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Strengthening of columns with different innovative composite materials for RC buildings without sufficient earthquake resistance

Yeterli deprem dayanımı olmayan betonarme binalar için kolonların farklı yenilikçi kompozit malzemelerle güçlendirilmesi

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Strengthening of Columns with Different Innovative Composite Materials for RC Buildings without Sufficient Earthquake Resistance

Highlights

- *RC Buildings without sufficient earthquake resistance*
- *Innovative composite materials*
- *Strengthening*

Graphical Abstract

Reinforced-concrete columns were strengthened with carbon fiber reinforced polymer and textile reinforced mortar. After that, these columns were subjected to axial load. Load-displacement measurement was taken during the experiment.

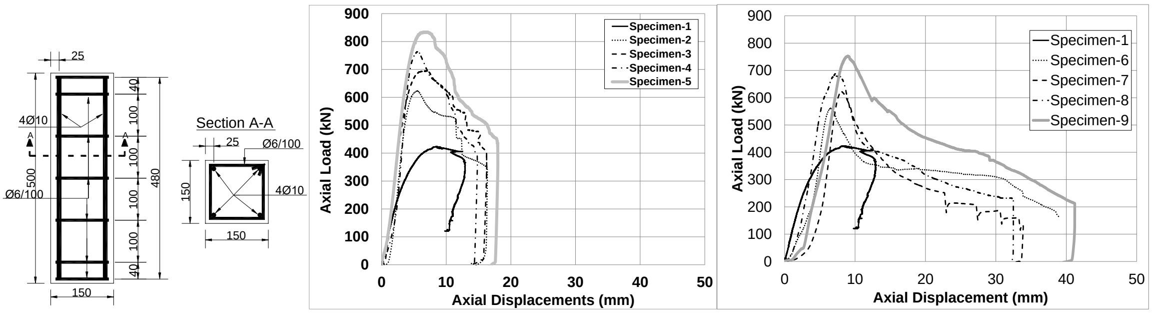

Figure. Dimensions of test specimen and load-displacement graphics

Aim

The aim of the study is to investigate the effectiveness of CFRP and TRM in the strengthening of RC columns.

Design & Methodology

Strengthened RC columns were tested under axial load.

Originality

It is a comparison of TRM and CFRP in retrofitting.

Findings

TRM has shown close success to CFRP.

Conclusion

Strengthening with both CFRP and TRM significantly increased the axial load carrying capacity of reinforced concrete columns.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Strengthening of Columns with Different Innovative Composite Materials for RC Buildings without Sufficient Earthquake Resistance

This study was presented at ICMATSE 2020 conference

Araştırma Makalesi / Research Article

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ABSTRACT

The Turkey includes the world's second most active faults and is geographically situated at a very high seismic activity. Research on strengthening RC (reinforced- concrete) structures without adequate earthquake resistance has become an extremely important issue. Taking into account the objectives of this research, an experimental study is designed to strengthen the columns without adequate earthquake resistance by using carbon-reinforced-fiber-fabric (CFRP) strips and textile-reinforced-mortar (TRM) layers with two separate types of advanced composite materials. The variables evaluated within the study horizon are the composite material type used for strengthening, the width of the strip, and whether or not the anchor is used at the point of strip overlap. In this experiment, nine RC column were produced and were tested by affecting axial load, which are the reference test specimens without strengthening and eight RC column test specimens strengthened with two separate types of composite material. The load-displacement behavior, initial stiffness value, energy dissipation capacities, ultimate load capacity and displacement ductility ratios have been measured according to the test results. It was also examined which of the two different composite materials used to strengthen the columns of the RC is more efficient in improving the columns performance.

Keywords: RC column, axial loading, composite materials, CFRP, TRM.

Yeterli Deprem Dayanımı Olmayan Betonarme Binalar için Kolonların Farklı Yenilikçi Kompozit Malzemelerle Güçlendirilmesi

ÖZ

Türkiye, dünyadaki en aktif ikinci fayları barındırmakta ve coğrafi olarak çok yüksek sismik aktiviteye sahip bir bölgededir. Yeterli depreme dayanımı olmayan betonarme yapıların güçlendirilmesi konusu son derece önemli bir araştırma konusu haline gelmiştir. Bu çalışma kapsamında, iki farklı tip yenilikçi kompozit malzeme olan karbon takviyeli elyaf kumaş (CFRP) şeritleri ve tekstil takviyeli harç (TRM) katmanlar ile yeterli deprem dayanımı olmayan betonarme kolonların güçlendirilmesi hedeflenmiştir. Çalışmada incelenen değişkenler, güçlendirme için kullanılan kompozit malzeme türü, şerit genişliği ve şerit örtüşme noktasında ankraj kullanılıp kullanılmadığıdır. Bu çalışmada, güçlendirme uygulanmayan referans test numunesi ve iki farklı tip kompozit malzeme ile güçlendirilmiş sekiz adet RC kolon olmak üzere toplam 9 kolon test numunesi üretilmiş ve eksenel yükleme etkisi altında test edilmiştir. Test sonuçlarına göre, yük-deplasman davranışı, nihai yük kapasitesi, ilk rijitlik değeri, deplasman süneklik oranları ve enerji emme kapasiteleri değerlendirilmiştir. Betonarme kolonların güçlendirilmesinde kullanılan iki farklı kompozit malzemeden hangisinin kolonların performansının iyileştirilmesinde daha etkili olduğu da incelenmiştir.

