International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:8, No:6, 2014

Effect of the Truss System to the Flexural Behavior of the External Reinforced Concrete Beams

Rudy Djamaluddin, Yasser Bachtiar, Rita Irmawati, Abd. Madjid Akkas, Rusdi Usman Latief

Abstract**—**The aesthetic qualities and the versatility of reinforced concrete have made it a popular choice for many architects and structural engineers. Therefore, the exploration of natural materials such as gravels and sands as well as lime-stone for cement production is increasing to produce a concrete material. The exploration must affect to the environment. Therefore, the using of the concrete materials should be as efficient as possible. According to its natural behavior of the concrete material, it is strong in compression and weak in tension. Therefore the contribution of the tensile stresses of the concrete to the flexural capacity of the beams is neglected. However, removing of concrete on tension zone affects to the decreasing of flexural capacity. Introduce the strut action of truss structures may an alternative to solve the decreasing of flexural capacity. A series of specimens were prepared to clarify the effect of the truss structures in the concrete beams without concrete on the tension zone. Results indicated that the truss system is necessary for the external reinforced concrete beams. The truss system of concrete beam without concrete on tension zone (BR) could develop almost same capacity to the normal beam (BN). It can be observed also that specimens BR has lower number of cracks than specimen BN. This may be caused by the fact that there was no bonding effect on the tensile reinforcement on specimen BR to distribute the cracks.

Keywords**—**External Reinforcement, Truss, Concrete Beams.

I. INTRODUCTION

CONCRETRE materials are still a dominant material for construction due to its advantages such as workability, low cost and fire resistance as well as its low maintenance cost. Even though the sustainability and green building are currently hot topics in the construction industry, but durability and longevity have always been major reasons for selecting reinforced concrete as the construction materials for building and other civil engineering infrastructure systems. The aesthetic qualities and the versatility of reinforced concrete have made it a popular choice for many architects and structural engineers. Therefore, the exploration of natural materials such as gravels and sands is increasing to produce a concrete material. Furthermore, the cement using in the concrete is almost 90% composed by lime stones that also coming from natural materials. The manufacturing of cement has contribution to the CO_2 emission. The source of CO_2 in cement production may come from the energy consumed in the heating process and transportation of cement from the manufacturer to the concrete production facilities. 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. We are as engineers have responsibility to reduce the effect of the application of concrete materials to the environmental impact. The concrete should be used as efficient as possible. The research on the fields of the concrete efficiency should be conducted intensively.

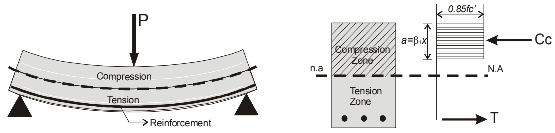


Fig. 1 Flexural Action of Reinforced Concrete Beam

According to the natural behavior of concrete material, it is strong in compression and weak in tension. The tensile strength of concrete falls between 8 to 15 percent of the compression strength [1], [2]. Therefore the contribution of the tensile strength of concrete to the flexural capacity of the beams is neglected as illustrated in Fig. 1. The flexural capacity (M_R) of the beam is influenced only by compression stress of the concrete and the tensile stress of the steel reinforcement [1], as expressed in (1), as follows:

$$M_R = 0.85 f_c' \beta_1 x b \left(d - \frac{1}{2} a\right) \tag{1}$$

In order to efficiently use the concrete materials, then the compressive strength of the concrete on the tensile stressed section may be reduced, or the concrete on the tensile stressed section may be removed. However, this will affect to the flexure mechanical action between the tension stress and the compression stress of the concrete beam section. As the results, the flexural capacity of the beam decreases [3]. The strut action between compression zone and tension zone is necessary to develop an effective flexural action. In this matter, the strut in the truss structure system may be a good alternative to be applied in the concrete beams without concrete in the tension zone.

Truss system in flexural loading is a structure system with configuration of the tension bar for tension force at bottom and compression bar at the upper, respectively. The couple arm between tension force and compression force in sustaining of flexural action exists due to the strut action of the diagonal bars connecting between the horizontal bars on the upper cord and

Rudy Djamaluddin is with the Hasanuddin University, Makassar, Indonesia (phone: +62-411-856015; fax: +62-411-856015; e-mail: rudy0011@hotmail.com).

Yasser Bachtiar is a Doctor student of Civil Engineering Department of Hasanuddin University, Makassar, Indonesia.

