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Parametric Study of Web Opening Dimensions on Hybrid Reinforced Concrete T-Beams

[Jonie TANIJAYA]

Abstract—**This paper presents a nonlinear analysis of simply supported hybrid R/C T-beams with rectangular openings. The results from a nonlinear analysis using the finite element method, were substantiated by test results from three hybrid T-beams, partially conctructed of light weight concrete. An opening was provided in the web of the beams, the pure bending region, the high shear region, and the high flexural-shear region, respectively. The available experimental results were compared to the theoretical analysis. Good agreement is shown between analytical and the experimental results. An extensive parametric study was conducted to predict the effect of the openings on the behaviour of such beams. Increasing the opening width decreases ultimate load for beam with high bending opening. However, beam with pure bending and high shear opening show no significant difference with the presence of opening. Variation in opening width has significantly affected the deflection of beam with bending opening; but for beam with shear opening, this variation has no effect on the deflection. For beam with shear opening, variation in opening depth has no effect on ultimate load and deflection. However, for beam with bending opening, increasing the opening depth causes decreasing in ultimate load and deflection.**

Keywords—web opening, hybrid R/C, normal weight concrete, light weight concrete, pure bending, high shear, flexural-shear

I. Introduction

Utility requirements may make it desirable to use openings in reinforced concrete beams. Provision for openings leads to a reduction in the story heights in buliding and increases the economy of the structure. However, introducing an opening into the web of a reinforced concrete beam reduces its stiffness and leads to more complicated behaviour. Therefore, the effect of openings on strength and serviceability must be considered in a design process.

Numerous analytical studies have been carried out on reinforced concrete beams with openings [2-9]. Mansur et al. [2,3] proposed a method to predict the ultimate strength when the beams are subjected to concentrated load. But these theoretical studies are based on linear analysis, not accounting for failure of the concrete.

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In the present paper, a method of nonlinear analysis of simply supported hybrid reinforced concrete T-beams with rectangular openings is presented. The effect of an opening on the structural response of simply supported hybrid T-beams is examined. Three stages of loading are considered, namely, the working stage, the yielding stage, and the ultimate stage. Results from a nonlinear analysis are substantiated by an experimental investigation on three hybrid reinforced concrete T-beams, partially conctructed of light weight concrete. An opening was provided in the web of the beams, in the pure bending region, in the high shear region, and in the high flexural-shear region, respectively. An extensive parametric study was conducted to predict the effect of the openings on the behaviour of such beams.

II. Analytical Study

The nonlinear finite element program ABAQUS [1] was used for the analytical study. A rectangular plane stress element named CPS4 (Figure 1) with two degrees of freedom at each node (U1, U2) is used to model the web and the flange of the T-sections.

In the nonlinear analysis, the load is applied gradually in small increments. The size of each increment depends on the convergence of the iteration process in the previous increments of loading. The concrete under compression is modelled by an elastic-plastic theory, using a simple form for the yield surface expressed in terms of the equivalent pressure stress and the von Mises equivalent deviatoric stress. Isotropic hardening is accounted for. Cracking is assumed to occur when the stress reaches the failure surface represented by a simple Coulomb line interms of the equivalent pressure, p, and the von Mises equivalent deviatoric stress, q.

The model is smeared crack model, in the sense that it does not track individual macro cracks. Instead, constitutive calculations are performed independently at each integration point of the finite element model, and the presence of cracks is accounted for through the changes in the stresses and material stiffness associated with the integration point. The concrete behavior is characterized by a stress-displacement response, in which the state of stress along the crack is a function of the operating strain across the crack. The cracking and compression responses of the concrete are shown in Figure 2. The response of the concrete in tension is illustrated in Figure 3, where the influence of tension stiffening due to the presence of the reinforcing steel are shown.

