Journal of Engineering and Applied Sciences 15 (7): 1861-1867, 2020
ISSN: 1816-949X

Tensile Reinforcement Effectiveness in the Flexural Capacity Enhancement of Truss-System Reinforced Concrete Beam

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Abstract: This study aimed to analyze tensile reinforcement performance in the support area of the truss-system reinforced concrete beam. Seven specimens were tested, consisting of Normal Beam (BN) as the control beam, non-strengthened Truss Reinforced Beams (BTR) and five support-strengthened Truss Reinforced Concrete Beam (BTRP) specimens with length variation of 40D, 50D, 60D, 70D and 80D; (D = 13 mm reinforcement diameter). The specimen dimension is 15×20×300 cm. The results showed that the flexural capacity of the strengthened beam (BTRP) significantly increased but BTRP 40D was unable to prevent cracking in the support area while the BTRP 50D to BTRP 80D avoided its occurrence. The use of tensile reinforcement as a beam support strengthening was effective in improving its flexural capacity. BTRP 60D showed the highest flexural capacity compared to other beams with 23.77 and 19.60% enhancement for BN and BTR. Failure model was in the form of flexural failure and the destruction of concrete in the tension area.

Key words: Tensile reinforcement, flexural capacity, truss reinforcement, enhancement, significantly

INTRODUCTION

Concrete is the most used material in construction that results in increased natural material exploration such as gravel and sand as concrete basic material and it can destroy nature. Therefore, various innovations have been carried out to solve this problem. Mechanically and based on its characteristics, concrete in a flexural structure system is found to occur compressive and tensile action to produce resistance moment, then the concrete in the tensile does not have a direct role in determining how big the resistance moment as of the concrete volume in that area can be reduced, replaced with light material or completely removed. The concrete volume reduction is intended to minimize concrete constituent material and to make the construction lighter but still produce safe and strong construction.

Some research has been carried out to reduce concrete use in construction, especially, for the beam section as follows the results suggest that in general, cavity in a beam decreases the first cracking load and ultimate load capacity and is able to change the flexural failure mode to flexural-shear failure (Abdulrahman and Mahmood, 2019), the use of hollow ball to the reinforced concrete beam obtains weight reduction about 12 and 33% of the crack index and higher rupture compared to normal beam (Patel, 2018). Furthermore (Patel, 2018), structural material optimization introduce hollow-core to use expanded polystyrene foam in the tensile zone on RC beam. The result of the flexural test of hollow core sandwich beams performance showed that this hollow core is better if compared to the conventional normal beam (Manikandan *et al*., 2015), conducted the experimental program focused on two main variables which are dimensional reduction percentage and steel fiber use. Moreover, the longitudinal reinforcement ratio and the presence of lateral stirrups were likewise investigated. Based on the result obtained, it can be concluded that the hollow reinforced concrete beam with 1.0% of steel fiber and dimensional reduction up to 44.4% can replace normal beams without having a significant reduction in strength, ductility and toughness (Abbass *et al*., 2020). In the other research finding that the flexural capacity of PPSRC (Precast or Prefabricated Reinforced Concrete) and HPSRC (innovative hollow-core PPSRC) beam specimen is 3.60 and 4.49% lower than case-in-place. The effect of hollow-core on flexural performance is relatively small (Yang *et al*., 2017), furthermore, the flexural and shear behavior behavior of simply supported reinforced concrete beams with two layers of different grades of concrete. The top layer (1/3rd) concrete, mainly in compression is higher grade and the bottom (2/3rd) layer in tension is lower grade using rubber recycled aggregate concrete (Ataria and Wang, 2019), found a new concept of Ultra-High Durability Concrete (UHDC) which core concrete made from low concrete quality to reduce cement consumption and related to its sustainability. The tested eco-efficient high durability beams exhibited an excellent structural behavior, producing an increase in

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stiffness and flexural strength (Martins *et al*., 2020; Zhang *et al*., 2019). Another research, presented non-concrete flexural beam capacity in the tensile area (External Reinforced Concrete Beam, ERBC), the result showed that ERBC flexural capacity decreased up to 86% compared to control beam. Moreover, ERBC strength likewise decreased up to 60% compared to normal beam (Djamaluddin, 2013).

