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Strengthening of Reinforced Concrete Columns with External Steel Bars †

Inayat Ullah Khan *, Nasim Ayub, Akhtar Gul, Khalid Khan and Iqtedar Shah

Department of Civil Engineering, University of Engineering and Technology, Peshawar 25120, Pakistan
* Correspondence: 16pwciv4553@uetpeshawar.edu.pk
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Abstract: The column is the most important structural element that transfers load from floors to the foundation, and its proper strength is of utmost importance. Failure of the column may lead to the collapse of the whole framed structure. The focus of this study is to check the effectiveness of the strengthening technique for a column. This research was carried out by designing and constructing a total of four column specimens, two circular columns and two square columns. Two columns from each combination were then strengthened by removing their clear cover, and steel bars were welded to the ties of existing main bars and the clear cover was cast again. The columns were subjected to axial compressive loads. The load-carrying capacity of the strengthened circular and square columns was increased by 50% and 58%, respectively, compared to that of control columns. Moreover, the deformation capacity of the strengthened columns was enhanced significantly.

Keywords: strengthening; reinforced concrete columns; external steel bars

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1. Introduction

Strengthening is used in a structural system to improve its seismic resistance by increasing the strength or ductility [1,2]. There are many strengthening techniques available. The most used techniques nowadays include ferrocement overlay, external reinforcement, and center core technique.

Reconstruction of a weak building is not a wise approach and may impose huge stress on the national economy. Many current reinforced concrete (RC) structures need to be strengthened because of the increased demand, steel bar corrosion, insufficient maintenance, changes in the function of a structure, changes in code of practice, and exposure to unfavorable circumstances such as earthquakes and blasts. The strengthening of a column may also be required due to an increased number of stories, variation in concrete strength in the field, the percentage and type of reinforcement not being in accordance with the requirements of codes, or the inclination of the column and the settlement in the foundation being more than the allowable design limits. If proper attention is not given to the strengthening of a building, it will cause great loss in terms of lives and wealth. Strengthening of a building or its components is the best alternative approach to improve its seismic performance [3]. Steel strips are one of the easy approaches for strengthening of a structure. The steel strips are connected to a wall, either through a bolt mechanism [4] or external attachment to the foundation and top beam [5]. Literature is available on strengthening of walls through steel strips [5,6]. Some researchers used carbon fiber-reinforced polymer (CFRP) for strengthening of RC columns, and it was found that CFRP significantly enhanced the ductility and load carrying capacity of the column compared to the control specimen [7]. Some researchers used thin concrete jacketing [8], glass fiber RC [9], steel angles and strips [10], CFRP [7], ferrocement jacketing [11], and corrugated plates [12] for strengthening of RC columns.

The column is the most important element in the structure that transfers total floor load to the foundation, and its failure may lead to the total collapse of framed structure building [11].

Columns are mostly designed for axial compressive forces. In civil engineering, columns are classified based on slenderness ratios. This research is based on short columns. In short columns, the length of the column is less than the critical buckling length. The slenderness ratio for short columns is less than 12 [13].

Earthquakes in the near past [14,15] triggered the attention of researchers toward the strengthening of structural elements. In recent years, structural rehabilitation of deteriorated buildings has been one of the main issues. There is an increasing demand in the construction industry to repair, strengthen, and upgrade existing concrete structures with damage due to aging, poor maintenance, corrosion, poor design, environmental degradation, etc. In Pakistan, most of the RC structures are susceptible to damage during an earthquake as they are designed for gravity loading as per UBC-97 [16]. During a severe earthquake, these structures may undergo an inelastic deformation which leads to collapse. So, buildings that were designed for gravity loading need to be strengthened for better strength and stability. By adopting strengthening techniques, the axial strength, the bending strength, and the stiffness can be increased for the existing columns.

