Strengthening of Reinforced Concrete T-beam with web opening

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Abstract

This study examines shear capacity of strengthened reinforced concrete T-beams with web rectangular opening. Effect of opening orientation, presence of flange, different types of strengthening, and absence of shear reinforcement in strengthened beams are discussed and evaluated. The experimental work consisted of testing 13 beams under single point load. One of them considered as control beam without opening, while others are cast as beams with preplanned 100mm×200mm opening located at the web of the beam horizontally and vertically. The results of the beams indicated that the beams with horizontal openings show reduction in the ultimate shear capacity by about 17% while for vertical opening the reduction was about 27% compared to the control beam without opening .Moreover, the presence of the flange increased the shear capacity of the beams with horizontal and vertical openings by about 11% and 34.5% respectively. Also, the results indicated that the internal strengthening with inclined stirrups increased ultimate capacity by about 18% and 11% for horizontal and vertical openings compared to control T-beams with web opening respectively. The CFRP strips with spacing between them increased shear capacity by about 13.5% for horizontal opening but was not beneficial for vertical opening, also the CFRP strips for strengthening of opening made after construction were not beneficial for both types of opening and the capacity was decreased by about 11.5% and 10.1% for horizontal and vertical opening respectively. Strengthened beams with CFRP strips without spacing between them strengthened the bottom chord of the opening furthermore and they were best scheme of strengthening beam with vertical opening and increased shear capacity by about 12% for both types of opening.

Key Words : Reinforced Concrete T-Beam, Web Opening, CFRP Strengthening, and Diagonal Reinforcement.

1. Introduction

Beams are the main critical horizontal members subjected to bending, shear, and torsion in all types of structures [1]. Openings in the beam's web are provided for pipes and service ducts. Opening causes reduction in the beam stiffness, additional cracking, more deflection, and reduced the beam capacity. Additionally, high stress concentration around the openings particularly at the opening corners lead to alteration of the beam behavior from simple to complicated one [2].The best choice to improve the beam carrying capacity and extending its structural service life is strengthening of the beam. In the last decades, there has been a rapid pace in the role of Fiber Reinforced Polymer (FRP) for strengthening of an existing or new reinforced concrete structures, this is mainly because of the facility and quickness of construction, and the prospect of application without troubling the existing operation of the structure [3].

Hammad Y.H. et al[5] tested four reinforced concrete T-beams with strengthened openings located in shear span. CFRP fabrics and steel strips were used as a strengthening schemes. Test results indicated that the strengthening scheme enhanced the ultimate capacity of the beams with opening. They also, predicted the beams strength capacities using non-linear finite element analysis, and results were in a good agreement with ratio about (0.76-0.93) verse with load-carrying capacities.

Vuggumudi S.[3] tested eleven RC T-beams with web opening strengthened with bonded GFRP sheets. Shear reinforcement, shear span to depth ratio, and end anchorage considered as variables. GFRP to improve shear capacity had been confirmed in experimental results, and was concluded that GFRP strengthening was more effective in beams without web reinforcement than the beams with adequate shear reinforcement.

Kumari A.[4] (2013) investigated concrete strength of 13 GFRP strengthened T-beams which tested under two point loading, including two beams with web opening strengthened in the shear zone with and without anchorage of GFRP. In the first beam with opening, failure was initiated by debonding of GFRP sheets over the major shear crack at ultimate load. Also in the second one anchorage system avoided the debonding of GFRP sheet from concrete surface, the failure was initiated by tearing of GFRP sheets over the main shear crack.

Oukaili N.K. et al[6] investigated shear behavior of seven reinforced concrete T-beams with multiple openings. The beams were internally strengthened by steel reinforcement, or externally using CFRP. Results showed that the presence of opening led to decrease in shear capacity about 30% and 41% for four and six openings respectively, and internal strengthening led to improve shear capacity than the beams with CFRP sheets. They also predicted test results by using ANSYS 12.1 software for finite element analysis.

Oukaili N.K. et al [7] investigated the response of seven strengthened simple supported T-beams with multiple web openings located in constant shear span for static and impact loading condition. Number of opening, types of strengthening with diagonal reinforcement and CFRP sheets, and height of dropped loading in impact condition were considered as important variables. Results indicated that the reduction in shear strength capacity for static loading were 30% and 41% compared to the control beam for the beams with 4 and 6 openings respectively. However, the range of increase in strength was about 27% to 92% for internal and CFRP strengthened beams respectively. Impact loading results indicated that the number of required drops of loading compared with solid beam decreased about 30% and 86% for the beams with 4 and 6 openings respectively.

