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Strengthening of Reinforced Concrete Beams using Steel Sheets

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Abstract

Nowadays, deterioration of structural members by aging, overloading, environmental actions and so on is critical issues which faces safety of structures which faces many countries. It is important to restore performance of deteriorated structures to the desired level. For such purposes, strengthening of members using plate jacketing is common. In this study, experimental works and numerical modelling were used to investigate the flexural and shear behaviour of reinforced concrete beams strengthened with steel sheet. Reinforced concrete beams strengthened by attaching steel sheets with various configuration and layers of steel plates were tested until failure using two points loading. In the experimental works, one set of beam specimens with lower flexural strength were strengthened by attaching various number of steel sheets to the soffit, whereas shear-prone beam specimens were strengthened by using u-shaped plates and web plating on both faces. To evaluate the effect of additional parameters on strengthening that were not addressed by the experimental works, simulation software was used. According to the findings of the experimental and numerical simulations, strengthening using steel plates increases beam flexural and shear capacities by 16.2% and 22.68%, respectively. Moreover, it was observed that deflection of beams were reduced by 8.89% to 19.69% as compared to the control specimens, with U-wrapping of steel proving to be particularly effective.

Key Words: Deterioration, Strengthening, Plate jacketing, Flexure, Shear.

1. Introduction

1.1. Background

Reinforced concrete structures often have to face modification and improvement of their performance during their service life. Factors such as change in their use, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes affect their performance. Many elevated highways structures constructed in Japan have been built according to the Design Specifications issued before 1980, which did not fully address the current loading conditions, especially seismic effects (Adhikary et al., 2006). Federal Highway Administration (FHWA) statistics in 1989 stated that 40% of the highway bridges in the US are structurally deficient. These bridges were designed to take lower traffic loads than what is observed in practice (Chenna and Rahul, 2016). Moreover, structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the provision of new design codes (Chenna and Rahul, 2016; Ramin, 2016).

For instance, in Ethiopia, most of the existing buildings were designed for earthquake based on the provisions of Ethiopian Building Code Standard (EBCS, 1995). However, based on the revised code, in most areas or zones, the expected peak ground acceleration has doubled and new design codes have been made available as of 2015. This code uses a higher peak ground acceleration ratio as compared to the previous design code of standard (Ramin, 2016; ES-EN, 2015).

Since replacement of deficient elements of structures incurs a huge amount of money and time, strengthening has become the acceptable way of improving load carrying capacity and extends their service life (Ramin, 2016; Nishikant, 2009).

In most cases, strengthening of RC beams has conventionally been done by increasing cross sectional area of which it is time consuming, costly and problem of interfere of substrate materials. One of the developing methods is the externally bonded steel sheet application, which should be placed on the tension side of the beams to enhance its limit of flexural strength.

The objective of this study aims to provide a comprehensive assessment of the strengthening technique's and its applications in structural engineering. Hence, in this study, the use of steel plates to increase the shear and flexural capacities of reinforced concrete beams is investigated experimentally and numerically are investigated. The research includes slender beams with internal force of flexure and shear.

The experimental and numerical results of this study provide strong evidence supporting the use of steel plates for strengthening RC beams and an increase in flexural and shear capacities by 16.2% and 22.68%, respectively.

2. Literature Review

The awareness on strengthening of structures came into minds of engineers and scientists during the 1960s. Strengthening technique was essentially originated and developed keeping the bridge structures in mind (Ahmad, and Singh, 2018). Steel plates were also used to increase shear capacity of beams and the results showed that an increase upto 30% was achieved with the use of a 4mm steel sheets (Barnes et al., 2001). Strengthening of beams using Near-Surface Mounted - Glass Fiber Reinforced Polymer (NSM-GFRP) increased the flexural capacity by 10% to 35% (Gebre et al., 2020).

Different methods of structural strengthening techniques have been developed over the years such as external bonding of steel plates, glass fiber reinforced plastic (GFRP), fiber reinforced

polymer (FRP) sheets, external prestressing, carbon fiber wrapping and very recently improved external reinforcement techniques (Ahmad, and Singh, 2018). The ultimate strength, stiffness, ductility, and failure mode of reinforced concrete beams, retrofitted by steel plates, are affected by the fixation technique and adhesion type (Alaa, 2013).

