Comparison of Composite, Steel and Reinforced Concrete Columns

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Abstract. Architects now often require the use of slender load-bearing structures, but they must be sufficiently resistant to all loads. The use of the composite steel-concrete columns joins the main advantages of the individual materials. The most commonly used composite is the steel-concrete. Depending on the amount, shape, location and utilization rate of the steel or concrete, the composite columns are closer to the steel or reinforced concrete columns. The composite steel-concrete structures utilize high compressive strength of concrete and high tensile resistance of the structural steel. The steel-concrete connection is therefore highly efficient, and by combining, it is possible to produce relatively lightweight structures with wide use in high-rise buildings and bridges. The composite steel-concrete columns have high strength with a relatively small cross-sectional area. Composite efficiency also depends on the type of composite steel-concrete column. The most commonly used type is a steel tube filled with concrete. In the case of a steel tube filled with concrete, it is possible to use the confining effect of a steel tube, which prevents lateral deformation of the concrete and at the same time, the concrete core prevents compression of the steel tube. These two effects increase the total resistance of the composite steel-concrete column. Other types are partially or fully concrete-encased steel section. The use of a fully concrete-encased steel cross-section increases the fire resistance of the cross-section as the steel profile is protected by concrete against the effects of fire. The criterion for selecting the appropriate shape and type of the steel part of the column cross-section, the design of the global structural system of the object should be taken into account. Not only one European standard is needed to design composite steel-concrete structures. In addition to the standard EN 1994-1-1 Design of composite steel and concrete structures, it is also necessary to use standards EN 1992-1-1 Design of concrete structures and EN 1993-1-1 Design of steel structures.

1. Introduction

The use of the composite steel-concrete columns joins the main advantages of the individual materials. Advantages of composite steel-concrete structures [1, 2]:

- the reduction in steel consumption due to a substantial reduction in the steel cross-sections of the individual structural elements and the reduction in the required number of stiffening elements,
- they have stiffness and strength as reinforced concrete structures but at the same time they have ductility as a steel structure,
- the ability to absorb more energy before destruction, which is particularly advantageous in seismic areas,
- when compared to a steel structure, concrete coating solves the problem of pure steel elements with the problem of loss of local and global stability,
- in comparison with a steel structure, it is not necessary to protect the concreted structural steel from the effects of weather and fire. The protection of the steel structure is very difficult and expensive,
- the composite steel-concrete structures have smaller cross-sections compared to reinforced concrete, but the addition of a steel part complicates the concreting,
- the exploitation of the possibility of designing the structure, where the steel part is build-up in advance and additionally concreted. In this case, it is necessary to design a steel structure for the effects of temporary loads up to the concreted stage.
- The composite columns are divided into three groups [1]:
  - steel tube filled with concrete
  - fully concrete-encased steel section
  - partially concrete-encased steel section

2. **Steel tube filled with concrete**
   They can be circular or rectangular in cross-section (Figure 1). They are mainly used for axially loaded elements. By filling the steel tube with concrete, it is possible to significantly increase the load-bearing capacity of the column with a small increase in time consumption and construction costs. The steel tube has a function of the formwork for the concrete core and at the same time it forms the longitudinal reinforcement of the column, and in some cases, it may have a beneficial effect on the concrete core. By preventing transverse deformations, the resistance of the concrete is increased, and the confining of the concrete is used. This type of column raises the problem of quality control of the steel tube filling with concrete. Depending on the connection of the concrete core with the steel tube, the resistance of the column is affected. When separating the concrete core from the steel tube, the load is only transmitted by the steel tube, and only then the load-bearing capacity of the steel tube itself can be considered. To improve the interaction of concrete and steel, it is necessary to make adjustments to the inner surface of the steel tube. [1, 2]

![Figure 1. Steel tube filled with concrete (source: author’s archive)](image)

3. **Fully concrete-encased steel section**
   The concrete part of the cross-section increases the stiffness of the element and creates a protective layer for the steel core. (Figure 2 and 3)

![Figure 2. Fully concrete-encased shapes, single or grouped connected (source: author’s archive)](image)
In tall buildings, it is possible to use the same cross-section of columns for the number of floors above each other by using composite steel columns. The change of the stress of the column is solved by adjusting the reinforcement of the column, by changing the type of the steel section and by changing the strength class of the concrete.