Anahtar Kelimeler: BA kolon, eksenel yük, kompozit malzemeler, CFRP, TRM.

1. INTRODUCTION

Researchers have increasingly switched to the use of structural materials with advanced technical features over time, as the main purpose of reinforcement methods is to ensure sustainability and cost-effectiveness. First of all, sheathing was applied to the reinforced concrete construction elements with an additional cross-section created to increase the bearing capacity of the building by strengthening concrete and steel with a higher strength than the material strength of the current structure[1-6]. Although positive results were obtained in terms of bearing power, the difficulties caused a decrease in the use of the sheathing, such as the difficulties experienced in the formwork, reinforcement and concrete works, the inability to use the framework when reinforcing the building, deteriorating the building's architecture, etc. Instead, reinforcing structural elements against shear and bending forces with steel elements came into prominence

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[7-9]. Risks, costs, and architectural issues caused by adverse environmental impacts, unqualified workmanship, fire, or corrosion were met in this reinforcement process. Instead of these reinforcing techniques, reinforcement with FRP has been commonly used for the last 20 years and many structures have been improved with this technique. In addition, several scientific studies on the subject have been performed and FRP has become one of the most favored materials in the reinforcement and retrofitting literature [10-21,30-31]. Epoxy, an organic material, is also used to form a cohesive zone between the surface where FRP is applied and the FRP when the studies are examined. However, (a) low fire resistance[22], (b) inability to be applied to wet or damp surfaces[23], (c) inability to replace the coating layer[24], (d) to be labeled as a hazardous material during disposal, (e) high cost of FRP techniques[24], (f) permeability: insufficient permeability to vapor and the use of organic resins have been shown to damage the concrete [22]. Taking these negative factors into account, the advent of the Textile Reinforced Plaster Layer (TGSK) in scientific research some ten years ago can be seen as a remarkable development in the field of structural reinforcement [25,26]. TGSK (the same material is often referred to in English as TRM, TRC, and FRCM) is a composite building material consisting of inorganic cement-based mortar along with textiles made from various materials (such as steel, carbon, basalt, glass). Usually, textiles used as reinforcement of the composite material consist of two vertical fiber strands (bidirectional). TGSK has many advantages over fiber-reinforced polymers, provided that the mortar is made and applied by conventional methods (a commonly used epoxy-based composite material). These advantages are a) low cost, (b) high temperature resistance, (c) applicable to construction surfaces of concrete, reinforced concrete and masonry, (d) applicable to wet surfaces, and (e) low thermal permeability, (f) high bearing power. Researchers have performed several studies with TGSK in view of these advantages.

In terms of seismicity, the Turkey contains the second most active faults on the world and geographically placed at the very high seismic activity. For this reason, it is extremely important to design and manufacture reinforced-concrete structures in accordance with the codes of modern earthquake regulations. However, due to various reasons, the earthquake performance of the reinforced-concrete building in our country is insufficient due to the loss of lives and property and severe damage to many buildings. It has become an extremely important subject of research on strengthening reinforced-concrete structures without sufficient earthquake resistance. The strengthening of vertical bearing elements (columns) with different innovative composite materials, which are important for the earthquake performance of buildings, has become a critical research topic in the field of civil engineering.

In the last two decades, many studies have been carried out on columns. Some of them are analytical studies [27-29]. In most of these studies, stability and boundary conditions were examined. However, in reinforced concrete structures, axial load levels of columns, which are important bearing elements, can increase due to various reasons under the influence of horizontal earthquake loads and vertical static loads and it is necessary to be strengthened. For instance, occurrence of earthquake with loads at a higher level than expected in the design phase, increase in the axial load levels of the vertical bearing members due to changes in the purpose of use of the structure, increase in traffic effects over time or damage to any column due to manufacturing faults or environmental influences that may occur during construction, etc.. The strengthening of vertical bearing elements should have been considered to minimize the effects of these occurrences on the existing structure.

Chellapandian et al. (2017) explored an innovative hybrid strengthening technique where short RC square column specimens are strengthened by using both Near Surface Mounted (NSM) CFRP laminates and Externally Bonded (EB) CFRP fabrics for confinement. Ten square column specimens strengthened and tested under pure axial compression to investigate the efficiency of different combinations of strengthening techniques. Experimental results interpreted and hybrid strengthening technique was found to be more efficient, leading to a higher increase in strength, stiffness, and ductility as compared to only NSM strengthened or only CFRP confined RC columns [32]. Chellapandian et al. (2018) conducted a related analytical and numerical study on the behavior of axially loaded square cross-section reinforced short concrete columns loaded consecutively and eccentrically in another work. A computer simulation by a total of 20 columns was carried out using ABAQUS finite element software. The nonlinear analysis was carried out to determine whether the behavior of short columns reinforced with square cross-section CFRP strips was realistically consistent with the experimental results. As a result of the research, the hybrid retrofitting technique is more effective in improving the post-cracking stiffness, strength and ultimate displacement ductility of RC column specimens under compression [33]. Jain et al. (2017) investigated the extent to which the repair technique they were able to achieve success by repairing square-section reinforced short concrete columns damaged to a certain extent with CFRP strips and carbon bars near the surface. In the scope of the study, a total of 12 test specimens were produced and loaded up to the gravity at the axial concentric loading effect. The results obtained show that the repair detail of the used hybrid CFRP strips and carbide rods gives successful results for repairing the columns [34].