According to some previous studies, reducing or removing concrete in the tensile area can decrease beam flexural capacity. Thus, reinforcement is required to anticipate such a thing. Some studies related to this are (Djamaluddin, 2013), beam reinforcement utilizes FRP (Campione *et al*., 2016) composite steel-concrete reinforced flexural beam with Fiber-Reinforced Polymer (FRP) (Colajanni *et al*., 2017; 12; Alam and Hussein, 2017; Panzera *et al*., 2013; Benzarti and Colin, 2013; Sun *et al*., 2019), experiment to investigate beam shear and flexural strength with depth, width and distinct transversal reinforced (Tesser and Scotta, 2013). Shear reinforced significantly contributes to flexural strength (Trentadue *et al*., 2014).

Another research was related to internal reinforcement truss-system, the effect of shear truss reinforcement space over flexural behavior of reinforced concrete beam. The result showed that shear reinforced space provides a significant contribution to beam flexural strength . The results of this study showed that the spacing variation of steel truss system can enhance the ultimate capacity of the concrete beams compared to BN, the ultimate capacity of BTR25, BTR50 and BTR75 was 10.72, 7.83 and 4.82%, respectively. In addition, the stiffness of the beam can be also increased due to the effect of steel truss system. Styrofoam Filled Concrete beam (SFC-30) with truss-system, the emerging crack is slower and smaller than the crack length of the normal reinforced concrete beam and the increase of the ultimate load number is higher than normal reinforced concrete beam (Parung *et al*., 2015). However, the BTR specimen indicates deflection reduction over the load area, when crack occurred. The concrete beam directly failed as shown in Fig. 1.

Based on the previous research and experiment, truss-system reinforcement can improve flexural capacity but removing concrete in the tensile area can decrease

Fig. 1: The crack at the support area

inertia that causes a crack in the support area because of reduced flexural capacity as of an alternative to prevent a crack in the support area of BTR beam is required, one of which is placing the tensile reinforcement in the support area.

MATERIALS AND METHODS

Specimen and material

Specimen: Concrete beam specimen dimension is 330 cm with 15×20 cm cross-section. There were seven concrete beam variations observed including Normal concrete Beam (BN) with vertical shear reinforced, Truss Reinforced Beam (BTR) without strengthening and beam in the tensile area and five Truss Reinforced Beams (BTRP) without concrete in the tensile area which is strengthened in the support area with length variation of 40D, 50D, 60D, 70D and 80D, (D = 13 mm reinforcement diameter) as tensile strengthening in the support area as shown in Fig. 2.

Material property: The specimen was casted using a fresh concrete with design compression strength of 26.52 MPa. Cylinder test was done to measure the compression strength and tensile strength of concrete. Compressive strength of concrete was determined by using cylindrical specimen with 100 mm diameter and 200 mm. The specimen was tested after curing for 28 days as shown in Fig. 3a. The diameter of tensile rebars was 13 mm and the diameter of compression rebars was 8 mm. The yield strength of 13 and 8 mm rebars was 373.64 and 310.22 MPa, respectively. The test of rebars is shown in Fig. 3b. The result of material properties was summarized in Table 1.

Fabrication: Figure 4 shows the fabrication procedures of specimen. First, the beam truss making was started with truss reinforced beam assembly by welding, carried out following SNI 2847:2013 (Indonesian Code). Before the truss reinforced beam placed into the form work, the steel strain gauge was installed, followed by casting the beam opposite side. Curing process was done for 28 days.

Table 1: Material properties

Parameter	Values	Parameter	Values
Compressive strength (f'c)	26.52 MPa	Yield strength (fy)	373.64 MPa
Tensile strength (ft)	3 MPa	Ultimate strength (Fs max)	469.24 MPa
Flexural strength (fr)	3.64 MPa	Modulus of elasticity (Es)	198870 MPa
Modulus of Elasticity (Ec)	24.450×10^3 MPa	Yield strain of steel (s)	0.0019

