Proceedings of the 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), 7~9 February 2020, KUET, Khulna, Bangladesh (ISBN-978-984-34-8764-3)

STRENGTHENING OF REINFORCED CONCRETE BEAMS BY USING EXTERNAL STEEL ANGLE

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ABSTRACT

Strengthening of existing Reinforced Concrete (RC) structures may be required due to inadequate design, overloading, aging of building, environmental impact, corrosion of reinforcement, unfavorable condition such as earthquake, blasts, etc., the changes in the use of the structure and inadequate maintenance of the structure. The aim of this study was to investigate the flexural capacity of reinforced concrete beams after strengthening using external steel angles. Four reinforced concrete beams having cross-sectional dimensions of 150mm × 250mm and a length of 2700mm were prepared in this manner. 2-ø10mm bars were used as flexural reinforcement and 2-ø10mm bars were used on the top of the beam's web for holding the stirrups. The beams were designed strong enough against shear with ø6mm stirrups at a center to center distance of 100mm. Among the four beams, two beams were used ascontrol specimens. To find the ultimate capacity of the beams the control beams were tested after 28 days curing by using 3rd point loading. The average ultimate capacity of the control beams was 49.1kN. To simulate service load condition other two beams were preloaded up to75% of the ultimate capacity of the control beams. Some initial cracks formed due to the preloading. After the observation of initial cracks, the load was released. For the attachment of external steel angles (25mm×25mm×4mm)to the bottom corner by welding the lower and side (50mm) concrete cover of the beams was removed. After the attachment of external steel angles on the corner of the bottom stirrups by welding,the bottom part of the beams was cleaned. To cover the external steel angles the bottom part of the beams was cast again with new concrete. After 28 days curing the strengthened beams were tested in the same wayto find the ultimate capacity of strengthened beams. The ultimate capacity of the control beams was 124.4kN & 116.8kN which was 153% and 138% higher than the control beams. The experimental result shows the potentiality of using external steel angles as a strengthening technique to be followed with convenience.

Keywords: *Flexural strengthening, Strengthening techniques, Preloading, External steel reinforcement, External steel angles.*

1. INTRODUCTION

Civil infrastructure is a constituent of an uppermost portion of the national wealth. Nowadays, buildings are found to be out of service. The most widely used building materials in civil engineering applications is concrete (Zhang, Han, Ng, & Wang, 2018). Deterioration of RC structures is one of the major problems in the civil infrastructures, as a large number of buildings are constructed according to older design standards(Sundarraja&Rajamohan, 2009). Strengthening of reinforced concrete (RC) structures is usually required due to overloading, corrosion of the steel reinforcement, mechanical damage and inadequate maintenance, exposure to unfavorable conditions like earthquakes and blasts, the changes in the use of the structure and design and construction faults (Iskhakov, Ribakov, Holschemacher, & Mueller, 2013; Gul, Alam, Khan, Badrashi, &Shahzada, 2015). If a heavy earthquake with a 7.0 or greater magnitude arises in this country, it will lead to an extensive human wreck due to the faulty structural design of many buildings and proper awareness. According to the Geological Survey of Bangladesh, the country had experienced at least 465 earthquakes of several magnitudes between 1971 and 2006(Paul & Bhuiyan, n.d.).

Bangladesh is suffering from disasters such as Cyclones, Floods, Storm Surges and Tornados including Earthquakes regularly. Out of 5,000 public buildings in Bangladesh, around 3,000 were constructed before 1993 when the Bangladesh National Building Code (BNBC 1993) was enacted (Bangladesh, PWD, MHPW, 2015). These buildings have low resistant ability against earthquakes. According to the report of PWD, if an earthquake of M7.5 on Madhupur Fault in the Dhaka suburb occurs, the damage estimation for the Dhaka city became VIII of MMI seismic intensity scale, and out of the total 326,000 buildings, 72,000 buildings will damage beyond repair. About 50% of them would be reinforced concrete and about 30 percent would be brick masonry buildings. Also, moderately damaged buildings are estimated to be 49%. Further, if the earthquake occurs at 2:00 am, about 90 thousand people will die.

Also, most of the buildings in Bangladesh are low-rise buildings. With the rapid development of construction, the land becomes more and more scarce and the construction of the new structure is quite expensive (Islam, Islam, Talukder, & Hossain, 2013). Under such situations, maintenance of the building's construction quality and improvement of the safety of the buildings are necessary for Bangladesh. To overcome this upcoming hazard, the structures are required modification or strengthening to satisfy current building code requirements.

