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Effects of Truss System Reinforcements on Flexural Behavior of Reinforced Concrete Beams

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Abstract:* *Various methods are developed in order to increase the flexural strength of the reinforced concrete beams. One of the possible methods is by using the truss system reinforcement. Therefore, this study aims to investigate the effect of truss system reinforcement on flexural behavior of reinforced concrete beams. A total six specimens were tested which consist of three specimens for the normal beams with the vertical stirrups and three specimens of truss reinforced beam with diagonal stirrups which formed a truss shaped reinforcement systems. The spacing of the diagonal stirrups was fixed at 0.5 times of the effective depth of the beam (0.5d). The dimensions of concrete beams are 2700 mm length with 150 x 200mm of cross section, respectively. The result indicated that the ultimate load of reinforced concrete beams with truss system reinforcement was relatively higher compared to the beam with vertical stirrups. In addition, the beams with truss system reinforcement are also less deflected during the service stage (before yielding) and hence, have more strength and stiffness than the beams with vertical stirrups.

Keywords: **truss system reinforcement, flexural failure, stirrups.**

I. BACKGROUND

In the past few decades, various methods are developed in order to increase the flexural strength of the reinforced concrete beams. All these methods are focused on the enhancement of flexural strength by changing the geometry or by introducing additional aids in the flexural zone of the beams. Hence, those methods result in increased cost and time, as well as additional efforts.

If the reinforcement system within the concrete beam itself can provide better flexural strength without changing the geometry or by using additional aids in the flexural zone, it would be economic as well as convenient to overcome above conventional methods. Many researchers recommend the use of inclined shear reinforcement to increase the flexural capacity of the RC beams. The beams with inclined stirrups show more ultimate strength but less deflection than the vertical and horizontal bar systems[1), 2)].

Recently in the construction industry, a special steel-concrete composite beam which called Hybrid Steel Trussed Concrete Beams (HSTCBs) was introduced, in which prefabricated truss reinforcement is embedded

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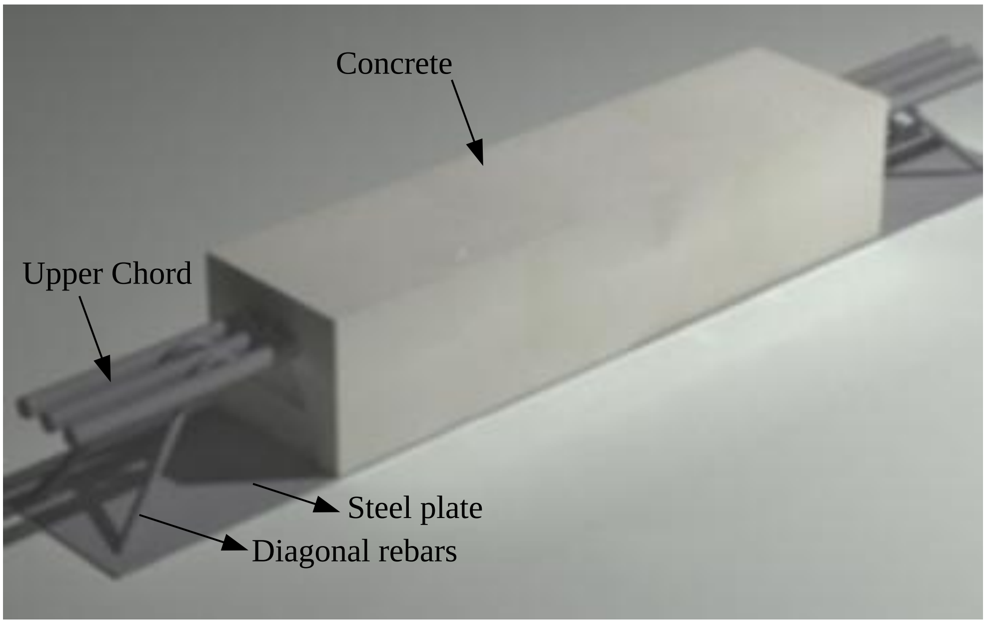
within the concrete[3]. HSTCBs represent a structural typology of composite beams typically employed as efficient structural solution for light industrialization and constituted by prefabricated steel truss embedded within a concrete matrix cast in situ. In the HSTCBs, the truss structure is usually made with or without steel plate or a precast concrete slab, which represents the bottom chord. A typical HSTCB is shown in **Fig. 1**. The load carrying capacity of HSTCB is found to be more than that of conventional RC beams[4),5)].