Recent hazards have revealed an urgent need to meet the requirements of current design codes, which leads to the development of strengthening techniques for the existing buildings. Most of the RC building constructed in Pakistan is vulnerable to damage due to aging, corrosion, and natural hazards. The available techniques for retrofitting and strengthening a column are jacketing, span shortening, steel bracing, plate bonding, section enlargement, near surface mounted bars, fiber-reinforced polymer strengthening, etc. All these techniques are effective but also lead to some demerits such as corrosion, high cost, and difficulty in erection [3,17]. While there are many available techniques for retrofitting and strengthening a damaged structure, the cost and the simplicity are among the main reasons for developing a new technique. To overcome the cost and erection problems, there is a need for a simple and cost-effective strengthening technique for a column. The use of steel elements for strengthening is one of the simple and easily implementable techniques.

In this study, a comparative study has been performed on a column strengthened with steel bars and a control specimen. The effect of strengthening has been evaluated on the axial strength, bending strength, and stiffness of the column.

2. Methods and Materials

In this study, two square and two circular columns were constructed, each column type represented by one control and one strengthened column as shown in Figure 1. Both control and strengthened columns were subjected to the same axial load setup to check the efficiency of the strengthening technique. Columns were strengthened with external steel bars welded to the stirrups of the already existing main bars. They were designed for the minimum area of steel ($A_{st\ min}$). The concrete of strength $f_c{}' = 3$ ksi and steel of $f_y = 40$ ksi were used.

Beams and foundations were also provided with the column so that it would behave monolithically and were fixed at both ends to give a more realistic approach to the load transfer mechanism of columns in civil engineering structures. All the specimens were tested under axial loading. The dimensions the of columns are given in Table 1. The dimensions of strengthened columns were increased slightly due to welding of steel bars and re-provision of cover.

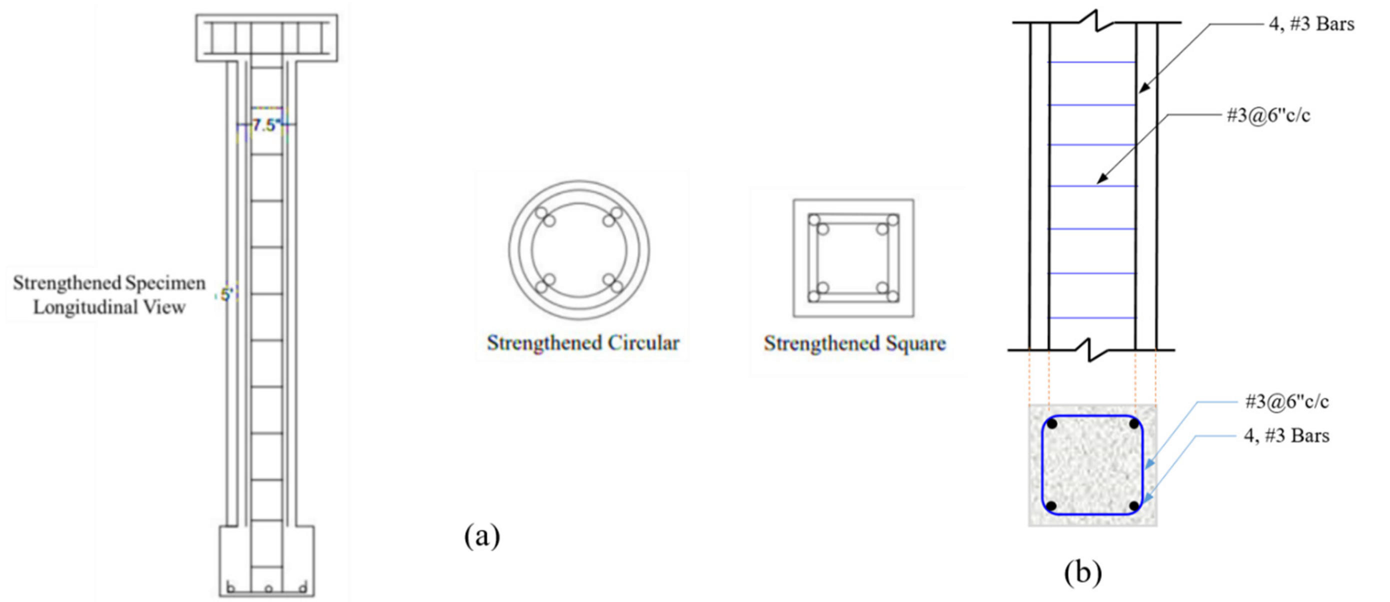

Figure 1. Visual representation of (**a**) strengthened column and (**b**) control column.