In addition to the CFRP reports, TRM reinforced concrete columns have been reinforced in recent years for the reasons explained above. As the first study, Triantafillou et al. (2006) emerges [22]. From the results obtained in this study, it is believed that TRM jacketing is an extremely promising solution for the confinement of reinforced concrete. Bournas et al. (2007) conducted the compression tests on 15 RC prisms [23]. Their tests show that TRM jackets provide a substantial gain in compressive strength and deformation capacity by delaying buckling of the longitudinal bars; this gain increases with the volumetric ratio of the jacket. Compared with their FRP counterparts, TRM jackets used in this study are slightly less effective in terms of increasing strength and deformation capacity by approximately %10. Tests on nearly full-scale columns under cyclic uniaxial flexure show that TRM jacketing is very effective (and equally to its FRP counterpart) as a means of increasing the cyclic deformation capacity and the energy dissipation of old-type RC columns with poor detailing by delaying bar buckling. The test results presented in this study indicate that TRM jacketing is an extremely promising solution for the confinement of RC columns, including poorly detailed ones in seismic regions. These considerations were supported by Colajanni et al. (2014) [35]. The main results of an experimental research aiming to investigate the behavior of medium-size low-strength concrete columns wrapped with Carbon Fiber Reinforced Cementitious Matrix (CFRCM) under monotonic and cyclic compressive axial loads are presented. Thirty columns with circular, square and rectangular cross-sections were tested under monotonic and cyclic axial loads to investigate the effect of the confinement level, the cross-section shape and the corner radius on the stiffness, strength, and ductility of CFRCM confined concrete columns under cyclic loads. The results prove that CFRCM confining jackets provide substantial gain in compressive strength, deformability and absorbed energy. Ombres et al. (2015) focused in own paper were: i) the effectiveness of the cement based wrapping systems to improve the strength of the reinforced concrete columns, ii) the influence of the load eccentricity and the reinforcement ratio on the structural response of wrapped columns, iii) the prediction, by an analytical procedure, of the structural behaviour of wrapped columns [36]. A total of 8 reinforced concrete columns with end corbels, wrapped with fabric meshes of PBO (short of Polypara-phenylene-benzo-bisthiazole) fibers embedded into a cement based matrix (PBO-FRCM system), were tested varying both the reinforcement ratio and the eccentricity-to-section height ratio (e/h). The influence of mechanical and geometrical parameters on the structural response of wrapped columns was analysed in terms of failure modes, strength and ductility. Liu et al. (2017) presented an experimental and numerical study on flexural strengthening by applying textile reinforced concrete at the tensile face [37]. Seven short columns were constructed and tested under eccentric load. One of the columns did not receive any strengthening and was used as the control column, whereas the rest six were externally upgraded by textile-reinforced concrete layers. The main parameters taken into account covered: (a) type of mortar, (b) preload level, and (c) number of textile-reinforced concrete layers. Besides the experimental program, a numerical investigation utilizing non-linear finite element analysis was carried out and a good agreement was obtained between the experimental and numerical results. Further, the numerical analysis was extended to additional cases to deepen the understanding of flexural-enhancing mechanism. It is concluded that textile-reinforced concrete substantially increases the flexural capacity of the eccentric compression columns; the more the textile layer, the greater the gain. However, the preload has an apparently adverse influence on the strengthening effectiveness, as it causes the strain loss of the textile; the bigger the preload level, the more the loss Al-Gemeel et al. (2018) presented a feasibility investigation of basalt fibre textile reinforced engineered cementitious composite (ECC) [38]. Three types of basalt fibre textile were used, in combination with ECC to confine square concrete columns. The experimental results revealed that the new strengthening system has significantly enhanced the load carrying capacity and ductility of square concrete columns compared to the unconfined specimens and the specimens confined with textile reinforced mortars (TRM); the axial compressive strength increased in the range of %54-%77 for the new strengthening system compared to %41 for the TRM system. The results also shown that ECC itself could be used as a new retrofitting material in column confinement. The experimental study is performed on a series of six reinforced concrete square columns tested to failure by Ngo et al. (2020) [39]. Two of them were un-strengthened as references, the other four were strengthened by one or two layers of Carbon Textile Reinforced Concrete (CTRC). The results indicated that the application of carbon TRC enhanced the ductility and ultimate strength of the specimens. Failure of all strengthened columns was together with tensile rupture of textile reinforcements at the corners of column. Finite element models of the CTRC strengthened columns based on ATENA software package were developed and verified with the experimental results. The analytical results show that in the specimen corner areas, textile reinforcements are subjected to a 3D complicated stress state and this may be the cause of their premature failure.

