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RESEARCH ARTICLE

A comparative study on retrofitting concrete column by FRP-Wrapping and RC-Jacketing methods: A feasibility study for Afghanistan

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Abstract

Background/Objectives: FRP (Fiber Reinforced Polymer) has a wide range of application areas within the construction industry and is used in various forms and shapes, primarily for maintenance purposes. Using FRP has numerous advantages and disadvantages driven by several factors, including the country where it is used. The present paper focuses on the feasibility of using FRP in Afghanistan, considering load carrying capacity, cost, time efficiency, and environmental concerns as the main parameters. **Method**: In this numerical study, RC-jacketing and FRP-wrapping methods were evaluated for strengthening/repairing RC columns, and a comparison of the two methods was carried out to understand which approach better meets the maintenance needs in Afghanistan. **Findings**: As a result, the RC-jacketing method was more efficient in terms of cost and strength, while the FRP-wrapping method proved its efficiency in terms of time and lower emission of CO_2. Moreover, the RC-jacketing method was found to be more suitable and aligned with the country's current architecture. Overall, as the cost is the leading parameter in a developing country like Afghanistan, RC-jacketing was more suitable for conducting the maintenance work. Additionally, the authors also recommended using the FRP-wrapping method in some particular circumstances where the RC-jacketing method was believed to be less efficient.

Keywords: RC-Jacketing; FRP-Wrapping; retrofitting; reinforced concrete columns; strength; cost-effectiveness

1 Introduction

Most of the structures in Afghanistan are weak and vulnerable to collapse because of the continuous war that lasted almost three decades[(1)]. These structures were bombed and subjected to different kinds of dynamic loads, which are still going on. Another reasons are; use of unstandardized and low-quality construction material, equipment, practices, overloading, aging, and corrosion, which significantly weakens even new structures and requires maintenance (2–12). Considering that building new structures in totality is costly and entirely out of Afghanistan's budget (and other third-world countries), a cost-effective strengthening method should be introduced. Recently, for the strengthening of the weak and deteriorated columns, fiber-reinforced polymer (FRP), which is a new maintenance material in Afghanistan, is being used and thought to be an ideal replacement for RC-jacketing.

FRP has caught the researchers' attention as a new strengthening material, and several studies have been conducted on its structural behavior and strength used as a maintenance material in the civil engineering field. FRP has been under study for few decades as a new strengthening method where it has proved its efficiency tremendously. Several studies have been conducted to scrutinize FRP's overall effectiveness, including strength and boundary conditions (13–17) and (18). FRP wrapping has promised improved ductility by averting brittle shear failure of columns (19,20), increase in shear strength (21), and can delay the damage in compression zone and buckling in longitudinal reinforcement (22). Moreover, it prevents brittle shear failure (23), and the nominal shear capacity of the column can also be attained (24). Besides, it prevents the Poisson's effect by providing confinement pressure and keeping the RC column in its three-dimensional state. However, debonding is a major issue with FRP wrapping assessed so far (25). Moreover, while using FRP wrapping, it was also noticed that displacement ductility and drift capacity do not increase beyond a specific limit (26). Furthermore, the circular or elliptical wrapping (for circular or elliptical columns) is recommended because square or rectangular wrapping (for square or rectangular columns) cannot resist slipping (Figure 1) (27,28). Its brittle behavior, low resistance to heat, and lower ductility than steel is another demerit that should be considered while using this material. While FRP has been scrutinized as a strengthening material based on its structural characteristics, but some parameters directly affect the decision while choosing an efficient strengthening method for structures, which are often ignored by most of the studies, such as its total cost and time analysis, including environmental safety concerns (CO2 emission amount). On the other hand, RC-jacketing, which is one of the most frequently used techniques to strengthen reinforced concrete (RC) columns, has also been studied by several researchers for strengthening the weak structures to efficiently restore the load-carrying capacity (29,30). A statistical study conducted to investigate methods used for strengthening 114 concrete structures damaged by an earthquake in 1985 revealed that RC-Jacketing was widely used as the strengthening method (31). Looking at RC jacketing's structural characteristics, this method can enhance both strength and ductility with stiffness (32). In addition to increasing the target member's strength and ductility, it uniformly improves the structure's overall behavior. It was also proved that RC jacketing could change a strong beam weak column's condition into a strong column weak beam (33). Furthermore, the RC-Jacketing method can enhance a damaged column's strength three times as the original one (34). A similar study on RC frames showed a five times increase in lateral strength than the original frame (35). However, the RC-Jacketing procedure is not sophisticated and needs much care during surface curing; else, the jacket can be separated (36). On the other hand, RC jacketing can enhance a moderately damaged column's strength only and is useless for strengthening severely deteriorated columns (37). Moreover, this method changes the column's cross-sectional area, adds to the members' brittleness, and decreases effective floor area, which also ends up in major architectural changes of the structure. Further, this method adds more load to an already weak structure, which puts rest members under extra load and leaves the whole structure vulnerable to further retrofitting. At the same time, it is more critical with high-rise structures. Drilling and providing holes for longitudinal reinforcement is also problematic in this method and can damage the structure if proper care is not taken (38).

