Seismic retrofit of columns using basalt mesh reinforced sprayed GRC jacket

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Abstract

Poor seismic performance of existing sub-standard reinforced concrete buildings is a serious problem that frequently cause fatalities, injuries and economic losses after earthquakes. Therefore, the seismic upgrade of such sub-standard structures is vitally important to avoid losses. In this study, a new retrofit method, which is achieved by using basalt mesh reinforcement together with glass fiber reinforced concrete (GFRC), which is externally sprayed onto existing columns, is presented. Then, initial results of an ongoing experimental campaign for seismic retrofit of sub-standard columns are summarized. Test observations indicate that significant enhancement in ductility as well as strength and energy dissipation characteristics can be achieved with this seismic retrofit method, which is also occupant-friendly and cost-effective.

Keywords
Basalt, column, GFRC, retrofit, seismic.

INTRODUCTION

Poor reinforcement detailing and low concrete quality are among the most important deficiencies that may lead to partial or total collapse of existing reinforced concrete buildings subjected to earthquake excitations. External confinement of columns by using fiber reinforced polymer (FRP) composites is a convenient and popular solution due to the high efficiency of this type of retrofit approach in enhancing the strength and ductility characteristics of sub-standard reinforced concrete members (Ilki et al. 2004 and Ilki et al. 2009). High strength to weight ratio, minimum geometry change and quick applicability are other advantages that make external confinement with advanced materials superior to other conventional methods (such as reinforced concrete and steel jacketing). However, FRP jacketing has also some drawbacks (Triantafillou et al. 2006);

- poor performance at high temperatures caused by low glass transition temperature of epoxy resin
- relatively high cost of base materials of composite
- hazardous chemical effects on workers' health
- limited application potential on wet surfaces and at low temperatures
- incompatibility between composite and substrate material.

These drawbacks are mainly caused by the organic epoxy resin matrix of the composite. In recent years, numerous research activities were undertaken for using inorganic cementitious matrix rather than organic resin matrix. Composite material obtained by replacing the matrix with cement based mortar is generally named as textile reinforced mortar (TRM) or fabric-reinforced cementitious matrix (FRCM). Studies performed in strengthening or retrofitting of masonry and concrete structures showed that using TRM or FRCM as a strengthening material is a promising solution, owing to the advantages of the mortar matrix (Triantafillou et al. 2006, Bournas et al. 2009, Nanni 2012, Yilmaz et al. 2013, Ombres 2014).

This paper presents a new retrofitting technique making use of sprayed up glass fiber reinforced concrete (GFRC) and basalt textiles. Basalt textiles in mesh geometry are used for reinforcement and GFRC is used as the cement based matrix of the formed composite jacketing. Due to the improved tensile characteristics of GFRC matrix, relatively better performance is expected than a cement based composite with standard mortars. In this paper, general information about materials and application of the developed technique are given. Also brief information is provided on experimental studies ongoing at Istanbul Technical University, Structural and Earthquake Engineering Laboratory.

RETROFITTING METHOD WITH BASALT MESH REINFORCED SPRAYED GFRC

Materials

Confinement of reinforced concrete members with advanced composite materials is a widely used method for enhancing the ductility and strength characteristics of structural members against seismic actions. These composites consist of two basic components; textiles or fabrics made by high strength fibers as the reinforcement, and inorganic polymer based resins or cement based mortars as the matrix material. Overall behavior of the composite is governed by the combined characteristics of the matrix and the reinforcement. In the case of the composite system investigated in this study, GFRC and basalt textile constitute the cement based matrix and textile reinforcement of the composite material, respectively.

The mix-proportion of the glass fiber reinforced concrete (GFRC) utilized in this study is as follows: 50 kg silica sand, 45 kg Portland cement, 5 kg mineral admixture, 1.65 kg polymer admixture, 16 kg water and 0.12 kg plasticizer. Chopped glass fibers added to the mixture (3.5% by weight) had an average length of 24 mm. In average, 13 cm slump value was measured in standard slump tests. For characterization of mechanical properties of GFRC, compression and bending test were carried out at 28 days. Average values obtained from these tests are summarized in Table 1.

