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Seismic Retrofitting of an Existing Structure & its Cost-Effectiveness

F. R. Anika[1], T. Sarker[2], M. Ahamed[3], M. R. Awall[4]

[1]Department of Civil Engineering, RUET, Bangladesh (fahmida.anika14@gmail.com)
[2]Department of Civil Engineering, RUET, Bangladesh (trishasarker06@gmail.com)
[3]Department of Civil Engineering, RUET, Bangladesh. (miraz@ce.ruet.ac.bd)
[4]Department of Civil Engineering, RUET, Bangladesh (robi95@ce.ruet.ac.bd)

Abstract

Nowadays, a large number of existing reinforced concrete structures have inadequate strength for earthquake load or are seismically deficient and need to be structurally strengthened. Demolishing and rebuilding the existing seismically deficient structure is highly impractical and also uneconomical. It is recognized that one of the most effective and economically feasible methods of reducing the risk of these structures is retrofitting. An existing G+1 laboratory building has been taken into consideration for this purpose. The existing structure was analyzed in the ETABS 2016 software in accordance with BNBC 2020 in order to identify the columns that failed due to seismic load. The failed columns were retrofitted by the column jacketing technique and again analyzed in the ETABS 2016 following BNBC2020. The numerical analysis showed that because of the jacketing, the column strength and the overall stability of the structure increased significantly. This study has found that the retrofitting technique is better in comparison with complete reconstruction in terms of cost-energy, efficiency and structural performance.

Keywords: *Retrofitting; Reinforced Concrete jacketing; BNBC 2020; ETABS*

1 Introduction

Earthquakes are natural events that occur in the geophysical system. Bangladesh may be most vulnerable to earthquakes. Modern seismic protection is centered on the need to improve structural performance during earthquakes. Existing buildings are often seismically unsafe. Most Bangladeshi buildings fail seismic evaluations. Thus, to accommodate seismic loads, structures must be strengthened and designed or modified. Retrofitting protects a building from earthquakes and other hazards. Rebuilding these infrastructures after demolishing the seismically unsafe ones is impossible and expensive. Another alternative is seismic retrofitting. It reduces risk. Retrofitting is vital for structural strengthening. Recent methods can help with earthquake strengthening, structural repairs, and building retrofitting. Base isolation, fiber-reinforced polymer (FRP), shear walls, steel bracing, and concrete and steel jacketing are the most common seismic retrofits. Retrofitting relies on concrete jacketing design. Concrete jacketing is the most common method for strengthening weak columns. Column jacketing is increasingly utilized to reinforce existing structures due to its various benefits, including strengthening the construction's lateral load capacity in a reasonably uniform and distributed manner and reducing the need for stiffness in shear buildings. Because the procedure doesn't change the building's geometry. This study examines the design of concrete column jacketing for strengthening an existing structure. It examined the seismic performance of existing structures, column jacketing performance, and cost-effectiveness. There are several research works have been carried out in the field of retrofitting using concrete jacketing. Some of the literature reviews used for reference during the study are given below:

Rodrigues (2018) has studied a few existing buildings in Nepal and proposed suitable retrofit measures in terms of concrete jacketing for weak columns, the addition of shear walls and the use of steel bracings. They have tried to bring out the effectiveness of these measures in terms of strength and ductility. Ismail (2013) in his article has studied the effectiveness of various jacketing using steel, CFRP and concrete as methods of retrofitting. In this study, the lateral displacement and lateral strength of the structural members with and without retrofit of an existing G+9 building. It was also concluded that the method of concrete jacketing improves lateral strength as well as stiffness substantially. Riyad (2016) in their work evaluated the effect of shear walls and CFRP as retrofitting measures. He considered an eight-storied RC building designed as per Moroccan code. He concluded that CFRP improved both the ductility as well as stiffness of the structure. Md. Asif Rahman (2015) studied an equivalent static force method used for applied seismic load and column jacketing used for the failure column. All of the columns were checked for vulnerability due to seismic load.

