NUMERICAL ASSESSMENT OF LOAD CARRYING CAPACITY OF REINFORCED CONCRETE BEAMS STRENGTHENED BY RC JACKETING

S. M. JOARDER[1], M.A.A. Siddique[2]

[1]Dept. of Civil Engineering, Bangladesh University of Engineering and Technology
Dhaka 1000, Bangladesh (Corresponding author)
[2]Associate Professor, Dept. of Civil Engineering, Bangladesh University of Engineering and Technology
Dhaka 1000, Bangladesh

---***---

Abstract - *Structural repair and rehabilitating is a process whereby an existing structure or a part of it is modified to increase the probability of surviving of structures for a long period of time. This can be accomplished through the addition of new structural elements or strengthening of existing structural elements. Both are applied to the structural members when their serviceability decreases or existing design of these members are no longer capable of withstanding the loads from current system. In the present paper, a numerical investigation is carried out to assess load carrying capacity of the strengthened reinforced concrete (RC) rectangular beam sections with reinforced concrete jacketing. The finite element package ABAQUS is used to assess the strengthened beam behavior. The bond between the existing and adding concrete is assumed to be perfect. A parametric study is conducted for different concrete cross section with different amount of longitudinal reinforcements. Failure pattern for each case is also observed. From the study, it is observed that the capacity of deficient RC beam section in terms of load can be enhanced to a great extent.*

***Key Words*: Reinforced Concrete, Beam Sections, Strengthening, Load Capacity, Failure Modes.**

1. INTRODUCTION

Structural members of civil infrastructures often face modifications and improvements. The main reasons behind this are change in their use, new design standards, reduction of serviceability, aggressive environment and events like earthquake. The buildings affected by earthquake may suffer both non-structural and structural damages. Nonstructural repairs may cover the damages to civil and electrical items including the services in the building. Repairs to nonstructural components need to be taken up after the structural repairs are carried out [5].

Retrofitting of building structures is the process of modifying the structural members after construction while they are in service. A number of retrofitting techniques are available for these structures such as adding new members, thickening walls, steel plate jacket, jacketing of beam and column with concrete etc. FRP (Fiber Reinforced Polymer) retrofitting is also an efficient way of strengthening different structural members of buildings. It consumes less space while enhance capacity, stiffness, corrosion resistance and easy to handle [6]. However, FRP material has high electric conductivity and considered costly in use from Bangladesh perspective. In this study, reinforced concrete (RC) jacketing is discussed as the retrofit method. It is a common method of retrofitting of building structures in Bangladesh due to economic and availability of materials.

A flexural member of buildings, reinforced concrete (RC) beam is considered for the present analysis. Different RC beam cross sections with different amount of reinforcements are assumed under uniformly distributed load. Serviceability of these beams is checked. Deflection is assumed as the main criteria of determining serviceability in this study. From the analysis, the load carrying capacity is determined according to the assumed deflection. Whenever each beam exceeds its deflection limit, retrofit is applied and enhancement of load carrying capacity of each beam is calculated. Finite element analysis software ABAQUS is used for modelling and analysis.

2. FINITE ELEMENT MODEL AND VERIFICATION

A numerical model is developed using ABAQUS software for a RC beam and is compared with the experimental results for the model verification. This control beam, Horsetail Creek Bridge is located in east of Portland, Oregon along the Historic Columbia River Highway and is reported by [1]. It was designed without shear reinforcement by K.S. Billner [1] and was opened to traffic in 1914. The details of experimental beam are shown in Figures 1 and 2.
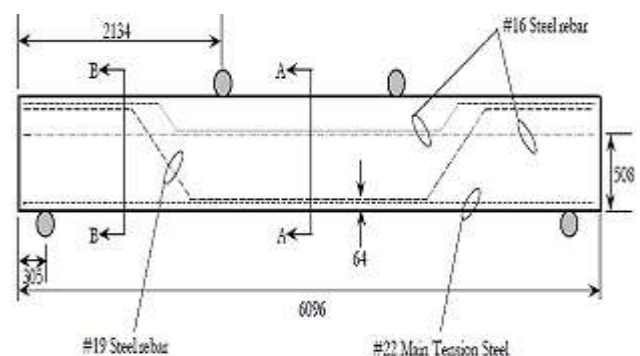
Fig -1: Control beam with details of loading span and reinforcements [Kachlakev and McCurry (2000)]