In this regards, this study aims to investigate the effects of truss system reinforcements on flexural behavior of reinforced concrete beams. During the test, the applied load, strain on the concretecompressive regions, the tensile steel at mid span, and the deflection at midspan were measured up to failure. The responses ofthe beams were examined and discussedin terms of deflections, strains, load capacity, crack pattern and failure mode.

Fig. 1. Hybrid Steel Truss Concrete Beam

II. METHODS

A. Specimens



a. Vertical stirrups (BN) **b. Truss system reinforcement (BTR)**

Fig. 2: Stirrup configuration

A total of six specimens were casted in this study. The dimensions of concrete beams are 2700 mm length with

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150 x 200mm of cross section, respectively. The specimens prepared in this study were separated into two types with three specimens for each type. The first type used the conventional vertical stirrups (BN) as shown in **Fig. 2(a)**. The second type used the diagonal stirrups (BTR) which form a truss shaped reinforcement systems (**Fig. 2(b)**). Spacing of diagonal stirrups was 0.5 times of effective depth of the beam (0.5d).

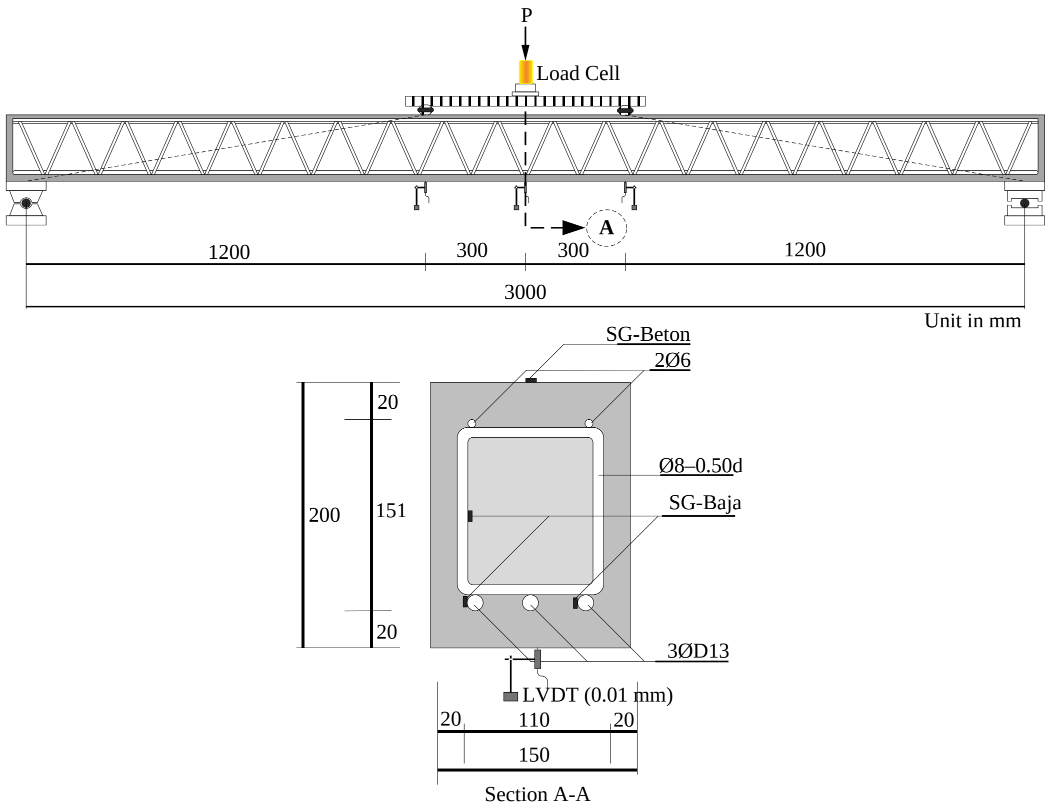

Fig. 3: Detail of beams with truss system reinforcement (BTR)

The beams BN with vertical stirrup are prepared as the control beam. Three numbers of 13 diameter bars are provided in the tension zone and two number of 6 mm diameter bars in the compression zone. For beam BTR with diagonal stirrups, three numbers of 13 diameter bars are also provided in the tension zone and two number of 6 mm diameter bars in the compression zone. Diagonal bars of 6 mm diameter are welded to the top and bottom chords to have a truss arrangement. The details of the BTR beams are presented in **Fig. 3**.