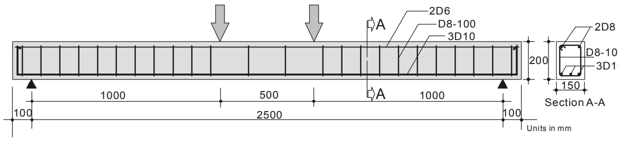
Rita Irmawati, Abd.Madjid Akkas and Rusdi Usman Latief are with the Hasanuddin University, Makassar Indonesia.

bottom cord, respectively. This system may be adopted to the concrete beams without concrete or low compressive strength concrete on the tension side in order to create the strut action between steel tensile reinforcement and the compression concrete [4]-[9].

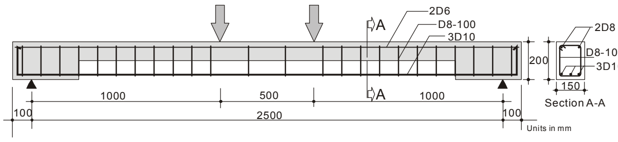
A series of the experimental specimens were prepared to clarify the effect of the truss structures in the concrete beams without concrete on the tension sides. Besides the control specimens of normal beam (BN), there were two types of beams were prepared. They were the beam with normal reinforcement as on BN without concrete on the tension zone (BT) and the concrete beams without concrete on tension zone using truss structures as the reinforcement (BR), respectively. It should be noted that all beams had the same tensile reinforcement ratio.

II. Experimental Program

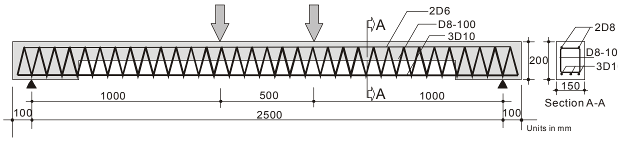
A. Specimens



(a) Specimen BN



(b) Specimen BT



(c) Specimen BR

Fig. 2 Detail of Specimens

TABLE I
MATERIAL PROPERTIES

Concrete		Steel Reinforcement	
Compressive Strength	25 MPa	Compressive Strength	425 MPa
Rupture Strength	3.9 MPa	Tensile Strength	425 MPa
Young Modulus	23 GPa	Young Modulus	200 GPa
Poisson Ratio	0.2	Poisson Ratio	0.3
Density	2.3 t/m3		

Specimen preparations were divided into the preparation of the truss reinforcements and the casting of the concrete beams. The concrete beams specimen dimensions are 2700mm length with 150 x 200mm of cross section, respectively. Detail of specimen is presented in Fig. 2. The specimens prepared in this study were three beams for the normal reinforced concrete beams (BN), three beams for normal reinforced concrete beams without concrete on the tension section (BT) and three beams for the beams without concrete on tension section using truss reinforcement (BR), respectively. Specimens BN and BT used three of D12 steel bar as tensile reinforcement and D8 as the shear (vertical) reinforcement. Both BN dan BR had two of D6 steel reinforcement at the compression side for reinforcement assembly purpose only. For specimen BR, the truss reinforcement was composed by three of D12 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 100mm. All connections in the truss reinforcement were done by welding. All beams had the same tensile reinforcement ratio. The casting of concrete was done by placing the reinforcement in the opposite position (tensile reinforcement at upper) in the formwork to easily create the hollow on the half height of the concrete beams on the specimens BT and BR. Both beam ends with length of 400 mm were casted fully for the support during testing. Fig. 3 shows the concrete casting of beam specimens. All specimens were cured for 28 days in the moisturizing condition before testing. Material properties of concrete and steel reinforcement used in this study are presented in Table I.

Fig. 3 Casting of Specimens

B. Test Setup

Prior to test, strain gauges were patched on the concrete surface on the three points at the span center which were one on the top of beam and two at the concrete web, respectively. The supports were prepared to behave as the hinge-roller support. The specimens were loaded under four point bending test. Strain gauges patched on the concrete surface as well as on the tension and diagonal bar were connected to a data logger to measure the strain for further analysis. The specimen was supported by simple support with the space of 2500mm. Two loading points were applied with the space of 500mm to the span center of the beams. Specimen setup is presented on Fig. 4. LVDTs were installed on the center 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 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. The deflection rate was used to control the further loading on the post peak steps until the specimen tended to loss its capacity.