Table 1. Dimensions of columns.

	Control Square Column			Control Circular Column		
	Column	**Beam**	**Foundation**	**Column**	**Beam**	**Foundation**
Cross-Section	6″ × 6″ (152 mm × 152 mm)	6″ × 6″ (152 mm × 152 mm)	12″ × 12″ (305 mm × 305 mm)	6″ Dia (152 mm)	6″ × 6″ (152 mm × 152 mm)	12″ × 12″ (305 mm × 305 mm)
Height	60″ (1500 mm)	6″ (152 mm)	6″ (152 mm)	5′ (1.5 m)	6″ (152 mm)	6″ (152 mm)
Reinforcement	Main Bars 4 #3 Bars, Stirrups #3 @ 6in c/c, ACI 318-11 Section 7.10.5 [18]					
	Strengthened Square Column			**Strengthened Circular Column**		
Cross-Section	7.3125″ × 7.3125″ (186 mm × 186 mm)	6″ × 6″ (152 mm × 152 mm)	12″ × 12″ (305 mm × 305 mm)	7.42″ Dia (188 mm)	6″ × 6″ (152 mm × 152 mm)	12″ × 12″ (305 mm × 305 mm)
Height	60″ (1500 mm)	6″ (152 mm)	6″ (152 mm)	60″ (1500 mm)	6″ (152 mm)	6″ (152 mm)
Reinforcement	Main Bars 4 #3 Bars, Stirrups #3 @ 6in c/c, ACI 318-11 Section 7.10.5 [18]					

For the strengthening purpose, first, the clear cover was removed from the column as shown in Figure 2. The external bars were used for strengthening and then welded with the stirrups of the pre-existing main bars. To protect the external bars, concrete was cast again to provide the clear cover which causes a slight increase in the column diameter. After the clear cover was provided, it was cured for a period of 28 days. LVDT and load cell were connected to the column to measure the displacement and load, respectively. Grout concrete was provided to enhance the bond between old and new concrete.

Figure 2. (**a**) Strengthening process of columns; (**b**) circular column after testing.

3. Results and Discussion

3.1. Tests for Circular Columns

As given in Table 2, and also graphically shown in Figure 3, the control circular column failed at a load of 49.74 kips (221 kN), which is almost 3.01 kips greater than the design strength. It is also important to note that the column failed at the beam/column joint, which shows the importance of beam/column joint design. However, the rest of the column was still able to bear the load, but joint failure stopped further load taking.

Table 2. Circular column test results.

Circular Columns		
Strengths	**Design Value, Kips (kN)**	**Test Results, Kips (kN)**
Control Specimen	46.73 (208)	49.74 (221)
Strengthened Specimen	80.19 (357)	98.98 (440)

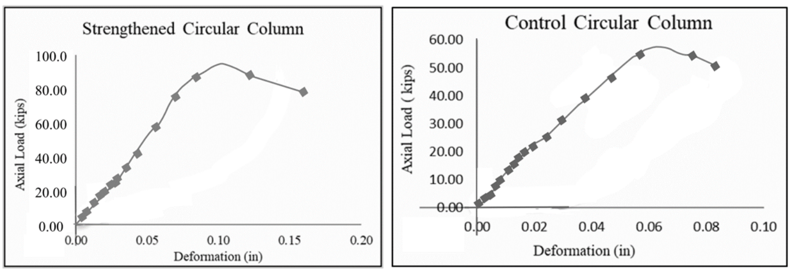

Figure 3. Graphs of axial load vs deformation for (**Left**) strengthened CC and (**Right**) control CC.

The column shows some deformation up to 0.02″ (0.51 mm) without taking load, which is due to unevenness of the surface and adjusting itself for proper grip. The column lateral deformation is increased with an increase in load up to 46.34 kips (206.1 kN), and after that local cracking occurs and the column deformation starts to decrease with an increase in load; finally, the column fails at 49.74 kips (208 kN).

The maximum lateral deformation is approximately 0.09″ (2.29 mm), which is very small in magnitude, and the load is within the kern of the section (e = r/6).