Table 1. *Mechanical characteristics of GFRC*

Bending Tests	Direction	Limit of Proportionality LOP, (N/)	Modulus of Rupture MOR, (N/)
	Longitudinal	7.55	15.94
	Transverse	6.81	14.65
Compression Tests	43.5 N/		

Due to the good compatibility with cement based matrix in term of durability, basalt fiber textiles are preferred for reinforcement of composite material. The basalt reinforcement used in this study had a 25x25 mm spaced mesh geometry. Mechanical specifications of basalt textile are given in Table 2.

Table 2. *Mechanical specifications of basalt textile*

Modulus of Elasticity (GPa)	Mesh size (mm x mm)	Tensile Strength (MPa)	Rupture Strain	Design thickness (mm)
32	25 x 25	1600	0.05	0.035

Application of the Retrofitting Method

First stage of the retrofitting aims to form an appropriate concrete surface for the jacketing and for this purpose the surface should be cleaned (Figure 1a). If the existing concrete substrate has defects and is not smooth, the surface may need to be repaired before the cleaning step. In case of square and rectangular cross-sections, corners of the members should be rounded at least to 30 mm radius for reducing any possible stress concentrations at the corners. In the next step, the application surface is saturated with water for preventing water absorption of existing concrete from GFRC. As a third step, first layer of wet mix of GFRC is sprayed directly on the existing concrete surface for a minimum thickness of 5 mm (Figure 1b). Then the basalt textile is wrapped around the application region of the member (Figure 1c). In case the retrofit design requires more than one ply of basalt textile, the basalt textile is wrapped continuously, however, a GFRC layer with a minimum thickness of 5 mm is sprayed between each basalt mesh ply. After each wrapped basalt textile ply, the textile is gently pressed with a roller into the GFRC layer (Figure 1c). Minimum 200 mm overlap length for the last ply of the textile should be provided for eliminating a probable debonding failure. Finally, the last GFRC layer is sprayed on the last basalt textile ply and the installation of the retrofitting is finished after smoothening of the jacket surface by the help of a trowel (Figures 1d and 1e).

a) Preparation of the surface b) Spraying of the first layer of GFRC c) Wrapping of the basalt textile

d) Spraying of the final layer of GFRC e) Retrofitted member

Figure 1. *Installation steps of the retrofitting method*

EXPERIMENTAL PROGRAM

In this section, initial results of an experimental campaign, which consists of two parallel experimental studies that are ongoing at Istanbul Technical University for investigating the efficiency of the above mentioned retrofitting technique, are presented.

Uniaxial Compression Tests on Low Strength Concrete Confined by Sprayed GFRC Composites with and without Basalt Mesh Reinforcement

In scope of this study, the effect of confinement with sprayed GFRC composites is investigated. Totally 40 short column specimens with different section shape and size are tested under uniaxial compression loading (Figure 2a). Mainly two different composite types are applied for external confinement of the specimens: i) only sprayed GFRC and ii) basalt textile reinforcement plus sprayed GFRC. The concrete utilized for specimen production is representative of the low quality concrete available in many sub-standard structures.

For exhibiting the contribution of the tested retrofit jacket on the behaviour of low strength concrete, typical axial stress-strain relationships obtained for specimens without confinement (reference), with GFRC jacket and with basalt textile reinforced GFRC jacket are presented in Figure 2b. As seen in this figure, with respect to the unconfined specimen, the GFRC jacket provides a significant enhancement only on the strength and stiffness characteristics, whereas deformation and energy dissipation characteristics of low strength concrete are also significantly enhanced through addition of basalt textile plies into the GFRC jacket as reinforcement.

