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Failure mode of truss system concrete beams strengthened with tensile reinforcement

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Abstract. Cracks usually precede beams failures. Cracks occurred due to the applied load exceeds the capacity of the cross-section in carrying the load. The use of a diagonal reinforcement or truss system can increase the flexural capacity of the beams. The previous research of using truss system reinforcement in the beam without concrete in the tension zone causes a decrease in flexural capacity due to the cracks in the area near the support. Therefore, it is necessary to add tensile reinforcement in the zone. This study uses a truss reinforced concrete beam specimen with dimensions of 15 cm x 20 m x 330 cm. There are four variations of the specimens, namely Normal Beams (BN) as control beam, BTRP 40D, BTRP 60D, and BTRP 80D. The flexural test is carried out by monotonic static loading. The results showed that the flexural capacity of BTRP 40D, BTRP 60D, and BTRP 80D increased due to the addition of tensile reinforcement in the support zone. Moreover, the failure mode of BTRP 60D and BTRP 80D are under reinforced and cracking does not occur in the support zone. Meanwhile, the BTRP 40D beam shows wide cracks in the support zone.

1. Introduction

Based on the research that has been done by reducing the use of concrete in construction, reinforced concrete beams open truss systems without concrete in the tensile zone, to reduce the volume of concrete. Truss analogy, which is based on any relevant experimental evidence, tends to assume that cracks formed in reinforced concrete beams result in failures such as cracks in the support area. Damage to the beam can occur according to one of these three types of collapse [1], namely flexural failure, diagonal tension, and shear-compression collapse failure.

Truss system can be an alternative to overcome decreasing flexural capacity [2], investigating on the shear and flexural strength of beams with different depths, widths and strengthening tendencies across [3], investigated the bending stiffness of steel-concrete composite beam steel truss systems reinforced. Sensitivity analysis and numerical application showed that shear reinforcement contributed significantly to bending stiffness. Testing of specimens is to determine the effect of frame structure on concrete beams without concrete in the tensile zone. The results show that the truss system is needed for external reinforced concrete beams. The truss system of concrete beams without concrete in the tension zone (BTR) can increase the capacity that is almost the same as the normal beam (BN).



Another study of truss reinforcement system related to the effect of spacing reinforcement on the flexural behaviour of reinforced concrete beams is conducted by Pieter [4]. The results show that the reinforcement space of reinforced concrete beam truss systems contributes significantly to flexural strength as well as the truss system reinforcement (BTR) on the flexural capacity of beams without concrete in the tension zone. The same results also obtained by Yasser [5]. Another research on the effect of truss reinforcement systems on flexural beam capacity by Djamaluddin [6].

Concrete materials are still the dominant material for construction because of its advantages such as workability, low cost and resistance fire and low maintenance costs. According to the nature of the concrete material, concrete is strong in accepting compressive loads but weak in tensile. Therefore, the contribution of the tensile stress of the concrete to the flexural capacity of the beam is neglected. However, removing concrete in the tension zone causes a decrease in flexural capacity. Truss system can be an alternative to overcome the decrease in flexural capacity. However, the results showed that the cracks occur in the support zone of the beam. Cracks in the support zone on BTR beam is shown in figure 1. To solve this problem, the additional reinforcement is required by using the tensile reinforcement. The objective of this study is to find out the effect of tensile reinforcement on the support zone on the collapse pattern on the truss reinforced system beam.

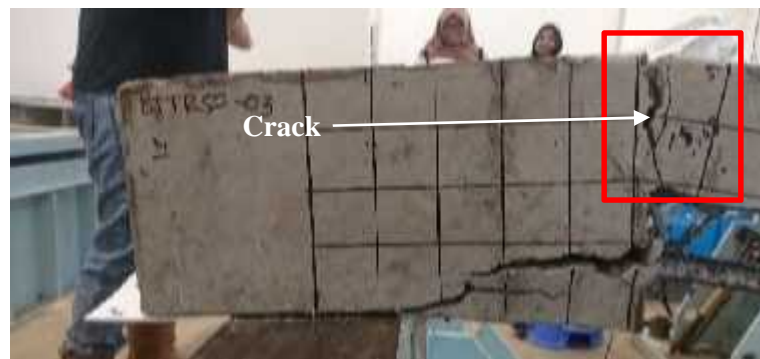


Figure 1. Cracks in the support zone.