To increase flexural capacity of structural members, FRP should be glued to the member in the way that fibers are parallel to the direction of the principal stress. FRP plates have been proved to increase the stiffness of the member and the load carrying capacity, and reduce the crack widths. The deflection of a retrofitted beam is considerably smaller than that of an un-retrofitted. This is due to the fact that stiffness is added to the member by the FRP plate or sheet.

Moreover, the number of FRP sheet layers has considerable effect on the ultimate load and stiffness of a beam. The load carrying capacity was shown to increase with an increased number of layers of carbon fibre sheets for up to six layers (Taleb, 2011). Bonding FRP reinforcement to the tension face of a concrete flexural member with fibers oriented along the length of the member provide an increase in flexural strength ranging from 10 to 160% have been acheived (Meier, 1991). When taking into account the strengthening limits of ACI, however, strength increases of up to 40% are more reasonable (ACI, 2008). Hussain et, al. explored the steel plate bonding repair technique including the effects of plate thickness and end anchorage on ductility, ultimate load and mode of failure. Their experimental results indicate that the ductility of the repaired beams decreases as plate thickness increases (Hussain et al., 1995).

Although end anchorages to the bonded plate can improve ductility, the improvement in ductility due to end anchorages decreases as plate thickness increases. Instead of pure flexure failure, the failure could due to increased thickness of bonded steel and splitting of concrete in the shear span are critical. From the previous researchers, reinforced concrete beams are widely retrofitted by FRP and steel plates. FRP though suitable for retrofitting, it is unavailable easily in the local market and it is costly whereas strengtheining using steel plates has a disadvantage of size limitation and its weight makes unsuitable (Ramin, 2016, Nishikant, 2009).

Due to overloading, increased peak ground acceleration, and other factors, existing structures are insufficient to resist the applied loads. Therefore, efficient techniques for strengthening and rehabilitation should be available for the structures with insufficient flexure and shear capacities. The process of concrete jacketing is one of the most recommended practices, which is employed in the strengthening and the retrofitting of the reinforced concrete (RC) beams. However, this study has some limitations and literature review gap. Some research gaps include there are no clear and precise recommendations concerning the thickness of concrete jackets, the arrangement of reinforcement in the jackets, and the methods for bonding the jackets to the demolished concrete one. Hence, the use of steel plates for the strengthening of RC beams for shear force and bending moment is found necessary.

3. Experimental Program

3.1 Materials

For preparation of the concrete mix, Portland Pozolana Cement (PPC), a crushed gravel coarse aggregate with a maximum aggregate size of 20mm and natural river sand with a fineness modulus 3.01 were used.

Deformed steel bars of diameter 8mm were used as fluxural reinforcement with a yield strength of 420MPa and diameter 6mm

bars were used for stirrups (the yield strength is 280MPa). Moreover, Steel sheets of gauge 35 with thicknesses 0.2mm was used. The property of the steel sheet (yield strength of 210MPa) was taken from previous local research which was conducted by (Rufael, 2003).

3.2 Concrete Mix

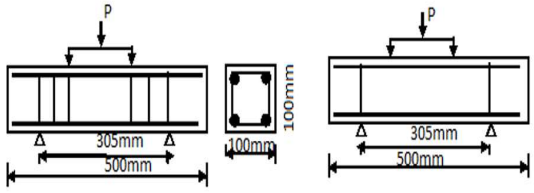
Concrete mix was designed according to ACI 318-83 (Hussain et al., 1995) method to have a cylinder compressive strength of 30 MPa with a water cement ratio of 0.4. Same material properties and mix proportions were used for all beam samples.

3.3 Specimens Preparation

Beams with rectangular cross-section of 100 mm width and 100 mm height, and 500mm long were prepared. The different cases are designated by letters and numbers. The first letters F and S represent flexural and shear-tested beam specimens, respectively. While the number of cases is stated as 1, 2, and so on. the The beams in group F were designed to have insufficient flexural strength with two tension reinforcement of diameter 8mm bars, and diameter 6 mm stirrups with spacing of 30 mm along the beam length in the shear span only as shown in Fig. 1 (a).

