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Shear Strengthening Behavior of Reinforced Concrete Beam Using Non-Stressing Strands

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Abstract: Increasing the capacity of structures especially bridges can be done by various methods, one of them is by strengthening. Strengthening using strands has been used in various constructions. However, strengthening in reinforced concrete beams has not been done much because it will have many difficulties in the implementation. The focus of this research is shear strengthening using non-stressing strands. Strand is attached to the beam with epoxy. In certain intervals, strands are also anchored on the vertical side of the beam with U-shaped reinforcing steel. The basis of the research is experimental testing in the laboratory. The test specimens have consisted of a specimen without strengthening (BU-Normal) and 2 specimens with strengthening (BU-SV1 and BU-SV2). Dimensions of specimens are 250mm x 400mm x 1700 mm. In the laboratory, all specimens are loaded by a monotonic static load until collapse conditions. The results of the loading test at yield condition show that BU-SV1 and BU-SV2 can increase shear capacity respectively by 13.735% and 10.300% when compared to beams without strengthening (BU-Normal). Whereas at the collapse condition, BU-SV1 and BU-SV2 can increase shear capacities respectively by 34.886% and 25.360% when compared to beams without strengthening (BU-Normal).

Keywords: Shear strengthening, non-stressing strand, static-monotonic load

1. Introduction

The development of technology and materials used to increase the capacity of structural elements is relatively fast. Increasing the capacity of structural elements can be done, among others, by external strengthening, such as FRP (Fiber Reinforced Polymer), prestressing, reinforcing steel, and steel plates. The choice of technology and material used for strengthening is highly dependent on various aspects such as cost and the condition of the structural elements.

Research on strengthening beam structures have been done. Among them is strengthening by using FRP, both for flexural strengthening and for shear strengthening. By using FRP, at least have two advantages because of good resistance to corrosion and a high value of the ratio of compressive strength to weight. Shear strengthening of reinforced concrete beams using aluminum plate material has been investigated, and the use of this material can increase the shear capacity of the beam in the range of 24% -89% of the beam without strengthening (Abdalla et al. 2016). The used FRP as strengthening in reinforced concrete beam structures not only bending capacity but also increase shear capacity, increase beam stiffness, reduce deflection, and slow down the diagonal cracking process (Zhao and Xu 2017). The T-section shear capacity of continuous beams of reinforced concrete structures strengthened with CFRP resulted in the shear capacity of the strengthening beam is 23.21% greater than the shear capacity of the beam without strengthening (Alferjani et al. 2015).

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The strengthening by comparing cement-based composite systems with epoxy-based systems shows that strengthening with cement-based types applied to CRFP and CFRCM resulted in better performance than the epoxy-based system (CFRP sheet) (Azam et al. 2017). Meanwhile, the use of Flax Fabric Reinforced Polymer (FFRP) material in the form of plates from natural as an external strengthening material from reinforced concrete can significantly increase the ultimate load, deflection, and ductility of the beam. Thus, this material can be effective to reduce the damage of reinforced concrete beams due to earthquake forces (Huang et al. 2016).

The strengthening of reinforced concrete beam elements by using vertical prestressed reinforcement was an efficient method for increasing the shear resistance of structures (Ferreira et al. 2016). However, the number of research on the performance of this strengthening is still relatively small. Besides that, methods for designing the optimum amount of vertical prestressed and the evaluation of the strengthening structure have not been carried out. The shear strengthening model called DPCM was expanded to estimate the shear strength of strengthened reinforced concrete beams by using externally-bonded FRP composites. In this model, it is still necessary to calculate the effect of the use of FRP type, fiber bond configuration, and FRP configuration (Lee et al. 2017).

In case of the strengthening column-beam joints, is done by comparing 2 types of strengthening. First, the beam is strengthened by using a vertical deformed reinforcing steel (added to the plate on the top side of the beam) and angles shape profile steel at the bottom side of the beam. Second, the beam is strengthened by using CFRP. Test results show that the two types of strengthening can increase shear strength and prevent bending of longitudinal reinforcement. However, the use of this deformed steel on strengthening beam is relative more economical and easy to do (Martins et al. 2000).