2 Experimental Program

2.1 Specimen

Five specimens were tested consisting of 1 beam with vertical reinforcement (BN), 1 beam with truss system reinforcement without concrete in the tensile zone, and 3 strengthened beams using tensile reinforcement with a length of 40D, 60D, 80D. The D is the diameter of the main reinforcement, 13 mm. The cross-section of the beam is 15 cm x 20 cm and length of 330 cm, as shown in figure 2.

The concrete and reinforcement properties material used for normal beam specimens (BN), truss system reinforced concrete beam (BTR), and strengthen truss systems reinforced beam (BTRP) are same, as presented in table 1.

Table 1. Material properties

Concrete		Reinforcement	
Compressive strength (f_c)	26,52 MPa	Yield strength (f_y)	373,64 MPa
Tensile Strength (f_t)	3 MPa	Ultimate strength (f_u)	469,24 MPa
Bending stress (f_r)	3.64 MPa	Elastic modulus (E_s)	198870 MPa
Modulus of elasticity (E_c)	24.450x10 ³	Strain yield (ϵ_y)	0.00199

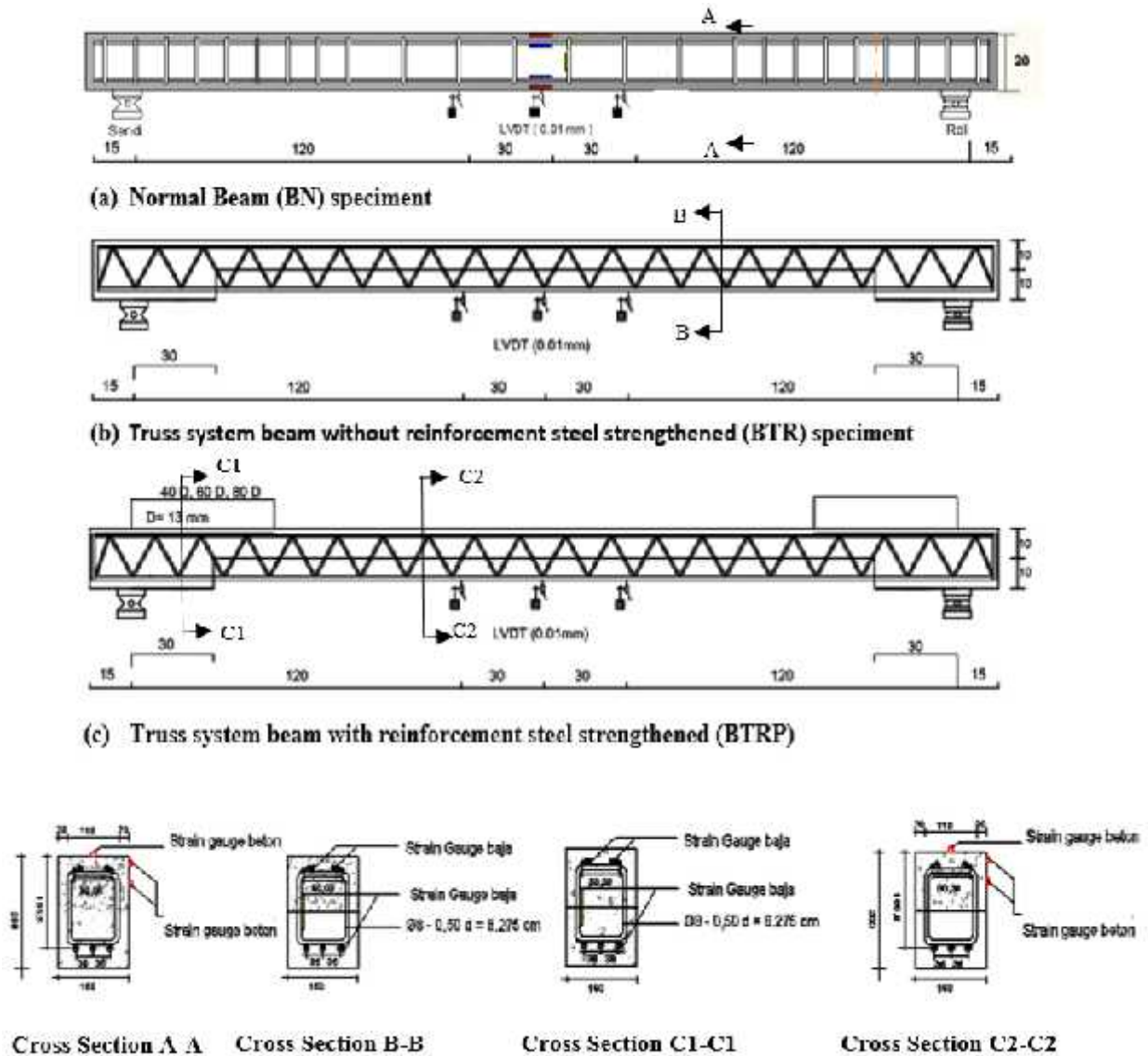


Figure 2. Test specimen.

2.2. Test setup