SECTION A-A
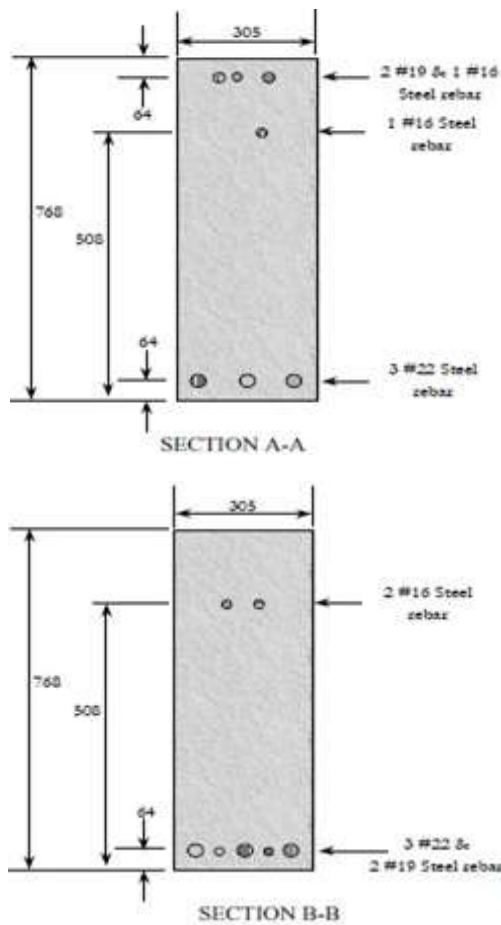
SECTION B-B

Fig -2: Experimental beam cross sections at different position [Kachlakev and McCurry (2000)]

The beam has 6096 mm span with 3 nos. #22 bar as tension reinforcement, 2 nos. #19 cranked bar from bottom and 2 nos. #16 bar at 508mm distance from beam bottom. Bar sizes are in soft metric designation. Concentrated load is applied on two points from 2134 mm from the end of each side. The beam is loaded as simply supported.

Design code AASHTO specifies the concrete strength of a bridge constructed before 1959 to be 2500 psi (17.2 MPa) and the steel yield stress to be 33,000 psi (228 MPa) (AASHTO, 1994). As this lower level strength is not readily available, for ensuring the same ultimate capacity of steel bars #5, #6 and #7 U.S. bars of smaller steel cross sections are used in place of #16, #19 and #22. Material properties of concrete and steel for the control beam is presented in Table 1.

Table -1: Material properties used for the control beam

Material	Limiting Stress	Limiting Strain	Limit State	Elastic Modulus
Concrete	20.7MPa	0.003	Crushing	21.5GPa
Steel	414MPa	0.002	Yielding	200GPa

A numerical model is developed for the control beam using commercial software ABAQUS [version 6.7, 2007] and the same load is applied for a simply supported span of 6096 mm. Figure 3 shows the ABAQUS numerical model having the same cross-section and reinforcements of the control beam.
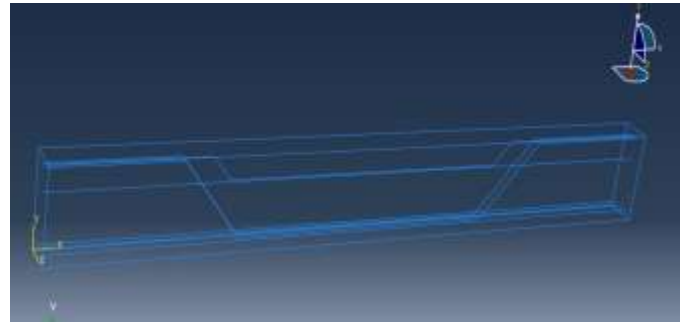
Fig -3: Schematic representation of the control beam using ABAQUS

Tables 2, 3 and 4 present the properties of steel and concrete used in the current finite element model. Concrete damage plasticity model by Lee and Han (1998) is used in the present finite element modelling. Concrete Damage Plasticity Model parameter dilation angle value 36.31 degree used in this model. Tensile behavior type was strain.