The material used for strengthening on reinforced concrete beams is proven to increase cross-sectional capacity. Research on strengthening by using prestresses indicates that this type of strengthening is very efficient for increasing the structural shear resistance (Ferreira et al. 2016). This is not only due to the effect of tension, but also because the strand material used has very high yield stress, 1670 MPa on average.
However, this strengthening is not easy to do for two reasons. First, the tension process is difficult to do. Second, the equipment used is quite a lot. Therefore, this study of shear strengthening behavior was carried out by using non-stressing strands attached to the beam with epoxy. In certain intervals, strands are anchored on the vertical side of the beam with U-shaped reinforcing steel.

2. Material and Method

The basis of this research is experimental testing in the laboratory. In the test, three specimens of the reinforced concrete beam are loaded by monotonic load until collapse condition. This research was carried out in a sequence of steps as shown in Figure 1. Materials and tool used for load testing are as follows:

a. The compressive strength of concrete, 19.47 MPa, based on the average of concrete cylinder test shown in Table 1.

Table 1 - The compressive strength of concrete

No	Specimen Type	f'c (MPa)
1	B1	20.46
2	B2	17.91
3	B3	22.52
4	B4	19.99
5	B5	16.48
	Average	19.47

b. Reinforcing steel (fy= 400 MPa), 13 mm diameter for deformed and 6m diameter for plain.

c. Strand (Grade 270) diameter of 13 mm.

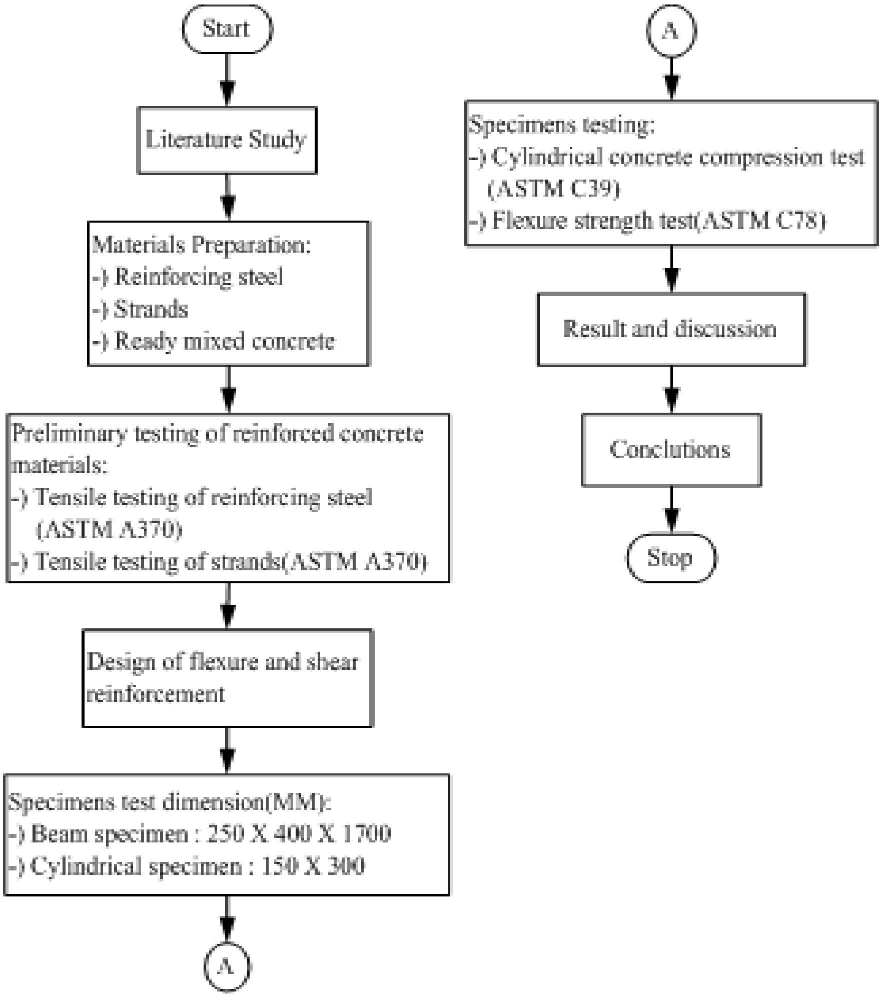

Fig. 1 - Flow chart of research

The descriptions of reinforced concrete beam specimens of size (250 x 400 x 1700) mm3 are as follows:

a. BU-Normal: normal beam test specimen without strengthening
b. BU-SV1: strengthening beam test object with 1 vertical strand
c. BU-SV2: strengthening beam test object with 2 vertical strands

