COMPARATIVE ANALYSIS OF REINFORCED CONCRETE AND CFT COLUMNS IN BUILDINGS

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Summary: Reinforced concrete columns are in common use in buildings, while CFT (Column Filled Tubes) columns are less used. Comparative analysis was done on a real multi-story building. Reinforced concrete column was designed according to Eurocode 2, while CFT column was designed using simplified method defined in Eurocode 4. Benefits and shortcomings of CFT columns in comparison to reinforced concrete columns regarding dimensions of the cross-section, cost, construction time and simplicity were quantified by this analysis.

Keywords: CFT column, RC column, comparative analysis, Eurocode 2, Eurocode 4

1. INTRODUCTION

It is well known that reinforced concrete columns (*RC columns*) are by far the most used vertical bearing elements in buildings. However, recently the use of CFT (*Column Filled Tubes*) columns is increasing due to their numerous advantages relative to reinforced concrete and steel columns [1]. Using as an example, a real reinforced concrete building structural model two cases were considered.

Originally, all vertical bearing elements in the structure model were reinforced concrete (*RC*) columns designed according to Eurocode 2 guidelines. One column, with dimensions designed solely from loading and stability conditions was further considered. As an alternative to this RC solution, the column was also designed as a CFT column, for the same loading conditions. CFT column was designed in the same manner, in order to make this study as accurate and realistic as possible.

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2. BEHAVIOR OF CFT COLUMNS

Since the use of reinforced concrete columns is wide spread, their behavior is thoroughly examined and well know. On the other hand, behavior of CFT columns is less known. Here a few of its key points will be presented shortly. CFT columns represent one type of composite columns. Steel tube forms the exterior of the cross-section, while concrete fills the core of the cross-section. Steel tube provides large moment of inertia, leading to high stiffness and flexural capacity, while concrete, that can also be reinforced, increases the compressive strength of the element. Also, concrete core delays buckling of the steel tube, forcing all buckling modes outward [1]. No need for framework exists when constructing CFT columns, since concrete is poured inside a steel tube. So the construction time is significantly reduced. When CFT columns are exposed to compressive loading, an increase in compressive strength is observed. Steel tube acts as stirrups, confining concrete core and increasing the compressive strength of concrete due to triaxial stress state. Circular steel tubes provide a higher degree of confinement than flat sides of rectangular tubes, so, the increase of compressive strength is more evident in circular than in rectangular cross-sections [1].

Effect of viscous deformations, such as creeping and shrinkage, have much smaller effect than in reinforced concrete columns. Steel tube serves as an enclosed environment for concrete, so conditions inside the tube remain ideally humid minimizing the effects of viscous deformations [2]. Due to the concrete core, CFT columns have increased fire resistance than hollow steel tubes. However, fire resistance of reinforced concrete columns is higher than for CFT columns. Since steel tube is directly exposed to fire, certain fire protection is necessary [2].

3. STRUCTURAL MODEL DESCRIPTION

In order to compare CFT and RC columns, a realistic multi-storey reinforced concrete structural model was used. The building had 7 storeys above ground and one basement storey. The total height of the building above basement is 24.8m. The story height is 3.1m. In the basement there are peripheral walls. The structural system consists of shear walls and frames. All slabs are monolith, directly supported by columns and shear walls. In this study, the structural system is considered as non-sway and, thus, the buckling length of the column was taken as equal to the column length. The 3D structural model is shown in **Error! Reference source not found.**, while Figure 2 shows the position of the considered column.

4. CFT COLUMN DESIGN

The design of the CFT column was done according to the simplified method proposed by Eurocode 4. In order to use this method, the following conditions must be met [3]:

(1) The scope of simplified method is limited to members of doubly symmetrical and uniform cross-section over the member length with rolled, cold-formed or welded steel

sections. The simplified method is not applicable if the structural steel component consists of two or more unconnected sections. The relative slenderness λ needs to fulfil the following condition:

$$\lambda \leq 2.0 \qquad\qquad (1)$$

(3) The longitudinal reinforcement that may be used in calculation should not exceed 6% of the concrete area.