Figure 3 presents the setup beam by using two-point loads on a concrete beam with monotonic loading. The load is given at a constant speed of 0.023 mm/s until the beam collapses. Deflection that occurs is measured by LVDT which is connected to the data logger TDS 530 which serves to record the increase in loading and deflection.



Figure 3. Test setup.

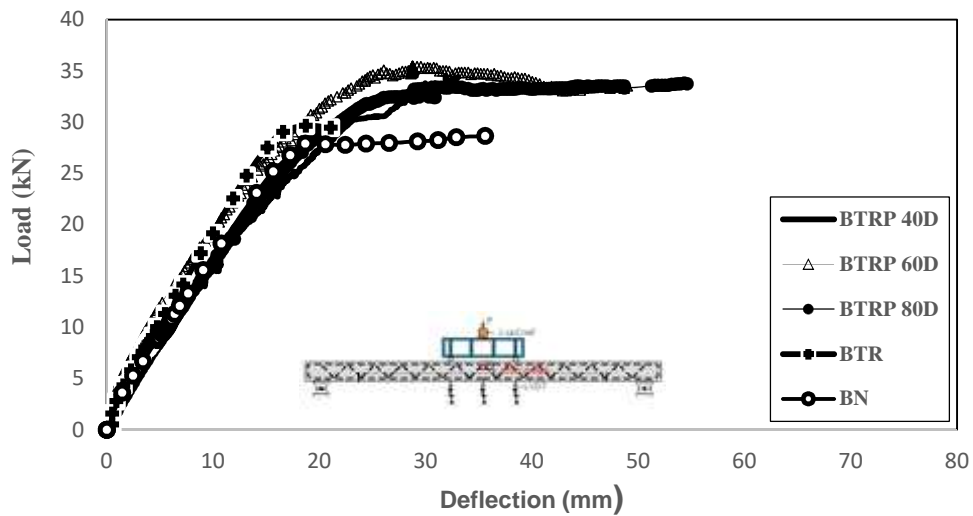
3. Results and discussion

3.1 Relationship between load and deflection

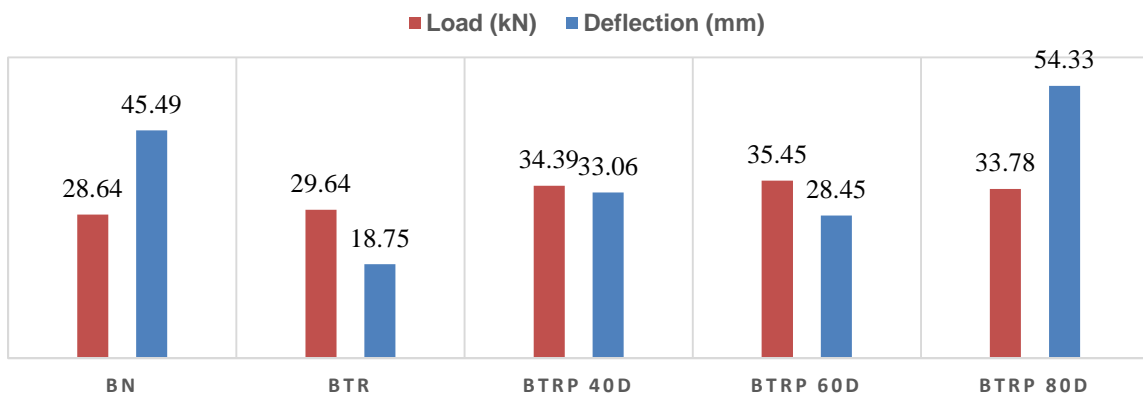
Specimen test results consisting of initial crack load, ultimate load, deflection, and moment are presented in table 2. An increase in ultimate load on the beam with the addition of tensile reinforcement namely BTRP 40D, BTRP 60D, and BTRP 80D compared to BN. The ultimate load for BTR beams is lower than BN and BTRP. The load at the first crack is almost same for all specimen beams. Load-deflection behaviour can be observed in figure 4, where deflection is measured in the middle span. Before the ultimate load is reached, bending cracks occurred at midspan.

