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Textile reinforced concrete for strengthening of RC columns: A contribution to resource conservation through the preservation of structures

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HIGHLIGHTS

- TRC is a suitable material to strengthen load-bearing columns.
- Resistance to axial loads and serviceability can be considerably improved.
- A maximum increase of up to 85% in axial load bearing capacity could be achieved.
- Loads can be reliably calculated with the help of the developed calculation model.

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ABSTRACT

In the context of renovation and repair work or when buildings are to be adaptively reused, the planning engineer is frequently required to strengthen the load-bearing structure. This is the case, for example, if live loads will increase due to changes in use or if the structural integrity of a building has to be restored after a fire or earthquake. Columns are particularly vital components and elements of the static system of many buildings. Their main task is to withstand axial forces. This article describes the results of experimental tests on the effect of strengthening 2 m long columns (with and without internal steel reinforcement) using textile-reinforced concrete (TRC). Two forms of strengthening were investigated: Complete wrapping with TRC along the full height of the columns and partial wrapping along 300 mm in the load introduction ranges. Findings show a maximum increase of up to 85% in load capacity compared to non-strengthened reference columns. The individual components of the load bearing properties were analysed and a simple calculation model applied.

1. Introduction

Much of Europe's building stock is in need of restoration. For example, in Germany more than 60% of construction activity is related to the reconstruction and repair of old buildings. If such renovation work is aimed at adaptive reuse, this can often result in higher loads than permitted by the original design. Clearly, in such cases buildings must be strengthened.

There already exists a wide variety of tried-and-tested methods of strengthening and repair. While carbon fibre reinforced polymers (CFRP) have grown in popularity over the past decade, in Germany they still make up less than 10% of the market for strengthening materials. The dominating technology to strengthen buildings is still shotcrete and steel reinforcement. This method has been thoroughly investigated. The increase in the load-bearing capacity of columns under the application of shotcrete is mainly achieved by the additional steel reinforcement in the strengthening layer and the new concrete jacket (Krause [1]). Clearly, the dimensions of the column increase significantly due to the additional concrete jacket and the concrete layer covering the new steel rebars. When using CFRP to strengthen columns, however, the original dimensions of the column are nearly unchanged. Here the increase in the load-bearing capacity is achieved solely through confinement of the old concrete core and the creation of a triaxial stress state (cf. Tan [2], Parvin & Wang [3], Pham, Hadi & Youssef [4]), especially if columns are circular or square shaped (Triantafillou et al. [5]).

Textile-reinforced concrete (TRC) can be applied for strengthening and repair (Mechtcherine [6]). Due to the fact that it constitutes a cementitious matrix, TRC can solve repair tasks such as realkalisation and reprofiling or adding to provide additional concrete

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cover while offering a high level of sustainability (Williams Portal et al. [7]. And, of course, the high-strength textiles serve to increase loading capacity, as confirmed by the retrofitting of prestressed concrete masts (Ortlepp & Curbach [8]). Application of TRC by spraying or laminating combines the advantages of CFRP (confinement of the core) and shotcrete with steel reinforcement (additional load bearing layer for axial load) to create an innovative strengthening method. The advantages of TRC are due to the *combination* of two materials, namely textiles and concrete. Together they produce a composite material with outstanding properties of high tensile strength, low layer thickness, low weight, high corrosion resistance and corrosion protection of the underlying original concrete reinforcement layer. TRC-strengthened RC members show not only an improvement in load carrying capacity but also energy absorption and impact absorption (Tsesarsky et al. [9]). The increase in the load-bearing capacity of columns using textile-reinforced concrete/mortar (TRC/TRM) is achieved by the additional load capacity of the new concrete jacket as well as through confinement of the original concrete core (Triantafillou et al. [10], Ombres [11]).

2. Experimental methods

2.1. Investigated parameters and aims

The aim of the study was to analyze the potential increase in the load-bearing capacity of slender columns when strengthened by TRC. Specifically, we considered the influence of three different parameters on load capacity. The first was the configuration of the steel reinforcement in the old concrete column. Columns with and without steel reinforcement were tested. Two different thicknesses of concrete cover were considered to determine how the positioning of the steel rebars influences load capacity. To this end, the study specimens were divided into three series, each with a different steel content. The level of textile reinforcement in the fine-grained concrete strengthening layer was the second parameter taken into consideration. Each series consisted of four specimens: one unstrengthened reference column and three strengthened columns with varying levels of textile reinforcement. Furthermore, the configuration of the strengthening layer was examined by partial column strengthening at head and base only of one additional specimen. Thus a total of 13 specimens were tested. Table 1 shows the parameters of all tested columns.