The primary goal of this study is to identify the failure columns under seismic load by calculating DCR and to seismically retrofit the failure column to increase the strength of the existing building by using column jacketing and to analyze the cost-effectiveness between retrofitting the existing building and the construction of the new building.

2 Model Used for Study

Data and materials properties used for the study are shown in the given tables.

Table 1. Building Data

Building Property	Data
Plan	91.25ft × 43.6 ft
Elevation	G+1
Story Height	15 ft
Building type	Laboratory (Academic building)

Table 2. Member properties

Item	Dimension
Slab thickness	6″
Beam size	15″×24″

Table 3. Details of column properties

Story No.	Column ID	Existing size	New Size	Name
Story 2	C1,C2,C3,C4,C5,C6,C7,C8,C9,C10, C11,C12,C13,C14,C15,C16	18″ × 18″	18″ × 18″	Exterior Column
	C17,C18,C19,C20	16″× 16″	16″× 16″	Interior Column
Story 1	C1,C2,C3,C4,C5,C6,C7,C8,C9,C10, C11,C12,C13,C14,C15,C16	18″ × 18″	18″ × 18″	Exterior column
	C17,C18,C19,C20	16″× 16″	24″× 24″	RET

Table 4. Materials properties

Item	Strength
Concrete grade	M15
Concrete grade for the retrofitting	M20
Steel Rebar bar	280MPa

Table 5. Basic load data

Type of Load	Load
Live Load	50 psf
Floor Finish	20 psf
Partition wall	55 psf

The plan and 3D of the building used for the modeling are as below:

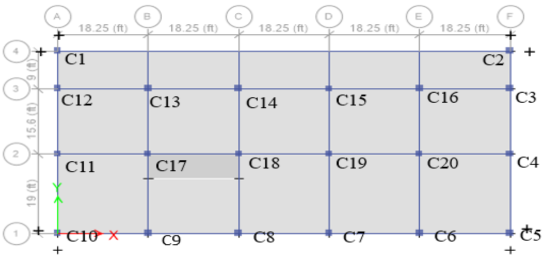

Figure 1. Plan view of the Existing Building

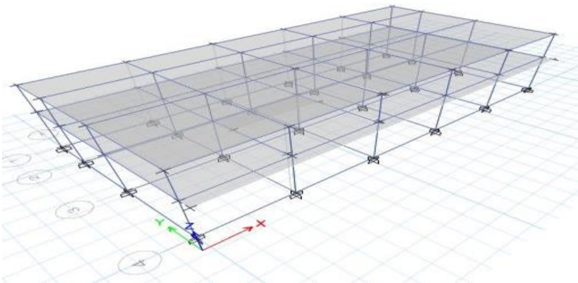

Figure 2. 3D view of the Existing Building

3 Methodology

There are many methods of retrofitting. Here, the column jacketing method by ETABS software was used. The details methodology can be shown in the following flowchart.

Designing the structure considering the load according to BNBC 2020

⇩

Modeling the structure using ETABS 2016 software and applying seismic load

⇩

Computing the DCR (Demand capacity ratio)

⇩

Provide retrofit for the failed columns by concrete jacketing for columns

⇩

The structure with retrofitted column is analyzed

⇩

The cost comparison between retrofitting and reconstruction is demonstrated

3.1 Modelling of concrete jacket in ETABS

There are various software which are used in concrete jacketing. Here the ETABS 2016 was for the modeling of concrete jacketing. First of all, the new jacketing material and section property were defined by adding new property under the frame and choosing the section designer option. In the section designer, the design type was defined as a concrete column keeping the 'reinforcement to be checked' option. The base material is the existing column material. After that, the 'Draw' option was gone, choosing the concrete shape as 'rectangle', and feeding the details of the existing column dimensions, reinforcement size, and quantity. The same procedure was repeated to draw the concrete jacket around the existing column section. The details of the web were defined and flanged along with the new reinforcements in the jacket section. The interaction surface was chosen by keeping the option of "include phi" in "show design code data" and closing the section designer. The columns were selected to be jacketed as planned and section properties were assigned in the frame as the new jacket section defined in the above steps. This completes the modeling of the concrete jacket. The section is depicted in the figure below