The beams in S group had the same longitudinal bars as F groups but hadn't stirrups in the shear span as shown in Fig. 1(b). Two sets of beams which were control beams, F1& F2 and S1 & S2, with identical cross sectional dimension and longitudinal reinforcement detailing were tested and their capacities are determined accordingly. Different arrangements of steel sheet for flexural and shear strengthening tests are shown in Table 1.

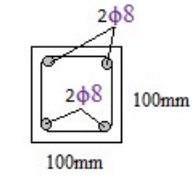
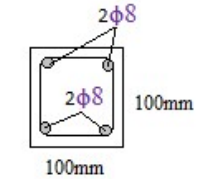
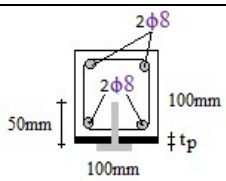
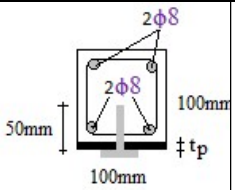
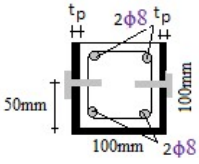
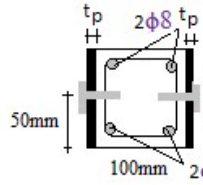
Four similar beams like that of F1 were prepared and strengthened for flexure as shown in Table 1. Three similar beams like that of S1 were also prepared and strengthened for shear strength enhancement. In this research, a total of 11 beams were experimentaly tested. In all beam specimens, the clear concrete cover to the main flexural reinforcement was set to 15 mm.



(a) (b)

Fig. 1. Beam specimen detailing for (a) flexure (b) shear

Table 1: Specimen descriptions for experimental works

Cases	Cross-section	Desription
F1 & F2		Control beam
S1 & S2		Control beam
F4 & F6		On the soffit of the beam, t_p= 0.2mm, bolt length 50mm
F3 & F5		On the soffit of the beam, two layers is applied, t_p= 0.2mm and bolt length 50mm
S4 & S6		U wrapping with double layer, t_p= 0.2mm and bolt length 50mm
S7		Plates on two sides with one layer, t_p= 0.2mm and bolt length 50mm

3.4 Test setups

The specimens were placed over the two steel rollers bearing leaving 100mm from the ends of the beam. The remaining 300mm was divided in to three equal parts of 100mm as shown in Figs. 1 and 2. To test the RC beam specimen, as per the recommendation of ASTM C 78 – 02, a standard test method for flexural strength of concrete beams using simple beam (ASTM, 2002).

All specimens were tested under two-point loading using a monotonically increasing load. This has the advantage of a substantial region of nearly uniform moment coupled with shears, enabling the bending capacity at the central portion, and the shear capacity in the shear zone to be assessed.



Fig. 2. Testing setup for control beam

4. Results and Discussion

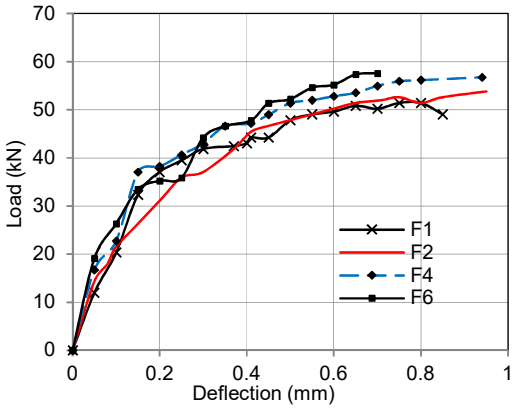
By varying the number of layers, arrangement and thickness of steel sheets, the load carrying capacity, deflections at ultimate load, failure modes were investigated and the results are discussed hereunder.