(4) The ratio of the depth to the width of the composite cross-section should be within the limits 0.2 and 5.0.

(4) The steel contribution ratio δ should fulfil the following condition:

$$0.2 \leq \delta \leq 0.9 \qquad\qquad (2)$$

Design of the CFT column in this paper met all of the above conditions, as will be shown. An effort was made to fully utilize the cross-section bearing capacity, in order to make this study as accurate as possible. The cross-section of the designed CFT column is shown in Figure 16.
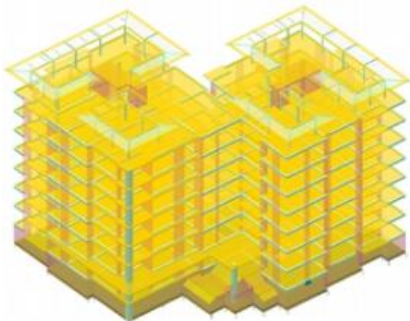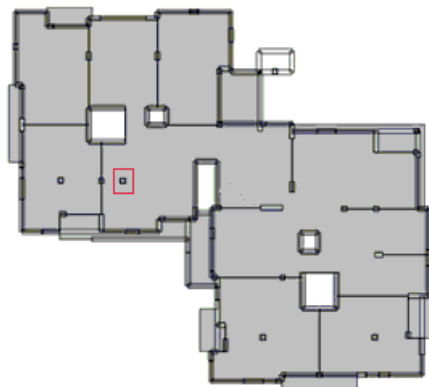

Figure 14: 3D structural model

Figure 15: Floor plan of the structural model, red square marks the selected column

Design data

  Steel tube: HSS 220x220x5

  Steel grade: S275

  Concrete grade: C30/37

  Axial load: 1855 kN

  Bending moment about Y axis: 1.08kNm

Bending moment about Z axis: 17.75kNm

Length of the column: 3.1m

Buckling length: 3.1m

Partial material safety factors:
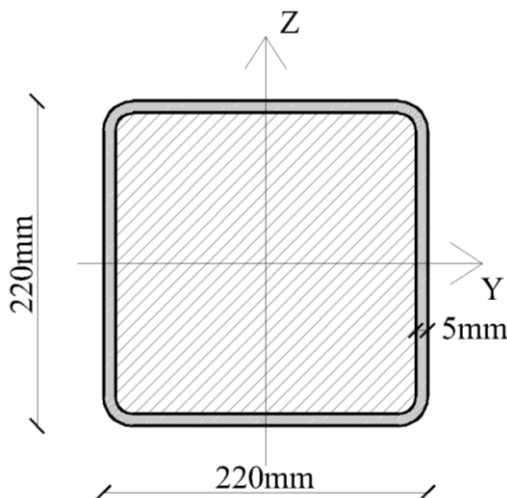$$\gamma_M = 1.0 \quad \gamma_C = 1.5$$

Figure 16. CFT column cross section

Calculation results

- Material properties:

$$f_{yd} = \frac{275}{1.0} = 275 MPa, f_{cd} = \frac{37}{1.5} = 2.47 MPa, E_s = 210 GPa, E_{cm} = 34 GPa$$

In the design of reinforced concrete columns, creep coeffecient had value of $\varphi = 2.4$. However, concrete encased in the steel tube is less exposed to creeping and shrinking. It was found that creep coefficient for concrete in CFT columns is 50% of the value for concrete outside the steel tube [1]. Therefore, in the design of the CFT column, creep coeffecient had value of $\varphi = 1.2$.

Creeping and shrinking were taken into account by calculating effective modulus of elasticity [3]:

$$\frac{N_{G,Ed}}{N_{Ed}} = \frac{1555}{1855} = 0.84$$

$$E_{c,eff} = 34\,000 \cdot \frac{1}{1 + 0.84 \cdot 1.2} = 16\,933\ MPa$$

- Slenderness ratio

$$\lambda_y = 0.577 < 2$$
$$\lambda_z = 0.577 < 2$$

Simplified method can be used when relative slenderness for both axes are smaller than two, which is satisfied.

