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Strengthening of Concrete Columns under Axial Loading Condition with FRP

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ABSTRACT: *Fiber-reinforced polymer FRP confinement usually used in a column to improve their load-carrying capacity, compressive strength, and ductility. The effect of FRP confinement on improving the axial performance of confined columns under axial load, as well as the factors that affect the amount of axial performance improvement of confined columns, have been explained in this study. This study consists of reviewing many studies in the literature on restricting columns with FRP under axial load conditions. The result showed that FRP can improve the load-carrying capacity, compressive strength, and ductility of confined column, and the confinement effectiveness is higher for columns with circular cross-section shape than square and rectangular cross-section shape, as well as the confinement efficiency is higher in columns with lower aspect ratio (length/width ratio) and lower slenderness ratio. Improving the axial performance of confined columns is more elevated in lower strength of concrete, and the improvement increase with increasing thickness of the FRP. The increasing radius of the corner of columns leads to more considerable improvement in strength and ductility. Strength and ductility improving are better in fully wrapped columns with FRP than partially wrapped, as well as confinement effect reduction with the increasing eccentricity of loading. CFRP is higher in effect than GFRP.*

Keywords*: Axial load, Column confinement, CFRPcomposites, FRPcomposites, GFRP composites*

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I. INTRODUCTION

1-1 General introduction

Many civil structuresmay require to strengthen in severalsituations, including deterioration because of corrosion of steelreinforcement, destruction after an earthquake occurrence, insufficientdesign,overloading,construction errors, and functional modifications [1]. Strengthening of R.C structures is asignificantpart of the structural maintenance field. The purpose of strengthening is to promote the capability of an existing structural component [2].Variousmaterials &techniques have drawn to be feasible for strengtheningconcretestructures. These comprise sprayed concrete, steel plates,ferrocement, and fiber-reinforced polymer.

Spray concrete is one of themost common systems and the oldest substancesof strengthening and repairing of R.C structures. Sprayed concrete has utilized in strengthening the field for nearly90 years [2].Using sprayed concretefor strengtheningreinforced concrete beam as described in 1998s [3]. There are two methods for utilizing sprayed concrete. American Concrete Institute (1990) describes“dry and wet mix sprayed concrete," in “dry mix spray concrete” process thegreaterquantity of the blending water is addedby the nozzle, while in “wet mix sprayed concrete”the components of sprayed concrete, including water, are blended before applying to the concrete structure. Both dry and wet mixes sprayed concrete are used in concrete repair and strengthening effort; only the usage of “dry mix sprayed concrete” is more common [2].

Ferrocement is a kind of thin combined material preparation of cement mortar reinforced by uniformly distributed layers of continuous and small diameter wire meshes. Ferrocement ideallysuited as a strengthening technique for therehabilitation of RC structures [2]. The utilizing of ferrocement in repair was first introduced in(1987) by Romuldi and Irons [4,5].Ferrocement is beneficial in the enhancement of load carrying capacity [6], better cracking behavior, flexural capacity, ductility, and stiffness [7].The adaptability of the Ferrocement technique is low price, the broadavailability of component materials, realistic quality control, and good strength capacity [8].

The steel plate is one of the most usually usedtechniquesfor the strengthening of RC structures. It is usefulinpromotingtheshear capacity [9] and the flexuralcapacity of the RC beam [10]. Steel plate for Strengthening is a widespreadsystembecause of its cheapness,availability, uniform properties ofmaterials (isotropic), high ductility, high fatigue strength, andeasy to operate [11]. Inquiries into the operationof structural elements strengthened by thissystemstarted in the 1960s. This technique had used to enhance both bridges and buildings incountries such as France, Belgium, Poland, Japan, South Africa, United Kingdom, and Switzerland [12].The most commontype of plating is to paste, steel plates in the tension faces of beams.

Using fiber-reinforced polymer (FRP) for the strengthening of RC structures is tooimpressivebecause it has a high strength to weight proportion. It informed thatthematerials ofFRP had mechanicaland physical properties much more wholesome to those of steel, especiallytensile and fatigue resistance, and these qualities kept under a broad range of temperatures[13]. Though, the utilizing of FRP for civil engineering structures restricted for many yearsbecause ofits low failure strains,higher cost, and uninformed long-term performance [14]. In 1986, the first highway bridge utilizing FRP reinforcing tendons was constructed in Germany [15]. The first FRP pedestrian bridge built in 1992 in Scotland. In the U.S., the first FRP concrete bridge deck was put up in 1996 in McKinleyville [15].FRP has utilized for applications ofstrengthening in different industries.Though, common applications for bridge components include externally bonded(EB) composite fabrics or jackets oncolumns, beams, and bridge decks, wheresubstantialenhancements in compressive, flexuraland shear performance has beenachieved[16-22].The advantages of FRP compriselightweight, high strength-to-weight ratio, simplicityin installation, and excellent corrosion resistance. FRP composites are cheaper in transportingdue to their lightweight, no formwork requiredand no orless scaffolding to put up, and minimally add to a structure's dead load. Due to thestrength of FRP composites, only thin layers required to rehabilitatecolumns and beams, the leastchanging original dimension[23].