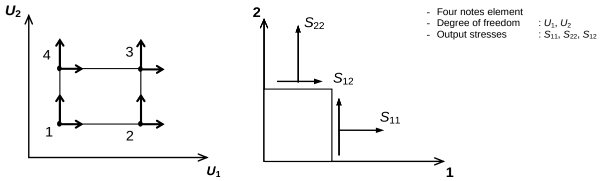

Figure 1. Plane stress element CPS4

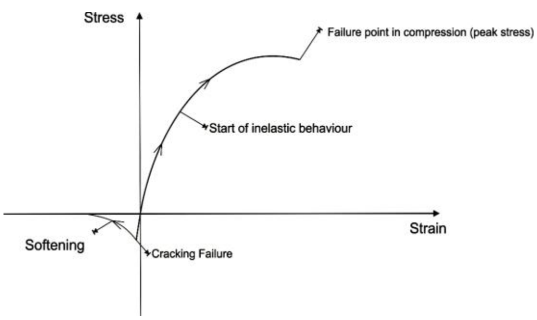

Figure 2. Compression and cracking stress-strain relation of concrete

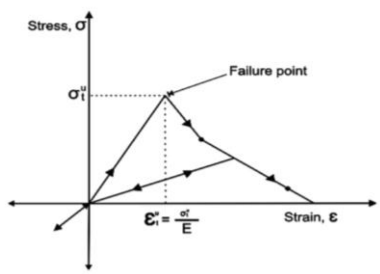

Figure 3. Tension stiffening of concrete

III. Experimental Investigation

The objective of the experimental investigation was to determine the maximum deflection due to the externally applied load. The results from the experimental study were also used to calibrate the modelling adopted in the nonlinear finite element analysis. Tests were carried out on three hybrid reinforced concrete T-beams. Typical specimens and reinforcement details for all beams, are shown in Figure 4. Each had a total length of 5700 mm and a constant depth of 250 mm. A flange of 330 mm wide and a thickness of 6 cm was cast of light weight concrete (LWC), which was prepared utilizing locally available expanded clay aggregates producing an ultimate strength f_c' = 42 MPa and Young's Modulus E_c = 16.00x10^3 MPa. The beam webs had a width of 150 mm, a depth of 19 cm and were prepared of normal weight concrete (NWC), which had an average 28 day cylinder strength and Young's Modulus of f_c' = 35 MPa and E_c = 20.00x10^3 MPa, respectively. Two types of steel bars complying to Indonesia's Industrial Standards were utilized. Plain bars of 8 mm diameter with yield strength of f_y = 240 MPa was used for stirrups and flange reinforcements. Deformed bars of 16 and 25 mm diameters with yield strength of f_y = 300 MPa and 400 MPa, respectively, were used for longitudinal bars.

