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## Evaluation of the effect of concrete strength increase on buckling resistance of concrete filled tubes

To cite this article: P Bukovska 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **566** 012004

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# Evaluation of the effect of concrete strength increase on buckling resistance of concrete filled tubes

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**Abstract.** The paper deals with the behaviour of steel tubular columns filled by high-strength concrete at compression load. Attention is paid especially to the strength of the used concrete and its effect on the buckling resistance of column. Results of the experimental part of research have shown that increasing of concrete strength is efficient only to a certain extent. It was found in the experimental analysis that the use of concrete class C80/95 has only little effect on increase of buckling resistance as compared with the use of concrete class C55/67. In order to evaluate the efficiency of the concrete strength increasing, a theoretical study was carried out, the results of which are presented in this paper. The paper also discusses the possibilities of using other types of concrete (light-weight concrete or slightly reinforced concrete) with regard to their contribution to improving the bearing capacity and taking into account the production costs of the steel - concrete tubular column.

## 1. Introduction

In recent years, the development of civil engineering has a tendency to use of high-strength materials. Also, in the field of steel-concrete composite structures, the combination of materials is sought which would be the most effective from the point of view of strength, reliability and economy. The combination of circular tubes and high-strength concrete seems to be one of the most effective ways to use the high-strength concrete because of eliminating the lack of concrete tensile strength.

The problem in high strength concrete construction designing is that there are no valid design rules or standards. Within many experimental works dealing with tests on concrete filled circular tubes, behaviour of normal and high strength concrete was monitored and compared with behaviour predicted by the Eurocode 4 in order to evaluate the possibility of using the design standard for high strength concrete. The results of these researches show that the normative recommended calculation of buckling resistance corresponds to the actually observed values. American Specifications and Australian Standards were found conservative, while those of the European Code were for high strength concrete generally unconservative [5, 7, 8]. To be more precise, the Eurocode 4 shows to be safe for extending for high strength concrete if the load is applied eccentrically, i.e. when interaction diagrams are used. However, it is less accurate in predicting cases where eccentricity is null [8].

This paper relates to the research program which was carried out in order to investigate the effect of the concrete strength on buckling resistance of steel tubular columns filled by high-strength concrete. Experimental analysis of axially compressed circular tubes filled by concrete was conducted. Within the evaluation of results there was found that the increase of concrete strength leads to the increase of column buckling resistance only to a certain extend. Lower buckling resistance of high-performed concrete filled tubes was achieved than that would be expected, compared to normal concrete filled tubes [4]. This fact was confirmed also in [7].



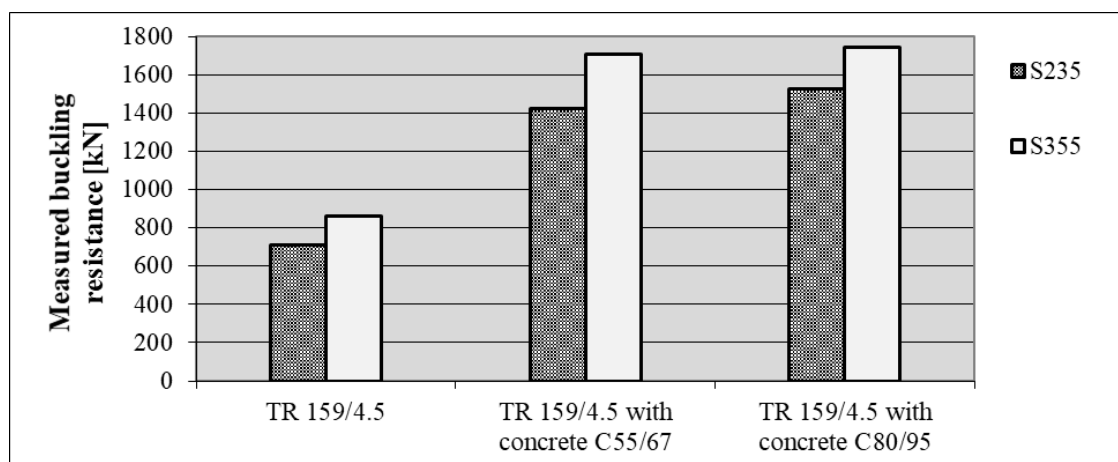
The solution included development of numerical model in order to ensure consistency of the output of the numerical calculation and the data obtained at the test specimens. The aim of the numerical model is to replace some of the tests performed actually and provide data for developing of buckling curves for tubular columns filled by high-strength concrete [2]. For finding out which of input parameters has the greatest influence on the buckling resistance of composite column made by steel tube filled with concrete, the sensitivity analysis was performed. Four models were analysed differing in grade of steel and strength of concrete. Outcomes show that the strength of concrete has the greatest positive influence on buckling resistance. Influence of strength concrete is twice greater than influence of steel yield strength. As for the geometrical parameters the greatest is the influence of tube thickness which is greater by tubes of steel grade S355 than that of steel grade S235 according to the expectation. Negative influence on the buckling resistance has the length of tube which corresponds to the critical length of member when considering pinned ends of columns. The critical length has greater influence in case of models with using steel of grade S355. The results of sensitivity analysis confirm the influence of concrete strength on the buckling resistance of the column [4].