Strengthening by steel is popular in the world due to its cheapness, easy to work, available, meet the required strength, good at the ductile property and high fatigue strength. Steel is a universal, cheap, and effective construction material. The addition of steel reinforcement significantly increases the strength of concrete but to produce concrete with homogeneous tensile properties, the micro-cracks develop inconcrete should be suppressed(Raut, & Kulkarni,2014).

Gul, A., et.al (2015) investigate the flexural strengthening of reinforced concrete beams by using external steel. External steel bar & steel angle was used by removing bottom concrete cover and welding with the stirrups for the strengthening of different reinforced concrete beams. The flexural capacity of reinforced concrete beams strengthened with external steel reinforcement was greatly enhanced and showed a uniform distribution of flexure cracks. The failure of the strengthened beam resulted in a very favorable mode as compared to the control reinforced concrete beam. Beams strengthened with steel angles enhanced the load-carrying capacity more than the beams strengthened with external steel bars, indicating high flexural resistance. Better ductility was showed by the RC beam, strengthened with external steel angles than the RC beams strengthened with external steel bars.

2. METHODOLOGY

For this study, eight half-scaled reinforced concrete beam specimens were constructed. The cross-sectional area of the beams was 150mm × 250mm and the length of the beams was 2700mm. The compressive strength of the concrete at 28 days was 33.3MPa. 500w deform bars used as main reinforcement. Table 1 shows the design summary of all specimens.

Table 1: Design summary of all beams

Specimen ID	Types of Beams	Cross-section b × h (mm × mm)	Main Reinforcement	External Reinforcement	Fastening Mechanism
B1-1	Control Beams	150 × 250	2- ø10 mm	-	-
B1-2		150 × 250	2- ø10 mm	-	-
B5-1	Strengthened Beams	150 × 250	2- ø10 mm	2- 25mm × 25mm × 4mm steel angle	Welding with stirrups
B5-2		150 × 250	2- ø10 mm		

2.1 Design of Control Beams

The moment capacity of the control beams $M_{n(c)}$ was determined by using basic concepts for the rectangular reinforced concrete beams as given in the ACI code ACI-318-08 section 10.5. For the comparison of results, the beams were designed with minimum steel ratio

$$A_{s(min)} = 3\frac{\sqrt{f_c'}}{f_y}bd \geq \frac{200}{f_y}bd \tag{1}$$

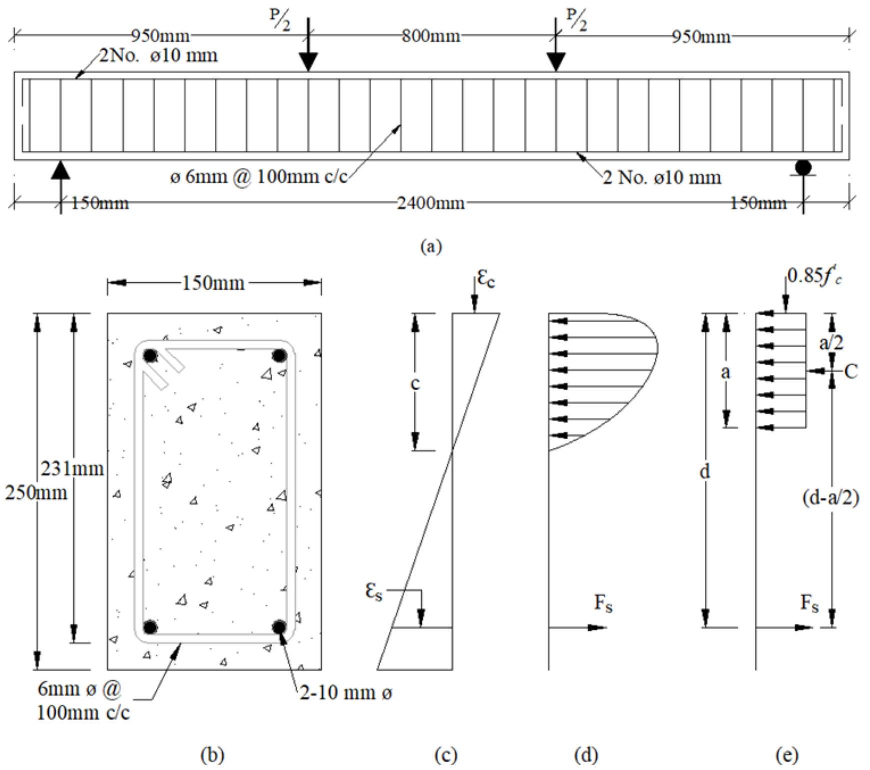

Figure 1: Schematic diagram of control beams (a) long section (b) x-section (c) strain diagram (d) nonlinear stress diagram (e) rectangular stress block