In the BU-SV1 and BU-SV2 specimens, non-stressing strands are installed on both vertical sides of the reinforced concrete beam by using epoxy. The strands are clamped with a U-shaped steel anchor at a certain distance and grouted by using epoxy. A more detailed explanation about strengthening can be seen in Figure 2. The end of the stirrups for all specimens made a hook with an angle of 135 degrees (Badan Standarisasi Nasional 2013). The uses stirrups with 90-degree ends but the ends of the stirrups are bound with wires can receive load the same with the 135-degree stirrups (Susanto et al. 2020).

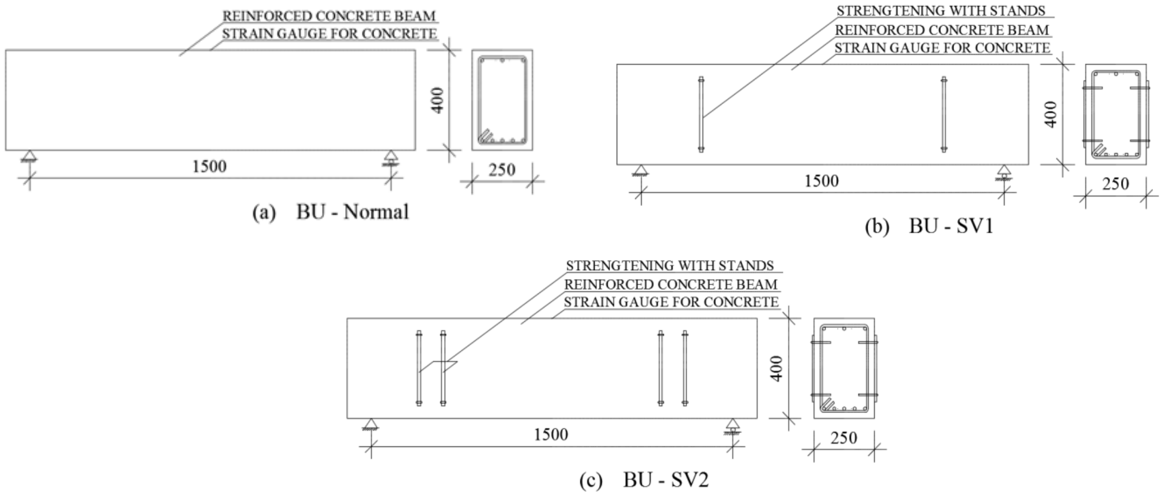

Fig. 2 - Reinforced concrete beam specimens

3. Equations Results and Discussion

By using a static-monotonic loading test, it will be known the value of load and deflection on yield conditions and collapse conditions. At the same time, it can also be seen in the pattern of cracks. Test results of all specimens can be presented in the form of load-deflection relationship not only on yield condition but also on collapse condition, as shown in Figure 3.