B. Material Properties

The concrete was designed with the average 28-day cylinder compressive strength of 25 MPa. The rebars having yield strength of 304 MPa and 240 MPa were used for tensile and compression bars, respectively. The rebars of 8 mm were used for the vertical and diagonal bars with yield strength of 417 MPa.

C. Instrumentations and loading methods

The beams were subjected to a static four-point bending test as shown in Fig. 4. The load was applied by a hydraulic jack setup on a steel contrast frame firmly anchored to the lab floor. The jack was controlled by a hydraulic control unit that imposed the prescribed displacement with the rate of 0.2 mm/sec. A load cell with the capacity of 200 kN was placed between the jack and a distributor beam to measure the applied force precisely.

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During the loading, all of the measurements were recorded through a data logger. The crack propagations were drawn and marked at each load level during the loading tests.

Before casting of concrete, the strain gauges were attached to the tensile bars and diagonal bars. The locations of the attached strain gauges are presented in Fig. 3. The linear variable differential transducers (LVDT) were used to monitor the vertical displacement of the specimens. One transducer was set at the mid-span and the other two were located under the loading point. In addition, the strain gauges were attached to the top fiber of concrete at the mid-span.

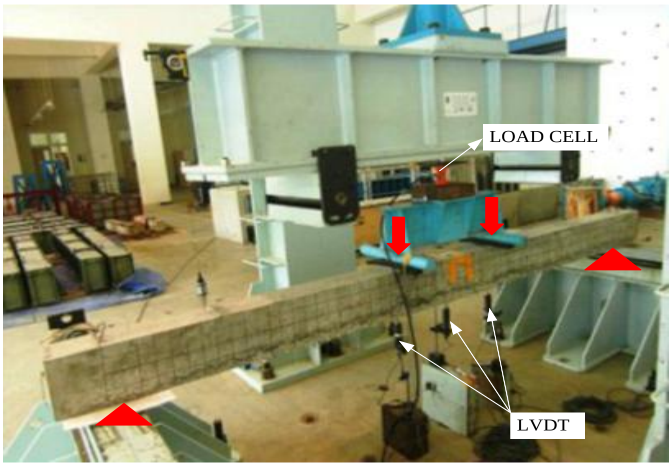

Fig. 4: Test setup

III. RESULTS AND DISCUSSIONS

Table 1 summarizes the experimental results of all specimen in terms of load and displacement at first crack (P_{cr}), yielding (P_y), and ultimate (P_u). The effects of the truss system reinforcements are discussed in the following sections.

Table 1: Summary of experimental results

Specimen	Load (kN)			Displacement (mm)			Failure mode
	First crack, P_{cr}	Yield P_y	Ultimate, P_u	First crack, δ_{cr}	Yield, δ_y	Ultimate, δ_u	
BN-01	5.20	25.30	26.60	2.35	18.44	43.08	Flexural failure
BN-02	5.20	27.80	28.80	2.49	20.56	31.71	
BN-03	5.10	23.20	25.70	2.62	43.07	50.39	
Rata-rata	**5.20**	**25.40**	**27.10**	**2.49**	**27.36**	**41.72**	
BTR-01	5.70	26.20	28.40	2.37	45.57	46.84	Flexural failure
BTR-02	5.30	26.00	28.20	2.14	38.70	38.32	
BTR-03	5.80	26.90	29.30	2.26	34.92	35.06	
Rata-rata	**5.60**	**26.40**	**28.70**	**2.26**	**39.73**	**40.07**	

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A. *Load-displacement relationship*

Figure 5 shows the typical load-displacement curves of the beam with vertical stirrups (BN2) and the beam with truss system reinforcements (BTR2). The displacement presented in this figure was the displacement measured from the mid-span of the beams. Initially, all beams were un-cracked and stiff. When the applied load reached the rupture strength of the concrete, a flexural crack occurred at the mid-span of the specimens.