As a requirement of minimum steel two ø10 mm bars were used as flexural reinforcement. To hold the stirrups two ø10 mm bars were placed on top of the beam's web. The beams were designed strong enough against shear. The maximum shear force was found on the basis of $A_{s(max)}$ calculated after the design of strengthened beams.

$$A_{s(max)} = \rho_{max} b d_{ave} \tag{2}$$

$$M_{n(c)} = A_s f_y \left(d - \frac{a}{2}\right) \tag{3}$$

$$a = \frac{A_s f_y}{0.85 f_c'} \tag{4}$$

$$M_{n(max)} = A_{s(max)} f_y \left(d_{ave} - \frac{a}{2}\right) \tag{5}$$

$$V = \frac{3M_{n(max)}}{L} \tag{6}$$

Where

V = maximum shear force

$M_{n(c)}$ = moment capacity of control beams

$M_{n(max)}$ = maximum moment capacity of strengthened beams

For the above maximum shear force, beams were designed and provided with ø6 mm 500w steel bars placed at 100mm on center throughout the length of the beams. Figure 1 shows the reinforcement detailing, strain diagram, nonlinear stress diagram and rectangular stress block of control beams.

2.2 Design of Strengthened Beams

The same flexural design procedure was used for the external strengthening of reinforced concrete beams as the regular rectangular beams. To find the external steel area the strain compatibility and rectangular stress block were used by Gul et al. (2015) in the case of Strengthening with external steel angles. This procedure was also the same as the ACI method for RC flexural members.

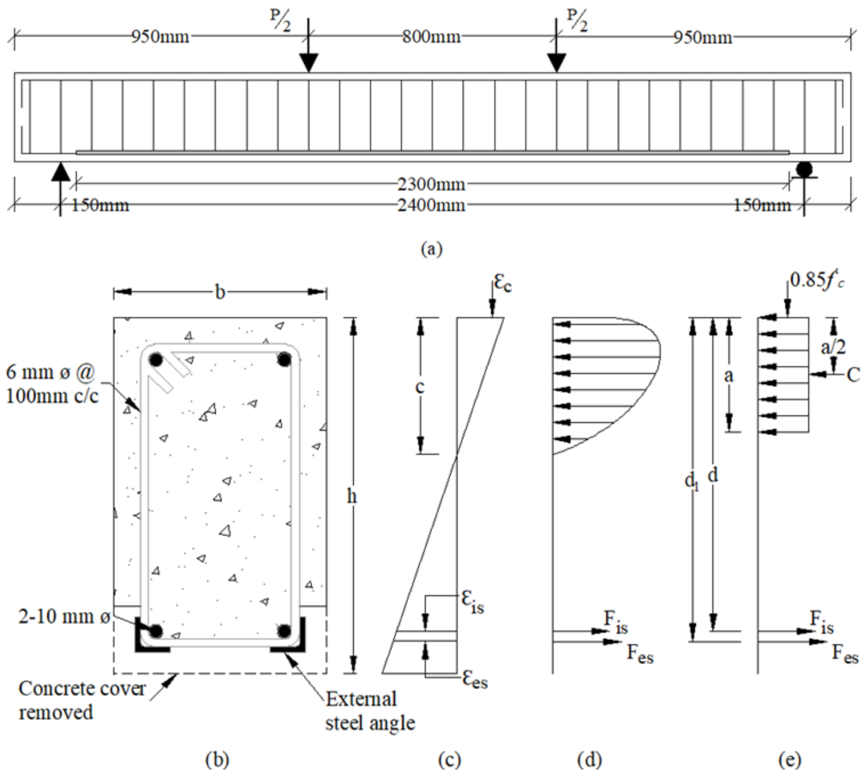

Figure 2: Schematic diagram of beams strengthened with external steel angles (a) long section (b) x-section (c) strain diagram (d) nonlinear stress diagram (e) rectangular stress block

The regular formulas for the design of RC beams were used to calculate the steel area for external reinforced concrete beams. The external steel area worked as the second flexural force acting member at the center of the external steel. Figure 2 shows the reinforcement detailing, equivalent strain, nonlinear stress and rectangular stress diagram of beams strengthened with steel angles. The design procedure for externally strengthening of RC beams was based on maximum reinforcement ratio as given by ACI 318-08 Section 10.2 $\rho_{max} = \rho_{balance}$. The calculate steel area divided into two parts. Internal steel area $A_{s(c)}$ and external steel area $A_{s(ext)}$.

$$A_{s(ext)} = A_{s(max)} - A_{s(c)} \tag{7}$$

Where:

$A_{s(c)} = steel\ area\ of\ control\ beams$

$A_{s(ext)}$= *external steel area provided for strengthening purpose*

The moment capacity of strengthened beams calculated as

$$M_{n(total)} = A_{s(c)} f_{y(c)} \left(d - \frac{a}{2}\right) + A_{s(ext)} f_{y(ext)} \left(d_1 - \frac{a}{2}\right) \tag{8}$$

Where:

$M_{n(total)} = momentcapacityofstrengthenedbeams$

$f_{y(c)} = yieldstrengthofsteelusedincontrolbeams$

$f_{y(ext)} = yieldstrengthofexternalsteel$

2.3 Capacity of Beams

The ultimate capacity of different beams (control beams and Strengthened beams) was calculated according to ACI 318-08. A beam can fail in two basic modes. Failure in compression and failure in tension. The ultimate capacity of beams in compression was found by equation 9 and the capacity in tension was found by equation 3or equation 8.

$$M_{u(c)} = \rho_{max} f_y b d^2 \left(1 - 0.59 \rho_{max} \frac{f_y}{f_c'}\right) \tag{9}$$

$$\rho_{max} = 0.85 \beta_1 \frac{f_c'}{f_y} \frac{\varepsilon_u}{\varepsilon_u + 0.004} \tag{10}$$

The maximum moment capacity $M_n$was found from the minimum value of equation 3, equation 8 or equation 9 and using this value the maximum load was calculated.

3. EXPERIMENTAL PROGRAM

3.1 Sample Preparation

Four reinforced concrete beams were prepared for the experimental investigation. The cross-sectional area of the beams was 150mm × 250mm and the length of the beams was 2700mm. 2-ø10mm deform bars were used as main reinforcement. To hold the stirrups, 2-ø10mm deform bars were used on top of the beam's web. ø6mm deform bars used as shear reinforcement at @100mm c/c. Table 2 shows the tensile properties of reinforcing steel. Wooden formworks were made for the casting of beams according to ACI 318-08 section 6.1. Polyethylene was used on the formwork to get a smooth surface and preventing water absorption by the wooden formwork.

Table 2: Tensile properties of steel bar, steel angle & steel plate

Description	Yield Strength (MPa)	Ultimate Strength (MPa)
Ø6 mm bar	565	668
Ø10 mm bar	552	643
Steel Angle	426	530

3.2 Test of Control Beam

To find the flexural capacity of control beams two beams (B1-1 & B1-2) were tested up to the failure loadby using 3rd point loading according to ASTM C78. The beams were simply supported at a clear span of 2400mm and loaded symmetrically in four-point bending. A 300kN hydraulic jack was used for the application of load arranged vertically and divided into two equal point loads at a distance of 400mm on each side of the centerline of the beam through a transfer beam. The rate of loading maintained at 4.5kN/min according to ASTM C78. A 500kN load cell and 5 LVDTs (Linear variable differential transformer) were used to collect data directly by TML TDS-303 data logger. The 1^{st}LVDT was placed at the center of the beam, $2^{nd}$and 3^{rd}LVDTs were placed under the beam to the point load. $4^{th}$and 5^{th}LVDTs were placed in the midpoint of support and the point load. Figure 3 shows the schematic diagram of the test setup.

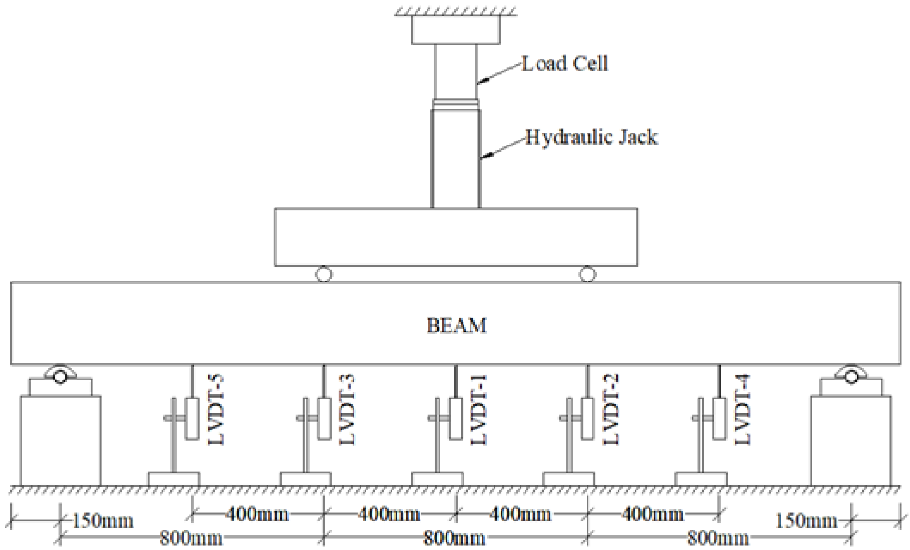

Figure 3: Schematic diagram of the experimental setup

3.3 Preloading

The other two beams (B5-1& B5-2) were preloaded up to 75% of the ultimate load of control beam by the standard test methods ASTM C78 to simulate the service load condition. The arrangement of LVDTs and loading patterns werethe same as the control beams. Some initial cracks formed due to preloading. After the observation of the initial cracks, the load was released.