- Steel contribution factor

$$0.2 < \delta = 0.5 < 0.9$$

- Squash load

$$N_{pl,Rd} = A_a f_{yd} + 0.85 A_c f_{cd} \qquad (3)$$

To take into account the increase of concrete compressive strength in square CFT columns, coefficient 0.85 is replaced by 1.0.

- Buckling of the steel tube

Before the plastic resistance of CFT column is calculated, it should be ensured that local buckling of steel tube does not occur. To prevent premature local buckling, width to thickness ratio should be checked:

$$\frac{h}{t} = \frac{220}{5} = 44 \leq 52\varepsilon = 48$$

Where:

t-wall thickness of the steel tube
h-larger outer dimensions of the rectangular hollow section

$$\varepsilon = \sqrt{\frac{235}{f_y}}$$

- Interaction curve

Figure 17 shows the intercation curve for the CFT column. Interaction curve for both axes was calculated using the analytical expressions with a function written in "Matlab" program.
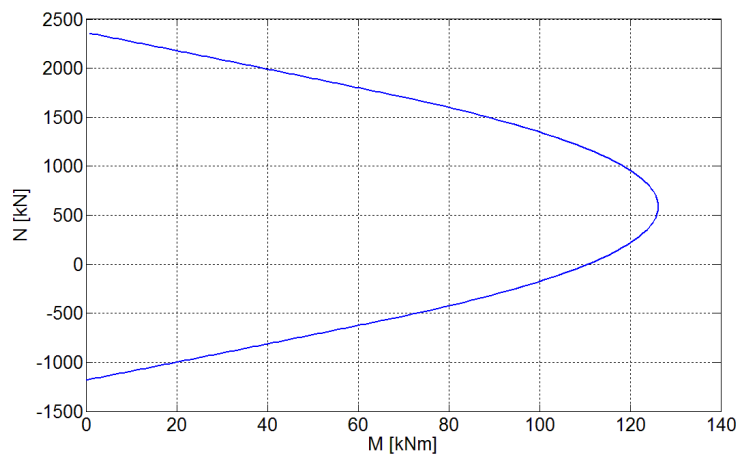

Figure 17. Interaction diagram (N-M) – CFT column cross-section

- Design checks

When calculating column resistance, second order effects were accounted for by using the appropriate methods given in Eurocode 4 (Chapter 6.7.3.4). All of the following conditions must be satisfied:

Assume buckling about Y axis as critical:

$$\frac{M_{y,Ed}}{\mu_{d,y} \cdot M_{pl,y,Rd}} = 0.48 \ < \ \alpha_{M,y} = 0.9$$

$$\frac{M_{z,Ed}}{\mu_{d,z} \cdot M_{pl,z,Rd}} = 0.33 \ < \ \alpha_{M,z} = 0.9$$

$$\frac{M_{y,Ed}}{\mu_{d,y} \cdot M_{pl,y,Rd}} + \frac{M_{z,Ed}}{\mu_{d,z} \cdot M_{pl,z,Rd}} = 0.81 \ < \ \alpha_{M,y} = 1$$

Assume buckling about Z axis as critical:

$$\frac{M_{y,Ed}}{\mu_{d,y} \cdot M_{pl,y,Rd}} = 0.02 \ < \ \alpha_{M,y} = 0.9$$

$$\frac{M_{z,Ed}}{\mu_{d,z} \cdot M_{pl,z,Rd}} = 0.66 \ < \ \alpha_{M,z} = 0.9$$

$$\frac{M_{y,Ed}}{\mu_{d,y} \cdot M_{pl,y,Rd}} + \frac{M_{z,Ed}}{\mu_{d,z} \cdot M_{pl,z,Rd}} = 0.68 \ < \ \alpha_{M,y} = 1$$

5. REINFORCED CONCRETE COLUMN DESIGN

Reinforced concrete column was designed according to Eurocode 2 guidelines. The column was designed using program "Radimpex Tower". Difference between the axial loads for the CFT and RC columns exist due to their different self-weights. In this case, although the difference was small, it was not neglected. All other loading conditions remained the same as in previous case. Figure 18 shows the cross-section of the RC column.

