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FLEXURAL STRENGTHENING BEHAVIOR OF REINFORCED CONCRETE BEAMS USING ONE LAYER OF COLD-FORMED STEEL PLATE

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Abstract

Cold-formed steel is the most widely used material in roof construction. In addition to being a lightweight material, cold-formed steel also has a high yield stress of about 550 MPa. Due to its high yield strength and low weight, this material is very suitable for use to increase the strength of building structural elements, especially reinforced concrete beam elements. The method used in this study is an experimental test in a civil engineering structural laboratory. The concrete beams in this study consisted of two parts: a reinforced concrete beam specimen without reinforcement (BU-B0) and a reinforced concrete beam specimen reinforced with cold-formed steel plates with a width of 50 mm (BU-B1). Epoxy is used for the connection between concrete blocks and cold-formed steel. The dimension of reinforced concrete beams is (150 x 250 x 2700) mm^3. The results show that under yielding conditions, the beam with strengthening (BU-B1) could increase the load by 80% when compared to the beam without strengthening (BU-B0), and collapse conditions increase the load by 11%. At yield conditions, beams of BU-B1 increased deflection by 100% when compared to beams of BU-B0, and increased deflection for collapse conditions by 16%.

Keywords: Cold-formed steel, Epoxy, Experimental, Flexural strengthening, Reinforced concrete beam.

1. Introduction

Earthquakes that have occurred in Indonesia in the last 20 years have continued to show an increase in earthquakes, so the existing building structures must certainly be evaluated against current conditions. One of the ways to improve the performance of the building must be strengthening. Many reinforcing materials have been applied in Indonesia, such as reinforcement with Fiber Reinforced Plastic (FRP), steel plates, prestressing, and others. Some of these materials are very expensive or very difficult to implement in practice.

Research related to retrofitting has also been carried out, one of which is strengthening with steel plates, among others, first, Sabahattin, et al, 2013, researched strengthening and improving the behavior of reinforced concrete beam structures by using externally mounted steel plates. The study was based on a full-called load test on 13 test objects. The results of this study indicate that the ductility of the beam increases when the slab thickness decreases [1].

Swetha and Rona [2] conducted a study on the reinforcement of reinforced beams using web-bonded steel plates. The test is carried out by comparing the conditions of several thicknesses of the plates used. From this test, it can be concluded that beams with steel plates 4mm thick and 8 mm wide have higher strength and lower deflections when compared to other specimens.

A study based on numerical analysis of beam reinforcement using intermediate external plates was conducted by Lotfy and Elkamash [3]. The results showed that beams reinforced with external steel plates can behave as composite materials until they fail. At the same time, this reinforcement can also increase stiffness and ductility. Ying et al. [4] conducted a study on the performance of reinforced concrete beams with retrofitted steel using shear anchors. At the end of this study, it can be concluded that this system can effectively reduce failure due to the loss of bond between concrete and steel plate and can inhibit the potential for cracks in the structure.

Abd-Elhamed [5] focused on retrofitting and strengthening reinforced concrete damaged beams using steel plates. One of the results of this study showed that the addition of both the steel cross-sectional area and the number of fisher bolts used can reduce the deflection in the middle of the span between 1% to 14%. Research on the performance of beam structures reinforced with steel plates was also carried out by John et al. [6]. The interesting thing about this research is the use of epoxy adhesive on the installation of steel plates as reinforcement. Reinforcement steel plate does not use additional bolts for installation so as not to reduce the inertia of the reinforced concrete beam. At the end of this study, it can be concluded that the glued steel plate can not only increase the stiffness but also reduce the occurrence of cracks thereby increasing the flexural and shear capacity of the cross-section [6].

Olajumoke and Dundu [7] identified problems related to the use of steel plates as reinforcement for reinforced concrete structures both on Externally Bonded Reinforcement (EBR) and on Near Surface Mounting (NSM). Regarding flexural reinforcement, they concluded that EBR has applications with better practicality than NSM. The results of the research by Sarhan et al. [8] on the behavior of the strength and ductility of steel plate reinforced concrete beams, showed that there was no significant difference (less than 2%) between the strength of reinforced concrete beams (with 2 thread reinforcements with a diameter of 20 mm) and concrete beams reinforced with steel plates. On the other hand, this steel plate significantly increases the ductility of the structure. Li et al. [9] conducted an experimental study on reinforced concrete beams with steel plates on the sides. The results of this study indicate that reinforced concrete beams are more effective in increasing flexural strength.