4.1 Experimental Results

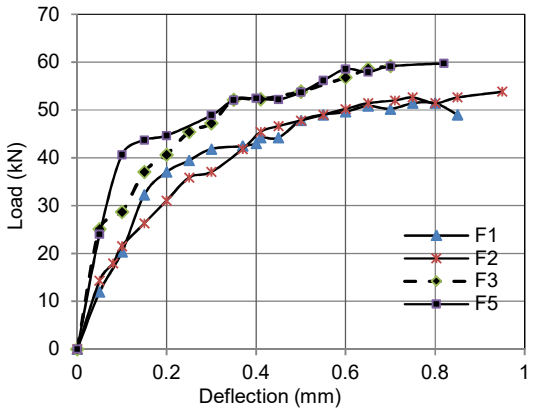
The average results of cube strength of concrete after 28 days, was found to be 42.5MPa. Load-deflection diagrams of different sets of beam specimens (F- and S-series) are shown in Figs. 3 and 4. Moreover, maximum load carrying capacity of the control beams and the strengthened beams are summarized in Table 2.

From the experimental results, it can be observed that strengthening of the beams with steel plates significantly enhances their flexural capacities. Specifically, an additional layer of a steel plate enhances beam characteristics, on average, by 10% when one layer of the steel plate has been used; the second layer enhances the beams' flexural capacity up to 16%. This gradual increment indicates that the extra layer offers greater stiffness and thus increases the beam's capacity to withstand bending moments. As shown in Figs. 3(a) and (b), use of single and two layers of steel plates reduces the beams deflections by 8.89% and 15.56%, respectively as compared to the control specimen. This highlights highlights the effectiveness of the strengthening techniques.

In the case of shear strengthening beam specimens, enhancements in shear capacities of 6% (one layer of steel plate) to 22% (for U wraping) have been obtained (Single layer of steel sheet was bolted on the web of S7 and its ultimate load carrying capacity was 53.63kN), which is in good agreement with similar experimental works (Gebre et al., 2020). It can therefore be suggested that both methods enhance the ultimate load-carrying capacity of the beams, with U-wrapping showing the most substantial improvement. As far as deflection of beams concerned, as shown in Figs. 4(a) and (b), the application of a single layer of steel plates on the beam faces led to a 7.98% reduction in deflection, while U-wrapping resulted in a more significant reduction of 19.63%, compared to the control specimen.

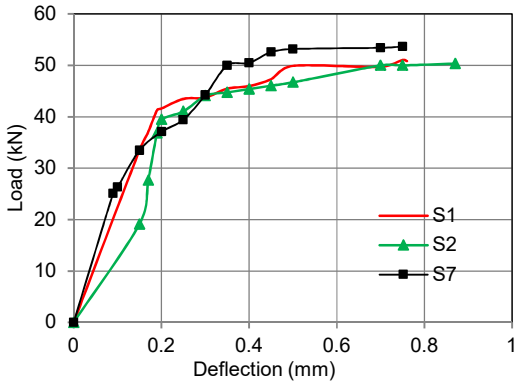


(a)

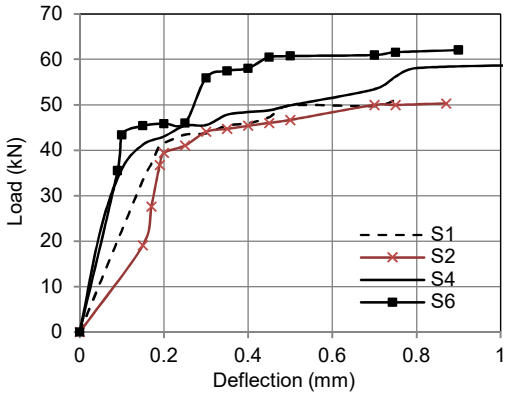


(b)

Fig. 3. Load deflection diagram of flexural enhanced beams



(a)



(b)