Fig. 4 Setup of Specimen (BR)

TABLE II
SUMMARY OF MAXIMUM CAPACITY

Specimen	Maximum Capacity		Moment Capacity (kN.m)	Average Initial Stiffness (P/Δ) (kN/mm)
	Load (kN)	Deflection (mm)		
BN-1	42.3	30.9	21.15	3.52
BN-2	40.8	29.2	20.40	
BN-3	43.7	32.1	21.85	
BT-1	24.2	25.8	12.10	1.01
BT-2	26.3	27.2	13.15	
BT-3	22.8	23.4	11.40	
BR-1	39.0	26.9	19.50	2.15
BR-2	41.5	28.1	20.75	
BR-3	40.1	27.3	20.05	

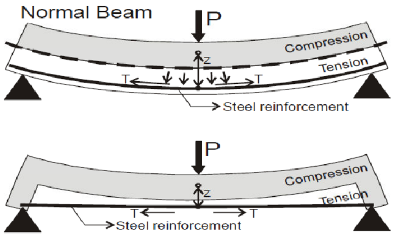


Fig. 5 Illustration of Flexural Action of Specimen BT

Fig. 6 Specimen Under Loading

III. RESULTS AND DISCUSSIONS

A. Maximum Capacity

Table II presents the maximum capacity and initial stiffness of the tested specimens. Initially, all beams were un-cracked beams. Further loading, the cracks occurred. As the result the beam stiffness decreased. On the specimen BN, average stiffness was approximately 3.52 kN/mm. On the specimen BT, the stiffness of the beams decreased to 1.01 kN/mm. This can be easily understood due to un-effective flexural action between the tensile reinforcement and compression concrete. By introducing the truss reinforcement system, the stiffness of the specimen BR could be increased to the value of 2.15 kN/mm. Even though it was still lower than the BN, this value increased significantly than the specimen BT.

Maximum load on specimen BN is higher than the specimen BT. The decreasing of maximum load on specimen BT may be caused by the weak strut action between compression and tension sections. As the results, the beams could not develop a perfect couple mechanical action between tension force and compression force. The compression bar connecting between tensile reinforcement and the compression concrete is necessary to keep the arm (z) constant between compression force and tension force as illustrated in the Fig. 5. On the normal beams (BN) the concrete on the tension zone resisted the tensile reinforcement on its position as well as connecting to the compression zone. While on the specimens without concrete on the tension zone (BT), the position of the tension reinforcement moving upward followed the deflection of the beams. As the results, the moment couple arm (z) reduced. By assume that the reducing of z is equal to the deflection (Δ) of the beams, than the resistant moment capacity (M_R) of BT beam may be simply expressed by:

$$M_R = 0.85 f'_c \beta_1 x b \left(d - \frac{1}{2} a - \Delta\right) \qquad (2)$$

Based on those reasons, the truss system was applied on the specimens BR. As the results, the maximum capacity of the beams increased. Comparing to the specimens BT, the maximum capacity of the specimen BR increased approximately 60 %. However, this value is slightly lower than the specimen BN. The increasing of the maximum load of BR compared to BT was caused by the truss system action of the reinforcement.

The effect of the truss reinforcement to the flexural capacity of the external reinforced concrete beams may be concluded simply as the effect of the truss mechanical action. This result indicated that the truss system is necessary for the external reinforced concrete beams. The truss system could develop almost same capacity to the normal beam (BN). Fig. 6 shows the beams without concrete on tension zone reinforced by truss system. The continuum interaction between tension zones of concrete covering the tensile reinforcement to the compression zone may the cause of the higher capacity of specimens BN compared to the specimens BR. However, the capacity may be increased by increasing the number of diagonal reinforcement (smaller space) that will be the next step of this study.

