

## REINFORCEMENT OF EXISTING CAST-IRON STRUCTURAL ELEMENTS BY MEANS OF FIBER REINFORCED COMPOSITES

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### Abstract

The paper deals with tubular, cast-iron columns which should be reinforced due to the planned new structural function of these elements. According to the requirements of the monument conservator the general appearance of columns should not be altered significantly. Reinforcement with an external, thin coating (sleeve or jacket) made of composite (carbon fibre reinforced polymer - CFRP) was proposed. Details of the proposed technique were represented. The reinforcement effect was verified in destructive tests performed on two columns without reinforcement and the two other columns reinforced with the chosen technique. Due to the expected very high load capacity of the axially loaded column, the test rig was designed in such a manner that the force could be applied on big eccentricity. For this purpose a special base was prepared (comp. *Fig. 1*). Destructive tests have confirmed the high effectiveness of the adopted strengthening technique.

Keywords: cast-iron columns, reinforcement, composite jacket, CFRP, destructive tests

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## 1. INTRODUCTION

Cast-iron structural elements manufactured in the 19<sup>th</sup> or at the beginning of the 20<sup>th</sup> century are quite often encountered in the engineering practice.

The adaptation of post-industrial buildings for habitable or other purposes requires sometimes the resistance assessment of existing cast-iron columns and the possible reinforcement with a technique dependent on the shape of the column and the load capacity requirement. The reinforcement technique also depends on the monument conservator's acceptance and sometimes this is the principal factor influencing the strengthening method. This problem arouses considerable interest especially in Germany and many works confirm this fact (cf. [1], [2], [3], [4]).

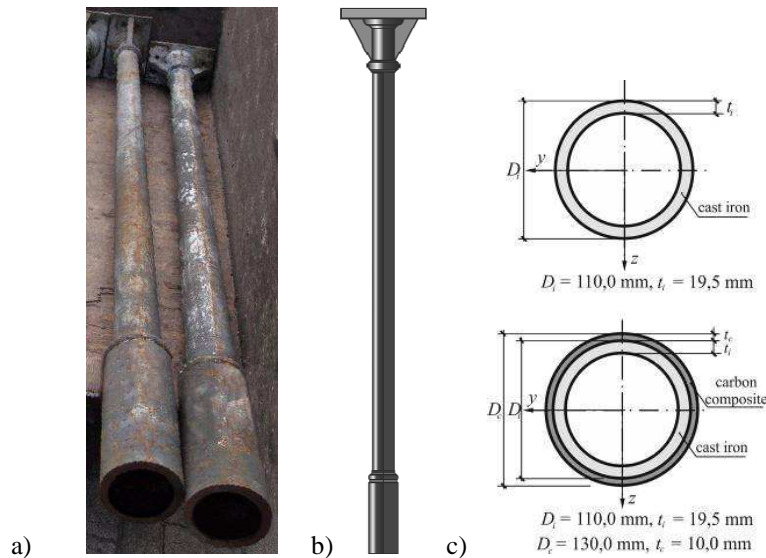


Fig. 1. Cast iron columns:

a) picture, b) figure with additional base, c) cross section of cylindrical part

The use of carbon fibre reinforced polymer (CFRP) jackets as an external coating to strengthen existing concrete columns has emerged in recent years with very promising results (cf. [5], [6], [7]). Several studies on the performance of CFRP wrapped columns have been conducted, using both experimental and analytical approaches. This type of strengthening technique has proved to be very effective in enhancing their ductility and axial load carrying capacity. This method is quite frequently used in the case of concrete columns of circular and rectangular cross section.

The authors did not know any attempts of strengthening cast iron elements with CFRP jackets but knowing quite a wide range of applications of CFRP, they

decided to apply this very technique to strengthen cast iron columns fabricated in the 19<sup>th</sup> century.