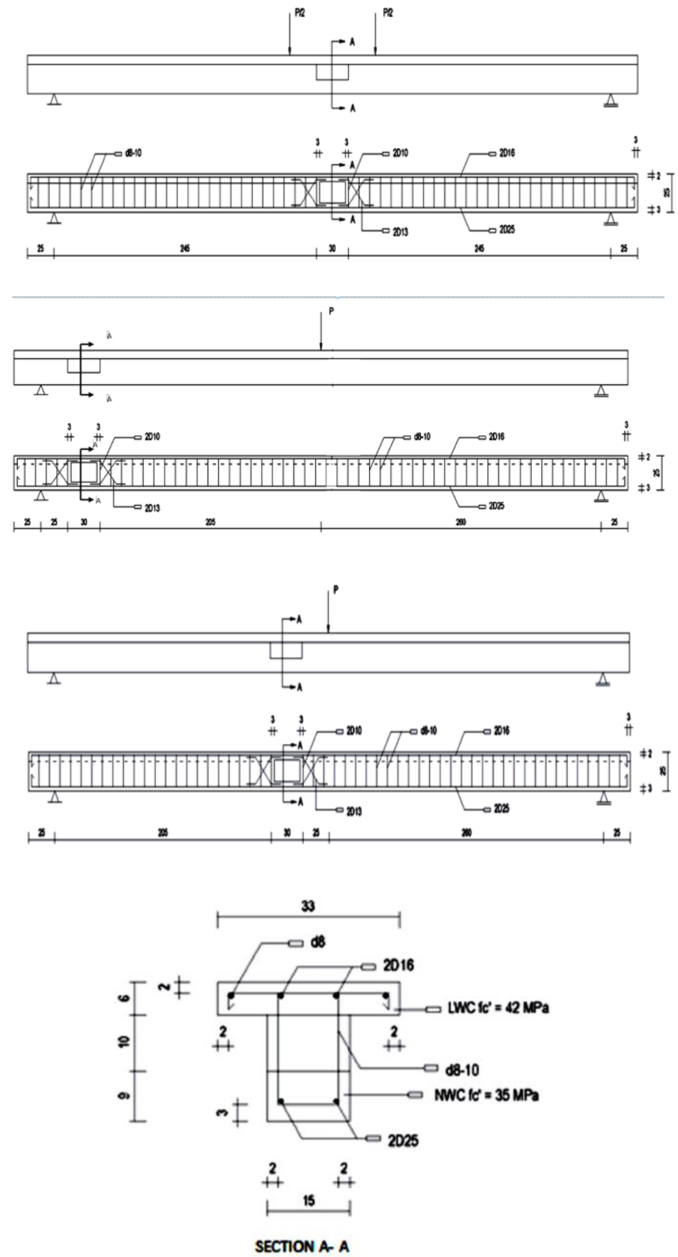

Figure 4. Typical specimens and reinforcement details

The beams were provided with bottom longitudinal bars to meet under reinforced requirements and the amount of longitudinal bars at the upper side was taken 0.5 of that at the lower side. Stirrups and diagonal reinforcements around openings were provided and properly detailed as recommended by Mansur et al. [5,8,9]. All of the beams were subjected to a monotonic loading until their complete collapse. BLT-1, was given an opening of 300 x 100 mm^2 at mid-span. Two equal loads were applied at two equally spaced points with respect to the beam center, however beyond the area of the opening, in such a manner that the opening was completely located inside a pure bending region. BLT-2, was given an identical opening size but located at a high shear region and BLT-3 was also given the same opening size but at a high flexural-shear region. They were also tested for their ultimate strengths and their collapse conditions under a concentrated load at a mid-span.

IV. Parametric Study

The "ABAQUS" computer program was used to conduct a parametric study varying a number of factors that could influence the hybrid R/C T-beams with web openings. Such factors included (see Figure 5):

1) Variations in the width of the opening.

The ratio of the opening width to the beam span was taken 0.03, 0.05, 0.07, and 0.09. For each of these ratios, the opening width (l_o) was taken as 200, 300, 400, and 500 mm in the beam span 5700 mm.

2) Variations in the depth of the opening.

The ratio of the opening depth to the beam depth was taken 0.30, 0.40, and 0.50. For each of these ratios, the opening depth (d_o) was taken as 75, 100, and 122.5 mm in the beam depth 250 mm.