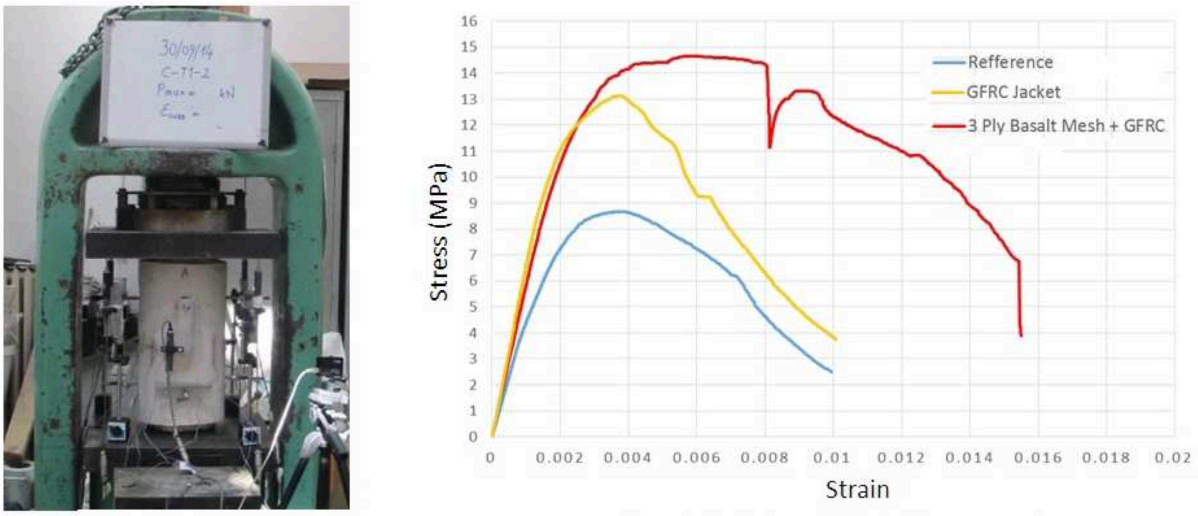
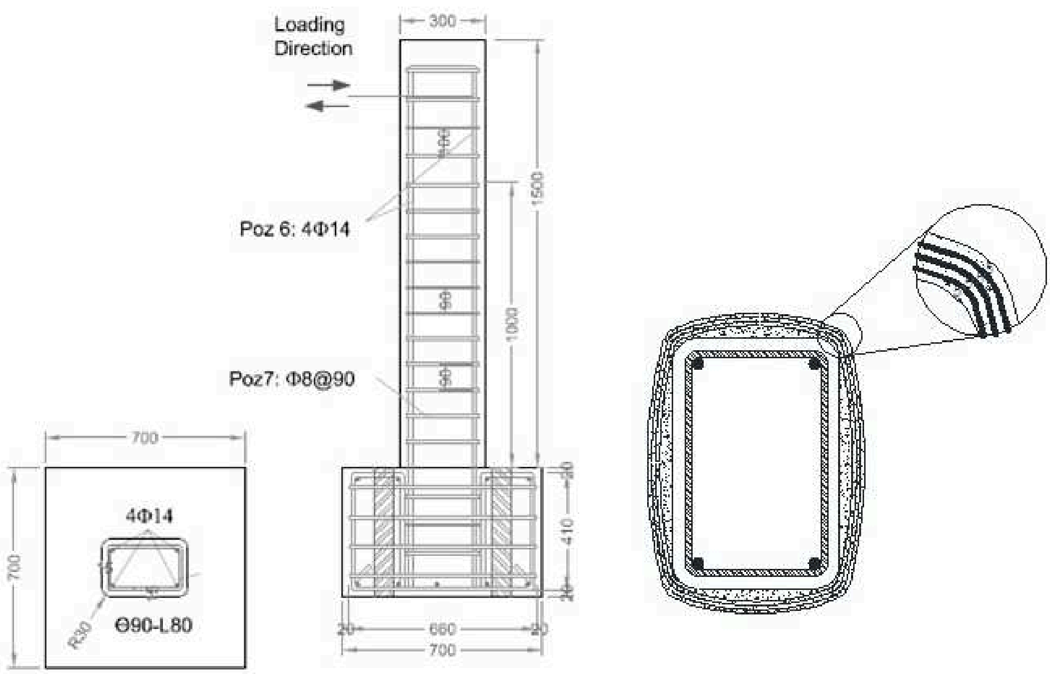


Figure 2. *Test set-up and stress-strain relationships obtained from uniaxial compression tests*

Seismic Retrofit of RC Columns with Basalt Mesh Reinforced Sprayed GFRC Jacketing or with only Sprayed GFRC Jacketing