FRP is valid in a variety of forms, such asgrids,sheets,bars, and pre-stress tendons. Some types of FRP components, such as bar and tendon form, are mainly used instead of steel reinforcement innew concrete members. For existing concrete elements, innovative rehabilitationsystems comprise the use of FRP sheets in the phase of wrapping ofbeam to strengthen shear or flexural capacity, wrapping of column to improveseismic and compressive performance, bonded FRP flange plates to promote bendingcapacity, and epoxying FRP rods in channels cut into the substrate to upgrademember strength [24]. The single of the most flexible strengthening options isthe use of externally bonded EB FRP systems.

FRP involved in combined fiber and the polymeric matrix.Typically, the volume fraction of fibers in FRPs is around 50-70% for strips and about 25-35% for sheets.Three types of reinforcing fibers commonly used:carbon, aramid,and glass. In recent times, basalt fibers were becoming commercially valid. Basalt fibersform from volcanic basalt rocks; they havesuperiorchemical and thermal resistance.Generally,carbon fibers have the highest elasticmodulus than glass fibers. All fibers typesdisplay linear elastic conduct whentested [23].Glass fibershave been commercially obtainablesince 1939.Glass fibers categorized into three kinds: S-glass fibers, E-glass fibers, and alkali-resistant glassfibers(AR-glass). Carbonfibers have been commercially obtainable since 1959.Aramid fibers created in the late 1950s, at thebeginning it was appearedwith the trade name Nomex by DuPont. Aramid fibers generally used for military and aerospace applications; they have high thermal resistance properties [25]. Vinyl ester,polyester, and epoxy are the most widely utilized polymeric matrix materials in FRP composite. They are thermosetting polymers with excellentchemical resistance. Epoxies are furthercostly than vinyl-estersand polyesters. Still, they have betterin mechanical properties and outstanding durability thanvinyl-esters and polyesters,the task of the matrix isto keep the fibersfromenvironmental corrosion or abrasion,the matrix has a greateffect on manycomposite mechanical properties, such as the shear properties,strength,the transverse modulus and theproperties under compression [26].

The strengthening of RC columns by FRP compositescomprises external FRP wrapping, FRP spraying, and FRP encasement. Columns can be strengthened toupgrade the axial, flexural, and shear capacities for a difference of reasons, for instance, lack of confinement,seismic loading,eccentric loading, corrosion,and accidental impacts [27]. Confinement is usuallyused ina column, with the purpose of improvingtheir load-carrying capacity and in cases of seismic promotion, to upgrade their ductility.Confinement involves column wrapping withFRP sheets, place cured sheets with fiber running in thedirectionof circumferentialor prefabricated jacketing [26, 27].

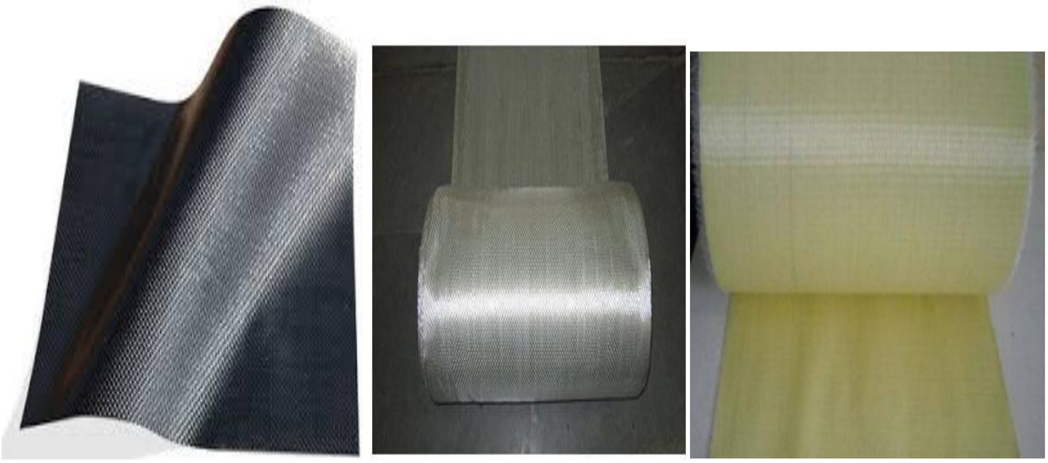
1-2 Objectives

The overall objectives were to quantify how the strengthening of concrete columns by FRP confinementimproves the axial performances of concrete columns under axial load condition, including load carrying capacity, compressive strength, and ductility,as well as to identify the factors that have the influence of on improving axial performance of confined columns under axial load.The specificobjectives are as follows:

1- To find out the effect of the compressivestrength of confined columns on improving axial performance under axial load.
2- To determine the influence of shape, aspect ratio, corner radius,and slenderness ratio of confined columnson the strength and ductility improvements.
3- To identify theeffect of the form of warping on improving columns axial performance under axial load condition.
4- To find out the influence of the thickness of FRP confinement on the amount of improving strength and ductility of confined columns.
5- To determine the effect of the type of fiber on the efficiency of FRP confinement.

