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# Flexural Capacity of the Concrete Beams Reinforced by Steel Truss System

*Rudy* Djamaluddin[1,*], *Pieter Lourens* Frans[2], and *Rita* Irmawati[1]

[1]Hasanuddin University, Civil Department, 90222 Gowa, Indonesia
[2]Hasanuddin University, Doctoral Student of Civil Department, 90222 Gowa, Indonesia

**Abstract.** Reinforced concrete beam is normally reinforced by steel bars to sustain tensile forces occurring due to flexural response, and vertical steel reinforcement to sustain shear stresses. On the other side, the truss system is a structure composed by triangle. Truss system develops its flexural capacity based on the inter-action of the bar elements. Therefore, introducing of the truss system to the reinforced concrete beams by modifying of the tensile and shear reinforcement may increase the beam flexural capacity. The study on the application of the truss system to the reinforced concrete beams has been conducted. The shear reinforcement was modified to form the triangles that were connected to the tensile reinforcement on the bottom and compressive reinforcement on the top. The steel bar elements were connected by welding to form a truss system. The effect of the buckling of the compression bar element on the truss system may be avoided due to the constrain effect of the surrounding concrete. In order to clarify the effect of the truss system reinforcement to the flexural behaviour, a series of specimens was prepared. The beams specimens have a length of 3.3 m with cross section of the 15 by 20 cm. A normal concrete beam was also prepared as control specimens. Results indicated that the concrete beams reinforced by truss system had flexural capacity higher than the normal beam.

## 1 Introduction

The constructions using concrete materials are still dominant due to its advantages. The most important characteristic of concrete materials such as workability, low cost and fire resistance as well as its low maintenance cost. The durability has always been a major reason for selecting reinforced concrete as the construction materials for building and other civil engineering infrastructure systems [1]. Due to the mass consuming of concrete materials, the exploration of natural materials such as gravels and sands are increasing to produce a concrete material. Additionally, the cement using in the concrete is almost 90% composed by lime stones that also coming from natural materials.

* Corresponding author: rudy0011@gmail.com

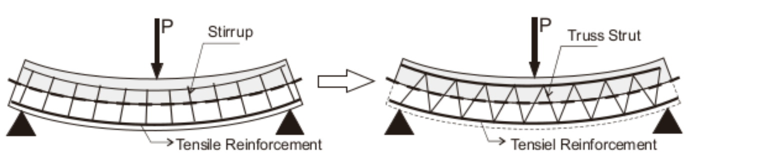
Massive exploration of the natural materials for producing concretes affect to the environment condition and global warning that may cause disasters such as flooding and land-slides. Therefore, the researches focusing on the optimizing of the structural capacity of the reinforced concrete structure elements are one of major research. Nes.L.G et.al [2] studied about structural performance of a concrete sandwich slab element, Pengfei L et.al [3] studied about concrete box girder with corrugated steel webs. The developing of the new concept in structures design to minimize the using of the concrete has been conducted and proposed, such as box type girders, corrugated beams, strengthened beams or column with FRP materials and sandwich structures [4-9].

By increasing the structural capacity while reducing the using of concrete materials will provide advantages on the environmental impact especially in the natural materials exploration. The concrete should be used as efficient as possible. The research on the fields of the concrete efficiency should be conducted intensively in order to save the natural resources.