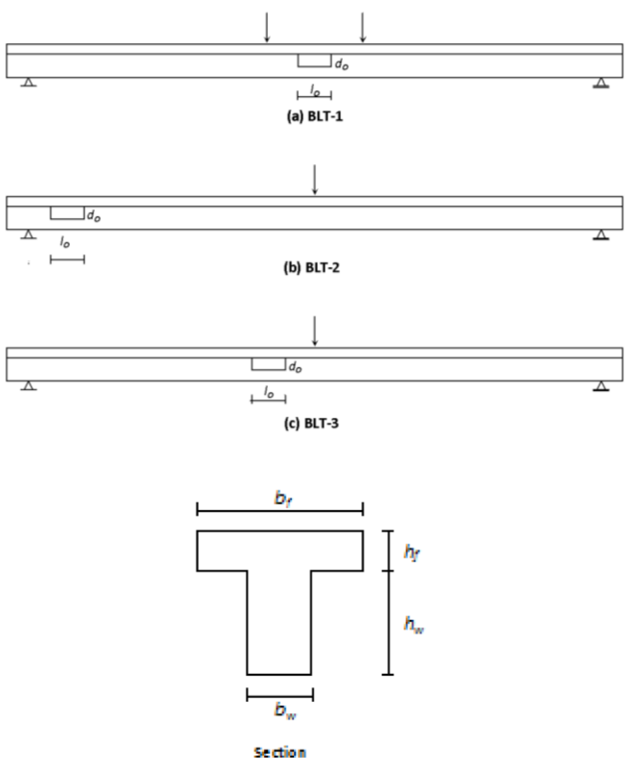

Figure 5. Beam identification

V. Results

Results from the nonlinear finite element analysis were compared to those obtained from tests of the three hybrid T-beams. The stages of loading were considered: (1) working stage, where the external loads were equal or smaller than the cracking load, (2) yielding stage, where the longitudinal reinforcement had a first yield, and (3) ultimate stage, where the external load was just below the collapse load. The influence of the opening on the deflection was examined.

A. *Deflection Response*

Comparison between the analytical and experimental results for the load versus deflection of BLT-1, BLT-2, and BLT-3 are shown in Figures 6 (a), 6 (b), and 6 (c), respectively. Deflections were evaluated and measured at mid span. These figures show that finite element analysis for BLT-1 achieved an ultimate downward deflection of 99.7 mm at an ultimate load of 65.9 kN which was practically identical to that obtained from test experiments. FEM analysis for BLT-2 generated an ultimate load of 57.7 kN at an ultimate deflection of 68.1 mm, while for BLT-3 it produced an ultimate load of 60.1 kN at an ultimate deflection of 68.1 mm.

Comparisons of ultimate load and deflection results for these two T-beams, reveal that there is no significant difference for ultimate loads, but the deflection curve of BLT-2 is shorter than that obtained from experiments. The process of analysis was discontinued by the program upon discovering negative values of the global syiffness matrix indicating a condition of structural instability. Accurate analysis results for the cracked and yield regimes as shown in Figure 6 were obtained by applying reduction factors to the moduli of elasticity of both concretes. For BLT-1 reduction factors of 0.43 and 0.59 were used for NWC and LWC respectively, while for BLT-2 those factors were 0.40 and 0.50 for NWC and LWC respectively and they were 0.43 and 0.53 for NWC and LWC respectively for the case of BLT-3.