3.4 Strengthening of Beams

After the release of the preload, the beams were ready for strengthening. The bottom concrete cover and the side concrete cover (up to 50mm) were removed to add steel angles with the bottom corners of the stirrups. The bottom face was cleaned. Twosteel angles were added in two sides of the beams with bottom stirrups by welding. After attaching the steel angles, the beams were cleaned and the exposed part was covered with new concrete.

3.5 Test of Strengthened Beams

After 28 days of curing of the new concrete, the beams were tested to find the ultimate capacity of the strengthened beams. 3^{rd} point bending test was used to test the strengthened beams according to ASTM C78. According to ASTM C78, the loading rate was maintained 4.5kN/min. The loading data was recorded and new cracks were marked with a red marker.

4. RESULTS

4.1 Control Beams

The reinforced concrete beams (B1-1) & (B1-2) shown the same elastic behavior up to a load of 16.5kN and 14.5kN respectively and the corresponding mid-span deflection at the elastic load was 1.38mm and 1.30mm respectively. The destruction of stiffness started after the elastic load and the relation was again linear up to a load of 44.5kN and 45.8kN for the control beams and the mid-span deflection was 10.55mm and 9.82mm at that stage. Figure 4 shows the load-deflection relationship of control beams. The first flexure crack formed at the bottom of the beam surface at a load of 23.9kN and 24.8kN respectively and propagated rapidly towards the upper part of the beams.