Recently, **Routray SH.**[8] tested a 22 T-beams to evaluate the contribution of Basalt Fiber Polymer (BFRP) sheets in strengthening RC beams, employing different configurations of BFRP sheets and end anchorage considered as variables. Out of these 10 beams were beams with different shapes of web opening. The results concluded that BFRP enhanced the shear capacity of the beams. Moreover, formation of cracks and failure of beams were delayed due to BFRP sheets with end anchorage and BFRP sheets are more effective than BFRP strips. The 45 degree strip configuration was more effective than vertical configuration, furthermore, among different shapes of web openings, square hole is found to be more effective in decreasing capacity as compared to circular and rectangular opening.

2.Objective of the research

The aim of this study is to investigate the behavior of T-beams with rectangular web opening oriented vertically and horizontally, and strengthening the opening region with diagonal stirrups and CFRP sheets.

3.Experimental program

The experimental program consisted of testing a 13 reinforced concrete beam specimens shown in table (1), the beam TC is considered as a control beam without opening, the rest divided into six groups with rectangular (100*200mm) openings. The center of the opening located at (550mm) from the end of the beam. The beams designated with number (1) have horizontal opening located directly at bottom of flange. The beams assigned with number (2) have vertical opening placed also directly at bottom edge of the flange. Figure (1) to (3) shows details of the beams and reinforcements.

3.1. Materials

Ordinary Portland Cement Type I Tasluja cement, Darbandixan natural sand (S.G. =2.66), and Natural gravel (S.G. =2.71) from Goptapa region with nominal maximum size (12.5 mm) are used in casting all the beams. After several trail mixes a mix proportion of 1:2.22:3.57 by weight with (w/c=0.55) is used, for reinforcement 16mm in diameter bar with (fy=522MPa) is used for bottom reinforcement, and 10mm in diameter with (fy=437MPa) is used for top reinforcement. The shear reinforcement consisted of steel bars of (4mm) in diameter with (fy=698MPa). Unidirectional woven sheet Carbon Fiber ASOFABRIC-C300 manufactured by AB-SCHOMBURG Company is used as a strengthening material, and ASODUR-1330 two component epoxy adhesive A and B is used as a glue for the fabric. The properties of the fibers and adhesive are shown in table (2).

3.2. Specimen preparation

The specimens are cast in wooden forms prepared from plywood block, the dimensions of the beams are 2m in length with total depth, web depth, web width, and flange width dimensions as 370mm, 290mm, 150mm and 350mm respectively. The concrete is mixed in an electrical tilting mixer of (0.20 m^3) capacity, then poured into the forms with the steel cage inside and compacted by a needle vibrator. Along with the beams 3 cylinders are cast to evaluate the compressive strength of the concrete.

3.3. Strengthening Process

Three methods are used to strengthen the beams, the first one internally strengthening by inclined stirrups at both sides of the opening in TX1 and TX2 beams as shown in figure (2 and 3-c).The second one, used for beams TS1, TS2, AS1, and AS2 which were strengthened by strips of CFRP at both sides of the opening as shown in figure (4-a).The last method used CFRP sheets around the opening including the bottom chord of the beam as shown in figure (4-b) for the beams TP1 and TP2. In all the beams strengthened by CFRP, the end of the CFRP sheet or strips is covered by CFRP anchorage to prevent debonding of the CFRP.

3.4. Testing procedure

All specimens are tested under single point loading at mid span. Loading is applied through a hand operated hydraulic jack with maximum capacity of (550kN) fixed to the loading frame. The load is applied gradually with 10 kN increments till failure. Displacement of the beam is recorded by using three dial gauges with (0.01mm) accuracy at three places, under the center of the beam, the center of the opening and at the other end away from mid span same distance as the one under the opening. The concrete cylindrical specimens are tested along with the respective beams.

4. Results and Discussion

Results of concrete compressive strength which tested according to C 39/C 39M – 05 [9] and ultimate capacity of the tested beams are shown in table (3).