Table -2: Elastic properties of materials for modelling using ABAQUS.

Material	Modulus of Elasticity (GPa)	Poisson's Ratio
Steel	200	0.3
Concrete	21.5	0.2

Table -3: Concrete compressive strength for modelling using ABAQUS.

Yield Stress (MPa)	Inelastic Strain
21	0
25	0.001

Table -4: Concrete tensile strength for modelling using ABAQUS.

Yield Stress (MPa)	Cracking Strain
9	0

Embedded region is used as constraint during the analysis. The reinforcement is meshed as T3D2 and concrete meshed as C3D8R element [Sinaei et al. 2012]. Loads are applied in points along the line of load application same as

the experimental setup. For a simply supported beam, pinned supports are used at the two ends of the beam.

Table 5 shows the experimental and numerical results of load vs. deflection at the mid-span of the beam. The relative error between FEM and experimental results were calculated by the following equation-

Erel = (Data by EXP. ~ Data by FEM)/Data by EXP.*100

Table -5: Deflection in mid span of beam.

Load (KN)	FEM Deflection(mm)	Experimental Deflection (mm)	Erel (%)
89	2.7	2	35
178	5.5	6	8.33
267	8.3	10.5	20.95
356	14	15	6.66
445	25	22	13.90
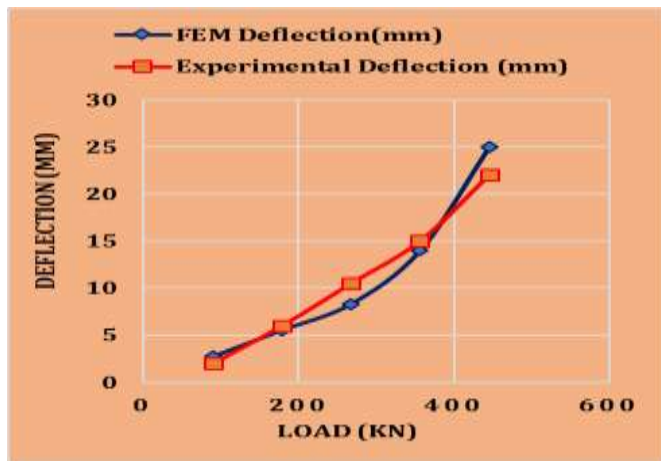
Fig -4: Comparison of the experimental data and FEM analysis using ABAQUS data of the beam deflection.

Figure 4 shows the graphical presentation of the deviation between experimental and numerical results of deflection vs. load at the mid-span of the beam.

3. DETERMINATION OF LOAD CARRYING CAPACITY

For normal weight concrete, tensile strength of concrete is considered to some portion of the compressive strength. For the determination of load carrying capacity of RC beam section, tensile strength of concrete is found to be 3.2MPa using the following formula:

$$fr = 0.7\sqrt{f'c}$$

Where, f_r = Modulus of rupture = 3.2 MPa,

f'_c = Concrete compressive strength

As a parametric study, three beam sections are considered. Beam properties are provided in Table 6 with cross-sections and reinforcement details. A simply supported beam of span length of 3500 mm is considered for all the analysis. A uniformly distributed force is applied vertically downward from the top surface of the beam along the span length of the beam.

Table -6: Beam properties, mesh pattern, load type and reinforcement details.