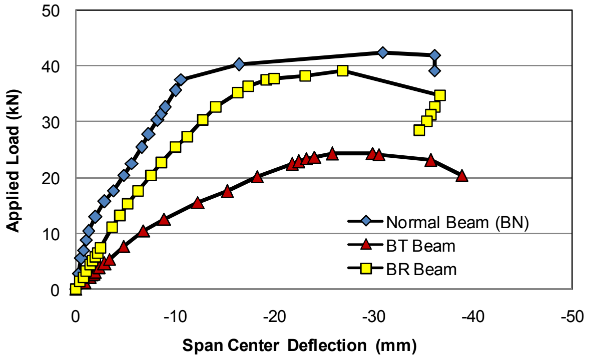


Fig. 7 Typical Load-Deflection Relationship

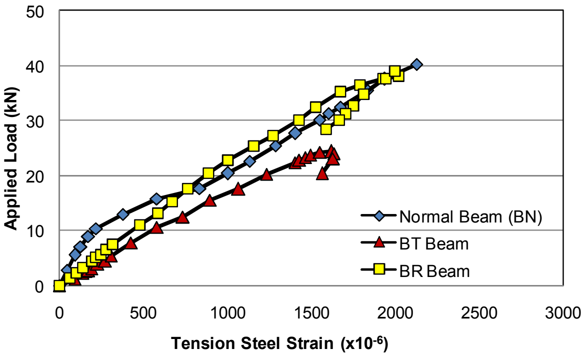


Fig. 8 Strain of the tensile reinforcement

B. Flexural Behavior

Fig. 7 presents the relationship between the applied load and span center deflection. At initial stage of loading, all beams were un-cracked beam. On the specimen BN, the concrete resisted both compression and tension forces. On the specimens BT and BR, the concrete resisted compression while the steel reinforcement resisted tension. 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. As presented in Table II, average stiffness of specimen BN was approximately 3.52 kN/mm. On the specimen BT, the stiffness of the beams decreased to 1.01 kN/mm. However, by introducing the truss reinforcement system, the stiffness of the specimen BR could be increased to the value of 2.15 kN/mm or increase more than 100% compared to the specimen BT.

Unbonded condition of the tensile reinforcement on specimen BT caused the stiffness of the beam was lowest compared to the others. Introducing of truss system on the specimen BR, effectively increased the flexural stiffness of the beams compared to the specimens BT. However, it was still lower that specimens BN (normal beam). The stiffness may increase by reducing the diagonal bars space.

Further loading caused the steel reinforcement entered to the plastic range which was indicated by the reducing of the beam flexural stiffness when the load level reached to approximately 40 kN on specimens BN and BR, respectively. However, on specimen BT, the steel reinforcement did not yield when the concrete crushed as its final failure. Fig. 8 presents the strain on the tensile reinforcement. The strain of the tensile reinforcement increased more than 2100×10^{-6} on specimens BN and BR indicated it has yielded. While on the specimen BT, the tensile strain was still at the value of 1300×10^{-6} when the concrete crushed. Fig. 9 shows the strain at the diagonal bar of the truss reinforcement of specimen BR. Further steps showed that the beams continuously deflected without significant increasing of the applied load until final failure which was indicated by crushing of the compression concrete.

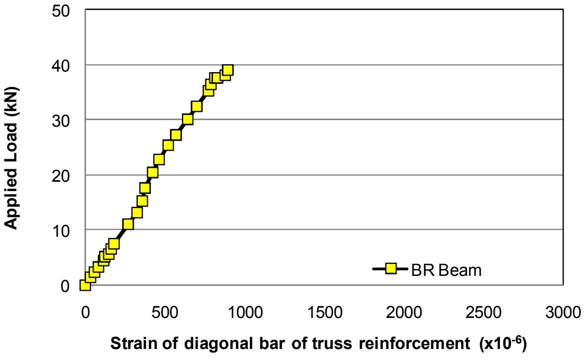


Fig. 9 Strain of the diagonal bar of truss reinforcement

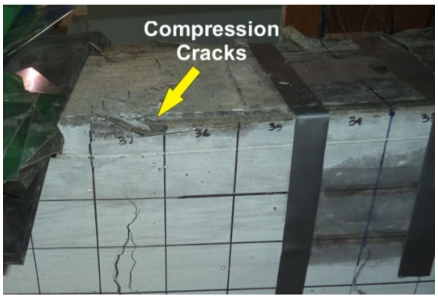


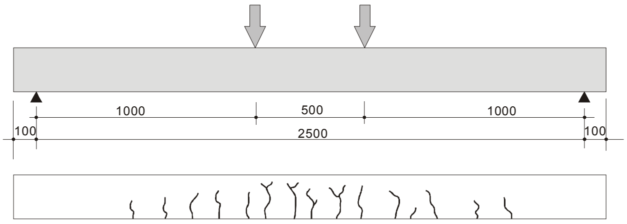
Fig. 10 Typical Failure on Concrete Compression

C. Failure Mode

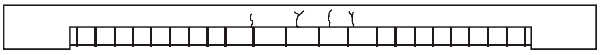
All specimens were design to fail under crushing of compression concrete. On specimens BN, the failure of concrete was initiated by the yielding of the steel reinforcement. As the result, the compressive stress of concrete increased over the compression strength of the concrete. For the specimens BT and BR, the failure was also on the concrete compression zone. However, the failure was earlier on the specimen BT before the yielding of the tensile reinforcement. This may caused by the un-effective mechanical flexural due to the decreasing of compression zone. As the results, the compression stress increased faster up to the compressive strength of concrete.

On the specimens BR, due to the truss action since the beginning of loading, an effective mechanical action could be achieved similarly to the normal beams. This phenomenon could be also observed through the beam stiffness. The stiffness of the beams BR increased compared to the specimen BT. The compression zone of this specimen became wider than the specimens BT. As the results the final failure of the specimens could be postponed compared to the specimen BT. Beams BR failed after yielding of the tensile reinforcement. Fig. 10 shows the specimen failure due to concrete crushing.