As can be understood from the literature review, a very limited number of studies on the development and examination of strengthening detail that can provide the load-carrying capacity, displacement ductility ratio, and energy dissipation capacities of reinforced concrete columns with square cross-sections can be found in the literature. The main purpose of the study is to develop a strengthening method that does not adversely affect displacement ductility ratios and energy dissipation capacities. Improved strengthening details have been applied to a square cross-section RC column with low axial load capacity, the low compressive strength of concrete, and the inadequate number of stirrups, which is not designed according to regulations. The study aims to increase the axial load carrying capacity and stiffness of the columns by using innovative reinforcement methods developed by the authors and using CFRP fan type anchors differently while at the same time displacement ductility ratios and energy dissipation capacities are not adversely affected or even increased. Within the framework of this research, an experimental study is designed to strengthened the columns without adequate earthquake performance using two different types of advanced composite materials by using carbon-reinforced fibre fabric (CFRP) strips and textile reinforced mortar layers (TRM). The variables evaluated within the study horizon are the type of composite material used in the reinforcement, the width of the composite strip and whether or not the anchor is used at the point of strip overlap. The load-displacement behaviour, initial stiffness value, energy dissipation capacities, ultimate bearing capacity and displacement ductility ratios were measured and interpreted as a result of the data obtained from the experimental study. The study also analyzed which of the two distinct advanced composite materials used to strengthen reinforced-concrete columns are more effective in improving column performance.

2. EXPERIMENTAL STUDY

In this study, a total of 9 column test specimens which are the reference test specimen with no reinforcement and eight reinforced-concrete column test specimens that strengthened with two different types of composite material (Table 1), were produced and were tested by affecting axial load. The reinforcement details and dimensions of the test specimens are given in Figure 1.

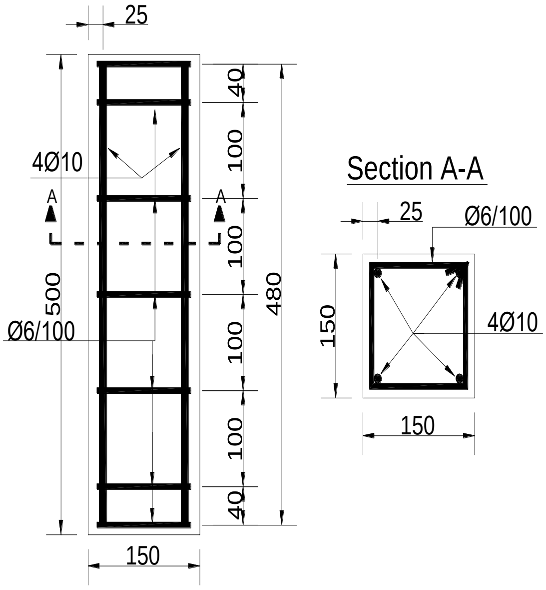


Figure 1. Reinforcement details and Dimensions and of specimens

The mix of concrete was designed to have a compressive strength of 16 MPa target cube according to the TS802 [41]. At least 6 cubes of 150x150x150 mm in size were taken from all test samples. Cube samples were kept under the same curing conditions in accordance with the standards and tested under axial load on the 28th day and their compressive strength was determined. In one step, the reinforcement used in the manufacture of the test specimens was taken and ensured that they had similar mechanical properties. Ribbed bars with a diameter of 10 mm were used as longitudinal reinforcement in all reinforced-concrete columns, and plain bar ties with a diameter of 6 mm were mounted at equal intervals of 100 mm. Five samples were taken from each of the ribbed and plain bar types used in the experimental study and mechanical strength values were determined by applying an axial tensile test. The elastic modulus, yield strength and tensile strength values of ribbed bar longitudinal reinforcement with a diameter of 10 mm were obtained as E = 208 GPa, f_{sy} = 478 MPa and f_{su} = 593 MPa, respectively. The yield strength, tensile strength and elastic modulus values of plain bar tie reinforcement with a diameter of 6 mm were obtained as f_{sy} = 325 MPa, f_{su} = 451 MPa and E = 202 GPa, respectively.

Table 1. Characteristics of test specimens

Spec. No	Material used for strengthening	Strip Witdth (mm)	Anchor Usage
1	Reference specimen		
2	CFRP	25	No
3		50	
4		25	Yes
5		50	
6	TRM	25	No
7		50	
8		25	Yes
9		50	

Figure 2 illustrates the manufacturing process of research specimens. 25 mm for Specimen-2, Specimen-6 and 50 mm for Specimen-3, Specimen-7, were selected for the width of the TRM layer and CFRP strips. In Specimen-4, Specimen-5, Specimen8 and Specimen-9, fan style CFRP anchor was used in the over lap region of the CFRP strip and TRM layer.

Specimen reinforcement information are shown in Figure 3. RC columns are strengthened with CFRP strips for Specimen 2 to Specimen-5 with unidirectional fibers and bonded with two-component epoxy. Mechanical properties of CFRP and epoxy provided by the manufacturer are presented in Table 2. RC columns are strengthened with carbon textile layer and bonded with using special mortar for Specimen 6 to Specimen-9. Table 3 shows the mechanical properties of the carbon textile layer and of the special mortar produced by the manufacturer.