(a) Roof truss structure (b) Bridge truss structure

**Fig. 1.** Truss Structures applied on Roof and Bridge

This paper discussed a study of the integrating of the truss steel structures mechanism into the concrete beams. The truss element develops its flexural capacity based on interaction between truss elements (tension-compression). Stand-alone truss steel structures have been applied on many fields. Due the stability mechanism, the buckling of the truss element of compression strut is an important part that should be considered in design. Fig.1 shows the application of truss system on the bridges and roof structures. Meanwhile, the concrete beam develops its flexural capacity based on the couple moment interaction between tension force on the steel reinforcement and compression force on concrete [10]. The stirrups that commonly exist in a reinforced concrete beams is considered only for shear reinforcement. By modify the stirrups angles to form a series of triangles on the reinforcement system of a concrete beams then the truss mechanism may occur in a concrete beams. The buckling effect of the stirrup reinforcement may be avoided due to the constraint effect of the surrounding concrete. In this concept, the flexural capacity of the concrete beams is the accumulation of two flexural actions, that are due to couple moment of tension and compression forces, and due to the flexural effect of the truss reinforcement system. Fig.2 shows the illustration of the proposed concept. Simply, the triangles were formed by pairing of inclined stirrups. This paper presents the experimental results of the concrete beams reinforced by steel truss system as the reinforcement.

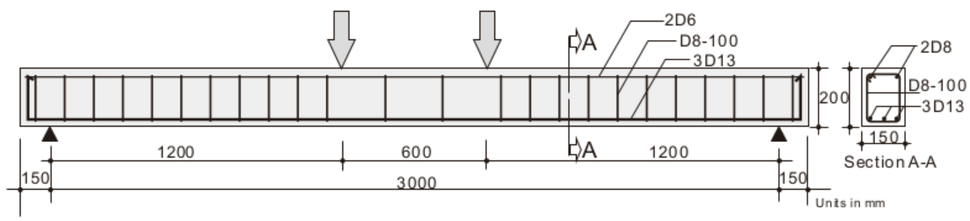



**(a)** Regular steel reinforced concrete beams (b) Steel truss reinforced concrete beams

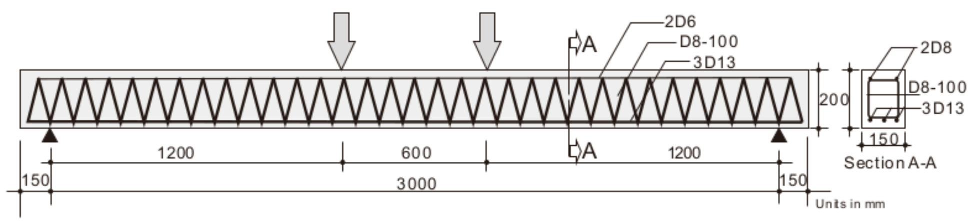
**Fig. 2.** Regular reinforcement system vs steel truss reinforcement

## 2 Specimens

A series of specimen was prepared to clarify the effect of steel truss as reinforcement on the concrete beams. The specimen preparation was divided to the preparation of the truss reinforcements and casting of the concrete beams. The concrete beams specimen dimensions are 3300 mm length with 150 x 200 mm of cross section, respectively. The Detail of specimen is presented in Fig.3. The specimens prepared in this study were three beams for the normal reinforced concrete beams (BN), three beams for truss reinforced concrete beams (BR).




(a) BN type




(b) BR type

**Fig.3** Detail of Specimens

**Table 1.** Material Properties

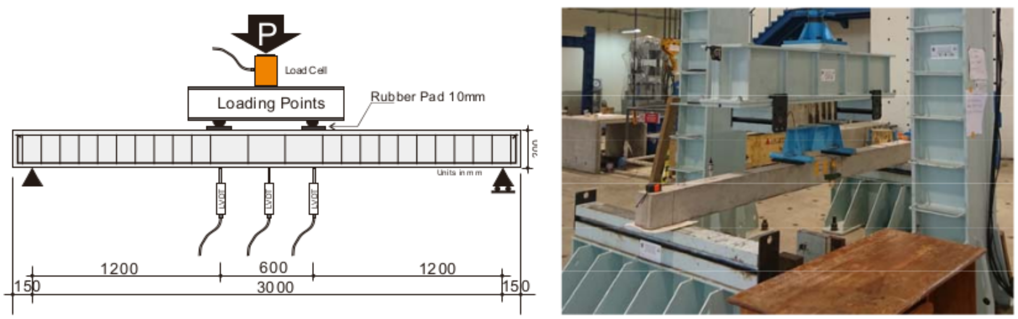
| Properties | Concrete | Steel Reinforcement |
|---|---|---|
| Compressive Strength (MPa) | 23 | 300 |
| Tensile Strength* (MPa) | 2.1 | 300 |
| Elastic Modulus (Gpa) | 24 | 200 |