4.1. Behavior of the beams

In the solid beam TC, the first hair crack initiated in flexural zone at a load of 70kN, at 120kN an inclined crack was visible near right support and propagated towards the maximum moment region, further flexural and shear cracks occurred with increasing loads till the beam failed in shear at 230kN as shown in the figure (5-A).
For T1 beam with horizontal opening, the first crack appeared at 50kN at the bottom corner of the opening close to the support, many inclined cracks developed with increasing loads at bottom chord till the beam failed in shear at a load of 192kN at the opening side as shown in figure (5-B). In beam T2 with vertical opening, the first hair crack was visible about 40kN at the bottom corner of the opening near to support, and propagated towards the point load. Finally failed in shear at 168kN in the opening side as shown in the figure (5-C). In comparison with TC beam, the results indicated 17% and 27% decrease in ultimate capacity for T1 and T2 beams respectively.
In the rectangular beam R1, the first crack observed at the bottom corner of the opening close to the support at a load of 60kN. With increasing load cracks appeared at the solid shear span, and propagated toward the top reaching the point load location, finally the beam failed at 171kN as shown in figure (5-D). However, for the other beam R2 with vertical opening, the first crack observed at 28kN around the corner of the opening at bottom near right support of the beam and propagated towards the support, a crack appeared also at the left top corner of the opening close to the point load and extended towards the point load till failure occurred at 110kN at opening side as shown in figure (5-E).These results show decrease in ultimate capacity about of 11% and 34.5% for rectangular beams R1 and R2 compared to T-beams T1 and T2 respectively indicating the contribution of the flange in shear carrying capacity.
For the internally strengthened beam TX1 with horizontal opening, the first hair crack was visible at the bottom corner of the opening close to the support at the load of 60kN, and extension of cracks developed at lower speed as compared to control beam T1. Finally, the extra diagonal reinforcement prevented failure at the opening side and it failed in shear at 234kN at the solid side as shown in figure (5-F). In the beam TX2 with vertical opening, the initial crack started at 20kN at the bottom of the opening, but strengthening did not improve the opening side and failed at 188kN in the opening side as shown in the figure (5-G).In comparison with T1 and T2 beams, the inclined stirrups increased the shear carrying capacities of the beams about 18% and 11% for the beams TX1 and TX2 respectively.
In beam AS1 where the opening is cut after construction. The first two cracks observed at flexural zone at the center of the beam at a load of 70kN. However at 100kN crack started at bottom chord of the opening, after that more cracks appeared at the opening side at bottom corner close to support, and failed at 170kN at the opening side as shown in figure (5-H). The second beam AS2 with vertical opening, the first two cracks were visible at 60kN at the bottom corner of the opening close to the support, cracks also appeared at mid span at the same time. Finally, the beam failed by shearing at the interface between the web and the flange where no CFRP exists at a load of 151kN as shown in figure (5-I). In comparison with control beams T1 and T2, the strength capacity is reduced about of 11.5% and 10.1% in AS1 and AS2 beams.
For the beam strengthened with CFRP strips. In beam TS1, the first crack observed at mid span of the beam at 32kN.After that, shear cracks occurred at the solid side and at the bottom chord of the opening close to support at loads of 60kN

and 70kN respectively. Finally, failed at the solid side at 222kN as shown in figure (5-J). In beam TS2, the first crack formed at mid span of the beam at a load of 20kN, after that, crack started at 70kN inside the opening at bottom corner near to support. Finally, the beam failed by crushing of concrete in the flange and at bottom chord of the beam at 170kN as shown in figure (5-K). When compared to T1 and T2 beams, the results indicated that CFRP led to increase the shear capacity about 13.5% for TS1 beam, but in TS2 the CFRP strips retained the original capacity same as T2 beam without any notable increase.

For the beams strengthened with full CFRP wrapping TP1 and TP2, the first crack in TP1 was flexure crack initiated at mid span of the beam at a load of 38kN. As the load increased no cracks were visible around the opening because all sides of the opening covered by CFRP sheets. When the load reached 70kN, an inclined shear crack started at the solid side of the beam and propagated toward top of the flange near to the point load also at the other end toward the bottom of the web near to support, finally the beam failed in shear at the solid side at a load of 218kN as shown in figure (5-L). Meanwhile in the beam TP2, the first crack appeared also at a load of 38kN at flexural zone in mid span of the beam. The major shear crack occurred in the flange at 150kN and propagated toward the location of the point load. Finally, the beam failed in shear with debonding of CFRP strips at the right side of the opening at a load of 190kN as shown in figure (5-M). In comparison with T1 and T2 beam, CFRP sheets in TP1 fully improved the opening side and increased the ultimate load capacity of the beam about 12%, similarly CFRP in the beam TP2 increased the ultimate load capacity about 12% compared to T2 beam.