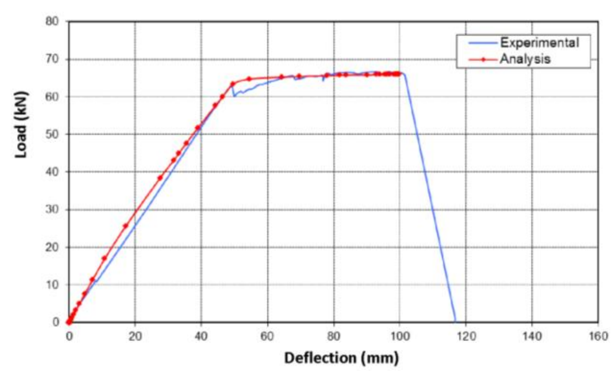

Figure 6. (a) Load vs deflection BLT-1

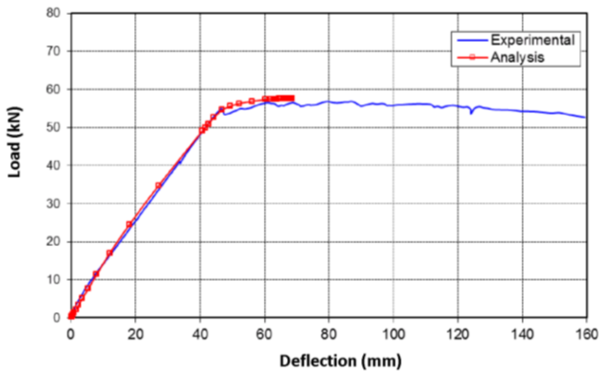

Figure 6. (b) Load vs deflection BLT-2

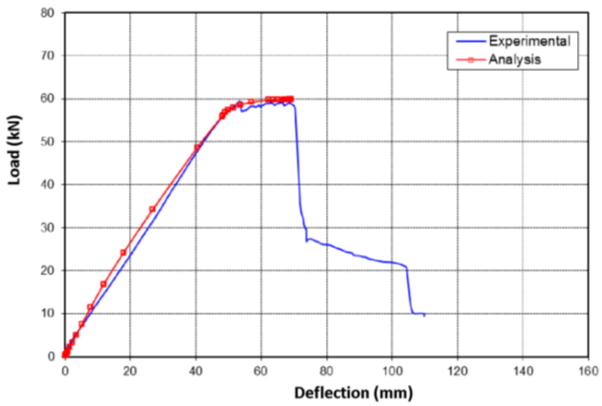

Figure 6. (c) Load vs deflection BLT-3

B. Parametric Study

It can be seen from Figure 7 that increasing the opening width has no effect on the pure bending opening and high shear opening (BLT-1 and BLT-2). However for high flexural-shear opening (BLT-3) increasing the opening width decreasing the ultimate load. This indicates that when an opening is located at the high flexural-shear span, the loss in stiffness has a greater influence.

For the bending opening (BLT-1 and BLT-3), the results in Figure 8 show that as the opening width increases, the deflection will changes significantly. However variation in opening width for shear opening has no effect on the deflection.

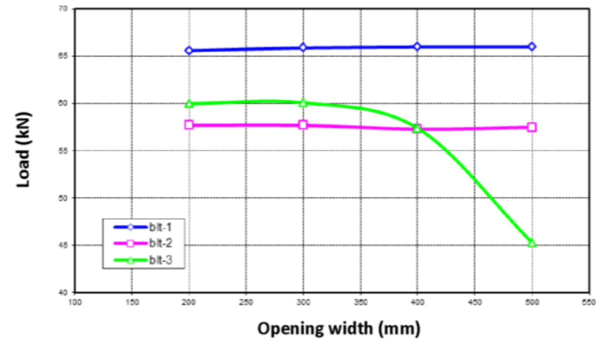

Figure 7. Load vs increasing opening width

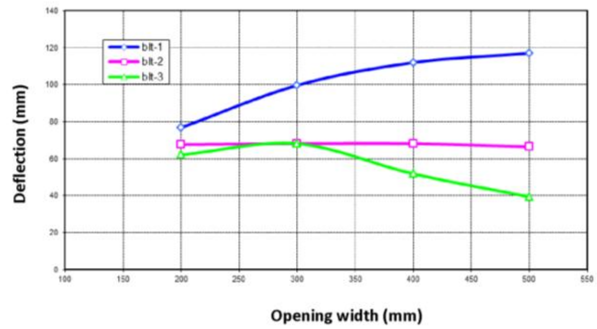

Figure 8. Deflection vs increasing opening width

Figure 9 shows that increasing the opening depth (tension chord depth is reduced), the cracking of tension chord will cause reduction of beam stiffness, so the ultimate load for bending opening increased, however for the shear opening the ultimate load will constant. For pure bending opening as the opening width increases, the deflection increases up to a certain limit and then it decreases with increase of the opening width. For the high flexural-shear opening (BLT-3) the deflection decrease with increase of the opening depth and for the shear opening (BLT-2) has no effect on the variation in the opening depth (Figure 10).