Table 2. Initial crack load, ultimate load, deflection, and moment.

Description	BN	BTR	BTRP 40D	BTRP 60D	BTRP 80D
P _{cr} (kN)	5.2	4.34	4.70	5.66	4.66
M _{cr} (kNm)	3.93	3.01	3.23	3.80	3.21
P _y (kN)	26.43	-	-	30.72	28.12
M _y (kNm)	16.67	-	-	18.84	17.28
P _u (kN)	28.64	29.64	34.39	35.45	33.78
M _u (kNm)	17.88	18.20	21.05	21.68	20.68
Deflection (mm)	45.49	18.75	33.06	28.45	54.33



(a) Load-deflection relationship



(b). Load-deflection histogram

Figure 4. (a) Load-deflection relationship, (b) Load-deflection histogram.

The addition of tensile reinforcement in the support zone increases the ultimate load on the BTRP 40D, BTRP 60D and BTRP 80D beams of 19.22% against BN and BTR, as clearly seen in Figure 4. In addition, the deflection that occurs in BTRP is much greater than BN and BTR. This indicates that the addition of tensile reinforcement in the support zone can increase beam ductility. From all specimens, BTRP 80D showed the greatest deflection of 54.33 mm, although the load was slightly lower than BTRP 60D. While the BTRP 40D and BTR beams have cracked in the support zone, therefore the load and deflection is smaller than the BTRP 60D and BTRP 80D.

3.2 Load-strain of concrete

The concrete strain was measured using strain gauge type PL-60-11-5L (gauge factor $2.13 \pm 1\%$). The graph of load vs. concrete compressive strain relationships is shown in figure 5. From all the specimens, only BTRP 60D which has a compressive concrete strain reaches an ultimate strain of 2500μ . Whereas BN, BTR and BTRP 80D concrete compressive strain exceeds 2000μ . Whereas BN, BTR and BTRP 80D concrete compressive strain exceeds 2000μ . Overall, concrete is crushed at a strain greater than 2000μ , except for BTRP 40D due to cracking in the support zone.

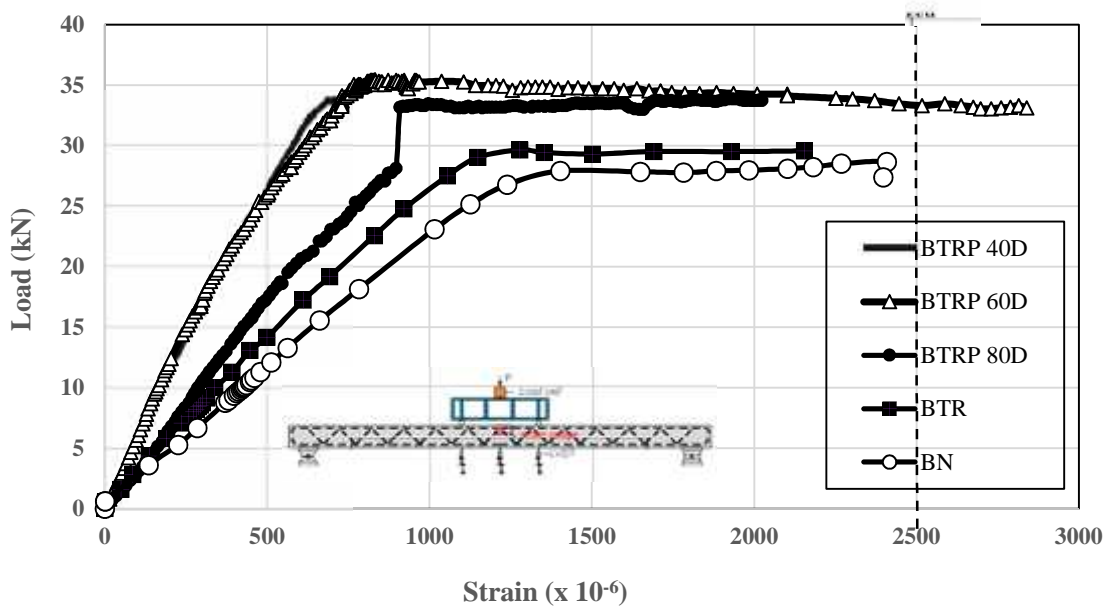


Figure 5. Relationship of load vs concrete compressive strain.