**) Yield Strength for Steel*

Specimens BN and BR used three of D13 steel bars as tensile reinforcement and D8 as the shear (vertical) reinforcement. Both BN and BR had two of D6 steel reinforcement at the compression side. For specimen BR, the truss reinforcement was composed by three of D13 steel bar reinforcement for the tension reinforcement, D8 steel bar for diagonal bars, and two of D6 steel on the upper horizontal bars. The space of the diagonal bars on the truss reinforcement was fixed on 100 mm. All connections in the truss reinforcement were done by welding. All beams had the same tensile reinforcement ratio. The strain gauges were patched on tensile reinforcement and, only for BR type, the strain gauges were also patched on truss strut (diagonal bar) at span centre for strain measuring during the loading. The casting of concrete was done using a normal concrete with compression strength of 23MPa. All specimens were cured for 28 days using a wet blanket. Material properties of concrete and steel reinforcement used in this study are presented in Table 1.

# 3 Test Setup

The specimens were loaded under four point bending test. The supports were prepared to behave as the hinge-roller support. Strain gauges were patched on the concrete surface on the three points at the span centre which were one on the top of beam and two at the concrete web, respectively. Strain gauges patched on the concrete surface as well as on the tension and diagonal bar were then connected to a data logger to measure the strain for further analysis. The specimen was supported by simple support with the span of 3000 mm. Two loading point was applied with the space of 600 mm to the span centre of the beams. Specimen setup is presented on Fig.4. LVDTs were installed on the centre point and both of under loading points to measure the deflection. All data was recorded using a data logger connected to the computer. The load measured using a load cell was applied gradually with the rate of 2 kN per step until first crack of concrete. Further loading, the load was applied with the rate of 5 kN until maximum load up to final failure.




(a) Support and Loading Position (b) Photograph of Test Setup

**Fig.4** Detail of Specimens

# 4 Results and Discussions

Generally, the effect of the truss system on the concrete beams (BR Type) was indicated by the increasing of the flexural capacity as well as the stiffness of the concrete beams compared to the normal steel reinforced concrete beam (BN Type). Detail discussion of the experimental results is presented in the following sections.

## 4.1 Load-Deflection Relationship

The relationship between the applied load and span centre deflection is presented in Fig.5. At initial stage of loading, all beams were un-cracked beam. On the specimens of BN type as well as BR type, the concrete resisted both compression and tension force. When the applied load reached to the rupture strength of the concrete on specimens, the concrete started to crack. This caused a decreasing of beam flexural stiffness. Once the tension zone of concrete cracked, its tensile force resistance becomes negligible. The tensile force due to external load was primarily carried by steel reinforcement. At pre-crack stage, both specimens had almost same flexural stiffness. However, after first cracking, the specimens BR showed higher stiffness compared to the regular concrete beams. This phenomenon may be understood clearly that on the BR type, the truss reinforcing system provided an additional stiffness in the total stiffness of the concrete beams. The load-deflection curves propagated under different path up to the yielding point of the tensile reinforcement. The average stiffness after first crack of specimen BN was approximately 1.55kN/mm, whereas the stiffness of the specimen BR type was 1.75kN/mm, respectively. The increasing of applied load was followed by the propagation of deflection up to the yielding point of steel reinforcement. On BN type specimen, the yielding of tensile reinforcement occurred when the applied load reached 25.4kN. For BR type specimen, the yielding of tensile reinforcement occurred when the applied load reached 29.0kN. Further loading after yielding of tensile reinforcement caused the decreasing significantly of the beams flexural stiffness on both specimens. As it can be observed that the effect of truss was no longer influencing the beam stiffness. The deflection was propagated without significant increasing of the load capacity. On the BN type specimens, the ultimate load capacity was 26.8kN when the span centre deflection achieved 43.0mm, while on the BR type specimens, the ultimate load capacity was 30.2kN when the deflection equal to 39.5mm, respectively. The final failure of specimens was caused by the concrete crushing on approximately at the span centre. Further steps showed that the beams continuously deflected followed by the decreasing of applied load.