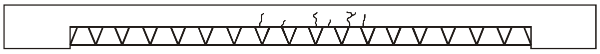
D. Crack Patterns



(a) Specimen BN



(b) Specimen BT



(c) Specimen BR

Fig. 11 Typical Crack Pattern of Specimens

Fig. 11 presents typical crack patterns of each specimen types. Specimens BN indicated typical crack pattern of the normal under reinforced concrete beams. 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 center. On the specimens BT and BR, the cracks also appeared. However, comparing to cracks number of the normal beams, the number of cracks on the specimen BT and BR was lower. This may be caused by the fact that there was no bonding effect to distribute the cracks. The propagation of the cracks on specimen BT and BR was also relatively slower than specimen BN.

IV. CONCLUSION

The truss system is necessary for the concrete beams without concrete on the tension zone (external reinforcement). Through the experimental study that was conducted, leads to the following conclusions:

1. The strut effect of the diagonal bars in the truss reinforcement structures increased significantly the flexural capacity of the external reinforced concrete beams using truss reinforcement (BR). The flexural capacity of the beam without concrete on tension zone using truss reinforcement was close to the flexural capacity of the normal beams.
2. The stiffness of the beams BT decreased to 1.01 kN/mm. By introducing the truss reinforcement system, the stiffness of the specimen BR could be increased to the value of 2.15 kN/mm or increase more than 100% compared to the specimen BT.
3. The propagation of the cracks on specimen BT and BR were relatively slower than specimen BN. The number of cracks on the specimen BT and BR were less than the number of cracks on the normal beams (BN). This may be caused by the fact that there was no bonding effect to distribute the cracks.

ACKNOWLEDGMENT

The financial support of the Directorate General of Higher Education of Indonesia (DGHI) under the scheme of BOPTN of Hasanuddin University is gratefully acknowledged. The assistance of the Laboratory of structural engineering, Civil Department, Hasanuddin University is also acknowledged.

REFERENCES

[1] James K.Wight and James G MacGregor (2005). “Reinforced concrete mechanics and design.”. Sixth Edition, Pearson

[2] Mindess, S., Young, J. F. and Darwin D. 2003, *Concrete in Special Applications*. Chapter 20. Second Edition, Pearson Education Inc. USA

[3] Rudy Djamaluddin, 2013, “Flexural Behavior of External Reinforced Concrete Beams”, Procedia Engineering 54, Elsevier, pp.252-260,

[4] Despandhe, V. S. and Fleck, N. A. 2001. *Collapse of Truss Core Sandwich Beams in 3-Point Bending.* International of Solid and Structures, Pergamon, 38, 6275-6305.

[5] Jae-ll Sim and Keun-Hyeok Yang. (2009). “Flexural behavior of reinforced concrete columns strengthened with wire rope and T-Plate units.” ACI Structural Journal. V.106. No.5. pp.697-705.

[6] Li, B. and Tran, C. T. N. 2012, *Determination of Inclination of Strut and Shear Strength Using Variable Angle Truss Model for Shear-Critical.* Journal Engineering and Mechanics, Vol. 41, No.4, 459-477.

[7] Li, B. and Tran, C. T. N. 2008. *Reinforced Concrete Beam Analysis Supplementing Concrete Contribution in Truss Models*, Journal Engineering Structures, 30 (11), Elsevier, 13 June 2008, 3258-3294

[8] Nes, L.G., Overli, J.A. 2011. *Composite and Hybrids Investigation of Material Parameters and Structural Performance of a Concrete Sandwich Slab Element.* fib Symposium PRAQUE 2011, Session 5-6

[9] Stevees, C. A., Fleck, N. A. 2004. *Collapse Mechanism of Sandwich Beams with Composite Faces and A Foam Core.* International Journal of Mechanical Science, Elvesier 46, 30 April 2004, 561-583.

Rudy Djamaluddin is a member of the Indonesian Society of Civil Engineers (HAKI) and Indonesian Engineer Association (PII) since 2005. He was born in Gowa district of Indonesia on November 8, 1970. He graduated from bachelor on 1994 from Hasanuddin University, Indonesia, Master degree on 2000 from Kyushu University, Japan and Doctor degree on 2003 from Kyushu University, Japan. He was awarded of Research Fellowship from the Japan Society of Promotion of Science (JSPS) on 2003 and done a postdoctoral research in Kyushu University on 2003 to 2005. Now, he is an Associate Professor on the Civil Engineering Department of Hasanuddin University. The major fields of study is structural concrete engineering including strengthening and retrofitting using FRP materials.