3.3 Load - main reinforcement strain relationship

Strain reinforcement was measured using strain gauge type FLK-6-11 (gauge factor $2.12 \pm 1\%$). If it is assumed that the reinforcement will yield at strain of 2000μ , then BN, BTRP 60D and BTRP 80D beams fail in under reinforced conditions, where the reinforcement yield before the concrete is destroyed. This is presented in figure 6 where all three beams have reinforcement yielding strains greater than 2000μ . Whereas the BTR and BTRP 40D experienced wide cracks in the support zone before the reinforcement yielded.

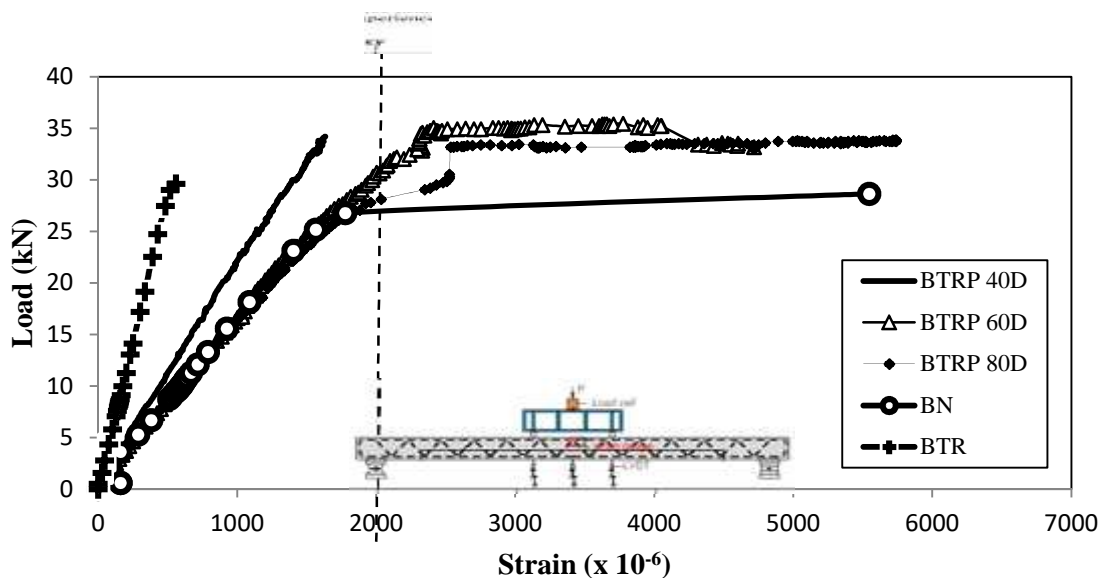


Figure 6. Relationship between load and strain of main reinforcement.

3.4 Load - strain relationship of strengthening reinforcements

Figure 7 shows the relationship of load and strain of strengthening reinforcements. Reinforcement is placed at the top of the beam with variations in reinforcement lengths of 40D, 60D and 80D (where D = reinforcement diameter).

