Review on Retrofitting of Column by FRP, Ferrocement, Steel, Thin Concrete and TRM

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Abstract— **Many researchers and designer keep the concept about structure designing is " Strong column, weak beam " which follows for earthquake resistance building. So, it is very important to design strong columns. Due to Engineers or owner sincerity or insincerity, the design and construction of building is not properly practiced and implemented. That's why the proper strength of building cannot achieved. Lack of awareness, natural climate, seismic or other causes reduce the structure (specially column) strength. So, retrofitting is one of the methods to regain strength in damaged column. Retrofitting means addition of new technology to older system; Jacketing is a method of structural retrofitting and strengthening. Encasement using suitable materials is a method used to restore or increase the size of a structural member. This process, known as jacketing, is commonly employed to bring the member back to its original dimensions. Here many researchers' investigations are reviewed for comparing five types of jacketing.**

Keywords— **Retrofitting, FRP, Ferrocement, Steel, Thin Concrete, TRM**

I. Introduction

The phrase "retrofit" refers to a broad range of treatments that include preservation[1], rehabilitation [2], restoration [2] [3], and rebuilding [3], [4]. The choice of an acceptable treatment technique is a significant difficulty in the retrofit process[1]. The most commonly practiced, widely used, and effective techniques of retrofitting is jacketing[5]. There is little research work on quantifying the effect of different types of jacketing in column. Some of them; Muhammad Hussain et al. (2015) proposed[5] that the influence of carbon fiber reinforced polymer (CFRP) jacketing on compressive strengths of cylindrical concrete was examined[5]. Amrul Kaish.A.B.M et al. (2013) [5] focuses on how to enhance the square ferrocement jacketing process for re-strengthening RC building columns that have already been built [5]. The impact of ferrocement and fiber reinforced polymer jackets on the restoration of post-heated square and circular-reinforced concrete columns was compared by Aqub. M et al. (2013)[5].

In all these research, the test specimens considered are non-heated and non-repaired, post-heated columns. [3][6].

II. Retrofitting

1. Fiber Reinforced Polymer (FRP) Jacketing:

Fiber reinforced polymer(FRP) is composed of glass, carbon, or aramid fibers with are mixed along with vinylester, epoxy or polyster[7]. In FRP, the fibers are the primary load-bearing component, while plastic matrixs transfer shear loads[8].

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Parvin et al(2001) investigated the behavior of fiber-reinforced polymer (FRP) jacketed square concrete columns exposed to eccentric stress. [9][10][11]. The data show that a smaller enhancement factor is taken into consideration while designing eccentrically loaded FRP jacketed columns [9][10].

Fig 1: FRP for retrofitting of RC columns [8][13][11]

Experimental studies [12] [13] [14] [15] [16] [10] [11] shows that the most common form of failure bonded by FRP sheets is the bottom strip being debonded from the concrete surface.

According to Ayush Srivastava (2016)[17],
For two layers of FRP,
Pu = 1416.79 KN = 1416.79 * 103 N
Area = 80,500 mm^2
So, strength = 17.59 N/mm^2

For one layer of FRP,
Pu = 1558.545 KN =1558.545 * 103 N
Area = 80500 mm^2
So, strength = 19.36 N/mm^2

There are different types of FRP in practice [18][19], such as-

A. Carbon Fiber Reinforced Polymer (CFRP)
B. Glass Fiber Reinforced Polymer (GFRP)
C. Aramid Fiber Reinforced Polymer (AFRP)

A. Carbon Fiber Reinforced Polymer (CFRP):

Reinforced with carbon fiber Polymers are often employed in industries with masonry building for retrofitting of existing building because of its low-density, increased corrosion resistance, relatively high specific strength along with stiffness, increased fatigue performance, and high elasticity modulus, ranging between 200 and 800 GPa[18][19][20]. The major advantage of utilizing CFRP as reinforcement is to decrease rusting and corrosion of the the steel.[21][18]. The CFRP is made of ultra-thin carbon fibers with a diameter of 5-10 µm that are embedded in a polyester resin[21][18]. Although CFRP reinforced concrete is capable of sustaining and resisting flexural loads, its failure pattern is concerning since it snaps abruptly, which is not desirable for buildings. [21]. Because of its high strength to weight ratio, improved fatigue performance, and corrosion resistance, it has become extremely popular in automobile, fuselage, wind turbines and other industry applications[18][22].