The strengthened column failed at a load of 98.98 kips (440 kN). The clear cover applied after the strengthening was peeled off from the top to almost the middle of the column at one side, due to which the LVDT was detached from the column and only recorded strain up to a load of 71.76 kips (319 kN). The column showed some deformation up to 0.01″ (0.25 m) without taking load, which is due to unevenness of the surface and adjusting itself for proper grip.

3.2. Tests for Square Control Columns

The results are given in Table 3 and graphically shown in Figure 4, The control square column was tested, and the behavior exhibited by the column is shown in the graph. The control column failed at an applied load of 46.98 kips (209 kN) just below the beam/column joint along with some cracks at the middle of the column corresponding to the strain graph line 0.04–0.07 as shown in Figure 5. The maximum lateral deformation is approximately 0.08″ (2.03 mm), which is very small in magnitude, and the load is within the kern of the section (e = B/6).

Table 3. Circular column test results.

Square Columns		
Strength	**Design Kips (kN)**	**Test Value Kips (kN)**
Control Specimen	57.16 (254)	46.98 (209)
Strengthened Specimen	94.74 (421)	112.66 (501)

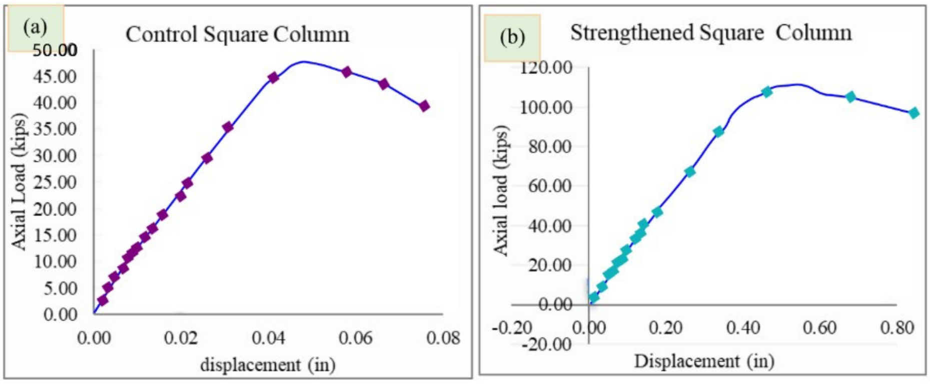

Figure 4. Graphs of axial load vs. deformation for (**a**) control SC and (**b**) strengthened SC.

Figure 5. Strengthened square column.

The strengthened square column failed right in the middle, in the form of buckling at an applied load of 112.66 kips (501 kN). This strength is almost 20 kips greater than the design strength of the column and almost 2 times the design strength of the control column. The column shows some deformation at the start of 0.02″ (0.51 mm) without taking load, and then the deformation returns to zero with an increase in load, which is due to unevenness of the surface and adjusting itself for proper grip. The columns fail due to shear (crushing) due to which the lateral deformation increases suddenly with no increase in load. The maximum lateral deformation is approximately 0.09″ (2.29 mm), which is very small in magnitude and is within the kern of the section (e = B/6).

4. Conclusions

The following conclusions have been derived after the result analysis:

- The load-carrying capacity of strengthened circular and square columns increases by 50% and 58%, respectively, compared to that of control columns.
- The design of the beam and column joint is of utmost importance
- This method can be effectively used for the strengthening of columns, as it causes significant enhancement in the capacity and ductility of structural elements.
- The design load is slightly less than the tested load due to the application of rational reduction factors.
- The deformation capacity of strengthened circular and square columns was improved by 33% and 20%, respectively.
- When using this technique for a real structure, a hydraulic support system for the slab should be provided to transfer the slab load to some temporary support during the application of the strengthening technique.