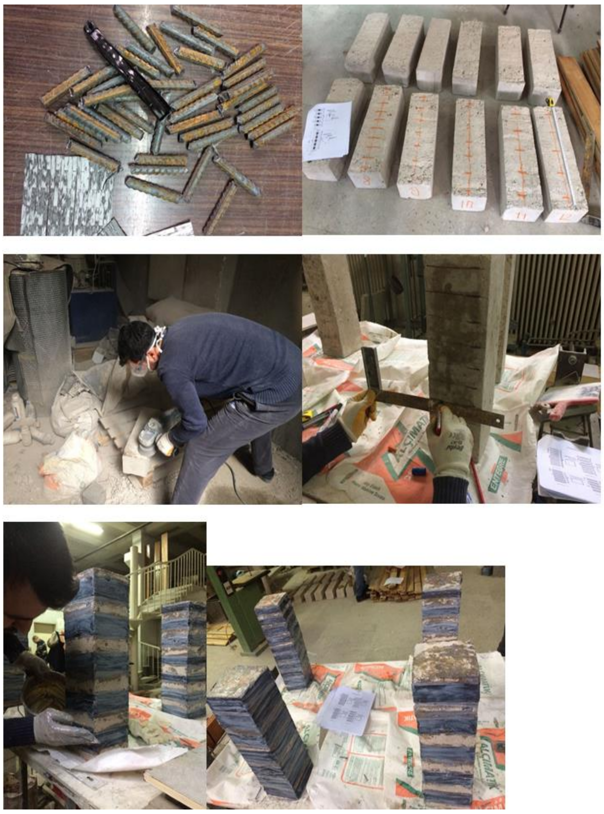


Figure 2. Strengthening processes of specimens

Table 2. Properties of CFRP Sikawrap 160-C (Unidirectional) and Resin Sikadur 330

Properties of CFRP	***Remarks****
Thickness (mm)	0,12
Tensile Strength (MPa)	4100
Elastic Modulus (MPa)	231000
Ultimate Tensile Strain (%)	1,7
Properties of Epoxy	***Remarks****
Tensile Strength (MPa)	30
Elastic Modulus (MPa)	3800

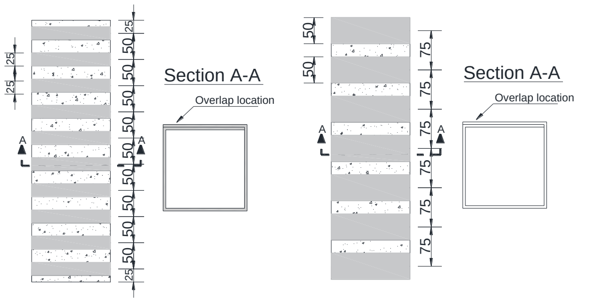
*These values are supplied by the manufacturer.

Special attention was given to the RC column surface preparation before bonding of the CFRP strip and TRM layer on to the concrete surface. Firstly, in the anchored specimen, the anchor positions were identified, and then the anchor holes were opened with the help of a drill. The CFRP strip and TRM layer positions on the RC column were roughened down to aggregate level mechanically by a grinding machine, and then the ground surface was brushed. Surfaces were vacuum cleaned to remove loose particles and dust. Some pressure was applied on them by hand along the fibre directions after bonding with CFRP strips or Textile layer to get rid of air bubbles trapped between concrete surface and CFRP strips or Textile layer soaked with mortar. Anchor holes were filled with epoxy following this process. The CFRP fan style anchors are shown in detail, and CFRP and TRM device measurements have been put in Figure 4. In all situations, the temperature during application was 20±2 ºC. Upon completion of bonding procedures, specimens were cured before testing under laboratory conditions for seven days.

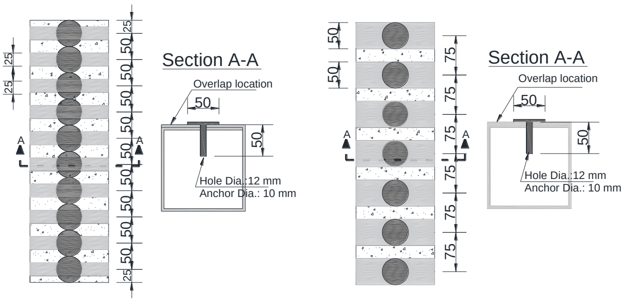
Table 3. Properties of carbon textile and mortar

Properties of Carbon Textile	***Remarks****
Thickness (mm)	1,43
Tensile Strength (MPa)	2550
Elastic Modulus (MPa)	235000
Ultimate Tensile Strain (%)	1,7
Properties of Special Mortar	***Remarks****
Compression Strength (MPa)	45
Elastic Modulus (MPa)	20000
Flexural Tensiel Strength (MPa)	7

*These values are supplied by the manufacturer.



Specimen-2 and 6 Specimen-3 and 7



Specimen-4 and 8 Specimen-5 and 9

Figure 3. Strengthening details of specimens

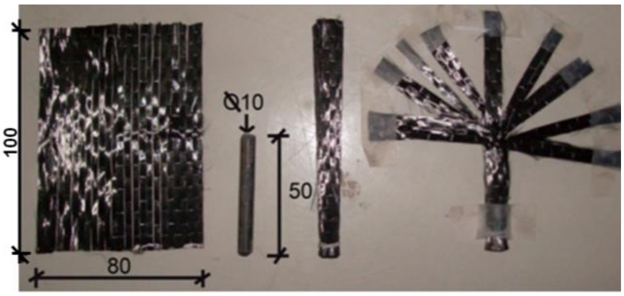


Figure 4. Fan type anchor dimensions and detail (Dimensions in mm.)