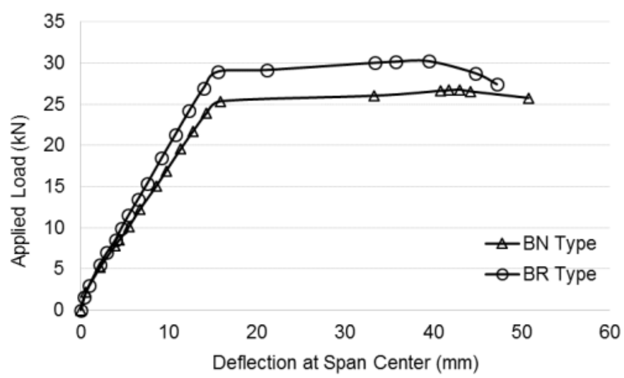



**Fig.5** Load-Deflection Relationship

## 4.2 Flexural Capacity

Table 2 presents the summary of loading steps as well as the deflection accordingly. The first cracking occurred when the applied load reached 5.21 kN on BN type and 5.47 on BR type, respectively. There was no significant effect of the truss reinforcement on the first cracking load. However, the effect of the truss reinforcement was identified when the applied load increased up to the yielding point of the steel reinforcement. The yielding load of the BN type was 14.26 kN and the BR type was 15.57 kN, respectively. The effect of the truss reinforcement was also identified on the flexural stiffness after first crack. The average stiffness after first crack of specimen BN was approximately 1.55kN/mm, whereas the stiffness of the specimen BR type was 1.75kN/mm, respectively

**Table 2.** Summary of Experimental Results

| Type | First Crack | | Yield of Steel | | Ultimate Capacity | | Ratio (BR/BN) | |
|---|---|---|---|---|---|---|---|---|
| | Pcr (kN) | Δcr (mm) | Py (kN) | Δy (mm) | Pu (kN) | Δu (mm) | Pu | Δu |
| BN | 5.21 | 2.21 | 23.90 | 14.26 | 26.77 | 43.03 | 1.13 | 0.92 |
| BR | 5.47 | 2.14 | 28.97 | 15.57 | 30.24 | 39.47 | | |

The ultimate flexural capacity of BR type specimen was higher than the BR type specimens. The ultimate capacity of the BN type was 26.77kN and the BR type was 30.24kN, respectively. The ultimate capacity of both specimens was decided by the crushing of the concrete on compression section. The ultimate load ratio between truss reinforced beams (BR) and the regular beam (BN) was 1.13. This indicated that the effect of truss system was approximately 13% in increasing the ultimate flexural capacity of the reinforced concrete beams.

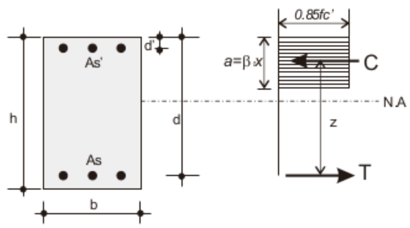



**Fig.6** Stress Block Model of the ultimate capacity of the Steel Reinforced Concrete beams

Using the stress model presented in Fig.6, the ultimate capacity of the regular steel reinforced concrete beam may be estimated using the internal couple moment between compression forces on concrete and tensile force on the steel reinforcement [10], as follows :

$$M_r = 0.85 f_c' \, b \, a \left( d - \frac{1}{2} a \right) \quad (1)$$

Therefore, simply the total moment $M_T$ of the BR type specimens is the sum of the moment capacity of the RC beams $M_r$ and the truss system $M_{ts}$.

$$M_T = M_r + M_{ts} \quad (2)$$

The increasing of the moment capacity was the effect of the increasing of the flexural stiffness on the BR type specimens. The increasing of the flexural stiffness was affected by the increasing of the moment of the inertia due to the existing of diagonal bars as on the BR type. By adopting the equation of the moment of inertia of the cracked section of the truss system reinforced concrete reported by Francesco T, et.al [11], then using Fig.7, the moment of inertia of the cracked section of BR type specimens may be expressed by Eq.(3).