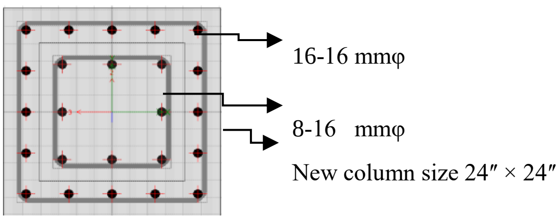

Figure 3. Column Section in ETABS

4 Cost Analysis

The cost analysis of Retrofitting and reconstruction of the building are given below-

Total Height of Column= Below PL+ Ground Floor Height= (1.5+5) +15 ft= 21.5 ft
Additional gross cross-sectional area of column= Total gross cross-sectional area of column- Existing gross cross-sectional area of column= (576-256) in^2 =320 in^2
Determination of required reinforcement
Assume, Steel is required 3% of the total volume of concrete.
Additional volume of concrete= cross sectional area × height= 320 × (12-2) ×21.5= 47.78 ft^3
Then, Volume of steel= 47.78×0.03 =1.43 ft^3
Weight of additional main bar= 490 Ib/ft3 ×1.43 ft^3=700.7 Ib = 317.83 kg≈ 318 kg
Determination of required sand, cement and khoa
Dry volume of additional concrete= 47.78 ft^3
Wet volume of additional concrete= 47.78×1.5 =71.67 ft^3
Net volume of cement concrete= 71.67-1.43 =70.24 ≈71 ft^3
Using, Mixing ratio= 1:1.5:3
Volume of cement= (1/5.5)×71=12.9 ft3= 13 ft^3 Volume of Sand= (1.5/5.5)×71=19.36 ft^3 = 20 ft^3 Volume of Brick Khoa= (3/5.5)×71= 38.72 ft^3 = 39 ft^3
Weight of cement=90 Ib/ft^3×13ft= 1170 Ib= 530.7031kg
So, cement required =530.703/50=10.61≈11 bags [1 bag cement=50kg]
Weight of sand=120 Ib/ft3×20=2400 Ib =1088.6217 kg ≈ 1089kg
For 100 ft^3 Brick khoa required brick=850 Nos.
∴ For 39 ft^3 Brick khoa required brick= (850/100)*39=331.5 Nos. ≈ 332 Nos. Machine cost for brick crusher=Tk 500/1000 Nos.
For plastering and whitewashing work,
Surface area=21.5×12×2× (24+24) =24768 in3 ≈ 15 ft^3

Table 6. Cost Estimation for Retrofitting

- Time of completion: 2-3 months
- Design life: 50 years
- Manufacturing raw materials-

Items	Required	Unit Cost (PWD, 2022)	Total Cost
1. Reinforcement	318 kg	Tk 65000/1000 kg	20670
2. Cement	11 bags	Tk 440/bag	4840
3. Sand	20 cft	55/cft	1100
4. Brick	332 Nos.	7500/1000 Nos.	24900
5. Brick Crusher Machine	450	500/1000 Nos.	225
6. Plastering work	15	Tk 110/ft^2	1650
7. White Washing	20 ft^2	Tk 7.5/ft^2	150
Total Cost			**53535 Tk**
Contingency	5%		2676.75≈ 2677
Lobour Cost		550 Tk/day	49500
Maintenance Cost			35000

∴ Total cost of one column retrofitting=53535+2677+49500+35000=140712 Tk (for 256 in2 of RCC column)
∴ Total cost in Tk for RC jacketing per m2 of surface area of RC column=140712*(1/.16516096)
=851968.8914 Tk
≈ 860000 Tk

Table 7. Cost Analysis of Column for Reconstruction

- Time of completion: 1-2 years
- Design life: 70 years
- Total cost in BDT-

Construction Cost	3967*3000*2 Tk/sq.ft	23802000 ≈ 240 *lakhs*
Erection Cost	138594802.7	≈ 139 *lakhs*
Maintenance Cost	99935	≈ 1 *lakhs*

5 Results

The DCR values of the columns before and after retrofitting are shown in Table 3 and Table 4. We can see that the capacity of retrofitted columns is increased largely as the demand capacity ratio of these four retrofitted columns reduces mostly. To avoid failure, the demand capacity ratio of the column should be kept less than one or at least equal to one.