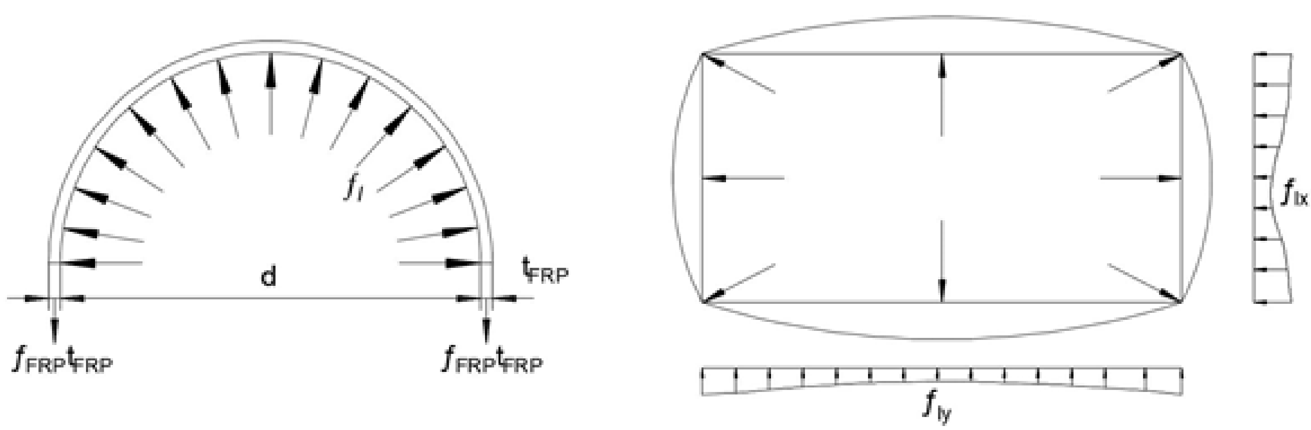

Fig 1. Confining pressure distribution of rectangular and circular cross-sections; *f*l – the confining pressure; *f*FRP – FRP longitudinal tensile strength; d – the diameter of the RC column cross-section; tFRP – thickness of the composite material; *f*lx,y – the confining pressures are given by x- and y-directions. (Ciprian.C et al.)