B. Glass Fiber Reinforced Polymer (GFRP):

Glass Fiber Reinforced Polymer (GFRP) is a FRP that is made of fine glass fibers[18], silica sand, limestone, folic acid, and other minor ingredients [19]. Although it has lesser strength and stiffness than carbon fiber, the material is often less brittle and raw resources are less costly. [23][18]. When compared to normal reinforced concrete, the additional glass fiber raises the toughness by 1157%[24]. When compared to ordinary reinforced concrete, the modulus of elasticity of glass fiber reinforced concrete improves by 4.14%. [24][25][26]. Comparing on days, this ratio increase in compressive strength of various grades of glass fiber concrete mixes is 37%, and the percentage increase in flexural strength is 5.119%. [24][27][26]. Practically speaking, the addition of glass fiber enhances the compressive strength, but if too much fiber is used, it can actually decrease strength due to reduced workability[25]. Concrete bridges, parking garages, tunnels, and water tanks have all benefited from the usage of GFRP bars as a key reinforcement. [28][18].

C. Aramid Fiber Reinforced Polymer (AFRP):

The aramid fiber is made up of aromatic polyamides (aramids) and is reliant on paraphenylene teraphthalamide, which adds an amide group[29] and benzene rings into polyamide molecules [30][31]. The inclusion of aramid fiber improves tensile strength and the higher the volume content of fiber, the greater the benefit [32][30]. It was discovered that when AFRP concrete is exposed to temperatures more than 300C, the majority of its mechanical qualities are lost[29] [33] [30]. Aramid fibers are abrasion-resistant when subjected to cyclic stress. They can endure extreme temperatures and are five times stronger than steel[34]. With a 2.2% to 4.4% elongation, the tensile strength stays within 2400 and 3600 N/mm^2. The tensile modulus ranges between 60 and 120 GPa. [35]. Because of its good resistance to abrasion, Good resistance to organic solvents[31], non-conductive[31], low melting point[34], low flammability[29] and good fabric integrity at elevated temperatures[34] it is mostly in use in aerospace, military applications and so on[33].

2. Ferrocement Jacketing:

Wire meshes [36][1] and cement mortar make up ferrocement, a building material [37][38][39]. In order to manufacture ferrocement, 95% cement mortar [37] [39] and 5% wire mesh are utilized [36] [38] [39]. It is resistant to elongation[40], ductility [41] and impact loads on reinforced-concrete columns[42] and it is fire[41] and corrosion resistance[42]. Because of its low self-weight, lack of qualified personnel, and absence of requirement for framework, ferrocement has a wide range of applications in building [43] [41] [42]. Ferrocement confinement increased the ultimate load-carrying-capacity of columns[46]–[48]. It is appropriate for low-cost housing since it is inexpensive and can be completed by inexperienced labor [1], [49], [50]. High strength, less weight, and strong environmental resistance are some of the advantages of this technology over other similar procedures[5] [51].

According to Aiswarya T S and Nithin Mohan (2013)[39],

P_u = 64.75 KN = 64.75 * 10^3 N

Area = 150 * 150 mm^2 =22500 mm^2

So, Strength = 2.87 N/mm^2

3. Steel Jacketing:

Steel jacket is another potential strengthening solution where steel plates or angles are used to confine the column concrete with various configurations like steel wrapping for circular columns, steel plating and steel caging[52], [53]. Steel caging is one of simplest and common technique among them. It consists of four steel angles, placed at each corner of a RC column and steel battens[53]. Non-shrink cement mortar or epoxy grout is used to cover the narrow gaps between the concrete and the caging [53][54]. It enhances the structure's overall seismic performance by increasing the lateral strength, axial load carrying capability, ductility, and shear capacity of structural members [53][55]–[58]. The technique utilizes external lateral pressure to securely fasten steel jackets onto concrete surfaces, eliminating the need for grout typically used in traditional jacketing methods. [54][59]–[61]. A fair agreement can be done by using steel jacketing because of its more flexural strength and longevity.

According to N. Islam and M. M. Hoque (2015)[53],

P_u = 2414 KN =2414 * 10^3 N

Area = 150 * 150 mm^2 =22500 mm^2

So, Strength = 107.28 N/mm^2

4. Thin Concrete Jacketing

Thin concrete jacketing is one kind of column jacketing [66]. Repairing technics must be inexpensive, comparatively low cost and fastly executed. And, thin cement does the exact thing, as its execution time is fast [67] [68]. It involves enlarging the existing cross section with a new layer of concrete that is strengthened with both longitudinal and transverse reinforcement [66]. The lateral strength of the specimen with a jacketing height of 100 cm [66]. is shown to rise by 35%.

From[62], “Applying two jacket thicknesses of 25 and 35 mm with A-B and X-Y jacketing types considerable improves ultimate load-carrying capacity in almost a similar rate to the rate of increase in jacketing area. Repairing and strengthening using UHPFRSCC and NSC-4.75 jackets significantly increases the ultimate load-carrying capacities and axial displacements of the specimens with respect to the UC and MC reference columns”.