4.2. Load-Displacement relationship of the beams

The Load-Displacement relationship is a mean to describe the load verse displacement response of the beam at various stages of loading up to failure. All the load-displacement relationships at mid span indicate a linear relationship up to the formation of the first crack after which a nonlinear relationship is observed. From figure (6-A) to (6-I) the following can be observed: The openings in T-beams have caused reduced stiffness, presence of flange has led to increased stiffness. Internal diagonal stirrups around the openings has no or little effect on the stiffness of the beams. Openings after construction tend to reduce the stiffness of the beams, and CFRP strengthening of the openings sides with web reinforcement around the opening also seems to have little effect on the stiffness of the beams.

5. Theoretical analysis

Many experimental studies have been conducted to understand the behavior and the mechanism of failure of beams with openings, but those could not fill the gap in the theoretical parts for the prediction of their actual shear strength carrying capacity, especially for the beams with rectangular openings. Inhere Strut and Tie [10] model is presented to predict the failure load of the tested beams .The design method to compute the capacity of the CFRP strips according to the ACI 440.2R-08 [11] procedure is also presented.

5.1. Strut and Tie Method (STM)

In the design of concrete members, there are two regions, one of them is the main region which has compatible interaction between stress and strain, and easily expressed by equilibrium conditions and called B-region. The other region, called D-region, is local and begins at discontinuity regions of the member , where stress and strain may not be compatible to each other , and the basic equations of equilibrium are inadequate to analyze the irregular relationship of stress and strain such as corbels, joints, region adjacent to point load, and adjacent to transverse openings. According to St. Venant's principle, the length of D-region extends to about one depth of the member at each side of the discontinuity point [12]. This means that the span of the beam close to the opening is D-region because of the presence of the opening and the concentrated load at the mid span of the beam.

This is based on the assumption of cracked beam adopted in the strut and tie model in ACI318-14[10] as a lower bound theorem, which is a simplified truss model that resists compression by concrete between cracks (Strut) with different finite dimensions, and resists axial tension by steel reinforcement (Tie) which intersects at nodal points of the model truss satisfying the conditions of equilibrium.

The strut dimensions are designated by width (b_{st}) which is in plane of the beam with thickness (t_{st}) perpendicular to the plane of the beam. The ties are considered as a diameter of the reinforcement plus the concrete cover surrounding their axes. However, the concrete cover is not used to resist the axial tension force, but only to reduce the elongation and confine the web reinforcement [10]. The width of the strut (b_{st}) is defined by the width of the loading plate (40mm) at mid span of the beam with different inclinations as shown in the figure (7-a), and the thickness (t_{st}) is constant (42mm) defined as shown in figure (7-b).

In this analysis, truss models are constructed as shown in the figure (8-a) to (8-k) for predicting the shear strength capacity of the beams with opening based on actual failure pattern of the beams with the following assumptions as requirements for the method:

- The section of the beam is adequate to transmit from the elastic response to plastic response.
- Concrete resists only compression stresses, and the steel reinforcements resist all tension stresses.
- All forces in the truss members are in equilibrium.
- The dimensions of the struts and ties are uniform throughout all parts of the beam.
- The line of action of the loads passes through the axes lines of struts and ties and coincides at the nodes [13].