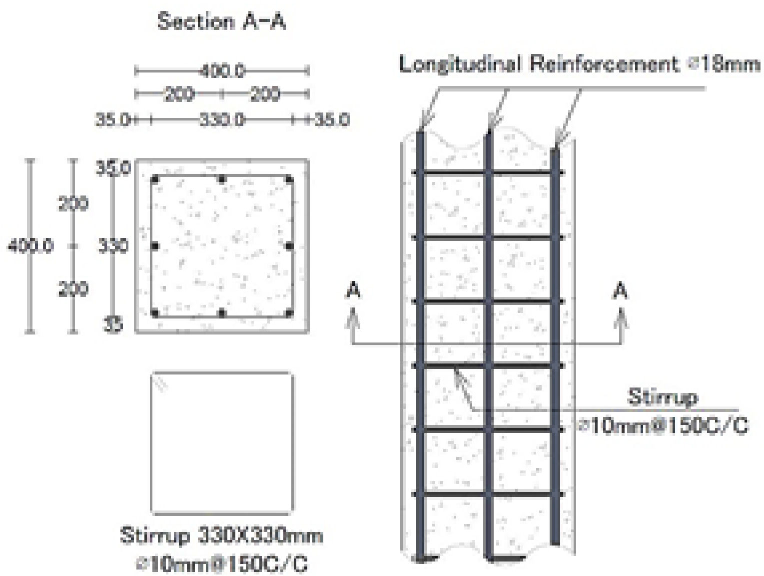

Fig 2. Geometry and reinforcement details of the original column

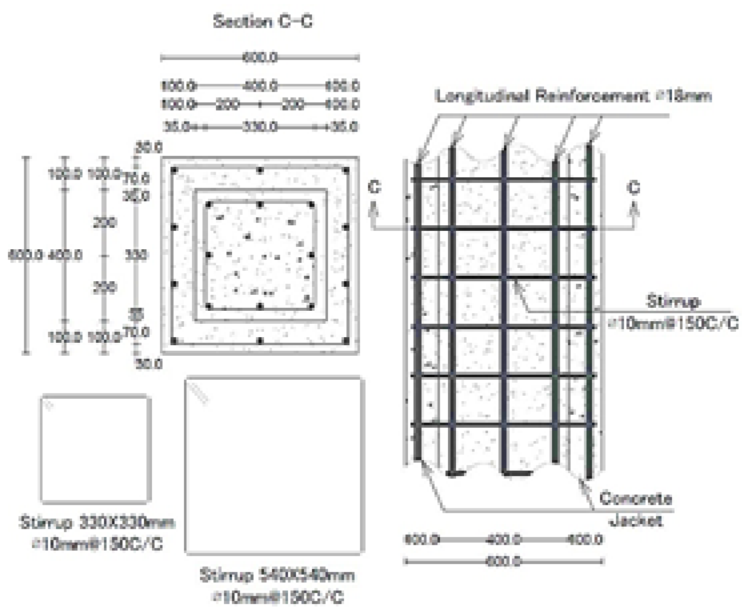

Fig 3. Geometry and reinforcement details of RC-jacketed column

Finally, several studies on the structural behavior of both FRP wrapping and RC-Jacketing have been conducted. Fewer studies have been presented to show their efficiency in cost, time, and environmental safety, which are major concerns in a country with limited resources like Afghanistan. Thus, this paper studied the feasibility of using the FRP-wrapping method as a strengthening/repairing material for concrete columns by comparing it to the RC-jacketing method by considering the mentioned parameters. The result of this numerical study showed that the FRP-wrapping method was more efficient in terms of time and environmental protection (less CO_2 emission); however, the RC-jacketing method was more efficient in terms of strength (recovering load carrying capacity), cost, and better matching the architecture of the country.

2 Methodology

The feasibility study of using FRP as a strengthening material for columns in Afghanistan is based on parameters such as its strength, cost, time, and environmental concerns (CO_2 footprint). This study includes the following steps for evaluating the feasibility of using the FRP-Wrapping method in Afghanistan widely.

1. A typical column of (450mmx450mmx3000mm) was considered for the study, which was projected to axial loading, and the load-carrying capacity was calculated for RC-jacketing and FRP wrapping methods before and after deterioration.
2. Architectural characteristic (geometry of structures in Kabul city was presented)
3. Cost analysis for both methods was presented.
4. Time analysis of both methods was presented.

2.1 RC jacketing

2.1.1 RC jacketing

Currently, the Indian code is utilized for calculations as Afghanistan codes are still under process. IS 456: 2000 section 39.3 proposes the following formula for calculating the column's load-carrying capacity/strength (Fiq. 2,3).

$$\mathbf{Pu} = \mathbf{0.4} \times \mathbf{fck} \times \mathbf{Ac} + \mathbf{0.67} \times \mathbf{fy} \times \mathbf{Asc} \tag{0.1}$$

Where;

$$\text{column} = 400 \times 400 \times 3000 \text{ mm}$$

Load carrying capacity before deterioration.

$8\phi 18$mm 156c/c has been used

$$Pu = 2283KN$$

Load carrying capacity after deterioration.

$fck = 18.2$ after 40% deterioration and around 60% of corrosion is calculated as bellow

$$Pu' = 1356.05KN$$

Load carrying capacity after jacketing.

$$\mathrm{Pu'} = 0.4 \times \mathrm{fck} \times \mathrm{Ac'} + 0.67 \times \mathrm{fy} \times \mathrm{Asc'} \tag{0.2}$$

$Ac' =$ Jacketing concrete area

$Asc' =$ Jacketing steel area

The area added as a jacket can also be calculated through the formula provided by ACI 318-08 as bellow

$$A_{g\ jacket} = \frac{P_u}{0.6375\left(\left(0.85 f_c'\right) + \rho\left(f_y - 0.85 f_c'\right)\right.} \tag{0.3}$$

However, this paper has used the IS (Indian Standard) code as it is most often used in Afghanistan. Thus, according to IS 15988:2013, 8.5.1.2 C, the minimum jacketing provided on each side should be 100mm.

$$= (600 \times 600) - (400 \times 400) = 200000mm^2$$

For maximum condition is calculated

$$As_{Jacket} = \frac{4}{3} As_{Concrete\ Original}$$

$10\phi 18$mm have been used

$$RC\ Jacket\ Strenth = 2894.66KN$$

$$Total\ Strength\ after\ jacketing\ \left(Pu''\right) = Deteriorated\ strength + Jacketing\ Strength$$

$$Pu''1 = Original + Jacketing\ Strength = 2283KN + 2894.66KN = 5177.66KN$$

$$Pu''2 = Deteriorated + Jacketing\ Strength = 1356.05KN + 2894.66KN = 4250.71KN$$

Strength increase in control column case

$$\left(\frac{(5177.66 - 2283)}{2283}\right) \times 100 = 126.8\%$$

Strength increase in deteriorated column case

$$\left(\frac{(4250.7 - 1356.05)}{1356.05}\right) \times 100 = 213.5\%$$

2.1.2 FRP Wrapping

Axial strength for the column can be calculated by equation (1.1) with the replacement of $f'cc = fck(1 + \alpha pc \times \omega w)$. The calculations are conducted in accordance with IS 15988: 2013 guidelines. The calculations are for two layers of FRP (Figure 4).