Evidently, concrete strength affects the increase in buckling capacity of slender columns. But it is unknown, if the use of higher and higher strength concrete makes a lot of difference. This paper presents the results of a theoretical study which was carried out in order to evaluate the efficiency of the concrete strength increasing. The paper also discusses the possibilities of using alternative types of concrete with regard to their contribution to improving the bearing capacity and taking into account the production costs.

## 2. Experimental analysis

Experimental analysis of compressed circular tubes filled by concrete was conducted within the research program. For the loading tests the tubes of the diameter of 159 mm and the thickness of 4.5 mm with the buckling length of 3 000 mm were used. One half of the test specimens were tubes of steel grade S235, other specimens were tubes of steel grade S355. Total of 18 test specimens were tested within the analysis. The specimens were divided into three groups of six pieces. The first group of specimens was tested without concrete, second group of specimens was filled by concrete of class C55/67 and third group of specimens was filled by concrete class C80/95. In combination with the two classes of steel strength six partial experiments were achieved.

The test specimens were gradually loaded by axial pressure in a vertical position. During loading process the loading force, vertical displacement in bearing and transversal deflection in middle of the length of specimens were measured. The maximum achieved load gives the buckling resistance of the specimen. More information about the loading tests see in [1]. The graph in figure 1 shows maximal measured load for each group of specimens (mean value), what is actually the buckling resistance. It can be seen that the buckling resistance increased by filling the tube with concrete C55/67 by approximately 100%, whereas the use of concrete C80/95 had only little effect.



**Figure 1.** Experimentally proved buckling resistance (mean values).

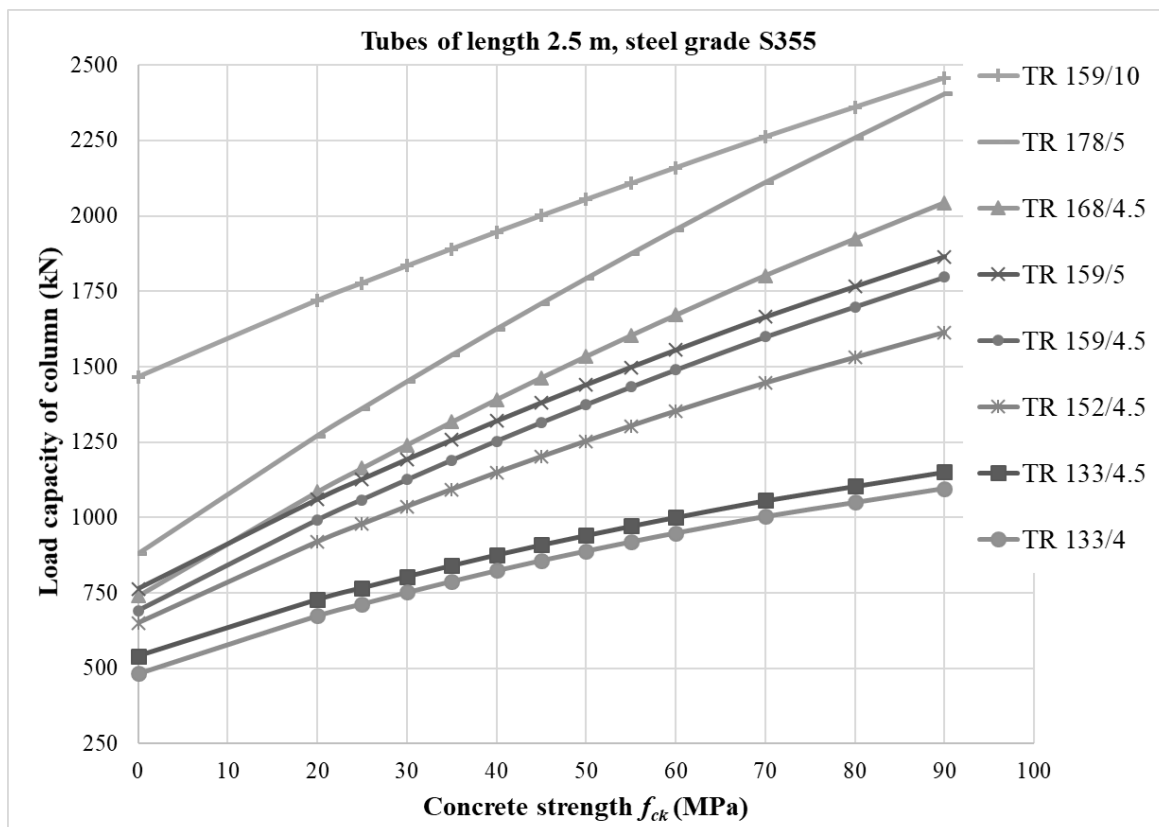
Real material properties were measured on material specimens in order to compare values of buckling resistance achieved experimentally and numerically determined values. Within the comparison it was observed that the normative recommended calculation of buckling resistance corresponds to the actually observed values for all groups of specimens including those filled by high strength concrete [4]. Experimental analysis confirmed that the calculation methods given in Eurocode 4 can be used for the following theoretical analysis.