Fig. 4. Load deflection diagram of shear enhanced beams

Table 2: Experimental results

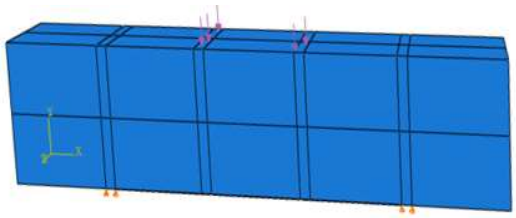
Beam sample	Steel sheet layers	Exp. failure load (kN)	% capacity increase	Deflection (mm)
F1	-	49.07		0.85
F2	-	53.79		0.95
S1	-	50.81		0.76
S2	-	50.33		0.87
F4	1	56.74	10.37	0.94
F6	1	57.57	11.98	0.7
F3	2	59.17	15.09	0.7
F5	2	59.729	16.18	0.82
S7	1	53.63	6.05	0.75
S4	U-wrap	58.94	16.55	1.15
S6	U-wrap	62.04	22.68	0.8

4.2 Finite Element Analysis

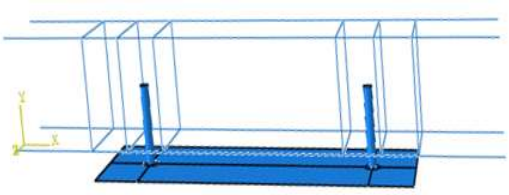
The general-purpose finite element program Abaqus (Abaqus 6-13-1) was used to investigate the behavior of reinforced concrete beams strengthened by steel sheets. It helps for further investigation by varying different parameters that were not addressed experimentally. Material properties, and interaction of different components is defined as shown in Table 3. The bond between rebars and concrete is modeled using an embedded region constraint. Boundary conditions in ABAQUS are used to define supports and loads are applied as concentrated forces at loading points. Mesh sensitivity analysis is done and a mesh size of 10mm is selected for all cases. Fig. 5 shows the support points, loading conditions, modeling of steel plates and rebars.

Table 3: Element types description

Part	Element	Element description
Concrete	C3D8R	8 node linear brick, reduced integration
Steel bars	T3D2	2 node truss element
Steel sheets	M3D4R	A 4-node quadrilateral membrane, reduced integration



(a)



(b)

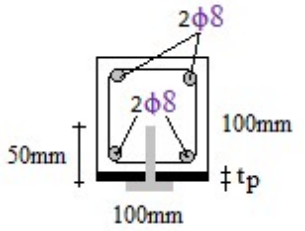
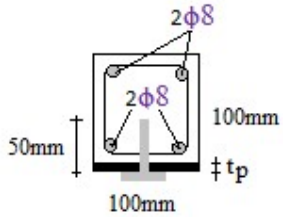
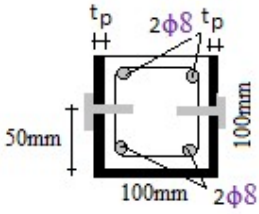
Fig. 5. (a) boundary condition and (b) modeling of reinforcement bars, steel sheet and bolts

4.2.1 Verification of the Finite Element Model

The experimental data and the finite element analysis are in reasonably good agreement as shown in Fig. 6. From the load-deflection diagrams, it can be noted that the initial stiffness of both beams predicted by finite element model was similar to that of the experimental one. The variation in ultimate load can be attributed to the simplifications made to develop constitutive models of the steel and the concrete for FEM.

Although there are a number of various parameters that could influence the behavior of strengthened reinforced concrete beam, only number of layers, varying thickness of the steel sheet, varying arrangement has been investigated as shown in Table 4.

Table 4: Beam cross-sections used for numerical simulation

Cases	Variable	Designation	Beam cross section
Number of layers	Three layers, t_p=2mm	FL3	
	Four layers, t_p=2mm	FL4	
Thickness of steel sheet	t_p=0.5mm	Ft0.5	
	t_p=1mm	Ft1	
	t_p=1.5mm	Ft1.5	
	t_p=2mm	Ft2	
	t_p=2.5mm	Ft2.5	
	t_p= 3mm	Ft3	
Arrangement of steel sheet	u-wrapping by single layer, t_p=2mm	Fuw1	
	u-wrapping by double layers, t_p=2mm	Fuw2	