Ahmed et al. [10] examined the effect of the thickness of the steel plate in the reinforcing beam. The results show that the addition of steel plate thickness does not have much effect on the maximum load capacity. In addition, Carbon Fiber Reinforced Polymer (CFRP) plates are more effective than steel plates in increasing the load capacity of the beam.

Reinforcement with FRP has also been carried out, including a study using finite element modelling on the behavior of FRP in concrete bridge beam reinforcement by Yazdani et al. [11] . The results of this study also show that FRP can significantly increase the capacity of concrete bridge beams, both flexible and flexible. as well as shear [11].

Kotynia and Cholostiakow [12] modified FRP reinforcement and profile I to increase the load capacity and stiffness of concrete beams [12]. Mashrei et al. [13] conducted a study to experimentally assess the efficiency of grooving techniques and provide quantitative data on the bonding behavior between concrete and CFRP sheets that are externally installed. At the end of the study, it can be concluded that in general CFRP can significantly improve the flexural capacity of the beam especially when the grooving technique has been used properly. Achudhan and Vandhana [14] researched on the strengthening of reinforced beam structures and concluded that the reinforcement of reinforced concrete structures using Glass Fiber Reinforced Polymer (GFRP) installed externally is an effective method to improve structural performance under service loads and ultimate loads. In addition, this reinforcement can increase the strength and stiffness of the structure.

Lavorato et al. [15] conducted a study based on experimental tests on reinforced concrete beams with flexural reinforcement and reinforced beams with a shear retrofit. One of the conclusions of this study is that FRP is one of the best solutions to increase the shear strength of beams because, in addition to being able to work quickly, it is also low-cost .

The average reinforcement using steel plates that have been carried out by the researchers results in an increase in strength from before there was reinforcement. Considering that steel is very costly and has a significant weight to increase the burden on the structure, especially in large amounts of reinforcement, the structure will increase the load on the building. Reinforcement with FRP is lighter and has higher strength than reinforcement with steel plates, but reinforcement with FRP is more expensive than steel plates.

Based on this, research using mild steel (cold-formed steel) has great potential, because, in addition to being light, it also has high strength. According to the Australian and New Zealand Standards, the yield stress of mild steel varies from 300 MPa to 550 MPa. strain is not more than 8%. Except for type G550 in AS 1397 which has a yield stress of at least 550 MPa and a strain of 2% [1]. The magnitude of the stress becomes an alternative as a reinforcement material. For this reason, in this study, the author will conduct research with Reinforced Concrete Beams Using Cold-Formed Steel Plates affixed to reinforced concrete beams using epoxy.

2. Method and Material

This research method is based on experimental testing of reinforced concrete beams in a civil engineering structural laboratory. During the load test, the reinforced concrete beam is monotonically loaded until it collapses. The procedure for this study begins with the design of reinforced concrete beams to obtain the dimensions and areas of reinforcement of the concrete beams. The next step is assembling the reinforcement and formwork, the reinforcement that has been assembled is then installed with a strain gauge. The concrete reinforcement is first subjected to a tensile test to obtain the quality of the reinforcement. Concrete constituent materials are prepared based on the results of the mix design. If the material and the test object are ready, then the concrete mix is poured. Samples of concrete cylinders are also made from the concrete mix to determine the quality of the concrete. After the age of the concrete reaches a minimum of 28 days, reinforcement is installed with cold rolled steel on one of the reinforced concrete beams. Cold-formed steel bonded using epoxy. The test object is ready for bending testing. At the same time, cylindrical concrete can also be tested for concrete compression. The results of this analysis serve as a reference for the design of reinforced concrete beams, and the check results for concrete materials and reinforcing bars serve as a reference for the analysis of the designed reinforced concrete beams.

The test object consists of two reinforced concrete beams of size (150×250×2700) mm^3. The dimensions of the test object are determined based on the maximum capacity of the force and deflection of the equipment in the laboratory, here is the explanation:

(a) BU-B0: reinforced concrete beam test object without strengthening (The test object as in Fig. 1(a).