### 3. Theoretical analysis

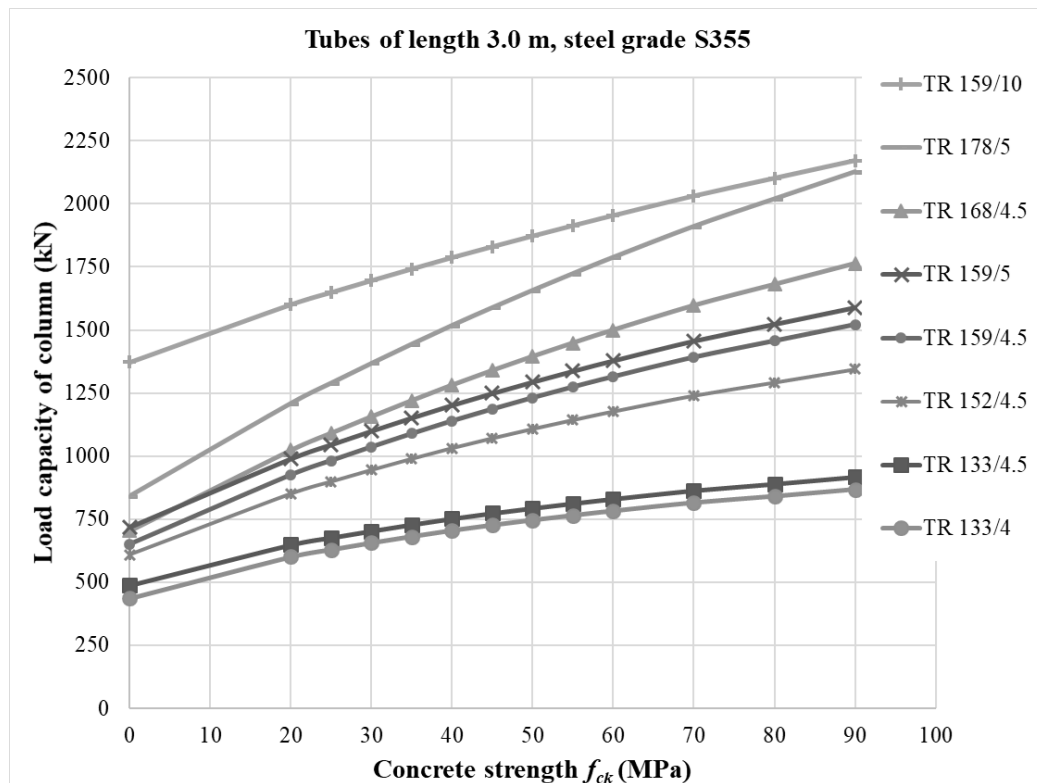
The theoretical analysis was performed for finding the effect of increasing concrete strength on buckling resistance of concrete filled steel columns. Columns of length 3.0 m and 2.5 m were taken into account, hinged and axially compressed. As for the choice of diameter and thickness of the tube, cross-sections were selected from the assortment of the steel tubes, which allow the steel tube to be filled with concrete and which are utilized evenly in terms of both characteristic plastic resistance  $N_{pl,Rk}$  and critical normal force  $N_{cr}$ . With regard to the parametric study in [1], tubes of diameter 133 mm, 152 mm, 159 mm and 168 mm are taken into evaluation. Grade of steel is S235 or S355. Concrete was considered of class from C20/25 to C90/105 with modulus of elasticity from 29 GPa to 44 GPa, respectively.