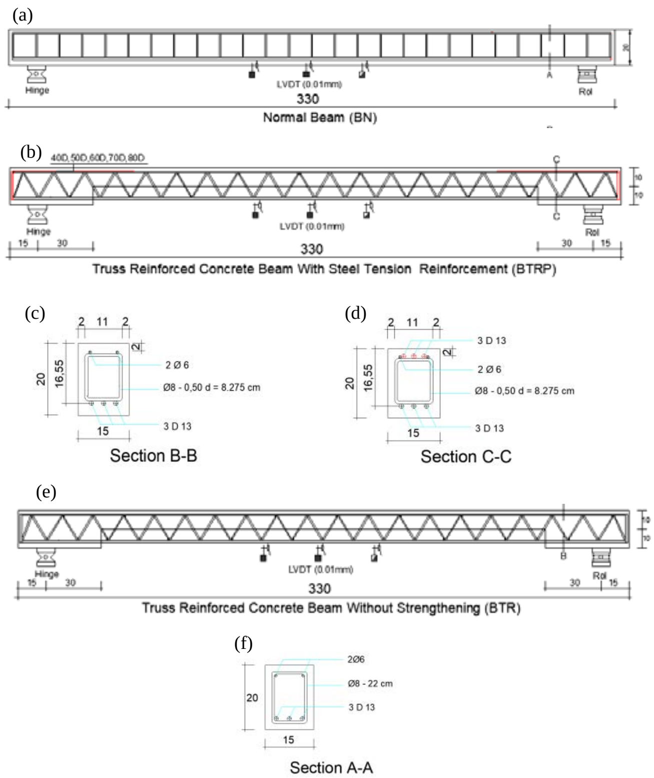

Fig. 2(a-f): Specimens

Fig. 3(a, b): (a) Cylinder test and (b) Rebar test

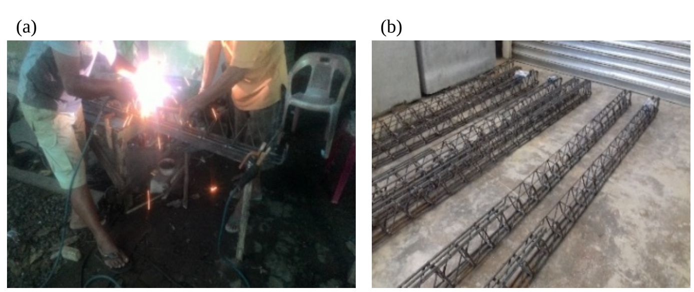

Fig. 4: Continue

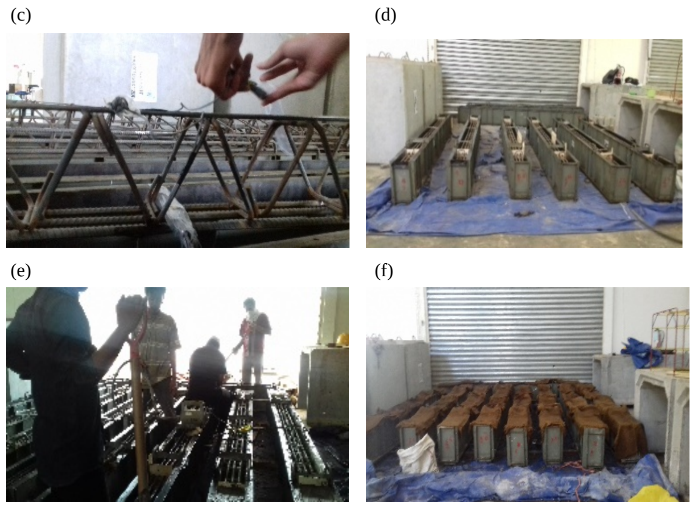

Fig. 4(a-f): The process of specimen installation, (a) Bar welding assembly, (b)Trusssystem reinforcement, (c) Strain gauge, (d) Formwork, (e) Casting and (f) Curing

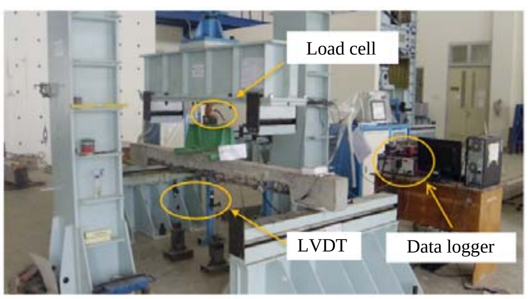

Fig. 5: Setup test

Setup test: Loading setup is shown in Fig. 5. The beam was loaded monotonically by using hydraulic jack with capacity of 2000 kN. The displacement control was applied with 0.03 $mmsec^{-1}$ constant ramp actuator speed until the beam collapse. Displacement of specimen was measured by using Linear Variable Displacement Transducer (LVDT). The strain of concrete and steel bars was measured by using strain gauge. Concrete gauge and steel gauge were placed in the midspan of the beam. All the data was recorded by using data logger.