(b) BU-B1: beam test object reinforced with one layer of cold-forming steel plate 50 mm wide. A cold-formed steel plate is attached with epoxy to the underside of the beam (The test object as in Fig. 1(b).

A version of the BU-B1 takes a look at items with cold-shaped plate reinforcement, as proven in Fig. 2.

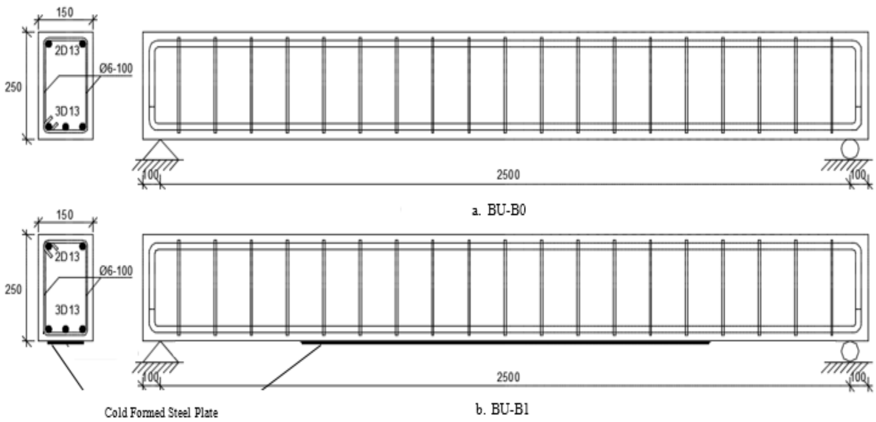

Fig. 1. The cross-section of (a) BU-BI and (b) BU-B0.

Fig. 2. Reinforced concrete beam specimens.

Reinforced concrete components are also tested in the laboratory for concrete compressive strength and rebar yield strength. The material test results are shown in Table 1.

Table 1. The result of the material testing.

No.	Material Testing		Value
1	The strength of concrete compressive	f'c	40.31 MPa
2	The 13 mm diameter yield steel	fy	401.92 MPa
3	The 6 mm diameter yield steel	fy	392.81 MPa

Based on Table 1, the results of the concrete compressive strength test are by the initial design, which is 40 MPa. The results of the 13 mm steel tensile test are also by the initial design, which is 400 MPa. The tensile test of 6 mm steel is greater than the design, which is 240 MPa. Therefore, based on Table 1, an analysis is made based on the results of laboratory material tests and a review of device capacity.

3. Results and Discussion

The test results of reinforced concrete beams with a static-monotonic loading test are the load and deflection values. The test results show strength and deflection values at yield and collapse conditions, as well as crack patterns. As shown in Fig. 3, test results for all test objects can be expressed in the form of load-deflection relationships, not only in the yielded state but also in the collapsed state. Figure 3 also shows the results of the test specimen beam reinforced with one layer of cold-forming steel plate with a width of 50 mm (BU-B1) and the normal beam test specimen without reinforcement (BU-B0).

Figure 3 shows that the initial load curve is still linear, so load is still directly proportional to deflection. When the load increases the deflection also increases. The curve shows the BU-B1 in the yield condition has a significant increase compared to the BU-B0, after that at BU-B1 the curve decreases but is still above BU-B0 then the behavior is the same as BU-B0, but the load is bigger, and the deflection is bigger. Figure 3 also shows the load at the yield condition, and the load at the elastic limit condition, which is 30 kN for BU-B0 and 54 kN for BU-B1. Tables 2 and 3 show the load values for each specimen, yield state, and collapse state.