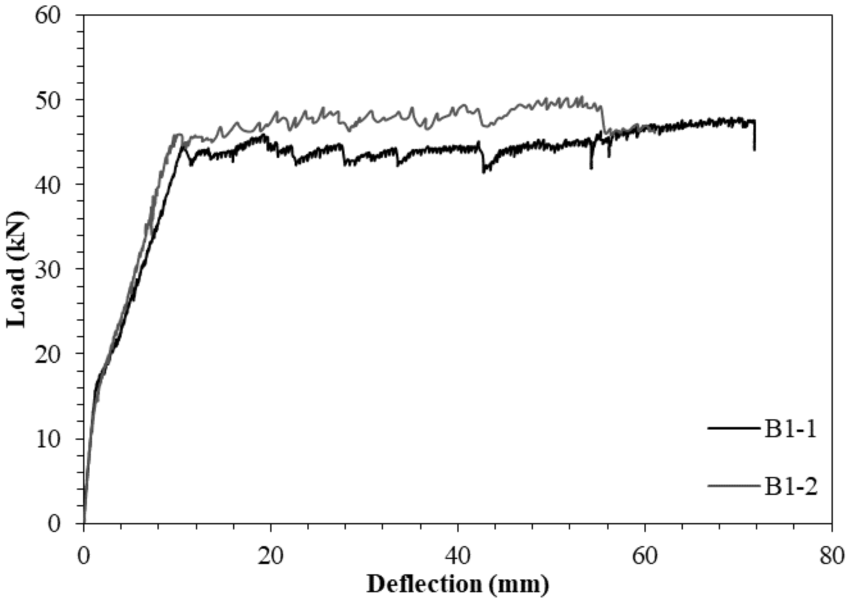

Figure 4: Load-deflection relationship of control beams

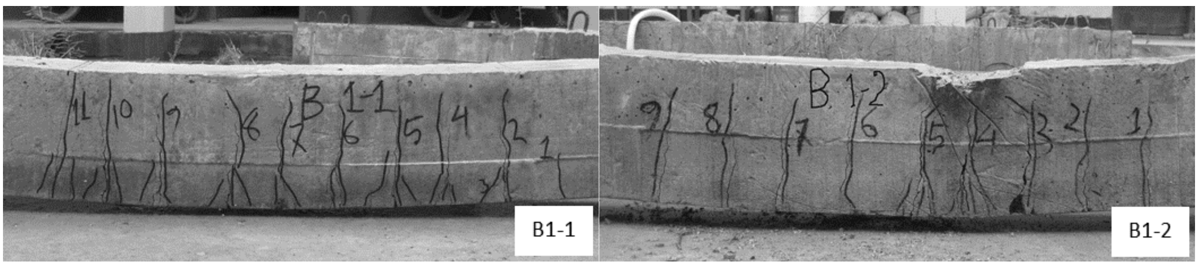

Figure 5: Failure mode and crack pattern of control beams

Most of these cracks were in the region of the maximum bending moment. The ultimate load of control beams was 47.9kN & 50.4kN. The calculated load-carrying capacity of the control beams was 43.1kN while the experimental ultimate load-carrying capacity was found to be 11% & 17% higher than the calculated load-carrying capacity. The average ultimate load of control beams was 49.1kN. The beams failed by flexure after the yielding of steel reinforcement and showed a pure bending behavior. Figure 5 shows the cracks pattern and failure mode of the control beams. The yield and ultimate load and ductility index of two beams were very close. The ultimate load for B1-1 was 47.9kN which was 50.4kN for B1-2. Those values were 11% and 17% higher than the calculated capacity of control beams.

4.2 Preloading

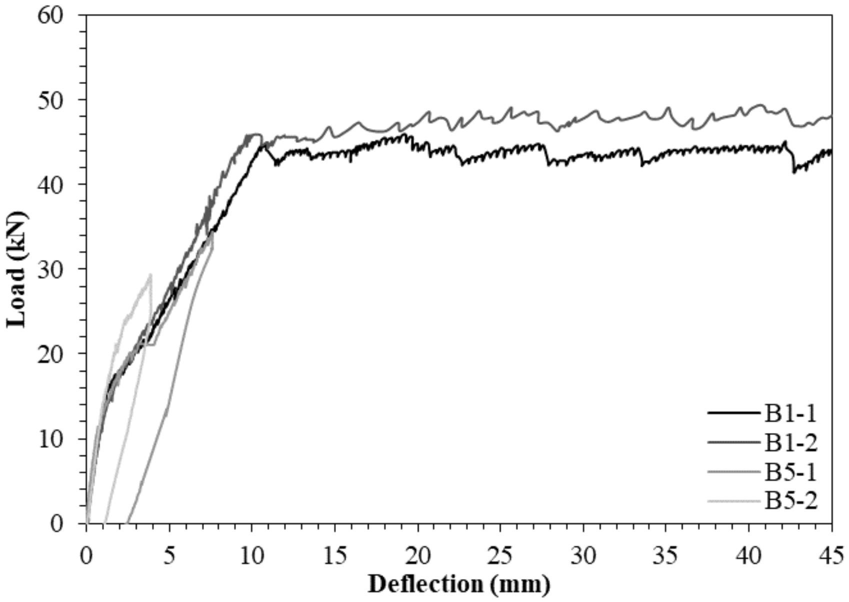

Figure 6: load-deflection relationship of beams due to preloading

Figure 6 shows the load-deflection relationship of beams (except control beams) preloaded with (65-75) % of the ultimate capacity of the control beams. All the beams showed similar behavior for preloading and had some permanent deflection after unloading. Table 3 shows the maximum applied load for preloading, maximum deflection with the corresponding load, permanent deflection after unloading and the number of cracks form due to preloading. Figure 7 shows the crack pattern due to preloading.

Table 3: Summary of preloading

Specimen ID	Applied Load (kN)	Maximum Deflection (mm)	Permanent Deflection (mm)	No of cracks
B5-1	34.5	7.58	2.36	15
B5-2	29.3	3.88	1.04	8