The paper deals with tubular, cast-iron columns (comp. Fig. 1a on which disassembled columns are shown) which should be reinforced due to the planned new structural function of these elements. According to the requirements of the monument conservator the general appearance of columns should not be altered significantly. The reinforcement by means of an external,

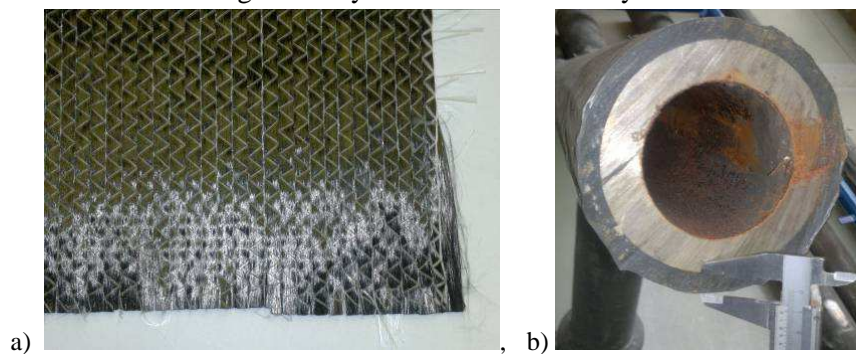


Fig. 2. The textile on the basis of carbon fibers a) and the cross section of the reinforced column b)

thin coating (sleeve or jacket) made of composite material (carbon fibre reinforced polymer - CFRP) was proposed. This specific solution adopted in this particular case was preceded by theoretical considerations results of which were presented in [8]. The final solution was verified also in destructive tests performed on two columns without reinforcement and two other columns reinforced with the chosen technique. Results of these tests confirm the effectiveness of the proposed reinforcement technique.

## 2. METHODS - THE PROPOSED REINFORCEMENT TECHNIQUE

Tubular cast-iron columns fabricated in XIX-th century in Germany were subject of the detailed considerations. Authors had in disposal four identical columns acquired after demolition of an industrial building. Two of them are shown in Fig. 1a. The total length of column was equal  $L = 3200$  mm. The cross section of the tubular part was shown in Fig. 1c.

Two columns were reinforced by the external jacket made of CFRP (carbon fibre reinforced polymer) composite of thickness 10 mm (comp. Fig. 1c and Fig. 2b). The jacket was fabricated from the textile made of carbon roving. The textile based on carbon fibers used to the reinforcement is shown in Fig. 2a.

The density of carbon fibers in the textile was equal  $309 \text{ g/m}^2$  and the tensile strength of fibers was equal  $3800 \text{ MPa}$ . Fibers were arranged parallel in a form of roving attached by glass fibers in perpendicular direction (white fibers visible in Fig. 2a).

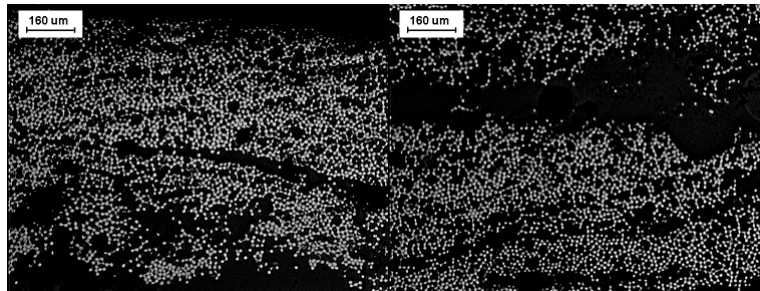


Fig. 3. SEM pictures of CFRP jacket

The diameter of a single fiber was equal  $\phi = 7,2\mu\text{m}$  and the carbon contents in fibers was on the level of 95 %. As a matrix the epoxy resin was used.



Fig. 4. The cast iron columns before a) and after b) reinforcement

Only central, tubular part of the column was reinforced and the jacket was made in the following manner. Each individual piece of the textile soaked with epoxy resin was laid down in such a manner that fibers were parallel to the column's axis. The width of the current textile piece was equal the perimeter of the basic surface. All consecutive seams were shifted in peripheral direction by the value of 20 mm always in the same direction. In this manner sixteen layers of carbon textile were put creating the main part of the CFRP jacket.

In this stage the column was put into vacuum sleeve and the underpressure of 0.8 bar was evoked. The external pressure acting on the column's surface had removed the excess of epoxy resin from the jacket. As an effect all fibers were well squeezed within the jacket in the best possible way.

To reinforce the jacket also in peripheral direction in the next stage four consecutive layers of the textile were laid down in the transverse direction. Particular layers were put in the way described above. Also the vacuum sleeve was used to remove the excess of epoxy resin.

