the wall is equal to the permissible axial stress in the wall:

\[ f_a = F_a \Rightarrow A_{w, \text{required}} = 0.40 \cdot f_{ck} \Rightarrow A_{w, \text{req}} = 612990 \cdot 10^3 \Rightarrow A_{w, \text{req}} = 17027500 \text{ mm}^2 \Rightarrow A_{w, \text{req}} = 17.03 \text{ m}^2 < A_w = 45.75 \text{ m}^2 \rightarrow \text{OK} \]

• **Required Section Modulus of Shear Wall**

The required section modulus for preliminary purposes is given by:

\[ S_w = \frac{p \cdot B' \cdot (n \cdot h)^2}{0.14 \cdot f_{ck}} = \frac{p \cdot B' \cdot (H)^2}{0.14 \cdot f_{ck}} \quad (6) \]

Thus, we find that:

\[ S_{w, \text{required}} = \frac{1.20 \cdot 42 \cdot 219.6^2}{0.14 \cdot 90 \cdot 10^3} \Rightarrow S_{w, \text{req}} = 192.90 \text{ m}^3 < S_w = 214.41 \text{ m}^3 \rightarrow \text{OK} \]

• **Required Moment of Inertia of the Wall**

For a shear wall with variable moment of inertia along its height, the required moment of inertia of the wall is given by:

\[ E \cdot I_w = 71.4 \cdot (p \cdot B') \cdot (n \cdot h)^3 \Rightarrow E \cdot I_w = 71.4 \cdot (p \cdot B') \cdot (H)^3 \quad (7) \]

Thus, we find that:

(7) \Rightarrow I_{w, \text{required}} = 71.4 \cdot (1.20 \cdot 42) \cdot (219.6)^3 \Rightarrow I_{w, \text{req}} = 866.11 \text{ m}^4 < I_w = 1533.30 \text{ m}^4 \rightarrow \text{OK} \]

10. **TOTAL VERTICAL FORCE AT GROUND LEVEL**

The calculations are made for the load case 1.35G+1.50Q.

One storey: \( P = p \cdot \text{Area} = 13.90 \cdot (42 \cdot 42) \Rightarrow P = 24519.60 \text{ kN} \)

At ground level: \( P_{\text{tot}} = P \cdot n = 24519.60 \cdot 49 \Rightarrow P_{\text{tot}} = 1201460.40 \text{ kN} \)

11. **COST ESTIMATION AND PARAMETERS**

The preliminary design of the high-rise building in question has given the preliminary sections of this building. Thus, as far as the structural system is concerned, the cost of the building can be calculated. This is done in Tables 2-10. Wherever it says “Detailed design”, it means that a detailed design of the building is necessary before the certain cost in question can be calculated.
11.1. Cost of Steelwork

Table 2 Cost of Beams.

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight (kgr/m)</th>
<th>Number</th>
<th>Span (m)</th>
<th>Weight per piece (kgr)</th>
<th>Total Weight (kgr)</th>
<th>Total Weight (tonnes)</th>
<th>Cost per type of section (pounds/tonne)</th>
<th>Total cost of type of piece (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary beams UB533x210x92</td>
<td>92,10</td>
<td>196</td>
<td>12</td>
<td>1105,20</td>
<td>216619,20</td>
<td>216,62</td>
<td>1050</td>
<td>227450,16</td>
</tr>
<tr>
<td>Secondary beams UB533x210x92</td>
<td>92,10</td>
<td>1764</td>
<td>12</td>
<td>1105,20</td>
<td>1949572,80</td>
<td>1949,57</td>
<td>1050</td>
<td>2047051,44</td>
</tr>
<tr>
<td>Primary beams UB762x267x173</td>
<td>173,00</td>
<td>196</td>
<td>9</td>
<td>1557,00</td>
<td>305172,00</td>
<td>305,17</td>
<td>1050</td>
<td>320430,60</td>
</tr>
<tr>
<td>Primary beams UB762x267x173</td>
<td>173,00</td>
<td>392</td>
<td>12</td>
<td>2076,00</td>
<td>813792,00</td>
<td>813,79</td>
<td>1050</td>
<td>854481,60</td>
</tr>
</tbody>
</table>

TOTAL WEIGHT: 3285,16  TOTAL COST: 3449413,80

Table 3 Cost of Angle Columns.