Design data

RC column cross-section: 350x350mm

Steel reinforcement grade: B500B

Concrete grade: C30/37

Axial load: 1907 kN

Bending moment about Y axis: 1.08kNm

Bending moment about Z axis: 17.75kNm

Length of the column: 3.1m

Buckling length: 3.1m

Partial material safety factors:
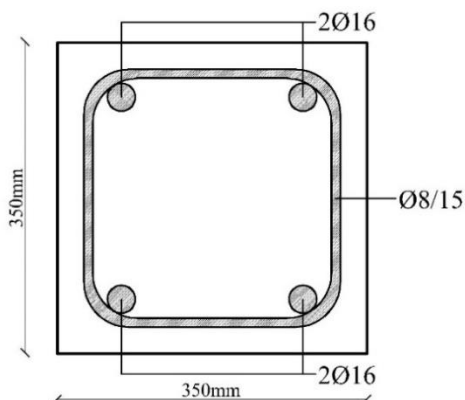$$\gamma_s = 1.15 \quad \gamma_C = 1.5$$

Figure 18. RC column cross section

Steel reinforcement area was obtained using program "Radimpex Tower" and Eurocode 2 guidelines. An effort was made not to over-reinforced the cross section in order to properly compare two column cross-section.

$A_{s,d} = 3.18cm^2$ – required area of steel reinforcement per side

$A_{s,p} = 4.02cm^2$ (2Ø16) – adopted area of steel reinforcement per side

$$\frac{A_{s,d}}{A_{s,p}} = 0.79 \ < 1$$

Figure 19 shows interaction curve for the RC columns cross-section, calculated using the program "Radimpex Tower".
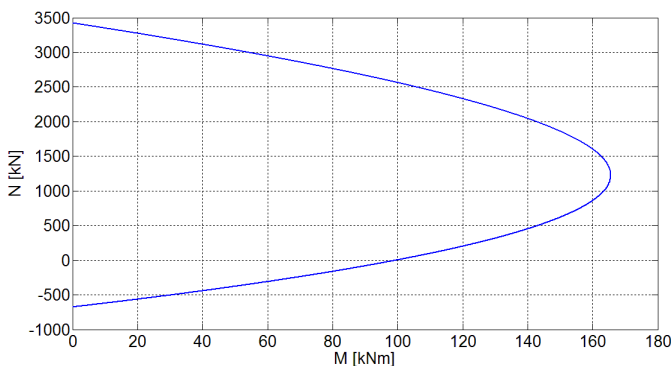

Figure 19. Interaction diagram (N-M) – RC column cross-section

6. COST ANALYSIS

In addition to the comparison of dimensions, the cost analysis for both columns was done. Cost of two columns was calculated for one floor height, with average prices for materials and workers in Serbia at the time when this paper is written *(Table 1)*.

Table 1: Materials and manpower prices

Materials and manpower	Price
Concrete-RC	220 €/m³
Concrete-CFT	120 €/m³
Steel	0.8 €/kg
Reinforcement	1 €/kg
Worker	30 €/day

When cost was analysed, a difference was made between concrete used for CFT column (*Concrete – CFT*) and concrete used for RC Column (*Concrete – RC*). Cost of concrete used for RC Column included framework, pouring and manpower costs. While for CFT column, there is no need for the framework, nor for the workers installing the framework,

so the price of *Concrete – CFT* only included cost of the poured concrete on the construction site.

Steel cost included finished product transported to the construction site ready for installing. Reinforcement cost included installed reinforcrement bars, together with manpower cost. Workers were included only in the cost of the CFT column, since for the RC column, manpower costs were included in material prices. It was assumed that it would take 1 day and 3 workers to install a CFT column for one floor. On the other hand, for the RC column it would take 2 days to install the column for one floor.