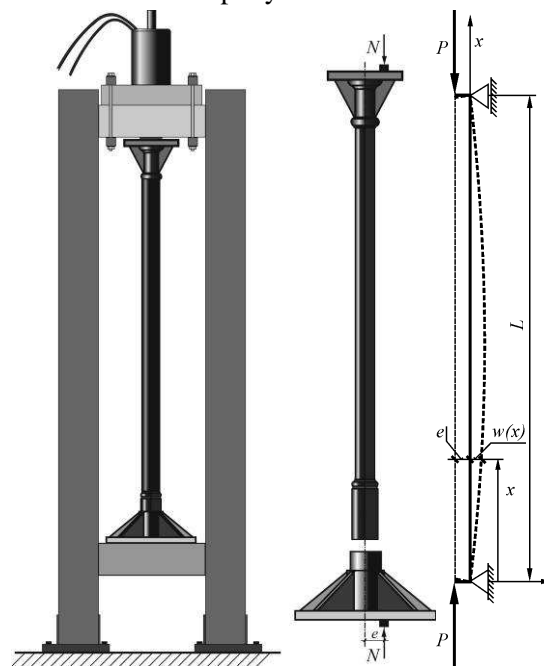


Fig. 5. The schematic of the test stand

The additional strengthening effect was achieved as a result of the column's placement in the thermal chamber and its heating during 15 hours in the temperature of 60°C.

By that means two columns were reinforced within the central, tubular part of the column. The reinforced column is shown in Fig. 4 and its cross-section in Fig. 2b. It is worth noting that the obtained composite layer was really very solid and nearly homogenous.

Its SEM (scanning electron microscope) pictures were shown in Fig. 3. Well visible white spots are carbon fibers, the black background in these pictures is the epoxy matrix. In these pictures one can see that the obtained internal structure is neither isotropic nor homogenous.

Looking at figures 4a and 4b one can ascertain that at the first glance original columns and reinforced columns are nearly identical. Even the colour is nearly the same.

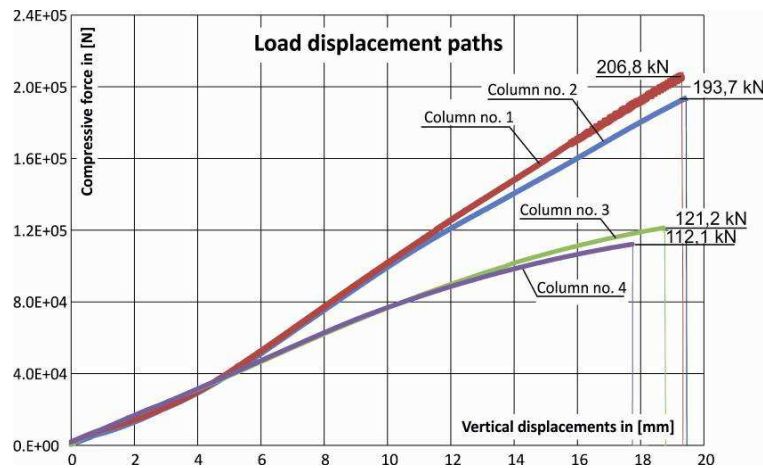


Fig. 7. Results of destructive tests

### 3. DESTRUCTIVE TESTS

In order to compare the resistance of the columns before and after the proposed method of strengthening, two columns were tested in their original form and the other two were wrapped with carbon composite and tested in this reinforced form.

Columns usually are loaded by a compressive force and a bending moment. For this reason it was reasonable to perform destructive tests of columns loaded by the compressive force applied on some eccentricity (comp. Fig. 5) To provide the eccentric compression the additional base was designed and fabricated. This base is shown in Fig. 5 below.

In Fig. 5 a schematic diagram of the stand is shown, while a view of the stand with details is shown in Fig. 6. Several electro-resistance strain gauges were attached to the external surface of the cast iron columns. Inductive displacement transducers were fixed to the wooden frame (comp. Fig. 6) mounted in the flooring.

The axial force was increased till the total collapse of the column. In this way the forces causing the column's destruction were obtained.

The results of the experiments are presented in Fig. 7 in the form of the load versus the vertical displacement of the column's upper end curves. The paths denoted as *Column no. 1* and *2* refer to the strengthened cast iron columns.