#### 3.1. Evaluation of the effectiveness

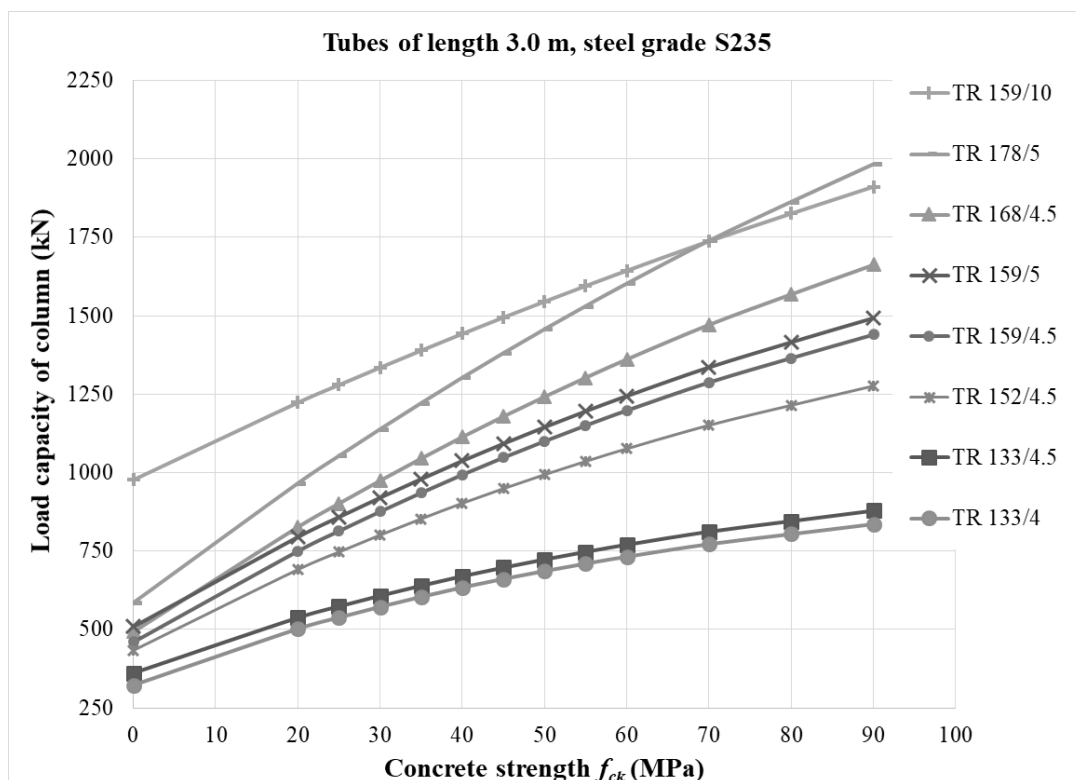
Relations between buckling resistance (as the load capacity) and concrete strength are depicted on figures 2 – 4 for considered types of tubes with variable thickness. Within the solution the characteristic values of buckling resistance ( $N_{Rk}$ ) are taking into calculation because the results of the experimental analysis have shown that the characteristic values better correspond to the actually achieved values. Concrete strength zero means that the tube is without concrete. It is clear from the graphs that the curves are concave - that is, the buckling load capacity growth gradually decreases. This fact can be seen in all investigated cases.



**Figure 2.** Effect of concrete strength on buckling load capacity of columns of length 2.5 m and steel grade S355.



**Figure 3.** Effect of concrete strength on buckling load capacity of columns of length 3.0 m and steel grade S355.



**Figure 4.** Effect of concrete strength on buckling load capacity of columns of length 3.0 m and steel grade S235.

Although the curves were plotted only for some cases of diameter and thickness, it is possible to imagine the form of dependence on other cases. When changing the thickness of the tube, the shape of the curve remains the same, it only moves in the y-axis direction - upwards with the increase of thicknesses and downwards when the tube thickness is reduced (see Figures 2, 3 and 4). Changing the column length has the opposite effect - the curve moves upwards when the column length is reduced and down when the column length is increased. For tubes with a larger radius (of 178 mm), the buckling capacity increases with increasing concrete strength more. In most cases, it can be clearly seen that the very filling the tube with concrete causes a relatively large increase in buckling strength, further increasing the strength of concrete does not have such a large effect, although it is not completely meaningless.