Two potentiometers were mounted to the test rig to measure vertical displacements due to compression loading. The test and measurement set-up were given in Figure 5. Tests were conducted using a column test rig with a capacity of 3000 kN for axial load. The test rig is fitted with a motor-controlled hydraulic loading system and the loading speed is adjustable and can be tested at constant loading speed In order to properly capture the post-peak reaction of the column specimens, the experiments were carried out in constant loading mode at a relatively slow load rate of 1 kN/sec. The displacement values read from the LVDT and the load affected by the hydraulic system were transmitted to the machine via the data logger system and the load-displacement graphs were plotted and traced. In addition, the required interpretations and measurements were carried out using axial load-displacement graphs plotted for the test specimens. During the measurements, the axial displacement value of the column was calculated by taking the sum of the two displacement values read from the left and right sides of the column taken over by the test setup and symmetrically plotting the load-displacement graphs using this value.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 6 includes comparative load-displacement diagrams of the CFRP strip and TRM strip research experiments with reference specimens. The failure modes and the damage distribution of the specimens examined can be seen in Figure 7 after processing. Maximum load capacity of the test specimens, displacement ductility ratios, initial stiffness, and energy dissipation capacities, which are important for structural efficiency and behavior, are measured and compared using axial load displacement graphs. The findings are interpreted to evaluate examined variables and to assess the effects on the actions and output of the specimens by experimental strengthening details. Table 4 summarizes the findings obtained from the experiment. Figure 8 presents the method used to measure the the displacement ductility ratio, initial stiffness and the energy dissipation capacity.

The objective of the study is to improve the behavior of RC columns which under the effects of axial loading with two different types of composite materials, have insufficient earthquake resistance, low strength concrete, and insufficient shear reinforcement. Bonding carbon fiber reinforced fabric strips with two-component epoxy to wrap the reinforced-concrete column is the first type of strengthening. The second approach is to put strips reinforced with carbon textile strips with a special mortar layer in such a way that the RC columns are wrapped. It is observed that both strengthening strategies increase the general performance of RC columns with inadequate earthquake resistance under the influence of axial loading by analyzing the experimental results. The axial load carrying capacity of reinforced-concrete columns, the energy consumption capacity and the initial stiffness values values were significantly improved by both reinforcement methods used with composite materials, but the axial displacement value caused by the loading effect decreased significantly, even though the displacement ductility ratio was not reduced.

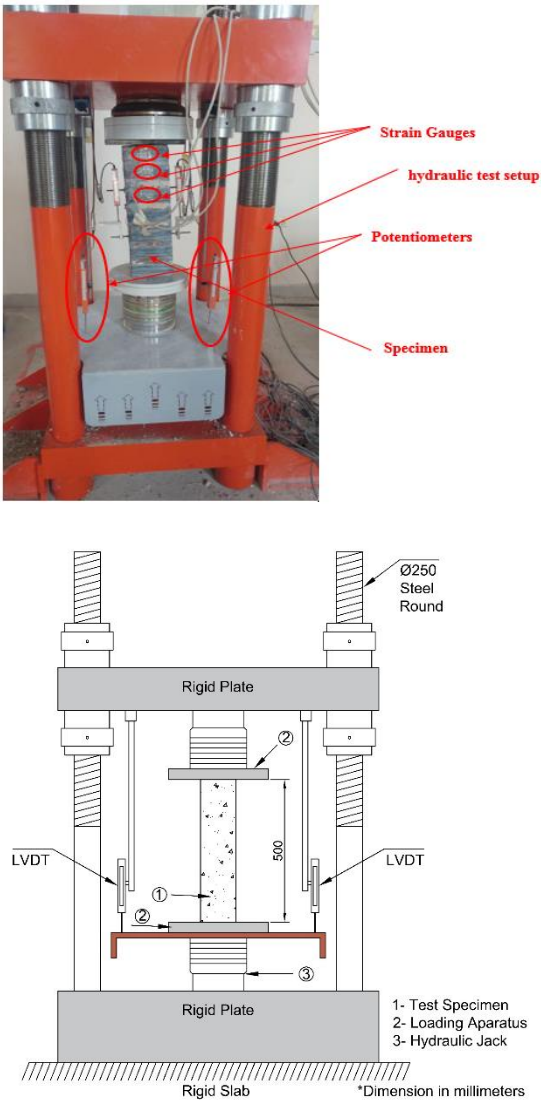


Figure 5. Instrumentation and test setup

The maximum bearing strength, initial stiffness, displacement ductility ratios and energy consumption capacity values of reinforced-concrete columns by wrapping and bonding CFRP strips increased by an average of %72, %118, %12 and %59, respectively, compared to the reference Specimen-1 test element without strengthening. The displacement value in max. strength decreased by an average of %178. The maximum bearing strength, initial stiffness, and energy consumption capacity values of the reinforced-concrete columns wrapped with a single-layer TRM increased by an average of %55, %50, and %73, respectively, from the reference Specimen-1 test element without strengthening. Displacement ductility ratios and displacement at maximum bearing value decreased by an average of %19 and %125, respectively.