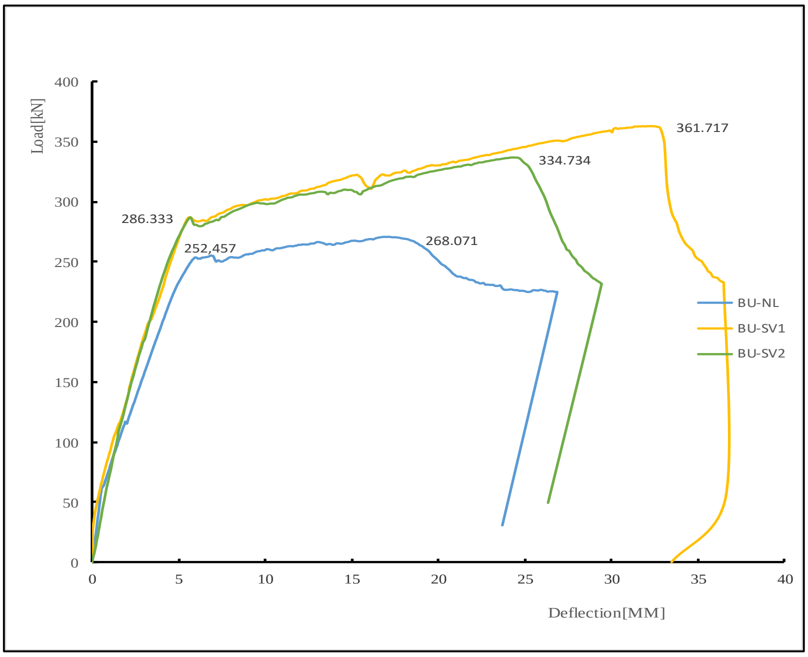

Fig. 3 - Load - Deflection Curve

Loading tests of all test specimens are carried out following ASTM - C78. It appears in Figure 3 that at the beginning of loading each test, the curve shape is still linear. At this stage, the stress is still directly proportional to the strain. If the strain increases, the stress will also increase. The addition will continue until the stress reaches the yield limit. After the beam specimen passes through the yield limit, it enters to strain hardening phase until it collapses. The magnitude of the loads on each specimen, both yield and collapse condition, are shown in Table 2 and Table 3.

Table 2 - Loads on yield conditions, Py

No	Specimen Type	Py	Relative to BU-Normal
		(kN)	(%)
1	BU- Normal	252.457	100
2	BU – SV1	287.132	113.735
3	BU – SV2	278.661	110.380

Table 3 - Loads on collapse conditions, Pu

No	Specimen Type	Pu	Relative to BU-Normal
		(kN)	(%)
1	BU- Normal	269.010	100
2	BU – SV1	362.856	134.886
3	BU – SV2	337.232	125.360

According to Table 2 and Table 3 above, it can be concluded that loading test at yield condition, beams with vertical strengthening BU-SV1, and BU-SV2 can increase shear capacity respectively by 13.735% and 10.300% when compared to beams without strengthening (BU-Normal). Whereas at the collapse condition, beams with vertical strengthening BU-SV1 and BU-SV2 can increase shear capacities respectively by 34.886% and 25.360% when compared to beams without strengthening (BU-Normal). Beam with vertical strengthening BU-SVI. The yield and collapse loads of the BU-SV1 specimen are greater than the yield load of the BU-SV2 specimen. At yield and collapse conditions of beams with vertical strengthening BU-SV2 decreased load respectively by 3.04% and 7.90% when compared to beams with vertical strengthening BU-SV1.

From this loading, the test can also be seen the magnitude of deflection on the yield and the collapse conditions, as shown in Table 4 and Table 5.

Table 4 - Deflections on yield conditions, Yy

No	Specimen Type	Yy	Relative to BU-Normal
		(mm)	(%)
1	BU- Normal	6.26	100
2	BU – SV1	5.89	94.09
3	BU – SV2	5.89	94.09

Table 5 - Deflections on collapse conditions, Yu

No	Specimen Type	Yu	Relative to BU-Normal
		(mm)	(%)
1	BU- Normal	18.68	100
2	BU – SV1	32.81	175.64
3	BU – SV2	24.86	133.08

Specimens may collapse due to bending or due to shear. The type of collapse of the structure will be known from the load test. A crack pattern is one parameter to determine the type of collapse of a structure. The crack pattern of all specimens due to the loading test can be seen in Figures 4 - 6.