Equations of (1) and (2) below are used to calculate the nominal capacity of the struts and ties respectively, and the load distribution in the flange of the beam is the same as the truss model applied in the web. The flange of the T-beam specimens behaves as compression member, and the strut inclination at the web is assumed to be 45°. This means that the shear capacity of the flange is equal to the horizontal components of the web struts, except at the reactions and at the concentrated load [12]. Calculations results of the theoretical capacities are listed in the table (4).

$$F_{ns} = 0.85\beta_s f_c' A_{cs} \qquad \text{Equation}(1)$$

$$F_{nt} = A_{ts} f_{yv} \qquad \text{Equation}(2)$$

Where:

F_{ns}: Nominal strength of Struts (N)

β_s: Struts coefficient, always equal to (1)

f_c':Compressive strength of concrete (MPa)

A_{cs}:Area of Struts $(mm^2) = b_{st} t_{st}$

F_{nt}: Nominal strength of ties (N)

A_{ts}: Area of ties (mm^2)

f_{yv}:Yield strength of web reinforcement (MPa)

5.1.1. Samples of calculation

General available data

f_c' According to table (3)

$f_{yv} = 698\ MPa$

$\beta_s = 1$ (unform strut)

$t_{st} = 42mm$

$A_{ts} = 25.12mm^2$

According to Figure (7-a):

$$b_{st} = \frac{20}{\cos 38.5} = 25.55mm$$

$$b_{st} = \frac{20}{\cos 42.6} = 27.17mm$$

Control specimen TC (Figure 8-a)

$F_{ns} = 0.85(1)(35.85)(42)(25.55)10^{-3} = 32.70kN$

$F_{nt} = (25.12)(698)10^{-3} = 17.50kN$

From right side of section 1-1

$$V_n = (3 \times 17.5) + (32.70 \times \sin 44.9) + (32.70 \times \cos 44.9) + (32.70 \times \cos 53)$$

$V_n = \mathbf{118.4kN}$

Control specimens with horizontal web opening T1, and R1 (Figure 8-b)

$F_{ns} = 0.85(1)(35.85)(42)(27.17)10^{-3} = 34.77kN$

$F_{nt} = (25.12)(698)10^{-3} = 17.50kN$

From right side of section 2-2:

For T-beam with web horizontal opening T1:

$$V_n = (4 \times 17.5) + (34.77 \times \cos 42.6)$$

$V_n = \mathbf{95.6kN}$

For rectangular beam with web horizontal opening R1:
Expected shear failure through the path of section 2-2 based on failure at T1 beam.

$V_n = (4 \times 17.5) = \mathbf{70kN}$

5.2. Strength of CFRP

The nominal shear strength of the strengthened beams with CFRP is calculated from equations (3) to (6) [11]. The required dimensions for calculating the CFRP strength are shown in figure (9). Results of calculations are reported in table (4)

$$V_n = V_c + V_s + \psi_f V_f \qquad \text{Equation (3)}$$

$$V_f = \frac{A_{fv} f_{fe} d_{fv}}{S_f} \qquad \text{Equation (4)}$$

$$A_{fv} = 2n t_f w_f \qquad \text{Equation (5)}$$

$$f_{fe} = \varepsilon_{fe} E_f \qquad \text{Equation (6)}$$

Where:

V_n : Nominal shear strength of the beam (N)

V_c : Nominal concrete shear strength (N)

V_s: Nominal web reinforcement shear strength (N)

V_f: Shear strength of the fiber (N)

ψ_f: Reduction factor for bonds of fibers ;

for three sided scheme=0.85

A_{fv}:Area of fiber strip (mm^2)

f_{fe}:Tensile stress of fiber strip (MPa)

d_{fv}:Distance center of rebar to end of the fiber strip (mm)

S_f:Space between fiber strips center to center (mm)

n:Number of ply

t_f:Thickness of fiber strip (mm)

w_f:Width of fiber strip (mm)

ε_{fe}:Effective strain of fiber

E_f:Modulus of elasticity of fiber (GPa)

The effective strain expressed in equations (7) and (8) is the maximum strain that can be achieved in the FRP system at the nominal strength and is governed by the failure mode of the FRP system and of the strengthened reinforced concrete member. ACI-440[11] recommends that the strain of the fiber reported by the manufacturer which does not consider long term exposure must be reduced by using environmental reduction factor (C_E=0.95) as in equation (8).The effective strain for U-type scheme of FRP strengthening differs from the full wrap system because the possibility of delamination between concrete and FRP is higher than the loss of aggregate interlock. The effective strain of FRP is calculated by using bond-reduction coefficient (*Kv*) as expressed in equations (9), (10), (11) and (12) [12].