2.2. Specimens – geometry and materials

2.2.1. Old concrete columns

The axial strengthening provided by TRC was tested on columns with quadratic cross section 140 mm × 140 mm and length 2 m. The slenderness ratio of the columns was $\lambda = 50$. All columns were made of the same concrete mixture. The average compressive strength of concrete cubes (150 × 150 × 150 mm^3) was about 37 N/mm^2 according to Standard Test Method [12]. The first series of columns was constructed of plain concrete, whereas the columns of the other test series were reinforced with standard structural steel B500B. Four bars of diameter of 8 mm were chosen for longitudinal reinforcement. Ribbed stirrups of diameter 6 mm inserted 60 mm apart at the column ends and 100 mm apart in the mid-section were chosen as transverse reinforcement with two different leg lengths in order to analyze the influence of a varying thickness of concrete cover. The geometry of the specimens and the reinforcement are illustrated in Fig. 1.

2.2.2. Strengthening layer

TRC consists of two basic components: fine-grained concrete and textile fabric. A mortar-like fine-grained concrete with maximum aggregate size of about 1 mm is used as a matrix. The small aggregates are necessary to enable the concrete to penetrate the interstices within the textile. Type III cement, fly ash and some pozzolans may be used as binding materials while water and superplasticizer are also added to the mixture. The low tensile load-carrying capacity of the matrix is compensated by the creation of a composite material using high capacity textile fabrics, much in the way that steel is used to reinforce concrete. These fabrics are made of glass fibres that absorb the forces released by the cracking of the concrete. Glass fibres or yarns are made of up to 2000 glass filaments each of diameter roughly 10–25 μm. The glass material must be alkali resistant to ensure no loss in function over time within the cementitious matrix.

In the current investigation of column strengthening, a bi-axial fabric of weight of 253 g/m^2 per unit area was used (Fig. 2). The textile consists of alkali-resistant glass yarns (AR-glass yarns) with a fineness of 1200 tex (i.e. 1200 g/km length) regularly separated at distance 7.2 mm in the main load direction. The weft yarns only act as nominal transverse reinforcement. A styrene-butadiene coating is applied during the warp-knitting process within the textile machine. The cross-sectional area of the fibres in the main loading direction is about 0.44 mm^2. The load carrying warp threads of the textile have a Young's modulus of 74,450 N/mm^2 and a tensile strength of 1232 N/mm^2.

Further experimentation was needed to determine the tensile strength of the fabric when bonded with the fine-grained concrete. Detailed information concerning such tensile tests can be found in Jesse, Ortlepp & Curbach [13]. Until now, it has not been possible to estimate strength merely based on the tensile strength of the fibres and the geometry of the weave due to the complex factors involved (Jesse, Ortlepp & Curbach [14]). For instance, some manufacturing processes bundle the filaments more closely together, so that such yarn is highly compacted. The circumference of the fibres is smaller, thereby impairing the transfer of bond forces between matrix

Table 1
Parameters of the experimental program.

Column No.	Cross section	Longitudinal bars	Stirrup leg	Concrete cover	Strengthening type	No. of textile layers
1.1	Plain concrete	–	–	–	–	–
1.2	Plain concrete	–	–	–	Full	2
1.3	Plain concrete	–	–	–	Full	4
1.4	Plain concrete	–	–	–	Full	6
2.1	Reinforced type 1	4 Ø8 mm	87 mm	26.5 mm	–	–
2.2	Reinforced type 1	4 Ø8 mm	87 mm	26.5 mm	Full	2
2.3	Reinforced type 1	4 Ø8 mm	87 mm	26.5 mm	Full	4
2.4	Reinforced type 1	4 Ø8 mm	87 mm	26.5 mm	Full	6
3.1	Reinforced type 2	4 Ø8 mm	100 mm	20 mm	–	–
3.2	Reinforced type 2	4 Ø8 mm	100 mm	20 mm	Full	0
3.3	Reinforced type 2	4 Ø8 mm	100 mm	20 mm	Full	1
3.4	Reinforced type 2	4 Ø8 mm	100 mm	20 mm	Full	2
4	Reinforced type 1	4 Ø8 mm	87 mm	26.5 mm	Partial	6