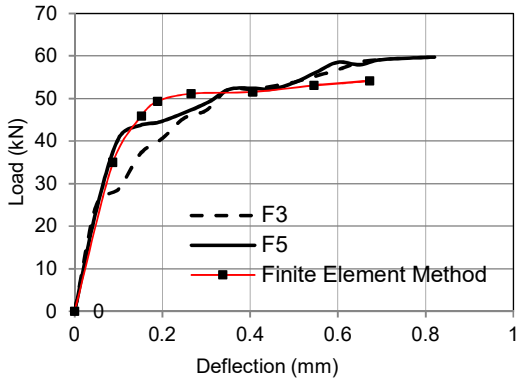


Fig. 6. Comparison of the load deflection behavior of the experment and ABAQUS simulation

The load capacity and the stiffness of the beams increased as the number of steel sheet increased up to three layers. However, the increase in load carrying capacity is not significant when the number of steel sheet layers was increased to four layers as shown in Fig. 7. In this case, comparison is made between three and four layers

Similarly, it can be noted that the capacity of strengthened beam increases with the thickness of the steel sheet as investigated in similar researches [6]. However, the relative capacity enhancement of the strengthened beams does not increase proportionally as the thickness increase as shown in Fig. 9. This may be due to the constant area of longitudinal reinforcement placed in the beam, which could limit the force that could be carried by concrete section.

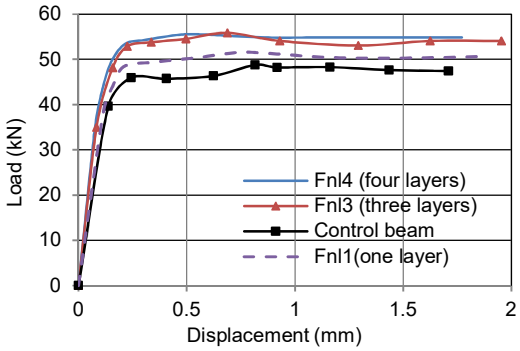


Fig. 7. Effect of number of layers on load capacity

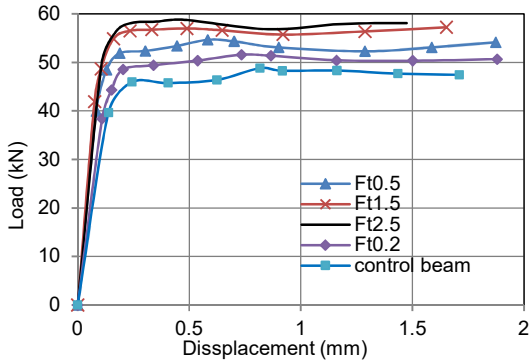


Fig. 8. Effect of thickness on load capacity

Wrapping the beams increase the load carrying capacity substantially than plating only on the soffit. Up to 40 % increase in load capacity was observed as shown in Fig. 9.

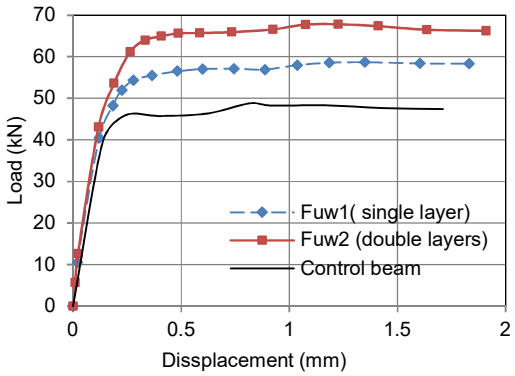


Fig. 9 Effect of steel sheet arrangement (U wrapping)

5. Conclusions

Generally, from the test results and finite element analysis the following conclusions are drawn.

1) The load capacity of the beam strengthened by plating at the soffit reached up to a maximum of 16%.
2) Use of single steel plates of 0.2mm under the soffit of the beam enhances its flexural capacity upto 12%.
3) Shear strengthening was found effective if it is done by u-wrapping which enhances the capacity in the range of 16.55% to 22.68%.
4) Increasing the number of layers plated on the soffit enhances the load capacity as expected. However, the relative

increment as the number of steel sheet layers increase is not substantial. Use of three steel plate layers are found to be the optimal number of layers and increases its capacity by 14.5%.

5) Increasing the thickness of the steel plate by 50% (from 2mm to 3mm) increases the capacity of RC beams by 20.72%.

Acknowledgments

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