RESULTS AND DISCUSSION

Load-deflection relation: The load-deflection behavior of the specimen can be observed in Fig. 6 as a load-deflection relationship curve. The deflection measured is the midspan of the beam.

The occurrence of the first crack indicates that the moment that occurs exceeds the capacity of the crack moment in the beam. The first crack causes a reduction in stiffness in the normal beam. However, the first crack in the BTR and BTRP beams does not cause a significant reduction in the slope of the load-deflection as in the normal beam. The load on the first crack is almost the same for all specimens. This shows that the influence of truss-system reinforcement on the increase in Pcr and strain values when Pcr occurs is not significant but the influence of truss system can be seen when the main reinforcement has yielded can be seen from the difference in yielding load (py) and ultimate load (pu), the more the large difference shows that after the main reinforcement yields, the failure of the beam is still able to be delayed. The stiffness of BTRP beams is higher than BN beams due to the use of reinforcing truss systems that can reduce deflection that occurs.

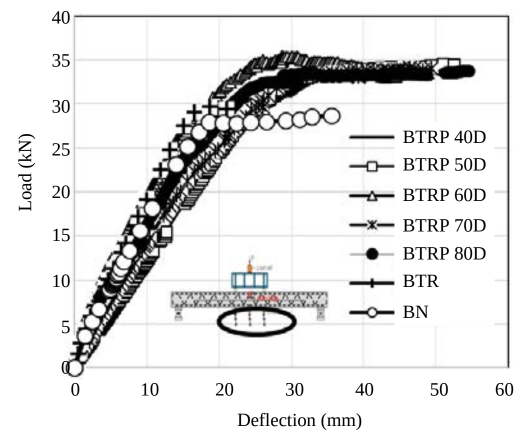

Fig. 6: The graphic of load and deflection

The relation of deflection load from the specimen test results of the load under initial crack conditions, ultimate load, maximum deflection and the moment that occurred using the BTR moment holding formula is presented in Table 2.

Table 2: Initial Crack, ultimate load, deflection and moment

		Specimens						
Description	Unit	BN	BTR	BTRP 40D	BTRP 50D	BTRP 60D	BTRP 70D	BTRP 80D
Pcr	kN	5.20	4.34	4.70	4.8	5.66	5.39	4.66
Mcr	kNm	3.93	3.01	3.23	3.29	3.80	3.64	3.21
Py	kN	27.90	-	-	30.40	30.72	30.89	28.12
My	kNm	16.67	-	-	17.00	18.84	17.08	17.28
Pu	kN	28.64	29.64	34.39	34.58	35.45	34.12	33.78
Mu	kNm	17.88	18.20	21.05	21.16	21.68	20.88	20.68
Makximum deflection	mm	35.60	18.75	33.06	51.03	28.45	46.45	54.33