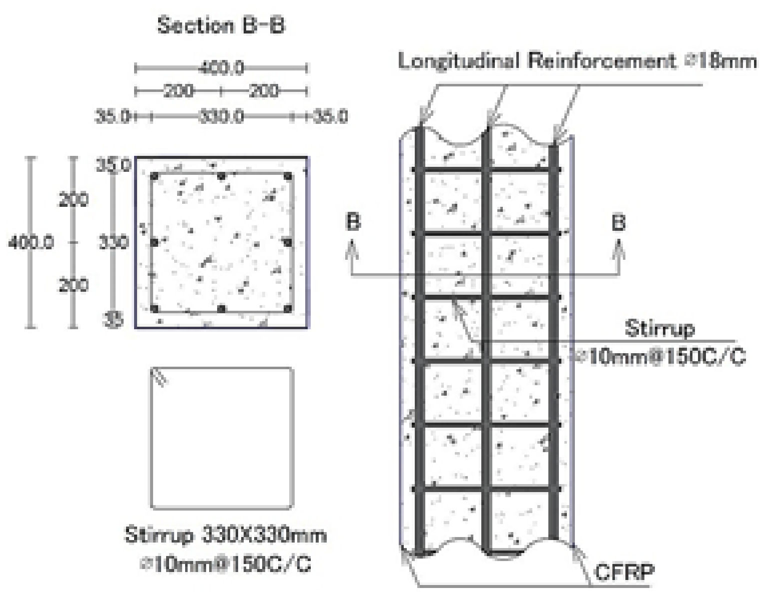

Fig 4. Geometry and reinforcement details of FRP-wrapped column

$$Pu' = 0.4 \times f'cc \times Ac + 0.67 \times fy \times Asc$$

$$f'cc = fck\,(1 + \alpha pc \times \omega w)$$

$$Pu = \phi c \times \alpha \times f'cc\,(Ag - Ast) + \phi s \times fy \times Ast$$

The calculation for two layers of FRP where α is equal to 0.6

$$FRP\ Wrapped\ Original\ Column\ Strength = 4176.25KN$$

$$FRP\ Wrapped\ Deteriorated\ Column\ Strength = 3082KN$$

Strength increase in control column case

$$\left(\frac{(4176.25 - 2283)}{2283}\right) \times 100 = 82.9\%$$

Strength increase in deteriorated column case

$$\left(\frac{(3082 - 1356.05)}{1356.05}\right) \times 100 = 127\%$$

2.2 Architectural characteristic (Geometry) of structures in Kabul city and overall Afghanistan

Considering Afghan architecture, the survey data shows that almost 60% of residential buildings are two floored structures, while up to 65% of government buildings are three to five floors (Table 1). Moreover, around 90% have rectangular columns regardless of their occupancy type. Additionally, in Afghanistan, people tend to build a house and later decide to add more floors; this puts RC columns under tremendous pressure and causes failure. Almost 90% of residential buildings add more floors after the structure's construction, and around 60% of governmental buildings do so because of the lack of budget. Thus, taking all these calculations and unique construction facts into consideration, RC-jacketing can be more useful for strengthening low-rise buildings in Afghanistan because 90 to 95 % of buildings rectangular column shape, which is inefficient because of their weak confinement adding several floors to the building after built is a prevalent practice in Afghanistan.

Table 1. Survey data from 190 residential, governmental buildings and facilities in Kabul City, Afghanistan

Type of occupancy	Material type		Floors			Initially build and later added floors	Column cross-sectional shape	
	Brick Masonry	Concrete	1	2	3-5		Rectangular	Circular
Residential House	30%-40%	60%-70%	30%	60%	10%	90%	95%	5%
Governmental and public facility	10%	90%	5%	30%	65%	60%	90%	10%

2.3 Cost analysis

A cost breakdown list was made for both methods, and local cost for each item/activity was assigned, where the unit was selected USD (United States of America) as a common practice and better understanding. The effort was made to create the breakdown list in such a manner that includes all activities/ items for both methods, and an average cost per item/ activity was used. The cost breakdown includes the cost for FRP (Table 2) and the fuel required (Table 3), as well as the cost for RC-Jacketing material (Table 4) and the fuel cost for it (Table 5).

Table 2. Breakdown of activities for FRP wrapping method.

NO	Descriptions	Unit	Quantity	Unit Cost (USD)	Total Cost (USD)
1	Mobilization and establishment of a temporary camp for storing/keeping equipment	LS (Labor Scale)	1	150	150
2	Pre-Curing	m2	4.8	16.5	79.2
3	Adhesive (Primer, Polyurea, Resin)	Pack	0.4		500
4	CFRP	m2	4.8	183.5	880.8
5	Extra costs such as delays and security calculated for a minimum of 25 Km	LS (Labor Scale)	15	20	300
6	Demobilization and site cleaning	LS (Labor Scale)	1	100	100
7	Total (USD)				2034

Table 3. Fuel required for providing uninterrupted electricity.

NO	Descriptions	Unit	Quantity	Unit Cost (USD)	Total Cost (USD)
1	Mobilization and establishment of a temporary camp for storing/keeping equipment	Liters	5	0.604	3.02
2	Pre-Curing	Liters	2.83	0.604	1.709
3	Adhesive (Primer, Polyurea, Resin)	Liters	2.83	0.604	1.709
4	CFRP	Liters	2.83	0.604	1.709
5	Extra costs such as delays and security calculated for a minimum of 25 Km	Liters	8.49	0.604	5.128
6	Demobilization and site cleaning	Liters	5	0.604	3.02
7	Total (USD)				16.296

Table 4. Breakdown of activities for RC jacketing method

NO	Descriptions	Unit	Quantity	Unit Cost (USD)	Total Cost (USD)
1	Mobilization and establishment of a temporary camp for storing/keeping equipment	LS (Labor Scale)	1	180	180
2	Pre-Curing	m2	4.8	20	96
3	Concrete (with formwork and all required activities)	m3	0.48	130	62.4
4	Hilti Hit-hy 200 adhesive for steel anchorage	No	1	160	160
5	Extra costs such as delays and security calculated for a minimum of 25 Km	LS (Labor Scale)	1	1	250
6	Demobilization and site cleaning	LS (Labor Scale)	1	100	100
7	Total (USD)				848.4

Table 5. Fuel required for providing uninterrupted electricity.