II. STRENGTHENING OF CONCRETE COLUMNS UNDER AXIAL LOAD WITH FRP

The commonly used of FRP are carbon FRP (CFRP), glass FRP (GFRP) and aramid FRP (AFRP)typical forms of FRP composites shown in Figure 2-1.FRP encasement or sheets can utilize to upgradethe axial load carrying capacity of the column with theleast increase in the cross-sectional area. Confinement involves column wrapping with FRP sheets, place cured sheets with fiber running in the direction of circumferential or prefabricated jacketing. The use of confinement leads to a higher load-carryingcapacity [27]. Confinement is fewerin effect for square and rectangular thancircular RC columns because of the confining stresses that transmitted to the concrete at thecross-section four corners as presented in Figure 2-2, where the effectiveness ofconfinementexposedby gray shaded area for differentshapes ofcolumns. Confinement effectivenessrises with the corner radiusincreasing [28].



(a) (b) (c)

Figure 2-1 FRP sheet (a) CFRP, (b) GFRP, (c) AFRP

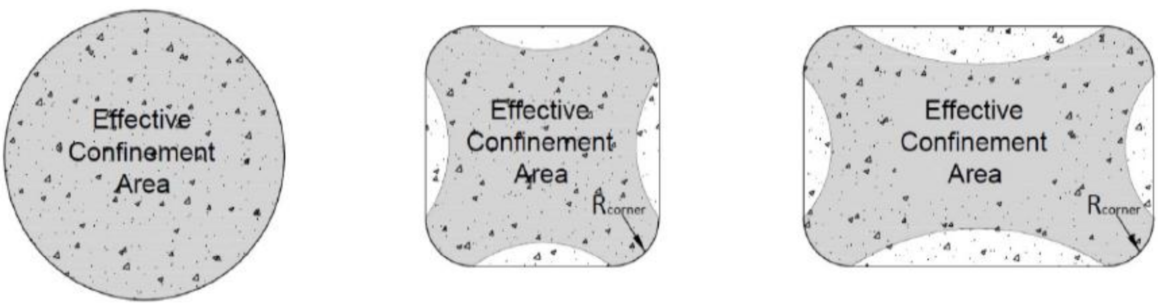


Figure 2-2 Confinement effectiveness areas in rectangular, square and circular columns [27]

Recent researchesdisplay that FRPapplyingin the lateral direction or hoop under axial loading can excellentlyupgrade the column's load-carrying capacity andconcrete strain capacity [29–34].In axially loaded columns, FRP confinement with sheets is considerably more in effect in upgrading concrete axialdeformation or capacity. Though the FRP amount and tensile strength areaccountable for growth in the strength,

theimprovement in ductility is contrarily proportional to the stiffness (Elastic-modulus) ofthe FRP,which meansthat the greater the growth in strength is the lesser the growth in ductility is,for a specific FRP wrap [29].The FRP wrap is effective in the strengthening of concentrically and eccentrically loaded columns,but the confinement efficiency drops when a column is under an eccentricaxial load [35, 36].
Some observational data on the influence of columns strengthening by FRPunder axial loadingexposed in Table 2-1. The growing in axial load capacities of the confined columns in these investigationsrangesfrom 6% to 177%. The increase relies on several variables, such asthe amount and properties of FRP reinforcement, concrete strength, the cross-section shape of thecolumn, and level ofaxial load.

Table 2-1 Experimental data toincrease in axial load capacities of axially loaded confined columns with FRP

Ref.	Test ID	Retrofit	Load Increase (%)
Matthys et al. [29]	K2 K3 K4 K5 K8	CFRP CFRP GFRP GFRP CFRP/GFRP	59.2 59.9 61.8 13.7 33.0
Wu et al. [30]	L-C-1 L-C-2 L-D-2 L-D-3 M-C-1 M-C-2 M-C-3 M-D-1 M-D-2 M-D-3 H-C-1 H-C-2 H-C-3 H-D-2 H-D-3	AFRP AFRP AFRP AFRP AFRP AFRP AFRP AFRP AFRP AFRP AFRP AFRP AFRP AFRP AFRP	68.6 176.7 30.5 61.2 50.7 112.8 136.7 6.8 19.6 29.4 21.8 52.2 102.1 14. 8 10.0
Toutanji et al. [31]	K9 K10 K11	CFRP CFRP CFRP	14.9 8.5 6.4
De Luca et al. [32]	R-0.5-5GA R-0.5-5GB	GFRP GFRP	13.0 18.0
Hu et al. [33]	F2-202 F3-202 F4-202	FRP and steel tube FRP and steel tube FRP and steel tube	24.0 42.0 64.0
Herwig and Motavalli [37]	Col. 5 Col. 6 Col. 7	GFRP GFRP GFRP	28.0 46.0 32.0
Abdelrahman and El-Hacha [38]	NR-CFRP	CFRP	38.0