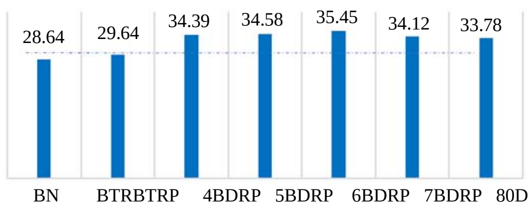

Fig. 7: The ultimate load histogram

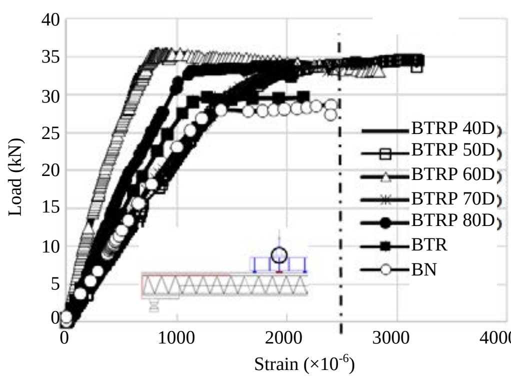

Fig. 8: Load and concrete compressive strain relation

Figure 7 it can be seen that the ultimate capacity of BTRP specimens when compared with the capacity of BTR and BN specimens. BTRP 40D beams with BTR beams 16.03 and BN beams 20%. The BTRP 50D beam is 16.66% compared to the BTR and BN beams 20.74%. Furthermore, BTRP 60D beams when compared with BTR beams 19.60% and BN beams 23.77%, BTRP 70D beams with BTR beams 15.11% and BN beams 19.13% and BTRP 80D beams with BTR beams by 11.39% and the ultimate load (Pu) of BN beams was 11.79%. The BTRP 60D beam has the highest ultimate load compared to other specimens. In general, the influence of the effectiveness of the tensile reinforcement can be seen from the load that can be achieved by all BTRP specimens which have exceeded the maximum load of BTR and BN beams.

Load-beam strain relation: Figure 8, showed load and strain compressive relationship. An increase in strain and load on the beam following the order of BTRP 50D,

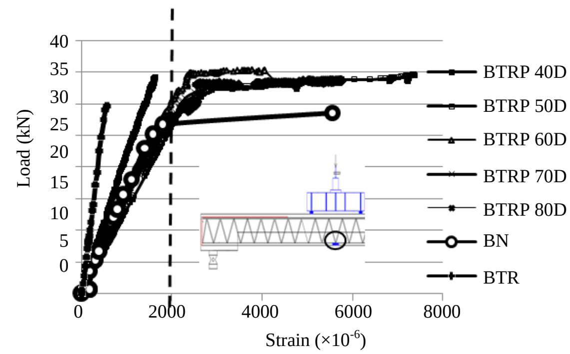

Fig. 9: Load-main reinforcement relation

BTRP 60D, BTRP 70D, BTRP 80D and BTR and BN. Moreover, BTR and BTRP 40D beams, cracks occur in the support area before the main reinforcement yield and the concrete breaking limit is reached. BTRP 50D, BTRP 60D, BTRP 70D and BTRP 80D reach ultimate loads, the main reinforcement has yield, before the concrete failure.

Load-strain main reinforcement: Figure 9 can be observed, steel reinforcement that goes through the stages, namely the stage when the first crack (Pcr), yielding and ultimate increases the steel load-strain on the BTRP 50, BTRP 60D, BTRP 70D and BTRP 80D beams compared to the BTR beam due to the influence of the tensile reinforcement in the support area. But in the BTR and BTRP 40D beams still occur in the support area which is the cause of decreased beam flexural capacity which causes early failure, the beam breaks before the main reinforcement yield. If it is assumed that the steel strain yielding limit at the 2000μ strain, the BN, BTRP 50D, BTRP 60D, BTRP 70D and BTRP 80D beams failure under reinforced conditions where the reinforcement yields before the concrete is broken because it has a strain >2000 μ. Whereas the BTR and BTRP 40D show wide cracks in the support area before the reinforcement yield.

Load-tensile reinforcement strengthening relation: Tensile reinforcement strengthening is placed on the top (compressed) beam with reinforcement length variations of 40D, 50D, 60D, 70D and 80D. As shown in Fig. 10.

Naturally, this reinforcement functions as a compressive reinforcement, so that, at the beginning of

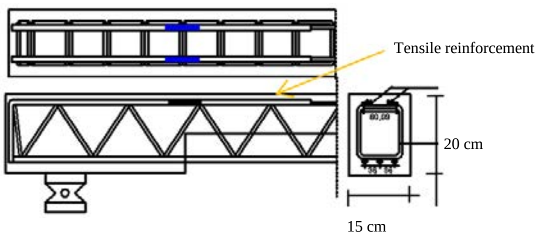

Fig. 10: Tensile reinforcement

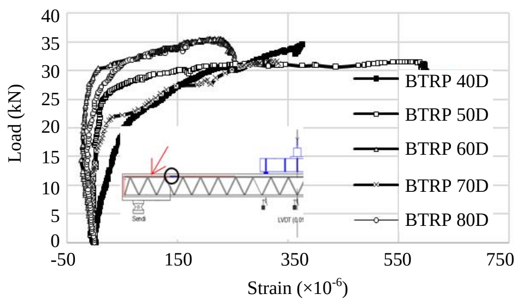

Fig. 11: Load-strain strengthening relation

reinforcement loading is shown by a negative strain value. But at certain loads, the treatment turns into tensile, so that, the measured strain is a positive value strain. This shows that the top side of the beam above the support experiences a tensile.