<table>
<thead>
<tr>
<th>Type</th>
<th>Length of piece (m)</th>
<th>Number of pieces</th>
<th>Weight per piece (kgr)</th>
<th>Total Weight (kgr)</th>
<th>Total Weight (tonnes)</th>
<th>Cost per type of section (pounds/tonne)</th>
<th>Total cost of type of piece (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle column CHS508x20</td>
<td>8,90</td>
<td>4</td>
<td>2144,90</td>
<td>8579,60</td>
<td>8.58</td>
<td>1300,00</td>
<td>11153,48</td>
</tr>
<tr>
<td>Angle column CHS508x20</td>
<td>14,90</td>
<td>4</td>
<td>3590,90</td>
<td>14363,60</td>
<td>14.36</td>
<td>1300,00</td>
<td>18672,68</td>
</tr>
<tr>
<td>Angle column CHS508x20</td>
<td>17,80</td>
<td>8</td>
<td>4289,80</td>
<td>34318,40</td>
<td>34.32</td>
<td>1300,00</td>
<td>44613,92</td>
</tr>
<tr>
<td>Angle column CHS508x20</td>
<td>241</td>
<td>17,80</td>
<td>12</td>
<td>4289,80</td>
<td>51477,60</td>
<td>51.48</td>
<td>1300,00</td>
</tr>
<tr>
<td>Angle column CHS508x20</td>
<td>241</td>
<td>17,80</td>
<td>12</td>
<td>4289,80</td>
<td>51477,60</td>
<td>51.48</td>
<td>1300,00</td>
</tr>
</tbody>
</table>
## Preliminary Design and Analysis of Cost Parameters of a High-Rise Building: Braced Shear Wall Core System

### Table 4 Cost of Internal Columns.

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight (kgr/m)</th>
<th>Length of piece (m)</th>
<th>Number of pieces</th>
<th>Weight per piece (kgr)</th>
<th>Total Weight (kgr)</th>
<th>Total Weight (tonnes)</th>
<th>Cost per type of section (pounds/tonne)</th>
<th>Total cost of type of piece (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal column CHS508x20</td>
<td>241</td>
<td>8,90</td>
<td>8</td>
<td>2144,90</td>
<td>17159,20</td>
<td>17,16</td>
<td>1300,00</td>
<td>22306,96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14,90</td>
<td>8</td>
<td>3590,90</td>
<td>28727,20</td>
<td>28,73</td>
<td>1300,00</td>
<td>37345,36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17,80</td>
<td>16</td>
<td>4289,80</td>
<td>68636,80</td>
<td>68,64</td>
<td>1300,00</td>
<td>89227,84</td>
</tr>
<tr>
<td>Internal column CHS508x20</td>
<td>241</td>
<td>17,80</td>
<td>24</td>
<td>4289,80</td>
<td>102955,20</td>
<td>102,96</td>
<td>1300,00</td>
<td>133841,76</td>
</tr>
<tr>
<td>Internal column CHS508x20</td>
<td>241</td>
<td>17,80</td>
<td>24</td>
<td>4289,80</td>
<td>102955,20</td>
<td>102,96</td>
<td>1300,00</td>
<td>133841,76</td>
</tr>
<tr>
<td>Internal column CHS508x20</td>
<td>241</td>
<td>17,80</td>
<td>24</td>
<td>4289,80</td>
<td>102955,20</td>
<td>102,96</td>
<td>1300,00</td>
<td>133841,76</td>
</tr>
</tbody>
</table>

### Table 5 Cost of Middle Columns.

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight (kgr/m)</th>
<th>Length of piece (m)</th>
<th>Number of pieces</th>
<th>Weight per piece (kgr)</th>
<th>Total Weight (kgr)</th>
<th>Total Weight (tonnes)</th>
<th>Cost per type of section (pounds/tonne)</th>
<th>Total cost of type of piece (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle column CHS508x20</td>
<td>241</td>
<td>8,90</td>
<td>4</td>
<td>2144,90</td>
<td>8579,60</td>
<td>8,58</td>
<td>1300,00</td>
<td>11153,48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14,90</td>
<td>4</td>
<td>3590,90</td>
<td>14363,60</td>
<td>14,36</td>
<td>1300,00</td>
<td>18672,68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17,80</td>
<td>8</td>
<td>4289,80</td>
<td>34318,40</td>
<td>34,32</td>
<td>1300,00</td>
<td>44613,92</td>
</tr>
<tr>
<td>Middle column CHS508x20</td>
<td>241</td>
<td>17,80</td>
<td>12</td>
<td>4289,80</td>
<td>51477,60</td>
<td>51,48</td>
<td>1300,00</td>
<td>66920,88</td>
</tr>
<tr>
<td>Middle column CHS508x20</td>
<td>241</td>
<td>17,80</td>
<td>12</td>
<td>4289,80</td>
<td>51477,60</td>
<td>51,48</td>
<td>1300,00</td>
<td>66920,88</td>
</tr>
<tr>
<td>Middle column CHS508x20</td>
<td>241</td>
<td>17,80</td>
<td>12</td>
<td>4289,80</td>
<td>51477,60</td>
<td>51,48</td>
<td>1300,00</td>
<td>66920,88</td>
</tr>
</tbody>
</table>
Table 6 Total Cost of Columns.

<table>
<thead>
<tr>
<th>TOTAL COST OF COLUMNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total weight of columns (tonnes)</td>
</tr>
<tr>
<td>846.78</td>
</tr>
</tbody>
</table>

Table 7 Cost of shear connectors.