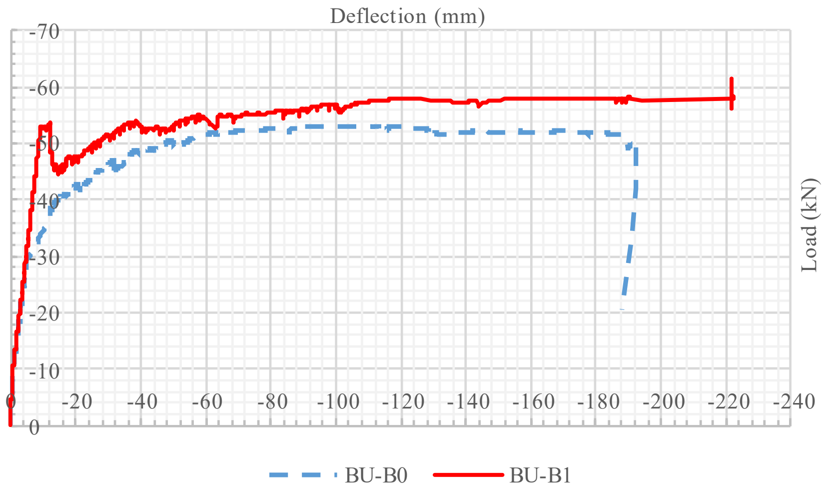

Fig. 3. Load-deflection curve.

Table 2. Reading result of yield state, Py.

No.	**Test Object Type**	**Py**	**Relative to BU-B0**
		“kN”	**“%”**
1	“BU-B0”	30	100
2	“BU-B1”	54	180

Table 3. Reading result of collapse state, Pu.

No.	**Test Object Type**		**Pu**	**Relative to BU-B0**
			“kN”	**“%”**
1	“BU-B0”	53	100	1
2	“BU-B1”	59	111	2

Tables 2 and 3 show that the yield load condition of the reinforced concrete beam of BU-B1 increased by 80% compared to the reinforced concrete beam without reinforcement of BU-B0. In collapsed conditions, reinforced concrete beams of BU-B1 can increase load capacity by 11% compared to reinforced concrete beams without reinforcement of BU-B0.

Tables 4 and 5 show the deflection of the bending test results under yield and collapse conditions for reinforced concrete beams BU-B0 and BU-B1.

Table-4. The deflections under yield conditions, δ_y.

No.	Test Object Type		δ_y	Relative to BU-B0
			"mm"	"%"
1	"BU-B0"	4.00	100	1
2	"BU-B1"	8.00	200	2

Table-5. The deflections under collapse conditions, δ_u.

No.	Test Object Type		δ_u	Relative to BU-B0
			"mm"	"%"
1	"BU-B0"	192	100	1
2	"BU-B1"	222	116	2

Tables 4 and 5 show that the yield condition of the beam with strengthening (BU-B1) has an increase in ductility when compared to the beam without strengthening (BU-B0), this is indicated by an increase in deflection of 100% for the yield condition and an increase of 16% for collapse condition.

Structural failure can be detected from load tests. The type of structural collapse can be known from the crack pattern of the structure. The pattern of cracking of the test object due to loading is shown in Figs. 4 and 5.

Fig. 4. BU - B0 crack patterns.

Fig. 5. BU - B1 crack pattern.

Figures 4 and 5 show that the bonding pattern for the beam with strengthening (BU-B1) and the beam without strengthening (BU-B0) has the same pattern, namely flexural cracks. While in a beam with strengthening (BU-B1), a cold-formed steel plate as strengthening has broken when the beam is in a collapsed condition. Cold-formed steel plate breaking as shown in Fig. 6.

Fig. 6. Cold-formed steel plate as strengthening.

The test results for the reinforcement of cold-formed steel plate reinforced concrete beams showed that the maximum load increased by 11% when compared to normal reinforced concrete, while the study using steel plate reinforcement on reinforced concrete beams by Sweatha and Huna (2018) showed that the results increased by 15, 13% compared to normal reinforced concrete beams, but the thickness of cold rolled steel is smaller than that of steel plates [2].

4. Conclusions

In the yield condition, reinforced concrete beams with BU - B1 reinforcement can increase the capacity by 80% of reinforced concrete beams without reinforcement (BU - B0). When at the collapse condition, beams of BU - B1 can increase the load by 11% when compared to beams of BU - B0. At yield conditions, beams with strengthening BU-B1 increased deflection by 100% when compared to beams without strengthening BU-B0, and increased deflection for collapse conditions by 16%. In the flexible state, the load capacity of the reinforced beam of BU-B1 is increased by 90% compared to the reinforced beam of BU-B0, and in the collapsed state the BU-B1 13.5% increase compared to BU-B0.

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