According to Bassam A. Tayeh et al. (2019)[62],

For Normal Strength Concrete,

P_u = 859 KN = 859 * 10^3 N

Area = 289 cm^2 = 289 * 10^2 mm^2 =28900 mm^2

So, Strength = 29.72 N/mm^2

For Ultra High-Performance Fibre-Reinforced Self-compacting Concrete (UHPFRSCC),

P_u = 1356 KN = 1356 * 10^3 N

Area = 289 cm^2 = 289 * 10^2 mm^2 =28900 mm^2

So, Strength = 46.92 N/mm^2

5. Textiles Reinforced Mortar (TRM) jacketing:

When different types of fibers are combined with cementitious matrices, such as cement-based mortars, it results in composite materials that exhibit impressive strength capabilities. The new materials are known as Textiles Reinforced Mortars (TRM) due to the manufacturing of fibers in fabric form and the use of an inorganic matrix. (cement based mortars) [69] [70]. TRM are referred to as textile meshes comprised of long woven or unwoven knitted fibers in at least two (usually orthogonal) directions, coated with inorganic binders [71]. Epoxy resin or inorganic mortar were used as the bonding agent, which was applied on top of to the of concrete surface [72] [73]. TRM jacketing is a sustainable solution for improving the confinement and shear capacity of reinforced concrete members, both of which are critical in seismic retrofits [73] [75].

According to T.C. Triantafillou and C.G. Papanicolaou[63], [64],

$P_u = 116.5$ KN $= 116.5 * 10^3$ N

Area $= 250 * 250$ mm$^2 = 62500$ mm^2

So, Strength $= 1.86$ N/mm^2

III. Comparing on Jacketing

TABLE I. Comparism strength between different types of jjacketing

Types Of Jacketing	*Strength, MPa*
Fibre Reinforced Polymer (FRP) jacketing	17.59 (For two layer of FRP)
	19.36 (For one layer of FRP)
Ferrocement jacketing	2.87
Steel jacketing	107.28
Thin Concrete Jacketing	29.72 (For Normal Strength Concrete)
	46.92 (For Ultrahigh-Performance Fibre-Reinforced Self-compacting Concrete)
Textiles Reinforced Mortar (TRM) jacketing	1.86

Comparative study of increase in strength depicted clearly that Steel jacketing exhibits higher than all of the jacketing.

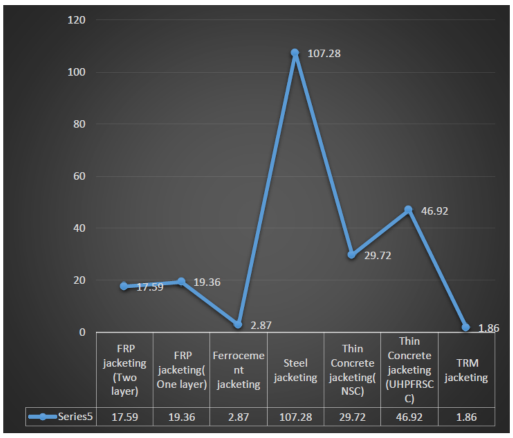

Fig 2: Strength variation between different types of jacketing

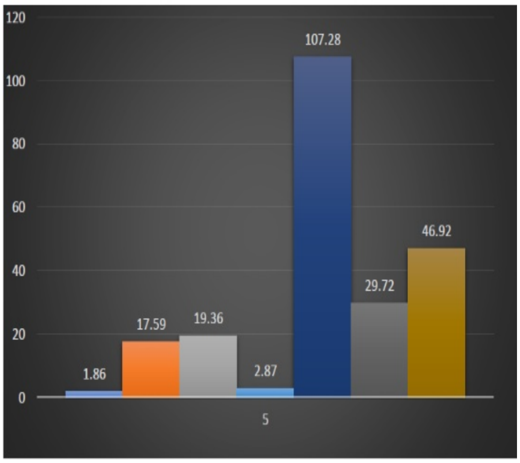

Fig 2: Strength variation between different types of jacketing

TABLE II. Comparism cost between different types of jacketing

Types Of Jacketing	*Cost*
Fibre Reinforced Polymer (FRP) jacketing	Comparatively much more and not available in Bangladesh.
Ferrocement jacketing	Comparatively less
Steel jacketing	Comparatively more
Thin Concrete jacketing	Comparatively much less
Textiles Reinforced Mortar (TRM) jacketing	Comparatively so much less

IV. Conclusion

This paper offers a systematic discussion of several ways for strengthening and repairing reinforced concrete columns. According to the findings of this study, there are several effective strategies for restoring ancient and damaged structures. These solutions can help to ensure the long-term viability of existing reinforced concrete infrastructure by allowing them to expand their capacity without having to rebuild or replace it. Each methodology is thoroughly described, with benefits and drawbacks noted. However, when compared to FRPs, the aforementioned approaches may be more expensive, but when considering the structure's safety, these approaches may be considered.

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