Table 4. Experimental results

Spec. No	Ultimate Axial Load Capacity (kN)	Dis.at Ult. Axial Load (mm)	Initial Stiff. (kN/mm)	Dis. Duct. Ratio	Energy Diss. Capacity (kN-mm)
1	423,06	17,13	72,67	1,51	3749,58
2	623,27	5,50	138,97	2,07	5095,45
3	694,40	6,77	159,97	1,64	6703,25
4	764,09	5,62	159,73	1,57	5132,04
5	833,82	7,02	175,70	1,49	6929,67
6	562,16	6,55	89,77	1,25	5701,30
7	622,49	8,07	92,18	1,21	6917,05
8	688,97	7,26	108,49	1,25	6071,50
9	752,04	9,02	144,55	1,37	7265,25

It has been shown that the strengthening technique using two different types of composite materials is efficient and competitive in improving the behavior of reinforced-concrete columns under the impact of axial loading with inadequate earthquake strength when the experimental results are examined. It was also found that when two techniques were compared with each other the strengthening technique in which the CFRP strips were bonded with epoxy to wrap the reinforced-concrete columns performed better than the reinforced textile mortar layer strips. The overall load carrying capacity, initial stiffness values and displacement ductility ratios exhibited higher values by an average of %11, %49 and %34 compared to the textile reinforced mortar layer strips in the strengthening process in which CFRP strips are bonded with epoxy to wrap the reinforced-concrete columns. In addition, in the strengthening approach in which the textile reinforced mortar layer strips wrapped the reinforced-concrete columns, on average %24 higher than the strengthening method in which the CFRP strips are adhered to epoxy to wrap the reinforced-concrete columns, the displacement was obtained at the highest load carrying capacity value. Better performance was achieved only in terms of energy consumption capacity in the strengthening procedure where the reinforced-concrete columns were wrapped with textile reinforced mortar layer strips. In the strengthening method where textile reinforced mortar layer strips were used, an average of %10 higher energy consumption capacity values were measured compared to the strengthening method where CFRP strips are bonded with epoxy to wrap reinforced-concrete columns.

The width of the strips used in the strengthening technique is another variable tested in the experimental analysis. Two separate 25 mm and 50 mm strip widths were used in the experimental sample. With a 50 mm wide strip, the performance of composite materials in both strengthening techniques was higher than with a 25 mm wide strip. Test specimens strengthened with 50 mm wide CFRP strips showed an average of %21, %12, and %2 higher values respectively, for overall load carrying capacity, initial rigidity, and energy consumption capacity values compared to test specimens strengthened with 25 mm wide CFRP strips. Test specimens strengthened with 50 mm wide TRM strips are %22, %39 and %6 higher than the test specimens strengthened with 25 mm wide TRM strips, respectively, with full load carrying capacity, initial rigidity and energy consumption capacity values.

When the ACI 440.2R (2008) Committee Report [40], which contains the rules and methods about the strengthening applications related to carbon fiber reinforced fabrics are examined, it is suggested that the entire surface of the load-bearing column element is confined. A method for calculating the bearing capacity of columns under axial load using the confined stress-strain behavior of concrete with the effect of confinement applied with a whole one-piece carbon fiber reinforced fabric is presented in the report. The report includes a method for calculating the bearing capacity of the column under axial load, based on the stress-strain behavior of concrete confined with one-piece carbon fiber reinforced fabric.

The method is based on the approach of improving the stress-strain behavior of concrete under pressure as well as increasing the bearing capacity of the column by the effect of confinement. There is also a stress-strain suggestion for confined concrete. However, this method is suitable for the case where the column is completely confinement around a single piece of carbon fiber reinforced fabric and it is only valid for this situation. Within the scope of this study, no generalized or proven literature study that can be used in the calculation of capacity for reinforcement details of CFRP strips to be confined with the column at different widths and intervals has not been found. It is not possible to use the method proposed under ACI 440.2R, 2008 Committee Report for reinforcement details where the column is not completely confined and the CFRP strips are in different regions of the column.