The effect of reinforcement is distinctly visible. The increase of the destructive force can be estimated on the 70÷72%. It is probably even higher because in both cases the failure mode relied on a sudden rupture of the column beyond the cylindrical part on which the carbon composite wrapping (jacket) has been fabricated.

It is worth noting that in all the cases the destruction mechanism was very sudden and the fractures were total like these shown in Fig. 8.

#### 4. CONCLUSIONS

During conservation works the necessity to strengthen existing cast iron columns appears. In the paper the proposal which relies on the fabrication of the jacket made of carbon fibre reinforced polymer (CFRP) is presented. The proposed method of strengthening old, cast iron columns seems to be very effective, and it was confirmed in destructive tests. The increase of the destructive force achieved in the case of the considered cast iron columns is at least 70 %. The actual level of strengthening depends on the thickness of the jacket and the mechanical properties of CFRP and is probably higher than this mentioned above because in both cases ruptures occurred beyond the cylindrical parts of the columns on which the CFRP jacket was fabricated.

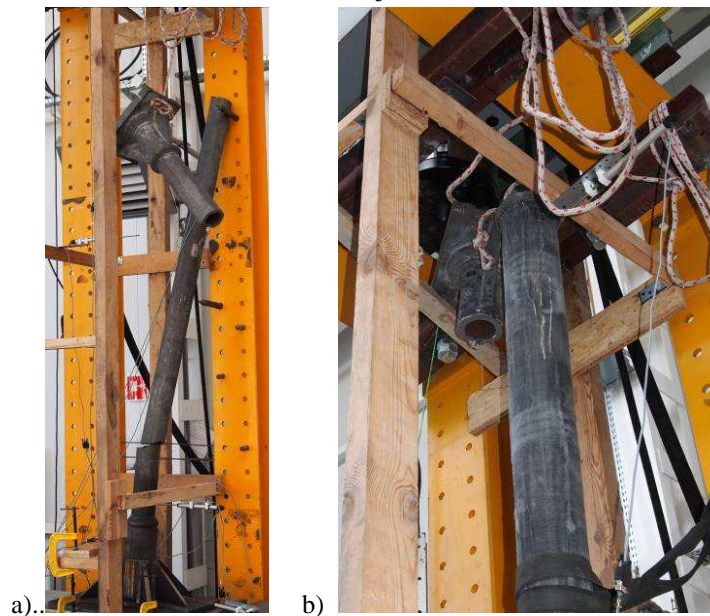


Fig. 8. Original a) and reinforced b) columns destroyed in tests

The comparatively thin and black CFRP jacket does not change the original shape of cast iron structural member. It is also worth mentioning that the proposed method of strengthening can also be implemented *in situ*. This advantage is especially important due to the fact that in many cases there is no possibility of the disassembling of cast iron column.

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## WZMACNIANIE ISTNIEJĄCYCH, ŻELIWNYCH ELEMENTÓW KONSTRUKCYJNYCH ZA POMOCĄ WŁÓKNOKOMPOZYTÓW

### Streszczenie

Praca dotyczy żeliwnych słupów cylindrycznych, które w związku z planowaną ich nową funkcją konstrukcyjną powinny zostać wzmocnione. Wymagania konserwatorskie nie dopuszczają znaczących zmian wyglądu zewnętrznego wzmocnianych słupów, z tego względu zaproponowano wzmocnienie za pomocą cienkiej powłoki



włóknokompozytowej CFRP nakładanej na zewnętrzną powierzchnię słupów. W pracy zaprezentowano szczegóły proponowanej techniki wzmocnienia. Uzyskany efekt wzmocnienia zweryfikowano w badaniach niszczących wykonanych na dwóch słupach oryginalnych i dwóch słupach poddanych wzmocnieniu proponowaną techniką. Z powodu spodziewanej bardzo wysokiej odporności słupów na ściskanie osiowe, stanowisko badawcze zaprojektowano w taki sposób, aby siła mogła być przykładana na dużym mimośrodku. W tym celu zaprojektowano i wykonano dodatkową głowicę. Badania niszczące potwierdziły wysoką efektywność zastosowanej techniki wzmocnienia.

Słowa kluczowe: słupy żeliwne, wzmocnienie, powłoka kompozytowa, CFRP, badania niszczące

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