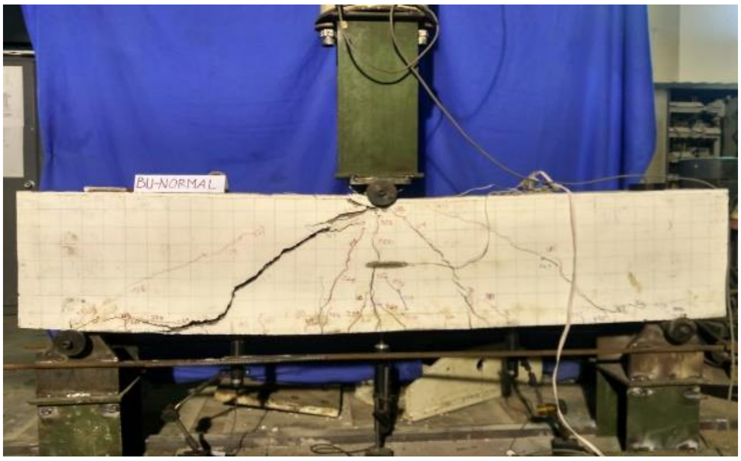

Fig. 4 - BU-Normal crack pattern

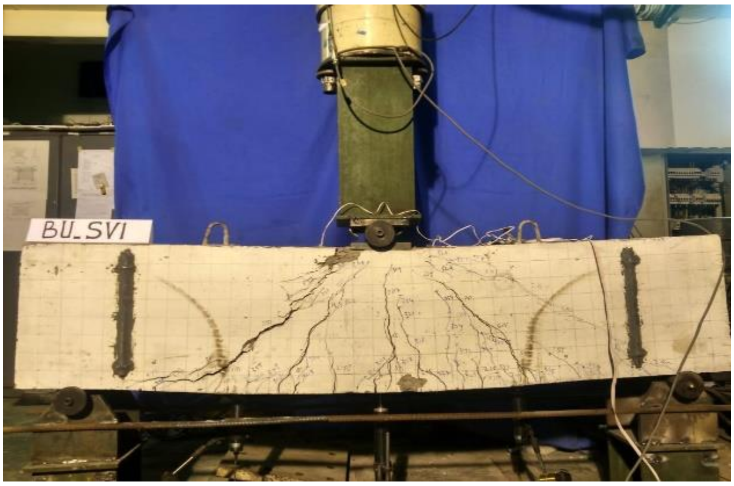

Fig. 5 - BU-SV1 crack pattern

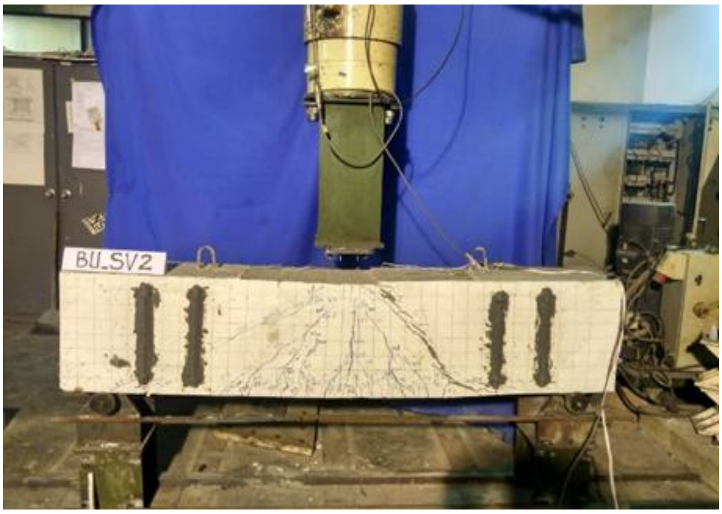

Fig. 6 - BU-SV2 crack pattern

Figure 4-6 indicates that all test specimens are collapsed because of shear. All figures show that all crack directions form diagonal lines, starting from the center of the load to structural supports.

4. Conclusion

The findings of the loading procedure can be inferred as follows: at yield condition, beams with vertical strengthening BU-SV1 and BU-SV2 can increase shear capacity respectively by 13.735% and 10.30% when compared to beams without strengthening (BU-Normal). Whereas at the collapse condition, beams with vertical strengthening BU-SV1 and BU-SV2 can increase shear capacities respectively by 34.886% and 25.360% when compared to beams without strengthening (BU-Normal).

The analysis of this paper has shown that the yield and collapse loads of the BU-SV1 specimen are greater than the yield load of the BU-SV2 specimen. At yield and collapse conditions of beams with vertical strengthening BU-SV2 decreased load respectively by 3.04 % and 7.90% when compared to beams with vertical strengthening BU-SV1. That is because beams with vertical reinforcement BU-SV2, besides the addition of strands also the addition of holes for anchor from a beam with vertical strengthening BU-SV1.

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