NO	Descriptions	Unit	Quantity	Unit Cost (USD)	Total Cost (USD)
1	Mobilization and establishment of a temporary camp for storing/keeping equipment	Liters	10	0.604	6.04
2	Pre-Curing	Liters	8.49	0.604	5.128
3	Concrete (with formwork and all required activities)	Liters	14.15	0.604	8.547
4	Hilti Hit-hy 200 adhesive for steel anchorage	Liters	2.83	0.604	1.709
5	Extra costs such as delays and security calculated for a minimum of 25 Km	Liters	14.15	0.604	8.547
6	Demobilization and site cleaning	Liters	10	0.604	6.04
7	Total (USD)				36.01

2.4 Time analysis

A time breakdown list was created under activities done for both FRP-Wrapping (Table 6) and RC-jacketing (Table 7) methods; minimum time was allocated for each activity per local labor demand.

Table 6. Time required for FRP wrapping method and hourly payment cost.

NO	Descriptions	Unit	Quantity	Unit Cost (USD)	Total Cost (USD)
1	Mobilization and establishment of a temporary camp for storing/keeping equipment	Hours	3	0.796	2.388
2	Pre-Curing	Hours	1	3.5	3.5
3	Adhesive (Primer, Polyurea, Resin)	Hours	24	3.5	84
4	CFRP	Hours	1	3.5	3.5
5	Extra costs such as delays and security calculated for a minimum of 25 Km	Hours	2.5	3.5	8.75
6	Demobilization and site cleaning	Hours	2	0.796	1.592
7	Total Time Required (Hr)	33.5			
8	Total Labor Payment (USD)				103.73

Table 7. The time required for the RC-Jacketing method and amount of payment for labor

NO	Descriptions	Unit	Quantity	Unit Cost (USD)	Total Cost (USD)
1	Mobilization and establishment of a temporary camp for storing/keeping equipment	Hours	5	0.796	3.98
2	Pre-Curing	Hours	3	0.796	2.388
3	Concrete (with formwork and all required activities)	Hours	24	0.796	19.14
4	Hilti Hit-hy 200 adhesive for steel anchorage	Hours	8	2	16
5	Extra costs such as delays and security calculated for a minimum of 25 Km	Hours	10	0.796	7.96
6	Demobilization and site cleaning	Hours	5	0.796	3.98
7	Total Time Required (Hr)	55			
8	Total (USD)				53.412

3 Results and Discussion

This paper evaluated the feasibility of using the FRP-Wrapping method to strengthen columns based on strength, cost, time, and environmental concerns (CO_2 Emission) in Afghanistan. To better support the argument, the results were compared with RC jacketing, a common strengthening method in Afghanistan.

The results show that the FRP-Wrapping method can increase the control column's load-carrying capacity from 2283 kN to 4176.25 kN and the deteriorated column from 1356.05 kN to 3082 kN. This shows 83% and 127% addition of strength in control and deteriorated columns where the final load-carrying capacities of these columns stand at 183% and 227%, respectively. In contrast, RC jacketing displayed a higher efficiency and increased the control column's load-carrying capacity from 2283 kN to 5177.66 kN and for the deteriorated column from 1356.05 kN to 4250.71 kN. This shows 126.8% and 213.5% addition of strength in control and deteriorated columns, where the final load-carrying capacity in these columns stand at 226.8% and 313.5% (Table 8) (Figures 5 and 6).

Table 8. Change in load-carrying capacity of both Control and Deteriorated Column after RC-Jacketing and FRP-Wrapping

Specimen	Ultimate load-carrying capacity as is	RC-Jacketed		FRP Wrapped	
		Capacity Added	Final Capacity	Capacity Added	Final Capacity
Control Column	2283 kN	2894.66 kN 126.8%	5177.66 kN 226.8%	1893.25 kN 83%	4176.25 kN 183%
Deteriorated Column	1356.05 kN	2894.66 kN 213.5%	4250.71 kN 313.5%	1725.95 kN 127%	3082 kN 227%