Table 8. DCR value comparison between before and after seismic application load

Column ID	**DCR Value**		**Remarks**
	Before EQ	**After EQ**	
C1	0.378	1.004	Retrofitting Required
C2	0.388	0.894	Retrofitting Not Required
C3	0.403	0.925	Retrofitting Not Required
C4	0.449	0.815	Retrofitting Not Required
C5	0.333	0.87	Retrofitting Not Required
C6	0.373	0.921	Retrofitting Not Required
C7	0.364	0.978	Retrofitting Not Required
C8	0.362	0.958	Retrofitting Not Required
C9	0.369	0.96	Retrofitting Not Required
C10	0.322	0.76	Retrofitting Not Required
C11	0.442	1.016	Retrofitting Required
C12	0.393	1.014	Retrofitting Required
C13	0.527	1.013	Retrofitting Required
C14	0.62	1.207	Retrofitting Required
C15	0.592	1.457	Retrofitting Required
C16	0.521	0.837	Retrofitting Not Required
C17	0.564	1.096	Retrofitting Required
C18	0.539	1.027	Retrofitting Required
C19	0.582	1.078	Retrofitting Required
C20	0.558	1.069	Retrofitting Required

Table 9. DCR value result of the retrofitted columns

Column ID	**DCR Value**	**Results**
	With Retrofitted Column	
C1	0.894	PASS
C2	0.931	PASS
C3	0.959	PASS
C4	0.992	PASS
C5	0.938	PASS
C6	0.963	PASS
C7	0.93	PASS
C8	0.901	PASS
C9	0.897	PASS
C10	0.789	PASS
C11	0.851	PASS
C12	0.873	PASS
C13	0.617	PASS
C14	0.699	PASS
C15	0.916	PASS
C16	0.63	PASS
C17	0.274	PASS
C18	0.264	PASS
C19	0.283	PASS
C20	0.294	PASS

Again, the Reconstruction cost is more than retrofitting in both cases (Maintenance cost and total cost) which is presented by the bar chart that plot in MS EXCEL.

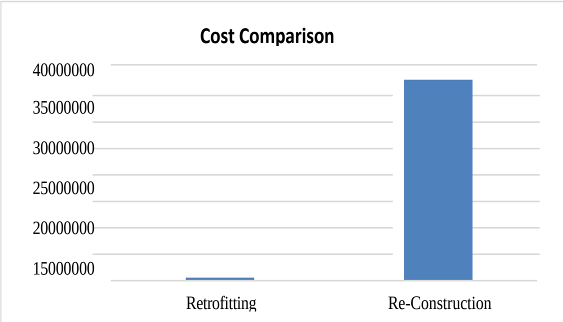

Figure 4. Cost Comparison (Total cost)

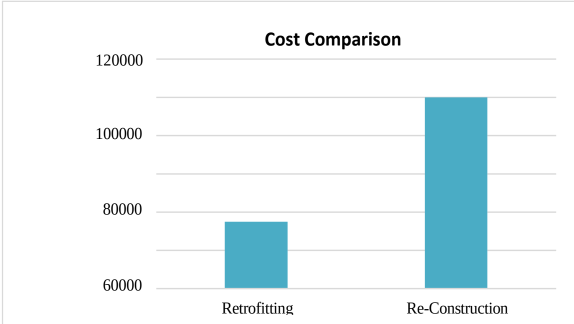

Figure 5. Cost comparison (Maintenance cost)

6 Conclusion

From this the numerical analysis following conclusions can be drown:

- The structure without retrofit shows more DCR value, story displacement, and story drift.
- Reinforced concrete jacketing method significantly decreases the DCR value of the structure, reduces the story drift and story displacement.
- The seismic behavior of the building is better after the application of the retrofitting techniques. Because of the jacketing, the column strength and the overall stability of the structure will increase.
- Retrofitting of existing structures is more practical and economical than re-construction of that structure.

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