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References

1. Tomazevic, M. *Earthquake-Resistant Design of Masonry Buildings*; Imperial College Press: London, UK, 1999.
2. Tomazevic, M. *Criteria for Repair and Strengthening of Masonry Structures in Seismic Areas, Rilem*; RILEM Publications: Paris, France, 1997; p. 43.
3. Ashraf, M. Development of Cost-Effective and Efficient Retrofitting Technique for Masonry Buildings in Pakistan. Ph.D. Thesis, Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan, 2010.
4. Taghdi, M.; Bruneau, M.; Saatcioglu, M. Seismic retrofit of non-ductile concrete and masonry walls by steel-strips bracing. *J. Struct. Eng.* **2000**, *126*. Available online: https://ascelibrary.org/doi/10.1061/%28ASCE%290733-9445%282000%29126%3A9%281017%29 (accessed on 8 September 2022). [CrossRef]
5. Rai, D.C.; Goel, S.C. Seismic strengthening of unreinforced masonry piers with steel elements. *Earthq. Spectra* **1996**, *12*, 845–862. [CrossRef]
6. Farough, S.; Ilyas, M.; Ghaffar, A. Technique for strengthening of masonry wall panels using steel strips. *Asian J. Civ. Eng. (Build. Hous.)* **2006**, *7*, 621–638.
7. Widiarsa, I.B.R.; Hadi, M.N. Performance of CFRP wrapped square reinforced concrete columns subjected to eccentric loading. *Procedia Eng.* **2013**, *54*, 365–376. [CrossRef]
8. Tayeh, B.A.; Naja, M.A.; Shihada, S.; Arafa, M. Repairing and strengthening of damaged RC columns using thin concrete jacketing. *Adv. Civ. Eng.* **2019**, *2019*, 2987412. [CrossRef]
9. Asokan, P.; Osmani, M.; Price, A.D. Improvement of the mechanical properties of glass fibre reinforced plastic waste powder filled concrete. *Constr. Build. Mater.* **2010**, *24*, 448–460. [CrossRef]
10. Tarabia, A.; Albakry, H. Strengthening of RC columns by steel angles and strips. *Alex. Eng. J.* **2014**, *53*, 615–626. [CrossRef]
11. Kaish, A.B.M.A.; Alam, M.R.; Jamil, M.; Zain, M.F.M.; Wahed, M.A. Improved ferrocement jacketing for restrengthening of square RC short column. *Constr. Build. Mater.* **2012**, *36*, 228–237. [CrossRef]
12. Farahi, M.; Heidarpour, A.; Zhao, X.-L.; Al-Mahaidi, R. Compressive behaviour of concrete-filled double-skin sections consisting of corrugated plates. *Eng. Struct.* **2016**, *111*, 467–477. [CrossRef]
13. Han, L.-H. Tests on concrete filled steel tubular columns with high slenderness ratio. *Adv. Struct. Eng.* **2000**, *3*, 337–344. [CrossRef]
14. Ali, S.; Gul, A.; Khan, I.; Shahzada, K. Effect on the Mechanical Properties of Brick Masonry by Replacing the Cement Sand Mortar with Marble Waste Tile Bond Mortar. In Proceedings of the 1st International Conference on Advances in Civil & Environmental Engineering, UET TAXILA (1st ICACEE-2022), UET Taxila, Pakistan, 10–16 February 2022.

15. Khan, K.; Khan, I.; Khan, M. Mechanical and Physical Properties of Cellular Lightweight Concrete (CLC) Blocks. In Proceedings of the 1st International Conference on Advances in Civil & Environmental Engineering, UET TAXILA (1st ICACEE-2022), UET Taxila, Pakistan, 10–16 February 2022.
16. UBC-97. 1997 Uniform Building Code. 1997. Available online: https://civilmdc.com/2020/03/09/uniform-building-code-ubc-97-volumne-i-ii-and-iii/ (accessed on 18 November 2021).
17. Gul, A.; Khan, K.; Khan, A.; Shahzada, K. Mechanical Properties of Dry Stack Masonry using Hydraform Blocks. In Proceedings of the 1st International Conference on Advances in Civil & Environmental Engineering, UET TAXILA (1st ICACEE-2022), UET Taxila, Pakistan, 10–16 February 2022.
18. ACI 318-11. ACI code 7.10.5 -Building Code Requirements for Structural Concrete (ACI 318-11) An ACI Standard and Commentary- Google Search. 2011. Available online: https://www.google.com/search (accessed on 17 November 2021).