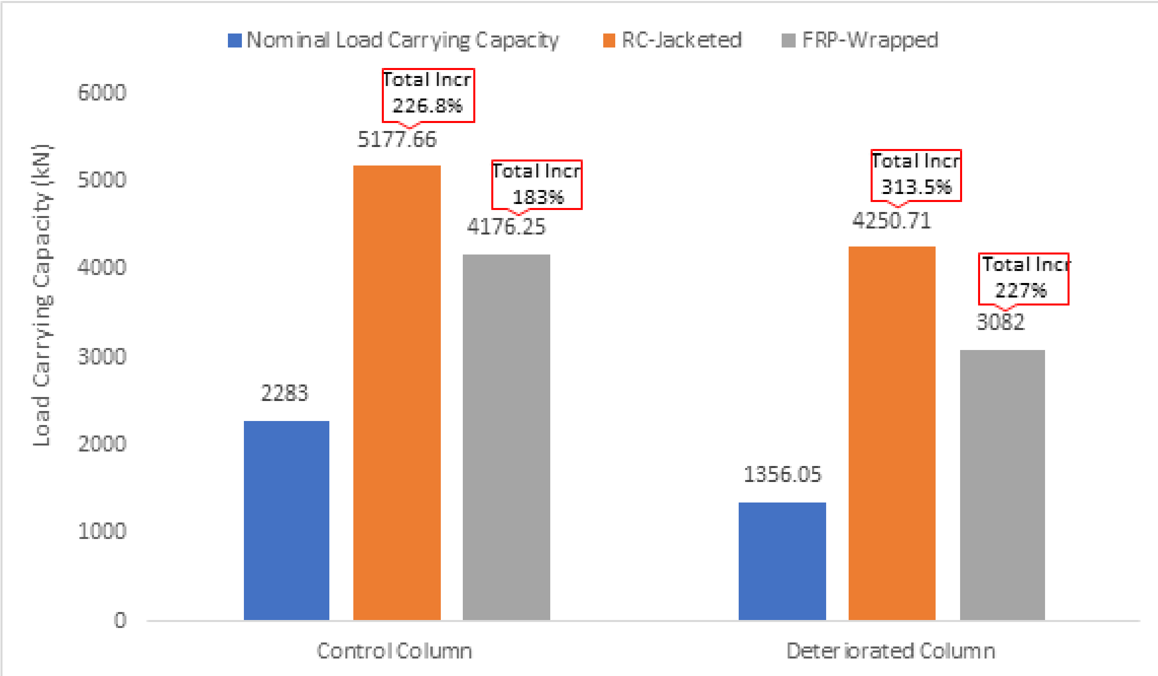

Fig 5. Increase in Total Load Carrying Capacity of Control Column and Deteriorated Column AfterRC-Jacketing and FRP-Wrapping

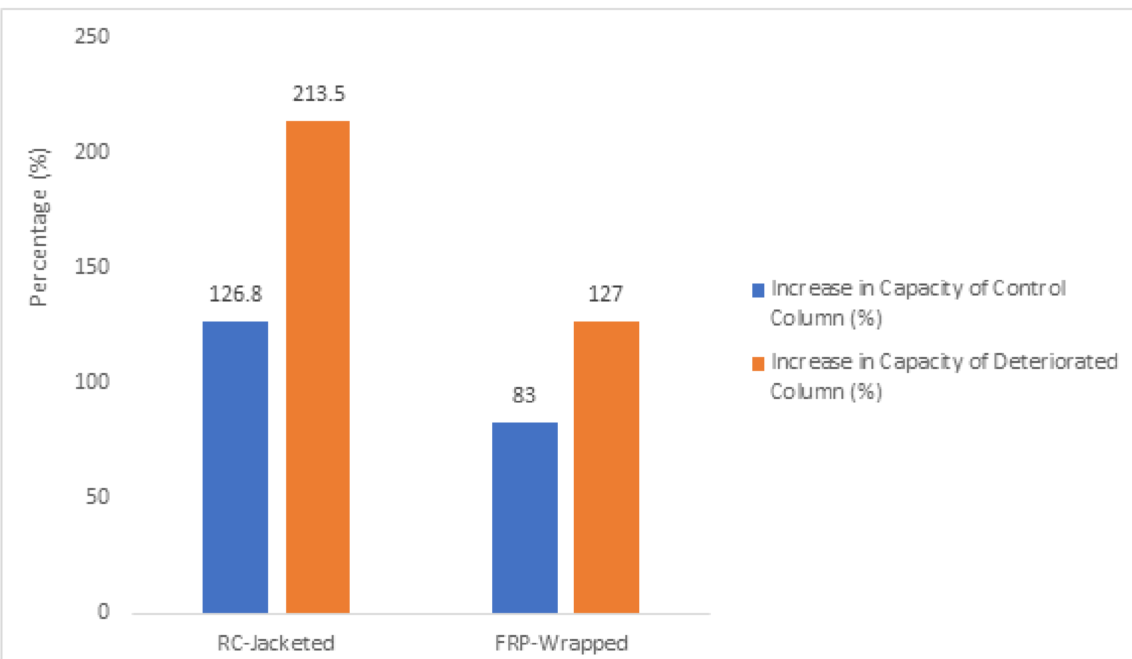

Fig 6. Net Increase in Load Carrying Capacity of Control Column and Deteriorated Column

The comparative cost analysis shows that the total cost for strengthening a concrete column by the FRP-wrapping method is around 2154.03 USD, while RC-Jacketing costs around 937.82 USD. Thus, as per the current market price in Afghanistan, the cost analysis reveals that the FRP-Wrapping method for strengthening the concrete column of structures is 2.3 times costlier than RC-jacketing (Figure 7).