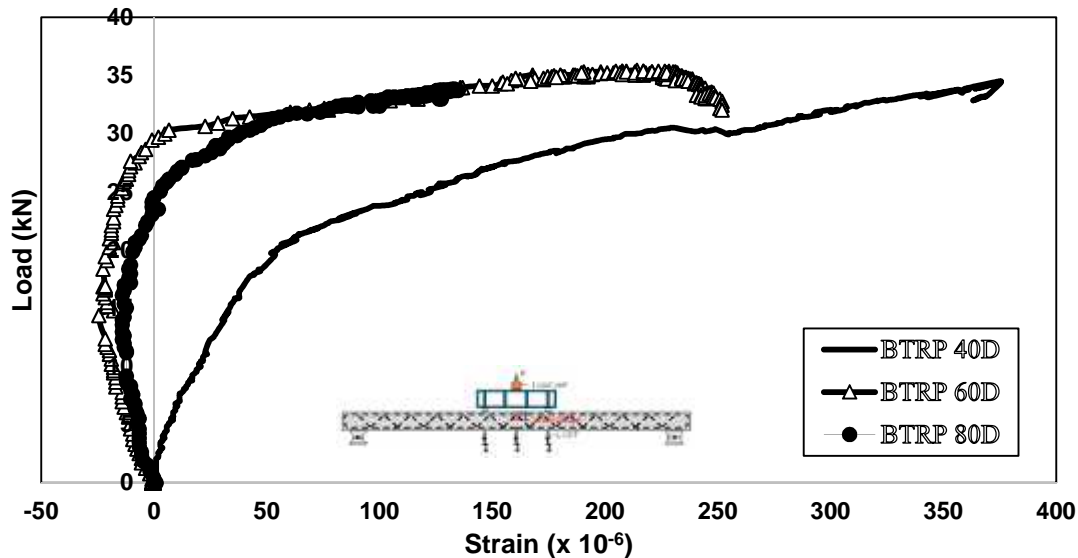


Figure 7. Relationship between load and strain of strengthening rebars.

Naturally, this reinforcement functions as a compressive reinforcement, so that at the beginning of loading, strain on the reinforcement is negative. But at a certain load, the behaviour changes to tensile, so the measured strain is positive. This indicates that the upper side of beam in the support zone is experiencing a tensile. From figure 7, it can be seen that this tensile reinforcement serves to increase the bending capacity of the beam when the beam is deformed due to load, and this reinforcement functions as a tensile reinforcement.

3.5. Crack pattern

The crack pattern of all specimens is shown in figure 8 to 11. Observation of crack patterns shows that all specimens have flexural cracks. Cracks start from the tension zone and propagate to the compressive zone of the beam. In the BTRP 40D beam cracks occur in the support zone, as shown in figure 9. Unlike BTRP 60D and BTRP 80D beams, a crack pattern is spread in the middle of the span, and no cracks occur in the support zone.

3.5.1. BN (normal beam)

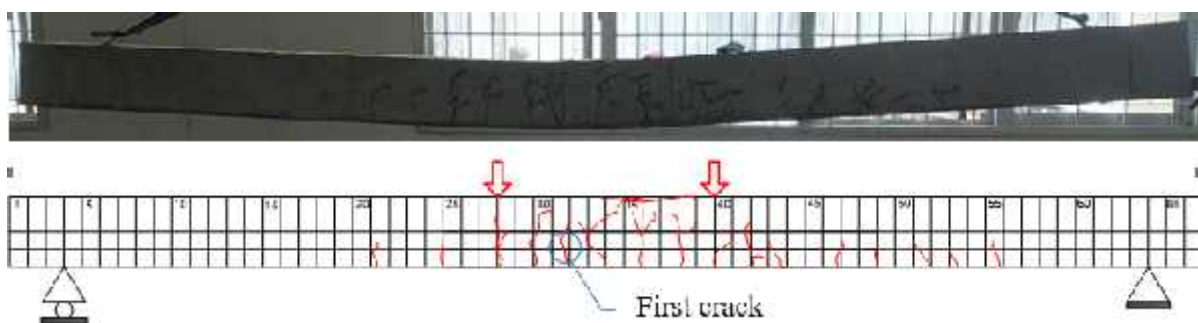


Figure 8. Crack pattern of BN.

Based on Figure 8, the initial cracks occur at BN when the load is 5.2 kN. When the load increases, cracks in the tension zone propagate to the compression zone until the load reaches ultimate at 28.84 kN, then the concrete is crushed in the compression zone. So it can be concluded that the beam has flexural crack.