Cross Section (mm x mm)	305x305	350x350	400x400
Reinforcement (tensile zone)	3#7 bar	3#9 bar	3#8
Reinforcement (Shear)	#3 bar 150mm C/C	#3 bar 150mm C/C	#3 bar 150mm C/C
Span Length, L (mm)	3500	3500	3500
Boundary Condition	Simply Supported		
Concrete Mesh in FEA	C3D8R		
Rebar Mesh in FEA	T3D2		
Concrete Cover (mm)	50		
Loading Pattern	UDL		

For determining the load carrying capacity of the beam, serviceability deflection is considered as the main criterion. The following formula is used for determining allowable deflection limit for the beams [11]:

Deflection, Δ= L/300; [11]

Where, L is the span length of the beam.

The allowable deflection limit was found to be 11mm for each beam having the same span length. Total load is applied as pressure by dividing the total force by the upper surface area of each beam. Load carrying capacities of the bare beams using the deflection criterion are shown in Table 7. In addition, the table shows the failure pattern for the bare beams.

Table -7: Deflection values for beams mid span due to applied force and their failure mode.

Load (KN)	Beam Size (mm x mm)		
	305 x 305	350 x 350	400 x 400
500	8.3	3.9	2.3
550	10.6	4.4	2.6
600	13	4.9	2.8

700	24	6.3	3.4
800	41	9.2	4
850	53	11	4.3
900	68	14	4.7
1000	-	21	5.6
1100	-	34	7.3
1200	-	-	10
1300	-	-	13
Failure Mode (From deformation pattern)	Flexure	Flexure	Flexure

From the analysis, the estimated load carrying capacity of various beams are determined as:

- Beam 305x305: 550 KN
- Beam 350x350: 850 KN
- Beam 400x400: 1200 KN

4. RETROFIT ANALYSIS OF RC BEAMS

Among the various retrofitting techniques, jacketing by concrete is considered for the present study. This is due to the availability of materials and cost-effective labor work. Following some general features [Waghmare 2011; Teran and Ruiz (1992), IS13945] of beam jacketing which were applied in the study-

1) 80mm thickness

2) 4-sided jacket

3) Material strength similar to the main beam

4) Perfect bonding between the main beam and retrofitted concrete

5) Reinforcements applied only for tension

6) 50mm cover for new reinforcement

7) 2 rebar provided in jacket with similar diameter and strength of the main reinforcement

8) #3 bar provided as shear reinforcement with 150mm spacing

Applying these features on ABAQUS model, load carrying capacity of the retrofitted beam is determined from the deflection criteria. A schematic presentation of finite element model using ABAQUS is shown in Figure 5.
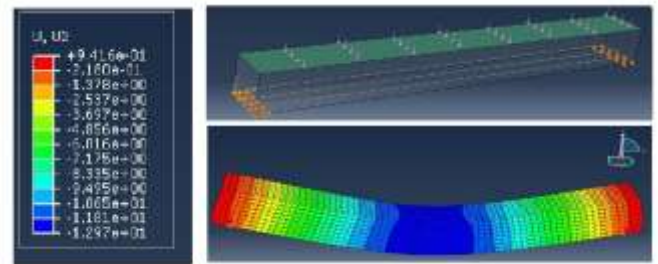

Fig -5: A schematic presentation of retrofitted beam with deflected shape.

Table 8 shows the deflection values at the mid-span of the retrofitted beam under different level of loadings.

Table -8: Deflection values for beams mid span due to applied force and their failure mode.

Load (KN)	Beam Size after Jacketing (mm x mm)		
	465 x 465	510 x 510	560 x 560
1600	5.8	3.4	2.3
1800	8.5	4	2.6
1900	10.6	4.8	3
2200	21	6	3.5
2400	32	8	4
2600	-	11	4.7
2800	-	15	5.6
3000	-	24	7
3200	-	-	9
3300	-	-	10.5
3600	-	-	16

5. RESULTS AND DISCUSSIONS

From the numerical results it is shown that each beam is failed gradually without sudden distortion of the model. Hence it can be said that concrete crushing will not occur before yielding of steel. A flexural mode of failure is ensured for the beam considering appropriate shear reinforcements. In addition, a parametric study is carried out for each beam without shear reinforcements. It shows that the beam deflects suddenly by huge distortion under different level of loading which may imply shear failure. The load carrying capacity of each retrofitted beam is shown in Table 9 and is compared with those of the bare beams.