2-1 Strengthening of concrete columnsunder axial load withCFRP

For concrete column strengthening under axial load, the most common systems of FRP are CFRP wrap.CFRPhas high durability,high tensile strength,corrosion resistance, andlightweight. Henceit is conceivable to meet the conditions for strengthening or structural rehabilitation; CFRP easy to put on in many positionssuch as columns, beams, decks,piles, andslabs [39].

A number of researchers haveinvestigatedalong the axial behavior of concretecolumn confinement with CFRR and the factorsthat has influence onthe performance of confined columns, includingconcrete strength, thickness of wrap (number of CFRP layers),wrapping condition (fully or partially wrapping),longitudinal reinforcement, geometric and loading faultiness, aspect ratio (length-to-width ratio) of the cross-section of column,corner radius of column cross-section.

In a research which has been done to determine the influence of concrete strength and CFRP thickness on carrying load capacity of the confined column with CFRP jacket under axial load, shortsquareRC columns with low to medium strength concrete under concentric axial loadtested, the result displayed that the CFRP confinement enhancedthe axial ductility and the axial load carryingcapacity of columns.The result also indicated that increasing the CFRP thickness led to in enhancing the axial ductility and the axial loadcarrying capacity, butthe wrapped columns with two layers and three layers of CFRP have a very closevalue ofmaximum axial strain and carrying axial load capacity,which it is mean that increasing theCFRP thickness will reach a high degree of efficiency and nomore. It wasconcluded that the improvement in the axial loading capacity wasmore significant for the more deficient concrete strength [40].

In another research which also the influence of CFRP wrapping thickness on the performance of confined columns was studied, it informed that increasing the CFRP layer number resulted in a higherincrease in the performance of the column andthe load-carrying capacity. In the same study using ofthe longitudinal CFRP straps in a combination of CFRP circumferentially wrapped was also investigatedunder large eccentrically axial load, it was described that the longitudinal CFRP straps considerably enhanced the columnperformance with a large eccentricity [41].

Inaddition to studies on CFRP columns confinement anotherstudybehavior of RCsquare columns fully and partially wrapped with CFRP underconcentric and15, 25 mm eccentric axial loads were investigated, the result of test is presented in Table 2-2, the result indicated that CFRP confinement promoted the strength of confined columns in both eccentric and concentric loading case, and the upgradein the strengthof columns with fully wrapped byCFRP was greater than the upgradein the strength of columns withpartially wrapped by CFRP under all three loading conditions [42].

Influences of aspect ratio (t /b mm) of the cross-section of the column on the strength and ductility improvement of the wrapped column with CFRC under axial load as well as fully and partially covered investigated in some study. Different aspect ratios (t/b) 1.0, 1.56, 2.04, and 2.56 were studied with both fully and partially wrapped columns by CFRP. The result of testing column specimens indicated that the enhancement in the carrying load capacity increases with the aspect ratio decrease. Without regard to the aspect ratio value, the fully confined columns showed a greater improvement in strength than the partially confined column as shown in Table 2-3 and Figure 2-3. For fully CFRP-wrapped columns with aspect ratios 1.0, 1.56, 2.04, and 2.56, the strength enhancements were 73, 44, 40, and 37%, respectively. Likewise, for columns that partially confined with CFRP, with the aspect ratios 1.0, 1.56, 2.04, and 2.56, the strength enhancements were 64, 27, 34, and 30%, respectively. From the result of the test, it can observe that theeffect of concrete confinement reduces when loading eccentricity increases [43].