### 3.2. Economical study

Comparison of the price of monitored tubes filled with different types of concrete can be seen in table 1. Unit prices for individual variants of material were determined from current price lists on web sides of concrete plants in surrounding of Brno city. Prices are converted to Euro. The prices are exclusive of VAT. Concrete class is limited by current assortment, maximal class commonly available is C70/85. Prices of lightweight concrete are inaccessible, although some concrete plants can produce this concrete, the price depends on the total quantity and the required material properties. The use of lightweight concrete was therefore not included in the comparison. Every variants of column arrangement are calculated for tube of diameter 159 mm with thickness 4.5 mm, length 3.0 m and steel grade S235. In this arrangement is consumption of steel 51.4 kg and of concrete 0.053 m<sup>3</sup>. The design values of buckling resistance are given (including coefficients of material reliability).

The price of concrete in the composite column can be reduced by replacing natural aggregate, whose price is around 13.6 €/t for fraction 8/16. An interesting substitute could be concrete recycled aggregate, where aggregate of fraction 0/16 costs 4.3 €/t. However, the price of steel plays the most important role in total costs of this type of composite columns. From table 4 can be seen, that the lowest relative price is for tube filled with concrete C70/85 which is the highest strength class used in this study. This is probably because buckling resistance increases with the strength of concrete more than the price.

**Table 1.** Economical comparison of concrete strength.

Concrete			Steel	Total price (€)	Buckling resistance (kN)	Relative price (€/kN)
Class	Price for unit (€/m³)	Price for unit (€/kg)				
Concrete according the CSN EN 206 + A1:2018 a CSN P 73 2404	C20/25	76,0	1,55	83,76	647,6	0,129
	C25/30	76,9	1,55	83,81	688,2	0,122
	C30/37	91,1	1,55	84,56	727,4	0,116
	C35/45	101,7	1,55	85,12	765,1	0,111
	C40/50	104,3	1,55	85,26	801,4	0,106
	C45/55	107,2	1,55	85,41	835,5	0,102
	C55/67	121,9	1,55	86,19	899,1	0,096
	C70/85	127,1	1,55	86,47	984,1	0,088
STEELCRETE - fibre concrete	C20/25	73,8	1,55	83,64	647,6	0,129
	C25/30	82,0	1,55	84,07	688,2	0,122
Self- compacting concrete	C25/30 SCC	99,3	1,55	84,99	688,2	0,123
	C30/37 SCC	110,8	1,55	85,60	727,4	0,118
	C35/45 SCC	117,4	1,55	85,95	765,1	0,112

#### 4. Conclusion

This paper discusses the influence of increasing strength of concrete on buckling resistance of circular steel tubes filled with concrete. The tubes are considered as columns subjected to axial compression. Results of experimental analysis shows that the increase of concrete strength from C55/67 to C80/95 has little effect. Therefore, theoretical analysis was performed to investigate this fact.

One part of analysis is the evaluation of effectiveness of concrete strength. Tubes of diameter 133 mm, 152 mm, 159 mm and 168 mm were taken in consideration. Grade of steel was S235 or S355. Concrete was considered of class from C20/25 to C90/105 with modulus of elasticity from 29 GPa to 44 GPa, respectively. The characteristic values of load capacity are used in the graphs. Graphs show that the buckling load capacity does not increase proportionally with the strength of the concrete, but its increment gradually decreases. Increasing the strength of concrete therefore gradually loses its significance, especially for tubes with a smaller diameter (133 mm).

Second part of theoretical analysis is economical study of the price of circular tubes filled with concrete where the prices of different arrangement of column were compared. It comes out from the study that use of higher strength concrete is still effective from the point of view of material price. The price for concreting is not included.

The results of the theoretical analysis can be used in practice. If the chart were extended to parameters of all tubes offered in the assortment of steel constructions and if the design values were used, a tool for design facilitating could be created.

With regard to efforts to mitigate the ecological impacts of building structures, it would be useful to monitor and evaluate the efficiency of concrete-filled tubes with respect to possibility of their recycling or reuse of building elements. This point of view will be included in next research.

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#### Acknowledgments

The paper has been elaborated within the framework of the solution of MSMT project FAST-S-19-6009 and FAST-J-19-6056(Specific Research Projects).