3.5.2 BTRP 40D

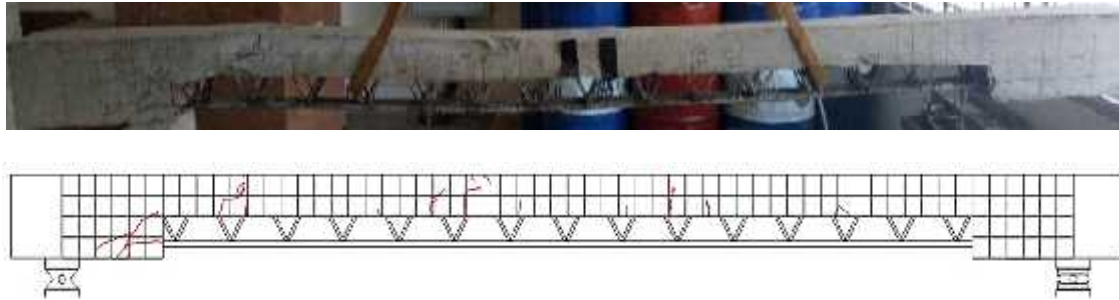


Figure 9. Crack pattern of BTRP 40D.

Based on the observations in Figure 9, the BTRP 40D experienced an initial crack when the load was 4.7 kN. As loading increased, cracks on the tension zone propagate to compression zone until the ultimate load of 34,186 kN. The crack spread exceeding 3/4 beam span. The failure mode of the BTRP 40D beam is wide cracking in the support zone at the upper side of the beam, while the concrete has not been crushed in the compression zone and the reinforcement has not yielded.

3.5.3 BTRP 60D and BTRP 80D

Figure 10 and 11 show crack pattern of BTRP 60D and BTRP 80D. Initial cracks occur when the load is 5.66 kN and 4.66 kN respectively. Same as BN and BTRP 40D, where cracks propagate from the tension zone to the compression zone with spread of more than 3/4 span. However, in BTRP 60D and BTRP 80D there were no cracks in the support zone. Therefore, it can be concluded that the crack pattern of both beams are flexural crack.

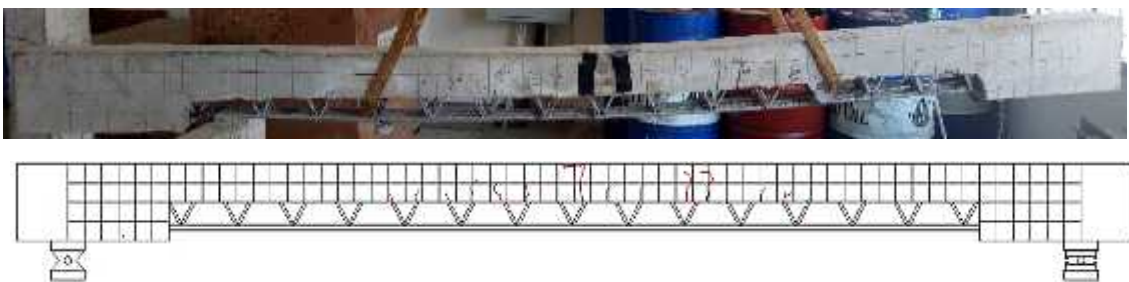


Figure 10. Crack Pattern of BTRP 60D.

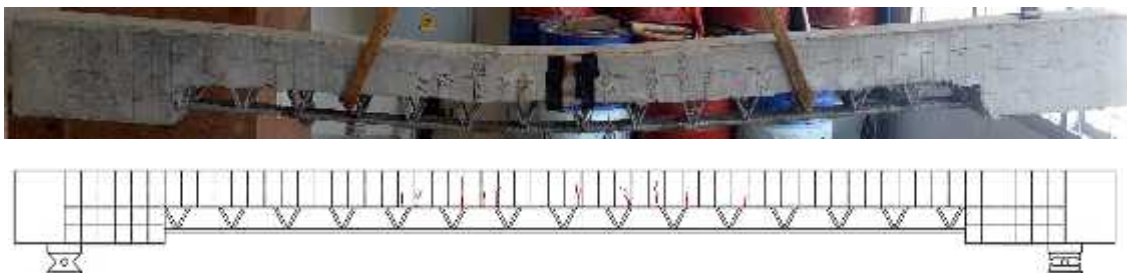


Figure 11. Crack Pattern of BTRP 80D.

4. Conclusions

Based on the results and discussion, it can be concluded as follow:

- a. The addition of tensile reinforcement in support zone of the BTRP beam can increase the bending capacity, ductility and delays the initial cracking.
- b. From the crack pattern, BTRP 40D is inadequate to prevent cracking in the support zone, while BTRP 60D and BTRP 80D do not crack in the support zone and provide greater deflection in mid span, therefore the beam is more ductile.

Acknowledgements

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