Table 2-2 Experimental results of the specimen under the concentrically and eccentrically loaded [42]

Specimen	Axial loading condition	Increase in P_{ult} relative to the reference specimen (%)
Reference	Concentric	-
Partially wrapped		12.1
Fully wrapped		62.5
Reference	15mm eccentricity	-
Partially wrapped		9.6
Fully wrapped		37.5
Reference	25mm eccentricity	-
Partially wrapped		8.6
Fully wrapped		39.1

Table 2-3 Result value of tested columns [43]

Specimens	Aspect ratio	σc, (MPa)	Strength increasing (%)
Reference	1.00	19.53	-
Partially CFRP wrap		31.98	64
Fully CFRP wrap		33.73	73
Reference	1.56	20.30	-
Partially CFRP wrap		25.85	27
Fully CFRP wrap		29.18	44
Reference	2.04	18.28	-
Partially CFRP wrap		24.58	34
Fully CFRP wrap		25.50	40
Reference	2.56	18.18	-
Partially CFRP wrap		23.65	30
Fully CFRP wrap		24.88	37

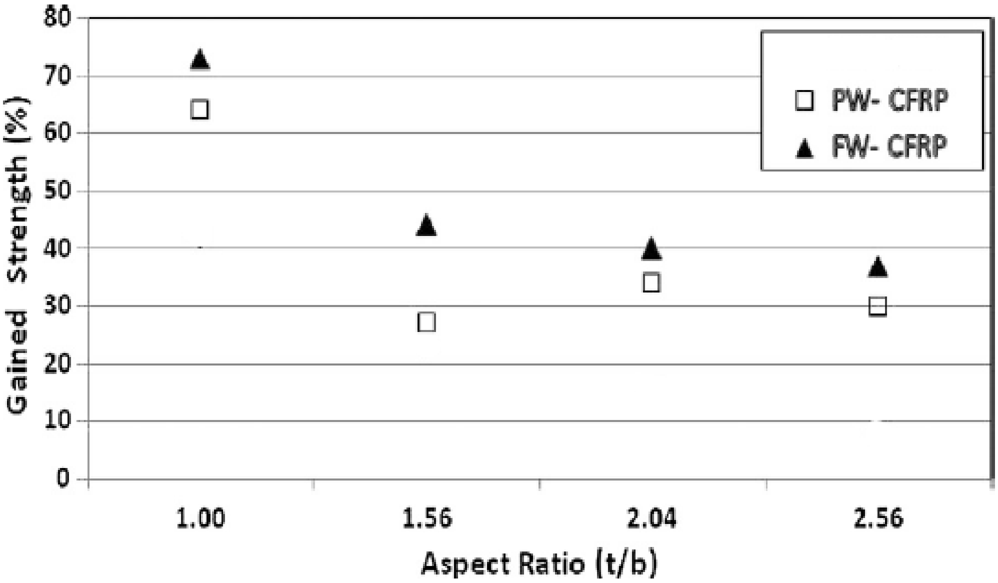


Figure 2-3 Increase in strength for the various aspect ratios [43]

The effects of the concrete strength,the layer number of CFRP,and the cross-sectionaspect ratio on the behavior of retrofittedcolumns with CFRP jackets under axial load havestudied in other research. Specimens with low strength concrete (3Ksi) and normal to high strength concrete (6Ksi), up to four layers CFRP, and aspect ratio 0.5, 0.65, and 1.0 prepared in the study, all samples tested under concentric axial load. The results of test indicated thatthe CFRP confinement provided improvement in both theductility andthecapacity of carryingload of the column, and also from the test result can observe that the strengthand ductilityenhancement of the CFRP confined columnis more substantial for lower strength concrete, and increasing layersnumber of CFRP confining leads to more improvement in strength as shown in Figure 2-4, it was also reported that column with greater aspect ratio showed lower improving in strength [44].

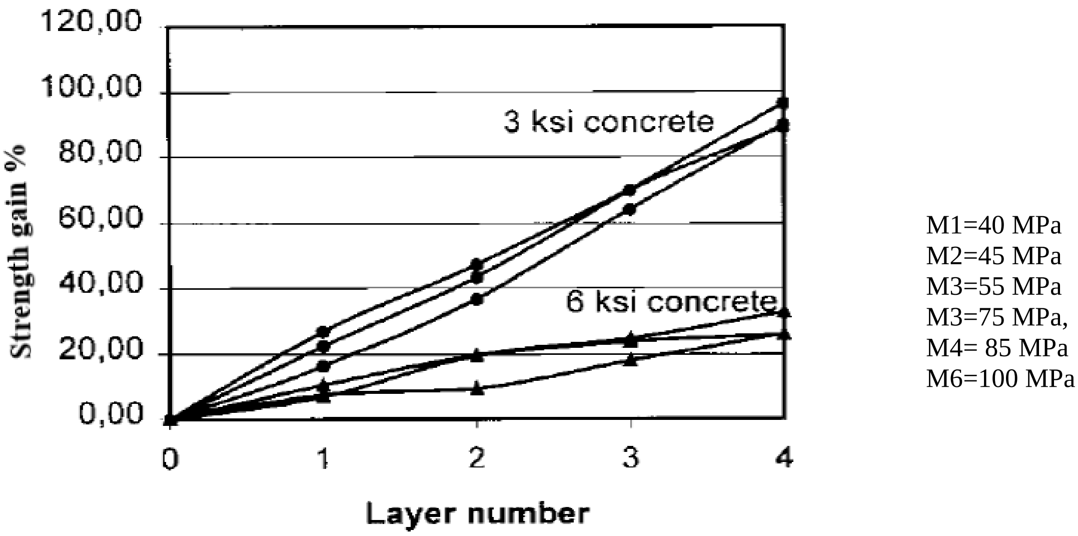


Figure 2-4 Compressive strength gain of concrete, % V.SNumber of confining layers [44]

Figure 2-4shows that for the same stiffness ofjacket (four layers),the three ksi concrete 90%, increase in the strength of the CFRP confined concrete achieved,while in the six ksi concrete, it was only 30%.