Prices per material and total prices of both columns are shown in tables below *(Table 2, Table 3)*.

Table 2: Cost analysis of the RC column

Concrete		Reinforcement		
Volume	Price	Weight	Price	Total
0.36 m³	79 €	51 kg	51 €	130 €

Table 3: Cost analysis of the CFT column

Concrete		Steel		Workers		
Volume	Price	Weight	Price	No	Price	Total
0.14 m³	17 €	98 kg	79 €	3	90 €	184 €

Despite the higher material and manpower costs, CFT columns can still be economical choice, if the difference in dimensions is accounted for:

$$\Delta A = A_{RC} - A_{CFT} = 0.35^2 - 0.22^2 = 0.0741 m^2$$

Where:

A_{RC} − RC column cross-section surface
A_{CFT} − CFT column cross-section surface

Obviously, CFT column takes up smaller surface of the building than RC column, increasing the amount of space that can be sold in a building. If, for example, we presume that cost of a square meter is 1000€, by using CFT column, there will be an increase in value by 74.1€ per column per floor. From this (long-term) point of view, CFT columns may be more economical solution than RC columns.

7. CONCLUSION

In this paper a comparative study of reinforced concrete and CFT column has been done. As an example, a multi-story residental building structural model was used. The selected column was designed as RC and as CFT column and the two solutions were compared. As excepted, CFT column cross-section has smaller dimensions than RC column cross-section. RC column cross-section was 35 by 35 cm *(Figure 18),* while CFT column cross-section was 22 by 22cm *(Figure 16).* Smaller dimensions of CFT column resulted, also, in smaller self-weight of the column, but in this case the difference was only 3% of total axial load.

Regarding the construction time and simplicity, it is obvious that the construction of a CFT column is less complicated than the construction of a RC column, since it doesn't require framework, nor it requires constructing the reinforcement bar cage. In this paper it was assumed, that it would take 1 day and 3 workers to finish the construction of CFT column for one floor. For the RC column, construction time would be at least 2 days, double than the construction time for the CFT column. However, cost of a CFT column is higher than cost of a RC column, as can be seen from the cost analysis done in this paper. CFT column was about 25% more expensive than RC column when prices of manpower and materials were compared. But, as it was explained earlier, smaller surface of the building is taken up by a CFT column, increasing the value of the building.

In order to properly compare two types of columns, it is also neccesery to account for the construction time and price of connections needed to connect CFT columns with rest of the structure. It should also be mentioned that when calculating seismic forces for the structural model, a difference can exist between RC and CFT columns if there is a difference in stiffness between two columns. In this paper, load combination used for the design of the columns did not include seismic forces. Also, when flat slabs are directly supported on columns, smaller dimensions of CFT column induce higher punching shear.

Based on this study, it can be concluded that when construction time and dimensions of the columns are a priority, CFT columns have significant advantages relative to RC columns, and should be considered as an alternative solution.

ACKNOWLEDGMENTS

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УПОРЕДНА АНАЛИЗА АРМИРАНО-БЕТОНСКИХ И ЦФТ СТУБОВА У ЗГРАДАРСТВУ

Резиме: Стубови од армираног бетона се најчешће примењују у зградарству, док је примена спрегнутих ЦФТ (Column Filled Tubes) стубова знатно ређа. На примеру реалне конструкције стамбено-пословног објекта спратности По+П+6 (подрум, приземље и шест спратова) извршена је упоредна анализа армирано-бетонског и ЦФТ стуба. Армирано-бетонски стуб димензионисан је према Еврокоду 2, док је ЦФТ стуб димензионисан упрошћеном методом дефинисаном у Еврокоду 4. Анализом су квантификоване предности и мане ЦФТ стуба у односу на армирано-бетонски стуб у погледу димензија попречног пресека, цене коштања и једноставности и брзине извођења стуба.

Кључне речи: ЦФТ стуб, АБ стуб, упоредна анализа, Еврокод 2, Еврокод 4