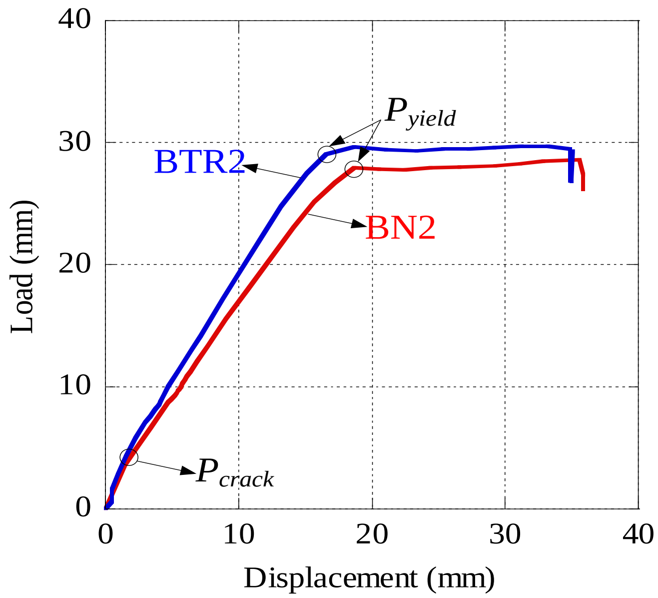

Fig. 5: Typical Load-Displacement curves

As shown in **Table 1**, the average first cracking load and displacement in the BN specimens (normal beam) from three specimens were 5.2 kN and 2.49 mm, respectively. The occurrence of the first crack indicated that the applied load exceeded the tensile strength of the concrete. First cracks caused a reducing in stiffness of the normal beams. On the other hand, the average first cracking load of BTR specimens (truss system reinforcement) was slightly higher than the normal one, but it has smaller displacement of 2.26 mm. The first cracking on BTR beams did not cause significantly decreasing on the load-deflection slope. As the load was increased to the yielding load (P_y), the steel reinforcement entered to the plastic range which was indicated by the reducing of the beam flexural stiffness at the load of 25.4 kN and 26.4 kN for BN and BTR, respectively. The yielding load of the BTR was higher than that of the BN due to the effect of the truss system action of the reinforcement. Considering the load-deflection diagram of the beams, it is clear that, the specimens with truss reinforcement is better than control specimen where the deflection is less for truss reinforced beams. Thus it can be concluded that, change in the pattern of reinforcement from vertical to inclined, increases the stiffness and strength of the beam. That is, the inclined diagonals of the truss reinforcement contributed to increased flexural strength of the beams. Whereas, the difference in inclination of the diagonals in truss reinforcement do not have any effect in the failure mode or load carrying capacity of the beams as they shows similar load-deflection pattern.

B. LOAD-STRAIN RESPONSE

Figure 6 illustrates the typical development of the strains at the tensile rebars.

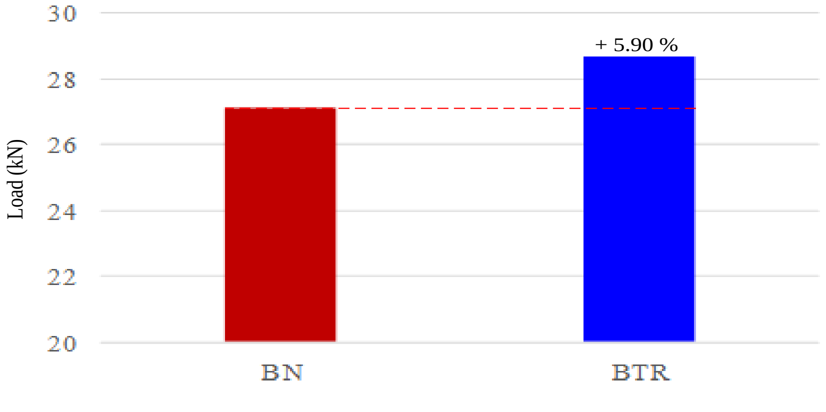

Fig. 6: Typical Load-strain curves at the tensile rebars

It was observed that the tensilere bars for beam with vertical stirrups and (BN2) and truss system reinforcement (BTR2) yielded at the load of 23.2 and 27.0 kN, respectively. The results indicated that the use of the truss system reinforcement was able to increase the yielding load.