$$\varepsilon_{fe} = K_v \varepsilon_{fu} \leq 0.004 \qquad \text{Equation (7)}$$

$$\varepsilon_{fu} = C_E \varepsilon_{fu}^* \qquad \text{Equation (8)}$$

$$K_v = \frac{k_1 k_2 L_e}{11900 \varepsilon_{fu}} \leq 0.75 \qquad \text{Equation (9)}$$

$$L_e = \frac{23300}{(n.t_f.E_f)^{0.58}} \qquad \text{Equation (10)}$$

$$k_1 = \left(\frac{f_c'}{27}\right)^{2/3} \qquad \text{Equation (11)}$$

$$k_2 = \frac{d_{fv} - L_e}{d_{fv}} \qquad \text{Equation (12)}$$

Where:

K_v : Bond reduction coefficient

ε_{fu} : Design rapture strain of FRP

ε_{fu}^{*} : Ultimate rapture strain of FRP

k_1 and k_2: Modification factors

L_e: Active bond length (mm)

d_{fv}:Ddistance center of rebar to end of the fiber strip (mm)

f_c':Compressive strength of concrete (MPa)

5.3. Comparison of the Results

The strut and tie method shows comparable results with the experimental results of the beams with an overall average $P_{th.}/P_{exp}$ about 1.015 as shown in table (5). The result of the control solid beam TC show good agreement with $P_{th.}/P_{exp}$ about 1.03. The results indicate very good comparison for all cases of opening for beams with both horizontal and vertical openings with $P_{th.}/P_{exp}$ about 1.04 and 0.99 respectively. Also the results of this method for the beams strengthened with CFRP are reasonable except for the beams TP1 and TP2, because of used smaller space between CFRP strips in calculation according to ACI440 [11].

6. Conclusion

From the outcomes of this experimental research, the followings can be deducted:

- The shear strength capacity of the T-beam with web opening is higher than the shear strength of similar rectangular beam with web opening.
- Changing of opening orientation from horizontal to vertical for the same opening size led to more reduction of shear strength capacity.
- The shear strength capacity of reinforced concrete T-beams with web opening can be enhanced by using internal diagonal reinforcement around the opening.
- Strengthening with CFRP strips alone in beams with openings made after construction could not retain capacity of the beams as same as strengthened CFRP beams with stirrups around the opening.
- Bonding of CFRP with concrete surface without proper anchorage results in debonding of CFRP strips or sheets.
- Beams strengthened with CFRP sheet showed similar behavior and strength capacity with the beams strengthened by addiational internal diagonal stirrups.
- Beams with horizontal opening can be made stronger than the solid beams by using adequate stirrups around the opening and external CFRP strips.
- The internal diagonal reinforcement and CFRP sheet were best technique for strengthening the beams with openings.
- The strut and tie model is a reliable method for shear strength prediction of beams with web opening.

References

1- Shit T., "Experimental and numerical study on behavior of externally bonded RC T-beams using GFRP composites", MSc thesis- National institute of technology-Rourkela, January 2011.

2- Mansur M.A., and Tan K.H., "Concrete beams with opening; Analysis and Design", CRC press LLC, 1th edition, 1999.

3- Vuggumudi S., "Experimental study on shear strengthening of RC T-beams with web openings using FRP composites", MSc thesis- National institute of technology-Rourkela, January 2013.

4- Panigrahi A.K., "Strengthening of shear deficient RC T-beams with externally bonded FRP sheets", MSc thesis- National institute of technology-Rourkela, January 2013.

5- Hammad Y.H., Abdel-Rahman G.T., and Said M., "Behavior of RC beams with strengthened openings in D-region", 9th Arab Structural Engineering conference, December 2003, pp. 163-174.

6- Oukaili N.K., and Shammari A.H., "Response of reinforced concrete beams with multiple web openings to static load", 4th Asia-Pacific conference on FRP in structures APFIS, December 2013.

7- Oukaili N.K., and Shammari A.H., "CFRP strengthening of RC beams with multiple openings subjected to static and impact loads", Journal of advances in structural engineering, Vol. 17, No. 12, November 2014, pp. 1747-1760.

8- Routray S., "Shear behavior of BFRP strengthened RC T-beams", MSc thesis- National institute of technology-Rourkela, June 2015.

9- ASTM standards, "Standard test method for compressive strength of cylindrical concrete specimens", C 39/C 39M – 05, West Conshohocken, United States, 2007.