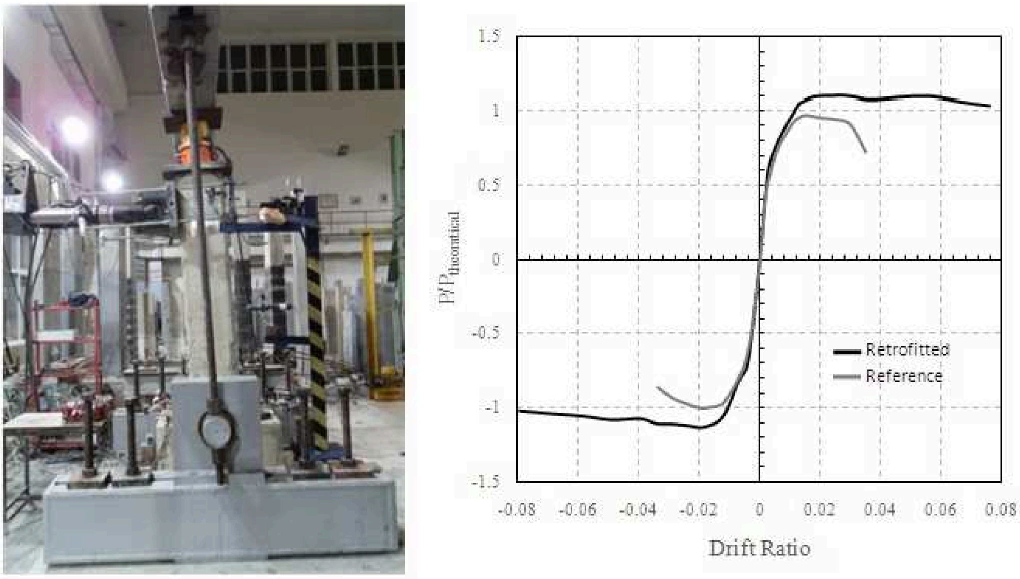
In scope of the second experimental study, seismic performances of reinforced concrete columns retrofitted with basalt textile reinforced sprayed GFRC or only sprayed GFRC under cyclic lateral and axial loads are experimentally investigated. For this purpose, cantilever reinforced concrete columns constructed with deficiencies such as low concrete quality (approximately compressive strength of 10 Mpa), plain bars and widely-spaced stirrups are retrofitted with sprayed GFRC jacket reinforced by three plies of basalt mesh or only with sprayed GFRC. Dimensions and reinforcement layout of the tested columns are shown in Figure 3a and the schematic cross-section view of a retrofitted column can be seen in Figure 3b. Detailed information about specimens, loading pattern, test setup and some basic test results on columns retrofitted with sprayed GFRC jacket reinforced by basalt mesh can be found elsewhere (Comert et al. 2014).



a) Column dimensions and reinforcement layout b) Retrofitted section

***Figure 3**. Reinforcement layout and retrofitted section (Comert et al. 2014).*

The specimens were subjected to combined actions of axial load and reversed cyclic lateral loads by using the test setup shown in Figure 4a. During the reversed cyclic lateral loading, the axial load was kept between 50 and 70% of the column axial load capacities. Typical normalized lateral load-drift backbone curves obtained for a reference and a retrofitted specimen can be seen in Figure 4b. Proposed retrofitting scheme provided enhanced strength with a significant increase in ductility of sub-standard columns.



a) Test setup b) Envelope curve

***Figure 4.** Test set-up and backbone curve of specimens (Comert et al. 2014).*

CONCLUSIONS

In this study, a new and practical seismic retrofitting method is presented and general information is given about the materials and application procedures of the proposed retrofit approach. When compared with other conventional and advanced retrofitting systems, introduced method has outstanding features in terms of application rate, performance at high temperatures, harm to workers health and cost-effectiveness. No formwork is needed since the GFRC is sprayed directly on the surface of existing columns. Furthermore, unlike conventional seismic retrofit techniques, no drilling and anchorage on existing structural members is necessary.

Preliminary results of two parallel experimental programs demonstrated that significant enhancement can be obtained on strength and ductility characteristics of sub-standard reinforced concrete structural members.

Therefore, it is believed that the proposed seismic retrofit technique is quite promising and can find a widespread application potential after further validation and generalization of these initial findings.

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