Figure 7: Crack pattern due to preloading

4.3 Strengthening

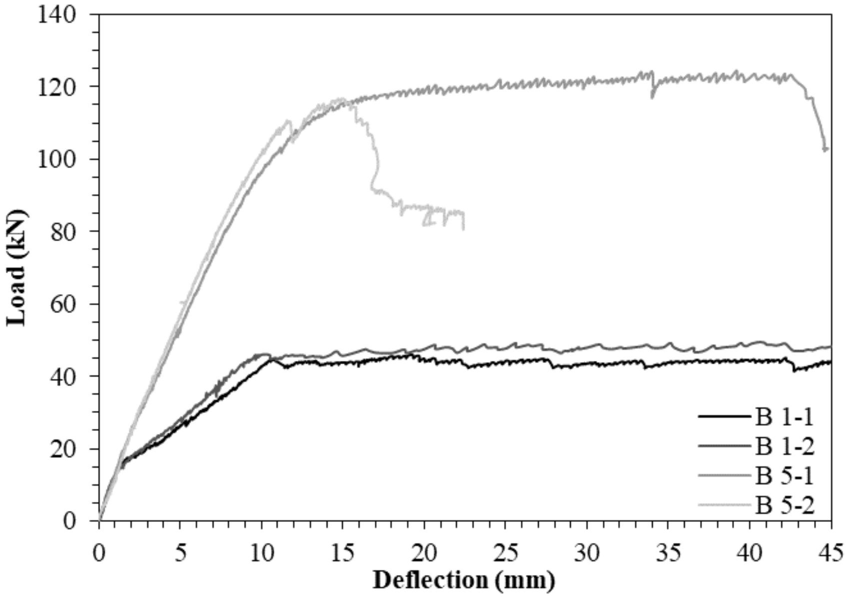

Figure 8: load-deflection relationship of strengthened beams

Figure 8 shows the load-deflection relationship of beams strengthened with external steel angles (B5-1 & B5-2) attached with bottom stirrups by welding. The elastic limit of B5-1 was 18.8kN at mid-span deflection of 1.11mm. The relationship was again linear up to a load of 79.2kN while the mid-span deflection was 6.94mm. The ultimate load was 124.4kN at mid-span deflection of 39.20mm. The experimental ultimate load-carrying capacity was 105% of the calculated load carrying capacity for that beam which was 118.2kN. The beam was failed by crushing of compressive concrete after the yielding of steel bars and external steel angles. Ten new cracks (red) formed some of them were in the shear region and some in the flexural region. The length and width of the new flexural cracks are smaller than the preloaded cracks. B5-2 showed similar behavior like B5-1 in flexure up to a load of 110.4kN and mid-span deflection of 11.26mm. The ultimate load was 116.8kN at mid-span deflection of 14.76mm. The experimental ultimate load-carrying capacity was 99% of the calculated load-carrying capacity. B5-1 showed better ductile behavior than B5-2. The ductility index for B5-2 was 1.27 which was 2.76 for B5-1. The reduction of ductility may be due to more welding failure in the case of B5-2. Total of seven new cracks (red) formed in the shear region. The bottom part which was cast after the attachment of steel angles tended to separate from original concrete which may be due to the failure of welding. The failure mode tended to switch from flexural to shear failure. Figure 9 shows the failure mode and crack pattern of the beams strengthened with external steel angles.

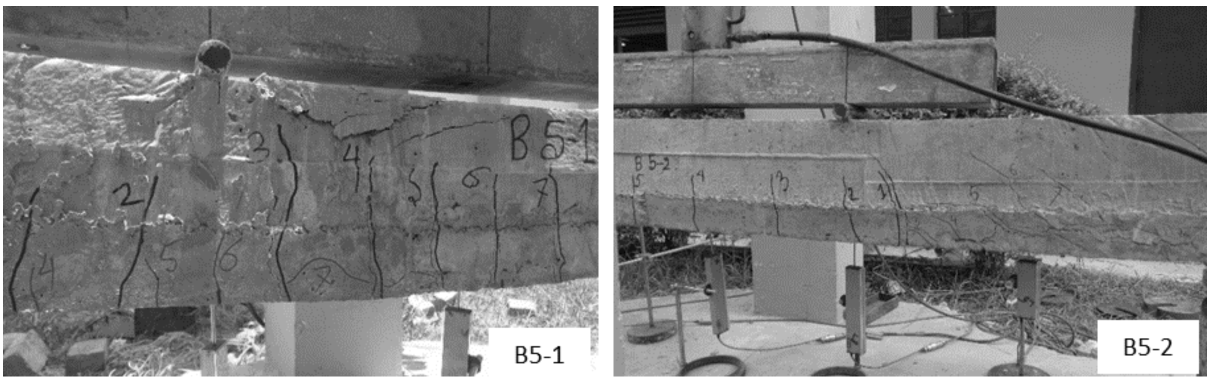

Figure 9: Failure mode of beam strengthened with steel angles

4.4 Comparison of results

Table 2: Summary of test results

Types of Beams	Specimen ID	$P_{u(c)}$ (KN)	$P_{u(e)}$ (KN)	Δ_u (mm)	I_u (%)	$\frac{P_{u(c)}}{P_{u(e)}}$
Control	B1-1	43.2	47.9	69.22	N/A	1.11
	B1-2	43.2	50.4	53.32	N/A	1.17
Strengthened	B5-1	118.2	124.4	39.20	153	1.05
	B5-2	118.2	116.8	14.76	138	0.99

$P_{u(c)}$= calculated ultimate capacity; $P_{u(e)}$= ultimate experimental load-bearing capacity; Δ_u= deflection at ultimate load; I_u Increase in ultimate load-bearing capacity.

Attaching external steel angles, the flexural strength of RC beams increased significantly. The ultimate capacity of the strengthened beams was 124.4kN and 116.8kN which was 153% and 138% higher than the ultimate capacity of control beams. The ultimate capacity was 105% and 99% of the calculated value for the strengthened beams. The beams failed by the yielding of main steel bars and external steel angles. Although ductility decreased due to strengthening the capacity increased at a significant rate.