<table>
<thead>
<tr>
<th>COST OF SHEAR CONNECTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Welded headed studs</td>
</tr>
<tr>
<td>Cold-fastened headed studs</td>
</tr>
<tr>
<td>TOTAL COST</td>
</tr>
</tbody>
</table>

11.2. Cost of Reinforced Concrete

Table 8 Cost of Reinforcement.

<table>
<thead>
<tr>
<th>COST OF REINFORCEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Reinforcement bars 18mm</td>
</tr>
</tbody>
</table>

Table 9 Cost of Concrete.

<table>
<thead>
<tr>
<th>COST OF CONCRETE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of concrete</td>
</tr>
<tr>
<td>Normal weight concrete C50/60</td>
</tr>
<tr>
<td>Light weight concrete C40/50</td>
</tr>
<tr>
<td>High-strength concrete C90/105</td>
</tr>
<tr>
<td>TOTAL COST</td>
</tr>
</tbody>
</table>
11.3. Cost of Erection of Steelwork

Table 10 Cost of Erection of Steelwork.

<table>
<thead>
<tr>
<th>Cost of Erection of Steelwork</th>
<th>Total number of pieces under 5 tonnes</th>
<th>Total weight of pieces under 5 tonnes (t)</th>
<th>Cost per tonne for under 5 tonne pieces (pound/tonne)</th>
<th>Total cost of erection of pieces under 5 tonnes (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed design</td>
<td>Detailed design</td>
<td>Detailed design</td>
<td>Detailed design</td>
<td>Detailed design</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost of Erection of Steelwork</th>
<th>Total number of pieces over 5 tonnes</th>
<th>Total weight of pieces over 5 tonnes (t)</th>
<th>Cost per tonne for over 5 tonne pieces (pound/tonne)</th>
<th>Total cost of erection of pieces over 5 tonnes (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed design</td>
<td>Detailed design</td>
<td>Detailed design</td>
<td>Detailed design</td>
<td>Detailed design</td>
</tr>
</tbody>
</table>

| TOTAL COST OF ERECTION        | Detailed design                      |                                          |                                                 |                                                 |

11.4. Total Weight of Steelwork

Thus, the total weight of steelwork is equal to:

4131.93 tonnes

11.5. Total cost of steelwork

Thus, the total cost of the steelwork is equal to:

4550224.68 pounds

12. ANALYSIS OF RESULTS

The analysis of the results of the preliminary design of the braced shear wall core system and of the cost estimation and analysis of its parameters results to the following:

- It is obvious that a shear wall core in the centre of the building is used as a structural system for the scheme in question. This is one of the most frequent uses of shear walls in the form of box-shaped cores around stairs and elevators, because this arrangement makes structural use of vertical enclosures required around the cores. This arrangement of internal cores is especially suitable for office buildings, as it is this certain building under examination, because it frees the lease space outside of the core from massive vertical elements.

- The walls around the core can be considered as a spatial system capable of transmitting lateral loads in both directions.

- A basic characteristic of this system, which is also a vital advantage of this system, is that because core structures are spatial structures, they have the ability to resist all types of loads: vertical loads, shear forces and bending moments in two directions, as well as torsion, especially when adequate stiffness and strength are provided.

- The shape of the core to a large extent is governed by the elevator and stair requirements. This is because the elevators shafts, stairwells and respective anterooms necessary for access in a high-rise building must be protected by fire walls, as demanded by fire safety regulations. Reinforced concrete walls are normally used and that is the reason why they were chosen as a crucial part of this design scheme.
Parameters affecting the cost of the structural system are: (a) Cost of steelwork (cost of beams, angle columns, internal columns, middle columns and shear connectors), (b) Cost of reinforced concrete (cost of reinforcement and concrete), (c) Cost of erection of steelwork.

As far as the cost of steelwork is concerned, the cost of the beams is the higher cost and the least cost is the cost of the columns (cost of shear connectors can be calculated only after a detailed design of the building takes place.).

As far as the cost of reinforced concrete is concerned, it can be calculated only after a detailed design of the building takes place.

As far as the total cost of the structural system is concerned, the highest cost comes from the cost of the steelwork and especially the cost concerning the composite beams.

13. CONCLUSION
The following conclusions have been derived from the aforementioned preliminary design and parametrical cost analysis of the high-rise building:

- Preliminary design plays a crucial role in making a first choice for the member sections, especially in the case of high-rise construction that computer analyses are extremely time-consuming.
- Preliminary design can help the consultant engineer evaluate the structural system chosen and propose the same or a better 3D structural system.
- Braced shear wall core system provides a good design proposal since it can withstand both vertical and horizontal loads.
- Cost is one of the most crucial parameters in high-rise construction due to the vast size of the buildings.
- Analysis of the parameters affecting the cost of the structural system, when this structural system is a braced shear wall core system, shows that the highest steelwork cost results from the beams (cost of shear connectors needs a detailed design).
- Further and more thorough research on the parameters affecting the cost of the buildings in general needs to take place.

REFERENCE


Preliminary Design and Analysis of Cost Parameters of a High-Rise Building: Braced Shear Wall Core System