4. Partially concrete-encased steel section
For partially concrete-encased steel cross-sections, both the steel and reinforced-concrete parts of the cross-section are fully statically utilized. Partially concreted cross-sections (Figure 4) are not fire-protected and in some cases, there may be a problem with local loss of stability as the flanges are not concreted. [1]

5. Comparison of the different types of columns
To illustrate the advantages of composite cross-sections compared to steel or reinforced concrete cross-sections, a study with columns of equal strength was conducted. (Figure 5) The columns were designed for resistance to an axial load of 25 MN. In comparison, the C50/60 concrete class, B500B reinforcement class and S355 structural steel class are considered. For the design of the steel cross-section, hinge supports at both ends, i.e. the buckling factor 1.0 and the column length 3.7 m, were considered. The columns were designed according to EN 1992-1-1 [3], EN 1993-1-1 [4] and EN 1994-1-1 [5].

| Table 1. Columns cross-section to be compared |
|-----------------------------------------------|
| **description**                               | **cross-section [mm]** |
| S1    | Steel column                                 | Ø 406.4 x 70             |
| S2    | RC column                                     | 790 x 790                |
| S3    | RC column                                     | 700 x 700                |
| S4    | Steel tube filled with concrete               | Ø 610 x 25               |
| S5    | Fully concrete-encased steel section          | 600 x 600                |
| S6    | Partially concrete-encased steel section      | 600 x 600                |
Figure 5. Comparison of the different types of the cross-section of columns

The comparison of material quantity and material price for individual cross-sections is in Table 2. The following assumptions were considered for the comparison of the columns: column length of 3.7 m, the stirrup diameter of 8 mm in distances of 150 mm evenly over the length of the columns, volume density of concrete of 2200 kg / m³ and of steel of 7850 kg / m³. The price was determined with the following unit prices: € 1.2 per kg for structural steel and concrete reinforcement and € 100 per m³ for C50/60 concrete.
### Table 2. Comparison of the weight and price of the individual column variants

| Cross-section | Concrete C50/60 [m³] | Steel S355 [kg] | Reinf. B500B [kg] | Overall [kg] | Concrete C50/60 [€] | Steel S355 [€] | Reinf. B500B [€] | Total [€] |
|---------------|----------------------|-----------------|-------------------|-------------|---------------------|----------------|-----------------|---------|
| 1             | –                    | 2149.7          | –                 | 2149.7      | –                   | –              | –               | 2579.64 |
| 2             | 2.265                | 4983.0          | –                 | 350.4       | 5333.4              | 226.50         | –               | 640.98 |
| 3             | 1.733                | 3812.6          | 628.8             | 4441.4      | 173.30              | –              | 754.56          | 927.86 |
| 4             | 0.873                | 1920.6          | 51.7              | 3308.0      | 87.30               | 1602.84        | 62.04           | 1752.18 |
| 5             | 1.160                | 2552.0          | 50.3              | 3909.3      | 116.00              | 1568.40        | 60.36           | 1744.76 |
| 6             | 1.162                | 2556.4          | 60.1              | 3894.5      | 116.20              | 1533.60        | 72.12           | 1721.92 |

A practical example of using the fully concrete-encased steel section is shown in Figures 6 and 7. There are the composite columns of the “Slovenska sporitelna” Bank in Bratislava.

**Figure 6.** Columns of the “Slovenska sporitelna” Bank, Bratislava (source: author’s archive)

**Figure 7.** General view of the columns of the “Slovenska sporitelna” Bank, Bratislava (source: author’s archive)
6. Conclusions
It can be seen from the comparison that the reinforced concrete columns are more favourable in terms of price, while according to the overall weight, it is most preferable to use a steel column, however with a not usually available steel profile. The composite columns are more advantageous because of the smaller column cross-sections required and because of the lower total weight of the columns compared to the reinforced concrete columns. Compared prices include only the necessary material, for the overall comparison of convenience, it is necessary to add the cost of production (lifting equipment, formwork reinforced concrete columns, welding, etc.).

Acknowledgment(s)
This work was supported by the Slovak Research and Development Agency under the contract No. APVV-15-0658 and by the Scientific Grant Agency VEGA under the contract No. VEGA 1/0522/20.

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