In addition to examinations on the behavior of columns confined with CFRP under axial load, theaspect ratio and the corner radius of column cross-sections have studied. Two square columns (355x355mm) cross-sectionwith(15mm) and (30mm) corner radius, and rectangular column (250x500mm) with (30mm) corner radius prepared for the study, the specimens confined with CFRP and tested under axial load. The outcomes of the experiment shown thatthe square column with the larger corner radius (30mm) has a resistance rise of 1.12 compared to the strength rise of 1.09 in the square column with the smaller cornerradius (15mm). Even the rectangular column has the same corner radius (30mm), but it has thelowest strength rise of all (1.07)due to its higher aspect ratio [45].

2-2Strengthening of concrete columnsunder axial load withGFRP

Glass FRP hassuperior physical and mechanical properties; in tension, they can be two times stronger than steel with only a 0.25 of the steel weight [46].GFRP composites have low stiffness, high elongation [23].GFRPwrapping isconsiderably efficient inimproving axial performance, but comparing to CFRP, it is smaller in effect on enhancing the axial performance of the confined column. It reported that for the same columns parameter and wrapped layers, the confined columns with CFRP show higher enhancement in ductility and load-carrying capacity than columns with GFRP confinement[47, 48].

Numerous of researchers have been investigated along the axial behavior of concrete column confinement with GFRR and the factors that has influence on the performance of confined columns comprising, concrete strength, thickness of wrap (number of GFRP layers), aspect ratio (length/width ratio) of the cross-section ofthe column, slenderness ratio (height-to-diameter ratio), corner radius of column cross-section.

In one of the studies which have performed in an axial performance of the GFRP confined column, the effect oftow parameters hasinvestigated; these parameters are the concrete compressive strength and number of wrappinglayers (composite thickness).In the study, high strength concrete cylinder columns with different compressive strength and (150*300mm) dimensions, preparedand then the samples are confined to 0, 1, and3 layers of GFRP. All samples tested under uniaxial compressive loads. The result of the experiment was indicated that GFRP confinement could upgradethe compressive strength and theductility of specimenssignificantly, and the percentage of improvementin both strength and ductility increase with increasing number of layers of GFRP, and it was observed thatthe percentage of increase inboth compressive strength and ductility was higher for specimens with a lower strengthof concrete as shown in Figure 2-5 [49].

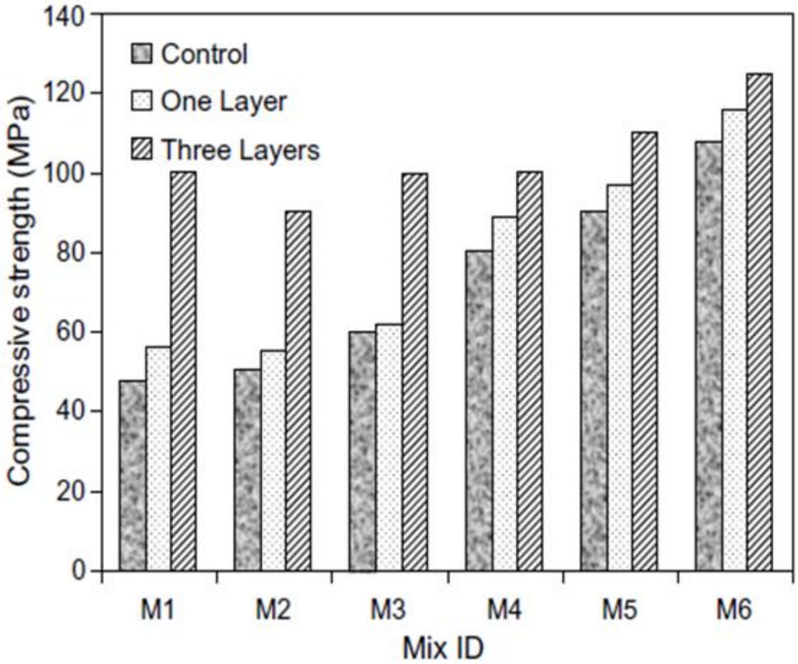


Figure 2-5 Compressive strength gain with the number of layers[49]

Cross-section shapes of confined columns with GFRP haveconsidered in aninvestigation. RC Columns with square, rectangular, and circular shapes withthe same cross-sectional area, 20mm of corner radius, andone layer of GFRP prepared, all the specimensloaded in axial compression. From the obtained result of the experiment, it concluded thatGFRP wrapping improves the carrying of axial load capacity. GFRP confining forcircular columns generates the most significant improvement in axial load, which 159%, increasing in axial load, noted. About 79% and 76%,improving in axial load for square and rectangular columns obtained, respectively.Square cross-section shape is better in the axial performance of GFRPconfinement than the rectangular cross-section shape due to its lower aspect ratio [50].