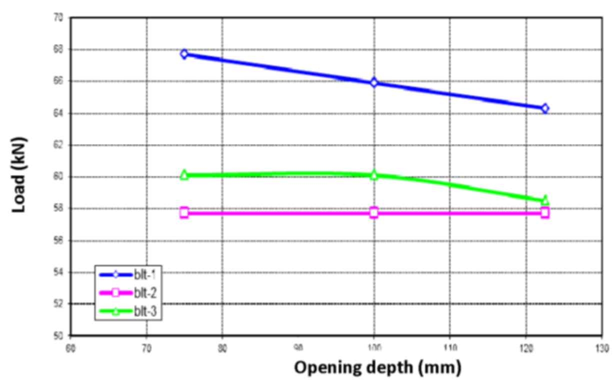

Figure 9. Load vs increasing opening depth

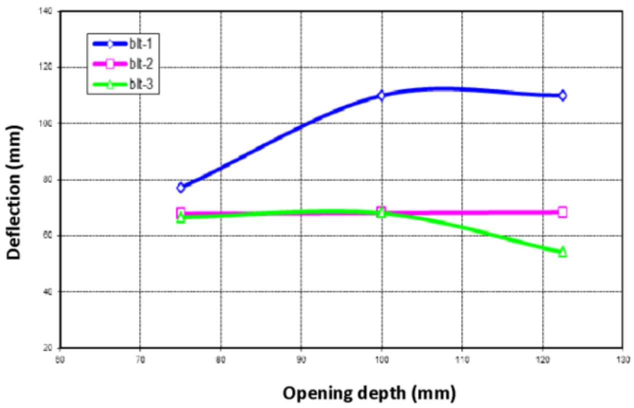

Figure 10. Deflection vs increasing opening depth

The results of the parametric study show that the presence of opening significantly influences the ultimate load and deflection. Increasing ultimate load or deflection become significant in the nonlinear loading stage.

Comparison to the results of solid beam with no opening show that the presence of opening increases the deflection about 10.3% for BLT-1 but for BLT-2 only about 1%. For BLT-3, increasing the opening width increases the deflection around 11.6%. BLT-1 reaches ultimate load about 5% lower than solid beam, however for BLT-2 and BLT-3 show no significantly decrease.

VI. Conclusions

An analytical and experimental investigation was carried out to determine the static load response of hybrid R/C T-beams with rectangular web openings. Good correlation was shown between the predicted and test results. Based on the results from this investigation the following conclusions can be made :

- Accurate analysis results for the cracked and yield regimes were obtained by applying reduction factors to the moduli of elasticity of both concretes. The reduction factors are 0.40 – 0.43 and 0.50 – 0.59 for NWC and LWC, respectively.
- Increasing the opening width decreases ultimate load for beam with high bending opening. However, for beam with pure bending and high shear opening show no significant difference with the presence of opening. Variation in opening width has significantly affected the deflection of beam with bending opening; but for beam with shear opening, this variation has no effect on the deflection.
- For beam with shear opening, variation in opening depth has no effect on ultimate load and deflection. However, for beam with bending opening, increasing the opening depth causes decreasing ultimate load and deflection.

Acknowledgement

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References

[1] Hibbitt, H.D., Karlsson, B.I., Sorensen, E.P. (1997), ABAQUS *Version* 5.7, Finite Element

[2] Mansur, M.A., Tan, K.H., and Lee, S.L. (1984), Collapse Loads of R/C Beams with Large Openings, Journal of the Structural Division, ASCE, Vol.110, No.11, Nov., 2602-2618.

[3] Mansur, M.A., Tan, K.H., and Lee, S.L. (1985), Design Methods for Reinforced Concrete Beams with Large Openings, ACI Journal, Vol.82, July-August, 517-524.

[4] Mansur, M.A. (1988), Ultimate Strength Design of Beams with Large Openings, International Journal of Structures, Vol.8, No.2, December, 107-125.

[5] Mansur, M.A., Tan, K.H., Lee, Y.F., and Lee, S.L. (1991), Piecewise Linear Behaviour of RC Beams with Openings, Journal of Structural Engineering, ASCE, Vol.117, No.6, June, 1607-1621.

[6] Mansur, M.A., Huang, L.M., Tan, K.H., and Lee, S.L. (1991), Analysis and Design of Reinforced Concrete Beams wiyh Large Web Openings, Journal of The Institution of Engineers, Singapore, Vol. 31, No. 4, July-August, 59-67.

[7] Mansur, M.A., Huang, L.M., Tan, K.H., and Lee, S.L. (1992), Deflection of Reinforced Concrete Beams with Web Openings, ACI Journal, Vol.89, No.4, July-August, 391-397.

[8] Mansur, M.A., Tan, K.H., and Lee, S.L. (1993), A Study of Concrete Beams with Web Openings, *Research Report* RP 880619, Dept. of Civil Engineering, National University of Singapore, 78 pp.

[9] Tan, K.H., and M.A. Mansur (1996), Design Procedure for Reinforced Concrete Beams with Large Web Openings, ACI Journal, Vol.93, No.4, July-August, 404-410.