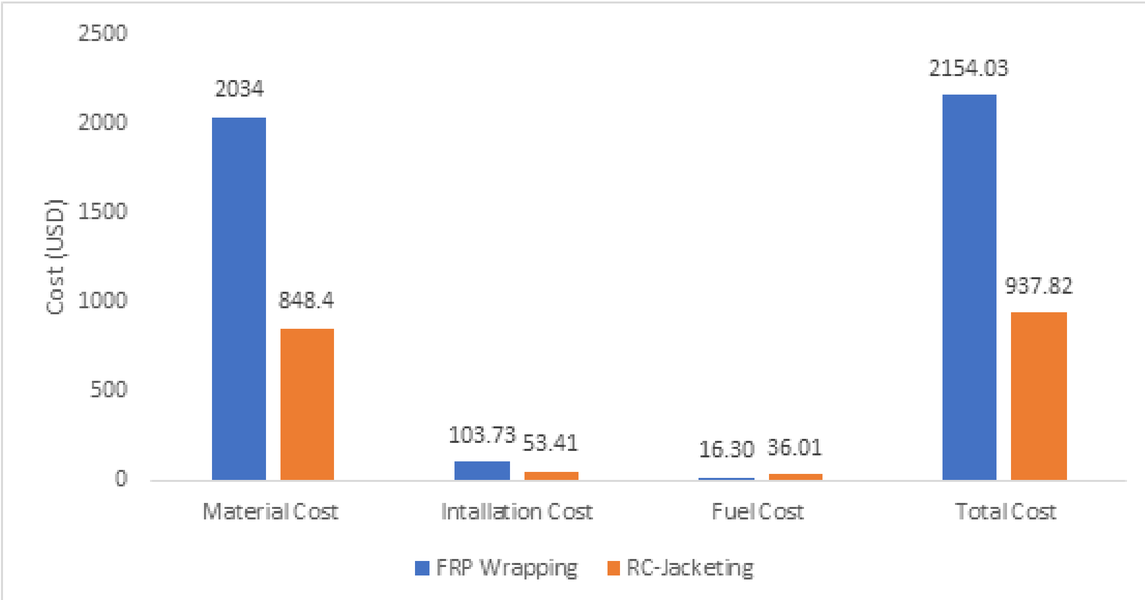

Fig 7. Cost analysis of FRP-wrapped and RC-Jacketed columns

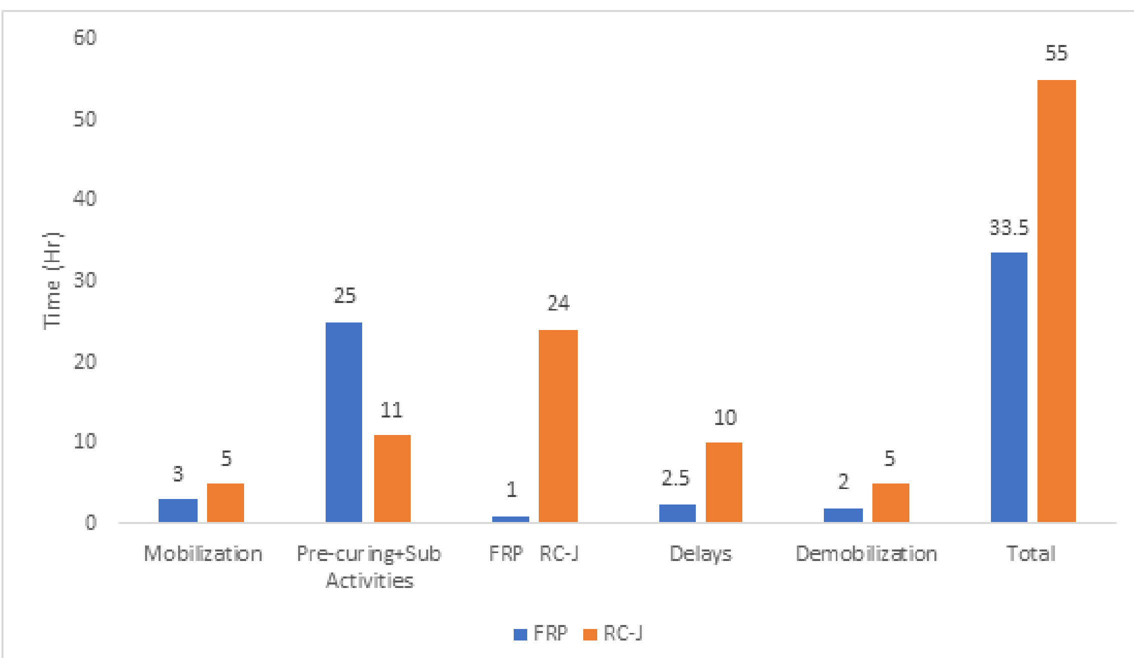

Fig 8. Time analysis of both FRP-wrapped and RC-jacketed columns procedure.