The thickness of the jacket, diameter of the column, slenderness ratio (height/diameter ratio=H/D) have studiedin other research. Severalsamples of the concrete cylinder with a different height (H=300mm, 450mm, 600mm, and 750mm) and two different diameters (D=150mm, and 250mm) prepared, then samples were confined with GFRP with 0,2, and 3 layers. Samples were axially loaded. The outcome of the experiment shown in Table 2-4. From the result of examination it can observe that (1) value of strength 91.9 MPa and 81.2 MPa for H/D=3 and 4, respectively, this is mean thatincreasing slenderness ratio (H/D) leads to reduction in strength increasing(2)for the sameH/D,strength of confined sample were 89.1 MPa for two layers of GFRP, and 128.1 MPa for three layers of GFRP, this is mean thatfor the same H/D increase the number of the layersleads to higher improvement in strength (3)for constant H/Dincreasingdiameterof the specimens, leads to a substantial reduction in thestrength of the cylinders [51].

Table 2-4 Samples identification and characterization [51]

Specimen ID	**Height (mm)**	**Diameter (mm)**	**Slenderness ratio(H/D)**	**Layers of GFRP**	**Compressive strength (MPa)**
EE-45-A	450	150	3	2	91.9
EE-60-A	600	150	4	2	81.2
EE-75-A	750	150	5	2	89.1
EE-75-C	750	250	3	2	55.8
EE-75-D	750	150	5	3	128.1

Performance of square concrete columnswith three various corners radii R=0 mm, 8 mm, 16 mmstrengthened with (GFRP) jackets andsubjected to axial compressive loading, 0, 1, and 2 layers of GFRP were used. From the result of an experiment, it was concluded that thecorner radius and the GFRP layernumber are the mainparameters, having a significant outcome on the behavior of confined specimens (as shown in Figure 2-6), the strength gain of confined specimens was increased by corner radii as well as the number of GFRP layer. In the specimen with 16mm corner radius and two layers of GFRP strength increased by 36 % with the respect of control specimen, while in the confined sample without corner radius and one layer of GFRP only 2% of strength increased concerning control specimen due to high-stress concentration at corners [52].

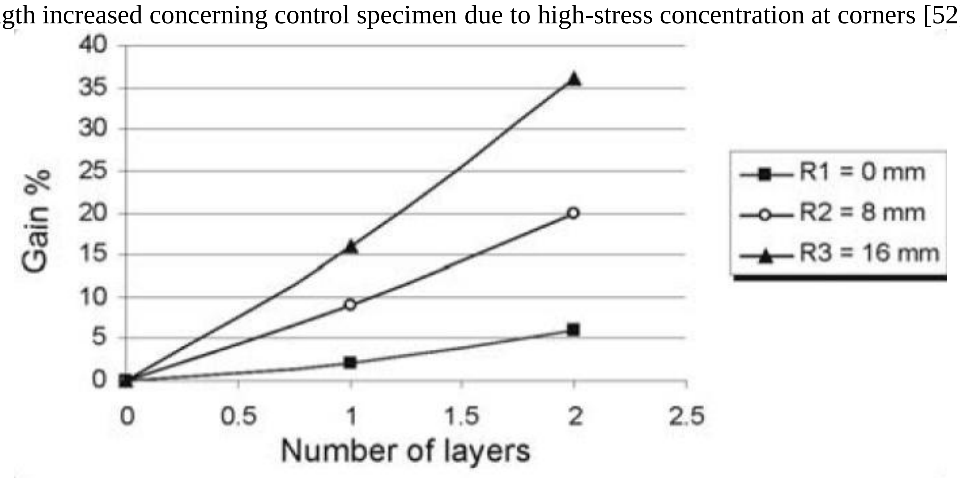


Figure 2-6 Compressive strength gain in versuslayersnumberof GFRP [52]

Confined columns with GFRP and hybrid FRP (glass-basaltFRP) tested under axial load in another work, and columns parameter, namely cross-section shape and aspect ratio investigated to determine axial performance. It concluded that the FRP wrapping improves concrete axial strength, but it is furtherin effect in improving concrete strain capacity.Moreover, the shape and aspectratio of the cross-section affects the efficiency ofthe confinement. Efficiency is greater for square than for rectangular cross-section and drops as the aspect ratio of rectangular cross-section increases. Besides, the axial performanceof column confinement with the glass-basalt hybridFRP and GFRP laminates was similar [32].