Based on the graph in Fig. 11 it can be seen that this tensile reinforcement serves to increase the flexural capacity of the beam when the beam is deflected due to load and this reinforcement serves to be tensile reinforcement, so that, there is an increase in the ultimate load on BTR beams and BTRP beams compared to BN beams. however, BTR and BTRP 40D beams fail early. Based on this, it can be concluded that the influence of reinforcement length variations is very influential on the stiffness and flexural strength of the beam.

Crack pattern: Observation of crack patterns shows that all specimens experience flexural cracks. Cracks start from the tension zone and propagate to the beam compressive zone. BTRP 40D, cracks still occur in the support area because the length of the reinforcement is not enough to prevent this. The crack location that occurred only shifted about 15 cm toward the center of the span, when compared to the BTR beam without tensile reinforcement as shown in Fig. 12. Unlike the BTRP 50D, BTRP 60D, BTRP 70D and BTRP 80D beams, the crack pattern is spread in the middle spans and no cracks occur in the support zone. BTR beams without reinforcement strengthening, although, the ultimate load is higher than BN beams also the main reinforcement has not yielded and the maximum load has not been reached when the beam failure.

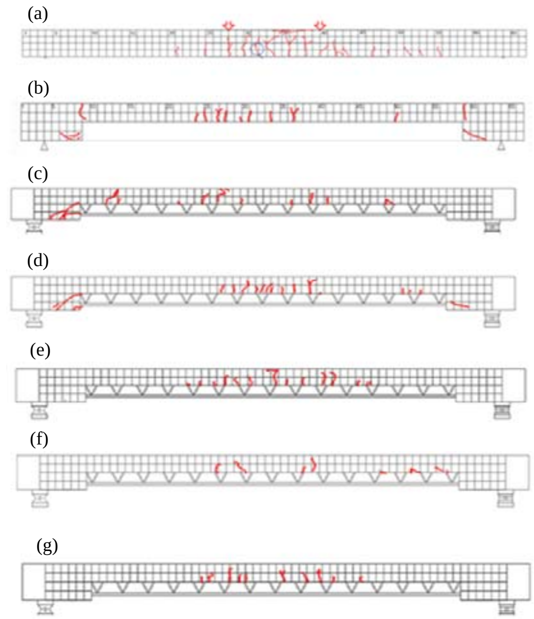

Fig. 12(a-g): The crack pattern of BN beam, BTR beam dan BTRP beam, (a) Normal Beam (NB), (b) BTR beam, (c) BTRP 40D beam, (d) BTRP 50D beam, (e) BTRP 60D beam, (f) BTRP 70D beam and (g) BTRP 80D beam

CONCLUSION

Based on the results and discussion, it can be concluded as follows: the effectiveness of strengthening on BTRP beams in the form of steel tensile reinforcement placed on the upper side of the support on the BTRP beam can increase the flexural capacity of the truss system reinforced concrete beam. The effective channeling length is 60D where length = 780 mm can anticipate cracks in the support area and has the highest ultimate load when compared to all specimens. Ultimate load increased by 19.60% against BTR beams and 23.77% against BN beams.

The length of the 40D reinforcement distribution (L = 52 cm) on the 40D BTRP beam has not been able to anticipate cracks in the support area but on the BTRP beam with the reinforcement length ranging from 50D (L = 65 cm) to 80D (L = 104 cm), the crack not longer happen.

The BTRP 50D-80D beam experience a flexural crack an under-reinforced failure. However, in the BTRP 40D beam the collapse mode is in the form of a crack which is almost broken in the support area only shifted 15 cm towards the center of the span from the crack position on the BTR beam while the concrete has not been destroyed and the steel reinforcement has not yielded.

ACKNOWLEDGEMENT

The researcher acknowledges that this research can be achieved with the financial support of LPDP (Institute of Education Fund Management). Also to students and staff of the Laboratory of Materials and Structures at Hasanuddin University.

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