Table -9: Comparison of load carrying capacities of bare and retrofitted beams

Beam Size (Retrofit Size), mm x mm	305x305 (465x465)	350x350 (510x510)	400x400 (560x560)
Bare beam capacity (KN)	550	850	1200
Retrofitted beam capacity (KN)	1900	2600	3300
Increase in capacity	3.45 times	3.05 times	2.75 times

The load carrying capacity of each beam is determined by the closest deflection limit of 11 mm. From the analytical results, it shows that the load carrying capacity of retrofitted beam is enhanced in range of 2.75- 3.45 times following the general measures of retrofitting. The reason behind this increase is the addition of similar strength concrete over the old surface which will work simultaneously with the old concrete surface.

6. CONCLUSION

A numerical investigation is carried out in the present study to assess the enhancement of load carrying capacity of reinforced concrete (RC) beam by concrete jacketing. The finite element package ABAQUS is used to assess the behavior of both the bare and the strengthened beams. The bond between the existing and additional concrete is considered to be perfect in FEM analysis although in practical cases this property may change due to variation in materials mechanical properties, retrofitting method and workmanship. The numerical model is validated considering experimental load-deflection values and shows a good agreement. A parametric study is conducted considering three RC beam sections and loaded in a span length of 3500 mm. Simply-supported beams subjected to uniformly distributed loads are considered in the present study. From the analysis, it is shown that the load carrying capacity of retrofitted beams can be increased between 175% to 245%. The failure mode of the retrofitted beam was ensured ductile by providing appropriate shear reinforcements. It is also shown that higher enhancement of load carrying is observed for the smaller RC sections than that of the larger section.

REFERENCES

[1] Damian I. Kachlakev and David D. McCurry, Jr, (2000) Testing of Full Size Reinforced Concrete Beams Strengthened with FRP Composites: Experimental Results and Design Methods Verification, Oregon Department of Transportation and Federal Highway Administration, Final report SPR 387.

[2] Hamid Sinaei, Mahdi Shariati, and Amir Hosein Abna, Evaluation of Reinforced Concrete Beam Behavior using Finite Element Analysis by ABAQUS, Scientific Research and Essays Vol. 7(21), pp. 2002-2009, 7 June, 2012

[3] Shri. Pravin B. Waghmare, December 2011. Materials and jacketing Technique for Retrofitting of Structures, International Journal of Advanced Engineering Research and Studies E-ISSN2249 – 8974

[4] IS13945, Repair and Seismic strengthening of Buildings-Guidelines, Bureau of Indian Standards, New Delhi 1993.

[5] Bangladesh National Building Code, Construction Practices and safety, maintenance management, Repairs, Retrofitting and Strengthening of Buildings, Vol. 7, Part 7, Chapter 5, BNBC 2012 (draft), Housing and Building Research Institute.

[6] Priyanka Sarker, Mahbuba Begum and Sabreena Nasrin, Fiber Reinforced Reinforced Polymers for Structural Retrofitting: A Review, Journal of Civil Engineering (IEB), 39 (1) (2011) 49-57.

[7] AASHTO Manual for Condition Evaluation of Bridges; 1994 Section 6: Load Rating

[8] ABAQUS Online Documentation, version 6.7, Dassault Systèmes, 2007

[9] Lee K and Han J (1998), Fatigue Behavior of Composite Beams with Pyramidal Shear Connectors under Repeated Loading, KSCE J. Civil Eng., 2: 119-128.

[10] A. Teran and J. Ruiz, Reinforced Concrete Jacketing of Existing Structures, Earthquake Engineering. Tenth World Conference, © 1992 Balkema, Rotterdem. ISBN 90 5410 060 5

[11] AS 1170.1 Minimum design loads on structures; https://www.dlsweb.rmit.edu.au/Toolbox/buildright/content/bcgbc4010a/04_struct_members/01_beams/page_009.htm