2-3Strengthening of concrete columnsunder axial load withAFRP

AFRP is dissimilarfrom GFRP and CFRP in the properties of elastic modulus,strength, and ultimate rupture strain. For example, the elongation-to-disruptionof aramid FRP is 60% greaterthan carbon FRPandmarginally higherthan glass FRP. In contrast, thetensile strength of aramid FRP is 20% lesser than the tensile strength of carbon FRP,aramid FRP higher in strength than glass FRP [53].Most of the earlierinvestigations were focusedon confined columns with CFRP and GFRP, while fewer concentrated on the confined columnswith AFRP.

Square shortcolumns withdifferent compressive strength 46.43 MPa, 78.50MPa, and 101.18 MPa cast and confined with 0, 1, 2, 3 layers AFRP sheets. Tree parameters, namely, the concrete strength, the form of AFRP wrapping, and the numbers of AFRP sheetsare studied. In some specimens, the AFRP sheets wrapped entirely,and in others, the sheets wrapped partially. All samples tested under axial compressive loading. It reported thatthe strength and ductility of theconfinedcolumns wereimprovedwhen fully covered withAFRP, though only the strength was enhanced when partially wrapped with AFRP sheets. It was also reported that strength and ductility of confined columns enhancewith increasingthequantity of AFRP sheets, as well as strength and ductility improvement is higher in the column with lower concrete strength [53].The same result obtained in another study about the number of AFRP wrapping, where square concrete columns were confined to 0,1,2, and 3 layers of AFRP and tested under axial load. From the result of an experiment, it concluded thatincreasing theAFRP confinement leads to improvements in ultimate axial strength and ultimate axial strain of confined columns, and this improvement increase with addition in number of confinement, in this study failure mode of columns confined with CFRP, GFRP, and AFRP were compared, and it reported that the failure of the confined columns with AFRP and CFRP were more violent than the columns confined with GFRP and often even explosive [54].

In addition to studies on AFRP, the effect of the concrete compressive strength, the system of AFRP confinement,and the number of the layers of AFRP on the axial performance of circular HSC columns wrapped with AFRPsheet have investigated in another study. Columns wrapped 0, 1, 2, and 3 layers, some specimens fully covered with AFRP, and others are partially wrapped,samples tested under axial compressive load.From the test result, it was concluded that the compressive strength of theAFRPwrapped columnsis enhanced as the number of the layers of AFRP increases, and strength improvement is higher in columns with full confinement than partially confinement, and also strength improvementhigher when the strength of concrete is lower. It was also reported that in AFRP confinement improved ductility significantly in columns which fully wrapped with AFRP, but in columns which partially confined with AFRP, the enhancement in ductility is limited [30].

III. CONCLUSION

Strengthening column with FRP in the form of confinement is usually used in a column to improve their load-carrying capacity and, in cases of seismic promotion, to upgrade their ductility. FRP column confinement dramatically improves the axial performance of concrete columns under axial load. Still, many parameters influence this improvement, including, concrete strength, the thickness of wrap (number of CFRP layers), wrapping condition (fully or partially wrapping), longitudinal reinforcement, load eccentricity, aspect ratio (length-to-width ratio) of the cross-section of the column, corner radius of column cross-section.Based on many previous investigations, the following conclusions can drown:

1- Improving the strength and ductility of high strength concrete confined columns with CFRP, GFRP, and AFRP than in lower concrete strength.
2- Increasing the number of layers of CFRP, GFRP, and AFRP leads to more considerable improvement in strength and ductility of confined concrete columns.
3- Confinement is fewer in effect for square and rectangular than circular RC columns confined with CFRP, GFRP, and AFRP.
4- The efficiency of the confinement decreases with increasing aspect ratio (length/width) ratio.
5- Increasing the corner radius of the cross-section of confined columns with CFRP, GFRP, and AFRP leads to a more significant improvement
6- The increasing slenderness ratio of columns leads to a reduction in strength improvement.
7- The effect of concrete confinement reduces when the eccentricity ofloading increases.
8- Strength improvement of confined columns is more significant in fully wrapped columns with CFRP, GFRP, and AFRP than partially covered columns.
9- The ductility of fully wrapped columns with FRP is dramatically increased, but in columns which partially confined with AFRP, the enhancement in ductility is limited.
10- FRP confinement is better in improving strength than improving ductility.
11- The efficiency of CFRP is higher than that GFRP has.
12- The axial performance of column confinement with the glass-basalt hybrid FRP and GFRP laminates is similar.
13- Failure of the confined columns with AFRP and CFRP were more violent than the columns confined with GFRP and often even explosive.

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