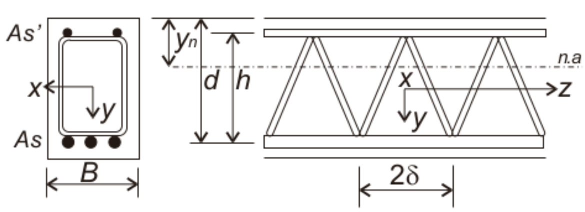


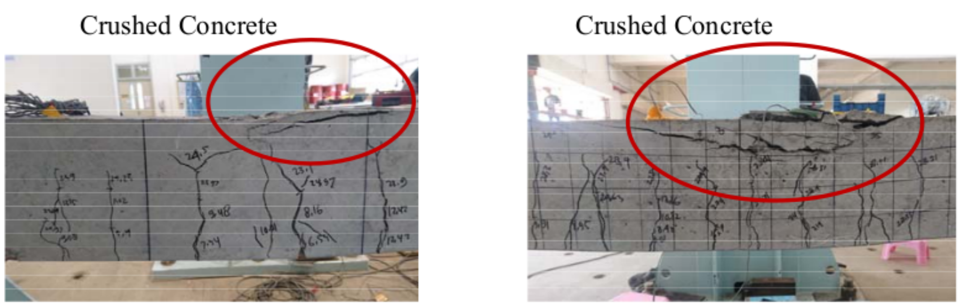

**Fig.7** Section of the truss reinforced concrete beam

$$J_{eq} = \frac{B y_n^3}{3} + n_E \left( A_s + 2 A_{diag} n_z^3 \right) (d - y_n)^2 + n_E A_s' (y_n - d')^2 \quad (3)$$

where, $B$ is the width of beam, $y_n$ is the distance from neutral axis ($n.a$) to the upper chord, $n_E = Es/Ec$, $As$ is the area of the tensile reinforcement (lower steel bars), $n_z$ is the cosine director of the diagonal bars along the z-axis ($\delta/l_{diag}$), $l_{diag}$ is the length of the diagonal bar, $A_{diag}$ is cross section of a single diagonal bar, $d$ is effective depth of beam, $As'$ is the cross section of the upper steel bars and $d'$ is the distance of upper steel bars to the upper chord.

### 4.3 Failure Mode and Crack Pattern

All specimens were designed to fail under crushing of compression concrete. On BN specimens, the failure of concrete was initiated by the yielding of the steel reinforcement. As the result, the compressive stress of concrete reached the compression strength of the concrete. This failure mode also occurred on the BR type specimens. However, the failure load of the BR type was higher than the normal reinforced concrete beams (BN type). This may be caused by additional flexural capacity of the truss system as the reinforcement in the concrete beam. It should be noted again here that the truss system also affected to the flexural stiffness of the concrete beams. The compression area of concrete was wider on the BR type, therefore the failure load was higher than BN type. The crushing failure of both specimens is presented in Fig.8.




(a) BN type Specimen (b) BR Type Specimen

**Fig.8** Failure Mode and Crack Pattern

Fig. 8 presents also the crack patterns on the constant moment region of each specimen types. BN type as well as BR type specimen indicated typical crack pattern of a normal under reinforced concrete beam. Further loading after appearance of the first crack, the other cracks appeared while the existing cracks propagated. The propagation of the cracks moved toward to the compression concrete. The long cracks were concentrated in the constant moment region at span centre. Comparison to the both specimens, it was observed that the BR type specimens had better cracks distributions.

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