C. Ultimate Capacity

Figure 7 shows the average ultimate capacity of the beams with vertical stirrups (BN) and truss system reinforcement (BTR). The results indicated that the beams with truss system reinforcement showed an enhancement of ultimate capacity of about 5.9% compared to the beam BN with vertical stirrups. The increasing of the ultimate load of BTR compared to BN was caused by the truss system of the reinforcement. The strut effect of the diagonal bars contributed to increased flexural strength of the specimen. Thus,it can be concluded that, higher flexural strength is obtained on replacement of the conventional vertical reinforcement in reinforced concrete beams with truss arrangement of reinforcement system.

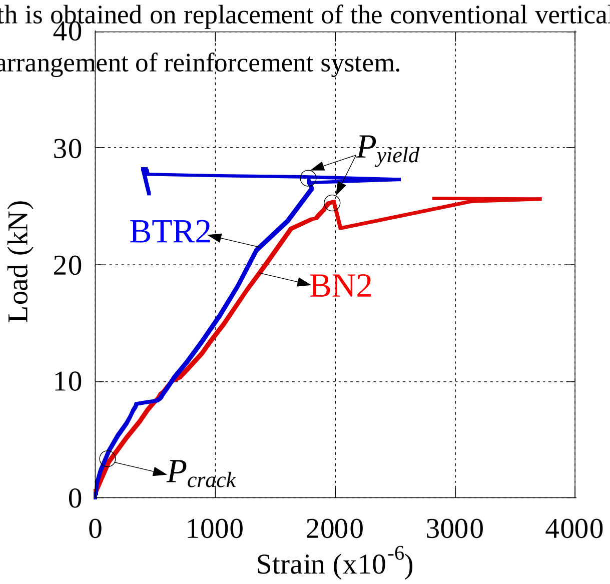

Fig. 7. Average ultimate load

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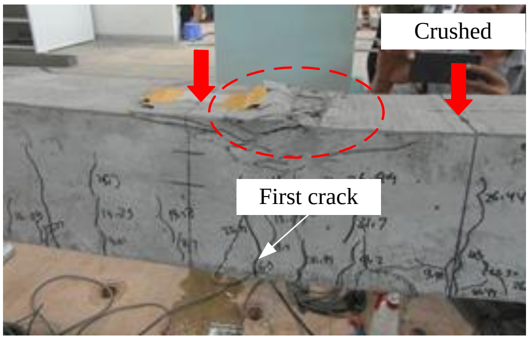
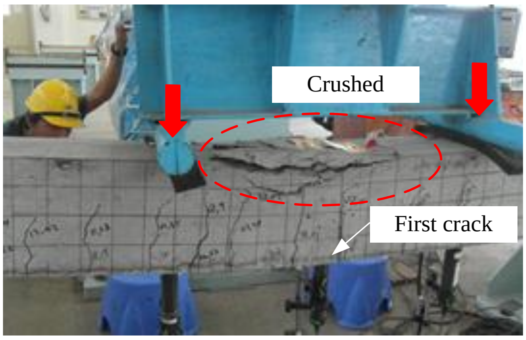
A. Crack Patterns and Failure Modes

Figure 8 present the typical crack patterns of each specimen types. The first flexural cracks appeared at the midspan of the beams.





a. BN (vertical stirrup) **b. BTR (truss system reinforcement)**

Fig. 8: Crack pattern

Based on **Fig. 8**, increasing of the applied loads induce additional flexural crack along the beams. Comparing to cracks number of the normal beams, the number of cracks on the specimen BTR was lower. Both the BN and BTR failed in the RC conventional flexural manner. The tensile steel yielded prior to concrete crushing at mid-span section. The wide flexural cracks were occurred at mid-span. This crack was extended to the compressive regions. The results indicated that the difference in inclination of the diagonals in truss reinforcement does not have any effect in the failure mode.

IV. CONCLUSION

The investigation of the effects of truss system reinforcements on the flexural behavior of reinforced concrete beams was investigated in this study. The results are summarized as follows:

1. The ultimate load of reinforced concrete beams with truss system reinforcement increased by 5.9% compared to the vertical stirrup system reinforcement.
2. The beams with truss system reinforcement are less deflected during the service stage (before yielding) and hence, the have more strength and stiffness than the beams with vertical stirrups.
3. The difference in inclination of the diagonals in truss reinforcement does not have any effect in the failure mode, where all the beams failed in flexural failure.

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