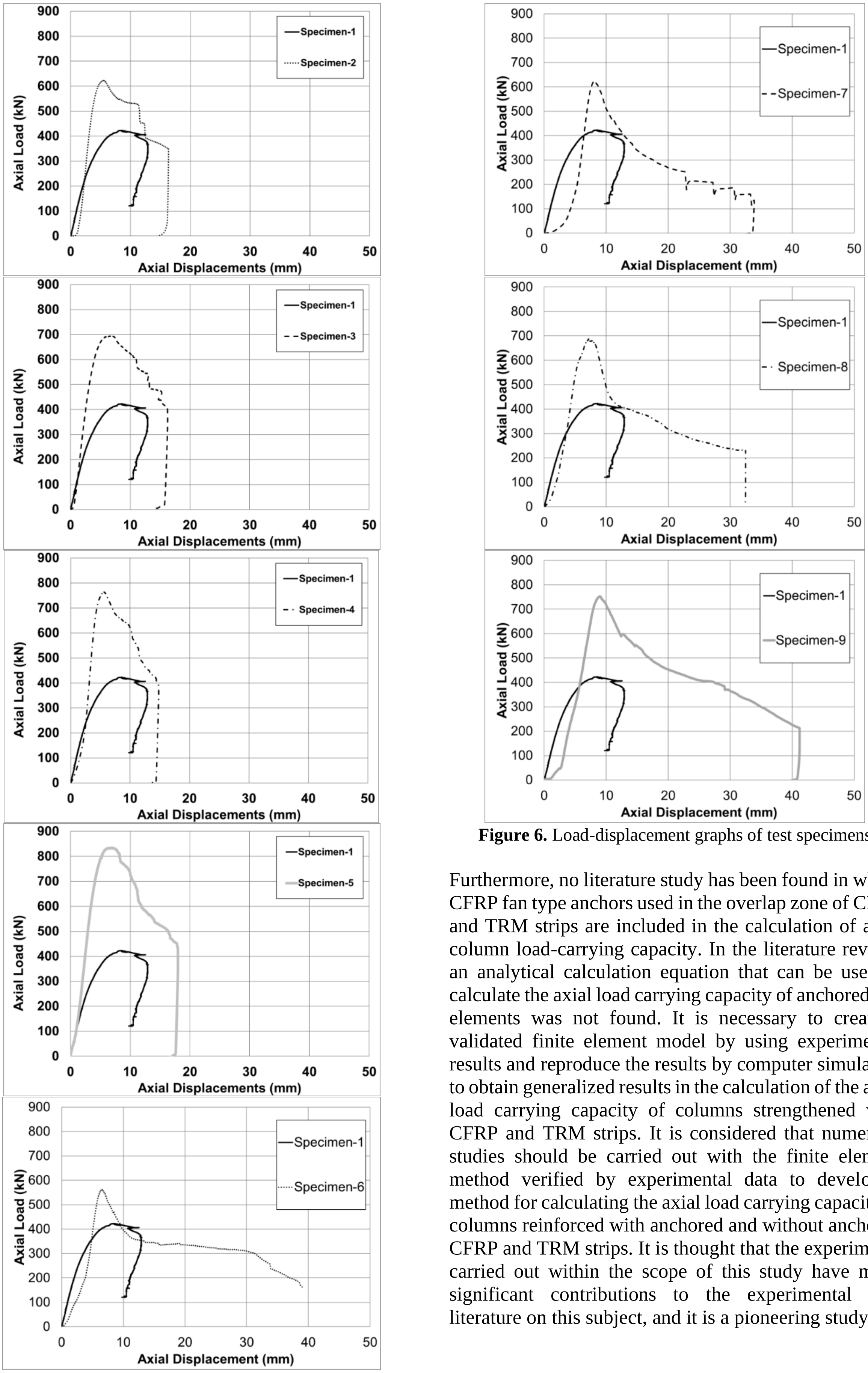


Figure 6. Load-displacement graphs of test specimens

Furthermore, no literature study has been found in which CFRP fan type anchors used in the overlap zone of CFRP and TRM strips are included in the calculation of axial column load-carrying capacity. In the literature review, an analytical calculation equation that can be used to calculate the axial load carrying capacity of anchored test elements was not found. It is necessary to create a validated finite element model by using experimental results and reproduce the results by computer simulation to obtain generalized results in the calculation of the axial load carrying capacity of columns strengthened with CFRP and TRM strips. It is considered that numerical studies should be carried out with the finite element method verified by experimental data to develop a method for calculating the axial load carrying capacity of columns reinforced with anchored and without anchored CFRP and TRM strips. It is thought that the experiments carried out within the scope of this study have made significant contributions to the experimental data literature on this subject, and it is a pioneering study.

Specimen-1

Specimen-2

Specimen-3

Specimen-4

Specimen-5

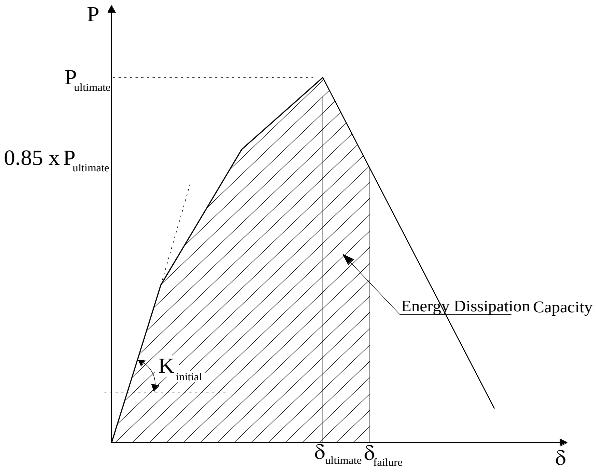
Specimen-6

Specimen-7

Specimen-8

Specimen-9

Figure 7. Failure modes of test specimens



$$\text{Ductility Ratio} = \frac{\delta_{failure}}{\delta_{ultimate}}$$

Figure 8. The approach used for calculation of initial stiffness, displacement ductility ratio and energy dissipation capacity

4. CONCLUSIONS

This study showed that the strengthening methods developed by applying different types of composite materials can be used to improve the performance of columns that are the most important components of the bearing system of reinforced-concrete structures under the influence of axial loading. The maximum load carrying capacity, initial rigidity and energy consumption capacity of inadequate capacity of reinforced-concrete columns under the impact of axial loading, which was not constructed in compliance with the regulations, were insufficiently increased by these two strengthening methods. The displacement ductility ratios were also not decreased by these two techniques and their general load-displacement behavior and efficiency were improved. The wrapping procedure with CFRP strips performed marginally better and performed much better than the wrapping technique with TRM strips.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Ömer MERCİMEK: Peroformed the experiments and analyse the results. Wrote the manuscript.

Rahim GHOROUBI: Peroformed the experiments and analyse the results.

Anıl ÖZDEMİR: Peroformed the experiments and analyse the results.

Özgür ANIL: Designed test specimens and wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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