Another parameter that this paper has focused on is the specification of structures in Kabul city, particularly the columns' geometry for which data was gathered through a survey. The results reveal that 90-95% of buildings in Kabul city have rectangular geometry, and only around 5-10% of the structures have columns with a circular cross-section, as mentioned in (Table 1). The geometry of the column is essential while selecting a strengthening method. In this case, comparing the confining pressure distribution between FRP-Wrapping and RC-Jacketing shows that the FRP-wrapping method is the more efficient while used for columns with circular cross-sections and has a lower slipping resistance if used for rectangular shaped columns (Figure 1).

While RC-Jacketing is much more efficient in terms of cost and strength than FRP wrapping, application time and CO_2 emission are the factors where FRP-Wrapping is more competent. The total application time of FRP wrapping for strengthening a concrete column was calculated around 33.5 hours. In comparison, RC jacketing application time was roughly 55 hours, almost 21.5 hours behind FRP wrapping. Both these methods require a stable electricity supply, which Afghanistan lacks, and thus, portable electricity generators are needed, which again adds to the overall process's cost. Thus, the amount of CO_2 emitted through burning fossil fuel was calculated and found around 62.1 Kg and 137.126 Kg for FRP-Wrapping and RC-Jacketing methods, respectively. The number of laborers required for the FRP-Wrapping method was also fewer than the RC-Jacketing method, around 4 and 7, respectively (Table 9). Furthermore, based on the study, this paper provided recommendations for using both FRP-Wrapping and RC-Jacketing methods appropriately, as the cost is a leading parameter for selecting the strengthening method in Afghanistan, yet there can be an exception for some structures.

Table 9. Additional facts regarding FRP-wrapping and RC-Jacketing.

Additional Findings	FRP	RC-Jacketing
Total Fuel consumption (Liters)	26.98	59.62
Total CO2 Produced (Kg)	62.1	137.126
Total Number of Labor (Ls*)	4	7

Ls*=Labor Scale

3.1 Recommendations for efficiently using FRP-Wrapping method in Afghanistan

Based on the results, the RC-jacketing method is much more cost-effective and easier to use than FRP-wrapping in Afghanistan. It is primarily because of raw material availability, better matching architecture, and prior usage experience; however, the FRP-wrapping should also be used in some particular conditions. As FRP-wrapping usage is slowly growing to provide a better scope of its usage authors, have provided some recommendations on where to use this method for having higher efficiency. It is recommended to use FRP-wrapping in structures where overall maintenance time is limited and immediate recovery of strength is crucial such as bridges, other highway structures, or post-disaster structures. Furthermore, it should specifically be considered for maintenance of structure with historical value (monumental structures) because of restrictions for changing its cross-section (shape) or effective floor area. Moreover, this method should be used for overall weak structures, where their overall load-carrying capacity is already reduced significantly and using the RC-jacketing method will only add more load and instability. Additionally, FRP-wrapping should be considered to maintain structures where pollution of any kind (Noise or Air) is restricted, such as hospitals, kinder gardens/schools, and old age facilities). Finally, this method should consider strengthening the columns of high-rise structures if maintenance is required on higher floors because using the RC-jacketing method will change the initially designed seismic behavior of the structure.

4 Conclusion

This paper studied the feasibility of using the FRP wrapping method to strengthen concrete columns in Afghanistan. To better evaluate its feasibility as a strengthening method for concrete columns, it was compared with RC-jacketing based on strength, time, cost, and environmental impact parameters. The study conclusively shows that the RC-Jacketing method is more appropriate for strengthening the weak and partially deteriorated concrete columns in Afghanistan because of a higher strength per cost ratio. On the other hand, results reveal that the FRP-wrapping method is more time-efficient and has a lower carbon footprint. As this study focuses on strengthening concrete columns (compression members), a separate study should be conducted for flexural members. This study focused on concrete columns because it is common in Afghanistan; however, the same type of study is required for steel.

The main findings of this paper are shown below.

1. The overall maintenance process of FRP-wrapping was time-efficient comparing to RC jacketing.

2. The carbon footprint through the FRP-Wrapping method was lower than that of RC-jacketing.
3. The RC-Jacketing method was able to add almost 50% extra strength to columns than FRP-Wrapping.
4. RC-Jacketing method suits better with the current architecture of Afghanistan.
5. The overall cost of the maintenance process of FRP-Wrapping was 57% higher than RC-Jacketing.
6. RC jacketing method increased load-carrying capacity of the control column 1.5 times and load-carrying capacity of a deteriorated column around 1.7 times compared to FRP-Wrapping.

To conclude, for strengthening columns in Afghanistan, it is recommended to consider the RC-jacketing method, while for some exceptional cases mentioned in the recommendations section, FRP-wrapping can be considered as well.

List of abbreviations

fck = Concrete compressive/characteristic strength
Ac = Concrete area
fy = Compressive yield strength of steel reinforcement
Asc = Longitudinal reinforcement area
$\alpha\ pc$ = Circular column performance coefficient
$ffrpu$ = Ultimate tensile strength of FRP
$Efrp$ = Modulus of elasticity for FRP
Nb = Number of FRP layers
$f1\ frp$ = Ultimate confinement stress because of FRP reinforcement
$tfrp$ = FRP thickNess
ωw = ultimate confinement stress ratio FRP to RCC strength
φfrp = FRP resistance factor (1 for laboratory condition)
εfrp = FRP strain (0.003)

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