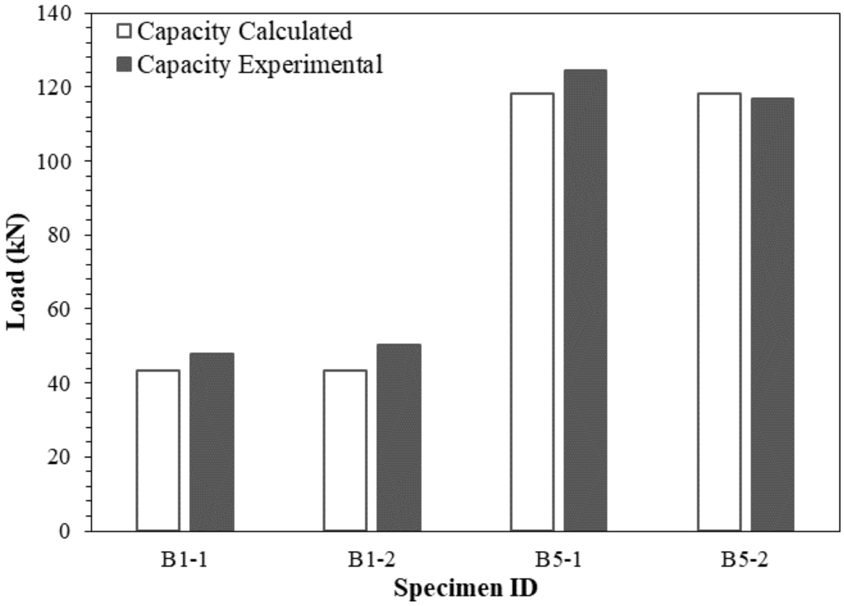

Figure 10: Relationship between calculated and experimental capacity

5. CONCLUSIONS

RC beams strengthened with external steel angles have shown that this is a very effective strengthening technique. The average flexural capacity of the simply supported control beams was 49.1kN. After strengthening the ultimate capacity increased to 124.4kN and 116.8kN which was 153% and 138% higher than control beams. In the case of external steel angles, the ultimate load was 105% and 99% of the calculated capacity.

ACKNOWLEDGEMENTS

Authorswould like to express profound respect and deepest gratitude and the hardest thanks to everybody who involved directly or indirectly in this study. This accomplishment would not have been possible without them.

REFERENCES

ACI Committee, & International Organization for Standardization. (2008). Building code requirements for structural concrete (ACI 318-08) and commentary. American Concrete Institute.

ASTM, C. (2010). Standard test method for flexural strength of concrete (using simple beam with third-point loading). In *American society for testing and materials* (Vol. 100, pp. 19428-2959).

Bangladesh, Public Works Department, Ministry of Housing 6677 and Public Works. (2015). *Project for Capacity Development on Natural Disaster-Resistant Techniques of Construction and Retrofitting for Public Buildings in The People's Republic of Bangladesh*. Retrieved from http://open_jicareport.jica.go.jp/pdf/12252391_01.pdf

Gul, A., Alam, B., Khan, F. A., Badrashi, Y. I., &Shahzada, K. (2015). Strengthening and Evaluation of Reinforced Concrete Beams for Flexure by Using External Steel Reinforcements. *International Journal of Scientific Engineering and Technology*, *4*(4), 260-263.

Iskhakov, I., Ribakov, Y., Holschemacher, K., & Mueller, T. (2013). High performance repairing of reinforced concrete structures. *Materials & Design*, *44*, 216-222. https://doi.org/10.1016/j.matdes.2012.07.041

Islam, S., Islam, M. R., Talukder, M. A. Q., & Hossain, S. R. (2013). Strengthening Technique of Reinforce Concrete Structure: Bangladesh Perspective. *American Academic & Scholarly Research Journal*, *5*(6), 17.

Paul, B. K., & Bhuiyan, R. H. (n.d.). Urban earthquake hazard: Perceived seismic risk and preparedness in Dhaka City, Bangladesh. *Disasters*, *34*(2), 337-359.

Raut, L. L., & Kulkarni, D. B. (2014). Torsional strengthening of under reinforced concrete beams using crimped steel fiber. *International Journal of Research in Engineering and Technology*, *3*(6), 466-471.

Sundarraja, M. C., &Rajamohan, S. (2009). Strengthening of RC beams in shear using GFRP inclined strips - An experimental study. *Construction and Building Materials*, *23*(2), 856-864. https://doi.org/10.1016/j.conbuildmat.2008.04.008

Zhang, P., Han, S., Ng, S., & Wang, X.-H. (2018). Fiber-Reinforced Concrete with Application in Civil Engineering [Research article]. https://doi.org/10.1155/2018/1698905