10- ACI committee 318M, "Building code requirements for structural concrete", ACI 318M - 14 and commentary, American concrete institute, Farmington Hills, United States, 2014.

11- ACI committee 440, "Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures", ACI 440.2 R - 08, American concrete institute, Farmington Hills, United States, July 2008.

12- Wight J.K., and MacGergor J.G., "Reinforced concrete mechanics and design", Pearson companies, 6th edition, New Jersey, United Stated, 2012.

13- Mansur M.A., Tan K.H., and Wei W., "Analysis of concrete beams with circular web openings using strut-and-tie models", Malaysian journal of Civil engineering, Vol. 18, No. 2, February 2006, pp.89-98.

تقوية مقاومة القص لعتبات خرسانية بشكل (T) حاوية على فتحات جانبية

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المستخلص :

الهدف الرئيسي من هذا البحث هو دراسة تقوية مقاومة القص لعتبات (T) الخرسانية المسلحة والحاوية على فتحات جانبية مستطيلة الشكل . شملت المتغيرات اتجاه الفتحة ووجود شفة (Flange) في العتبة وكفاءة أنواع مختلفة من التقوية وغياب تسليح القص حول الفتحات . شملت التجارب صب (13) عتبة خرسانية مسلحة وتحميلها بحمل محوري مركز في منتصف العتبة . احدى العتبات كانت بدون فتحة جانبية وتم اعتبارها عتبة معيارية لجميع العتبات ، اما العتبات الاخرى فقد تم صبها بفتحات جانبية وبابعاد 200ملم×100ملم اما افقية او عمودية.
اظهرت النتائج ان الفتحة الافقية تقلل من مقاومة العتبة بنسبة (17%) في حين ان الفتحة العمودية تقلل المقاومة بنسبة (27%) ، وان وجود الشفة ادى الى زيادة مقاومة العتبة للقص بنسبة (11%) و(5 ، 34%) للفتحات الافقية والشاقولية على التوالي . كذلك اظهرت نتائج العتبات المقواه باستخدام تسليح قص مائل حول الفتحات زيادة في مقاومة العتبات بنسبة (18%) و(11%) للفتحات الافقية والشاقولية على التوالي . كما وان التقوية بشرائح (الياف الكاربون) المركبة بترك مسافات بين قطعة واخرى زادت من مقاومة القص بنسبة (5 ، 13%) للفتحات الافقية ولكن لم يكن هناك تاثير كبير للفتحات الشاقولية . كذلك بالنسبة لشرائح (الياف الكاربون) المركبة لتقوية الفتحات التي تم قطعها بعد الانشاء ، لم يكن لها تاثير واضح بالنسبة لكلا النوعين من الفتحات حيث قلت مقاومة القص بنسبة (5 ، 11%) و (1 ، 10%) بالنسبة للفتحات الافقية والشاقولية على التوالي اذا ما قورنت مع العتبة المعيارية . كما تبين بان استخدام (الياف الكاربون) على اطراف الفتحة بكاملها كانت افضل طريقة للتقوية حيث زادت من مقاومة العتبة للقص بنسبة (12%) لكلا النوعين من الفتحات . وقد تم مقارنة النتائج المختبرية مع طريقة (Strut and Tie) و كانت النتائج متقاربة .

الكلمات المفتاحية : عتبة خرسانية مسلحة بشكل (T) ، فتحات جانبية ، الياف الكاربون ، حديد قطري .

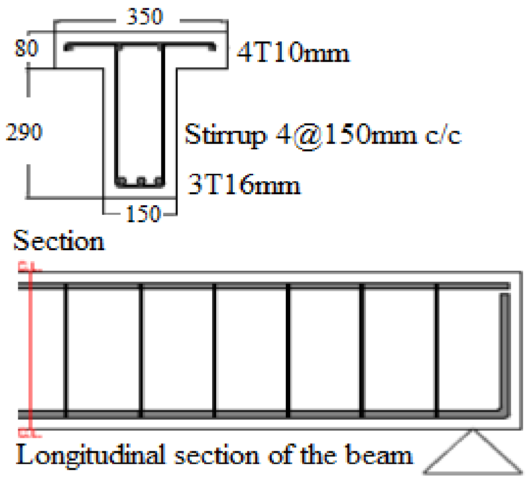


Fig.1: Detail of the TC solid beam.

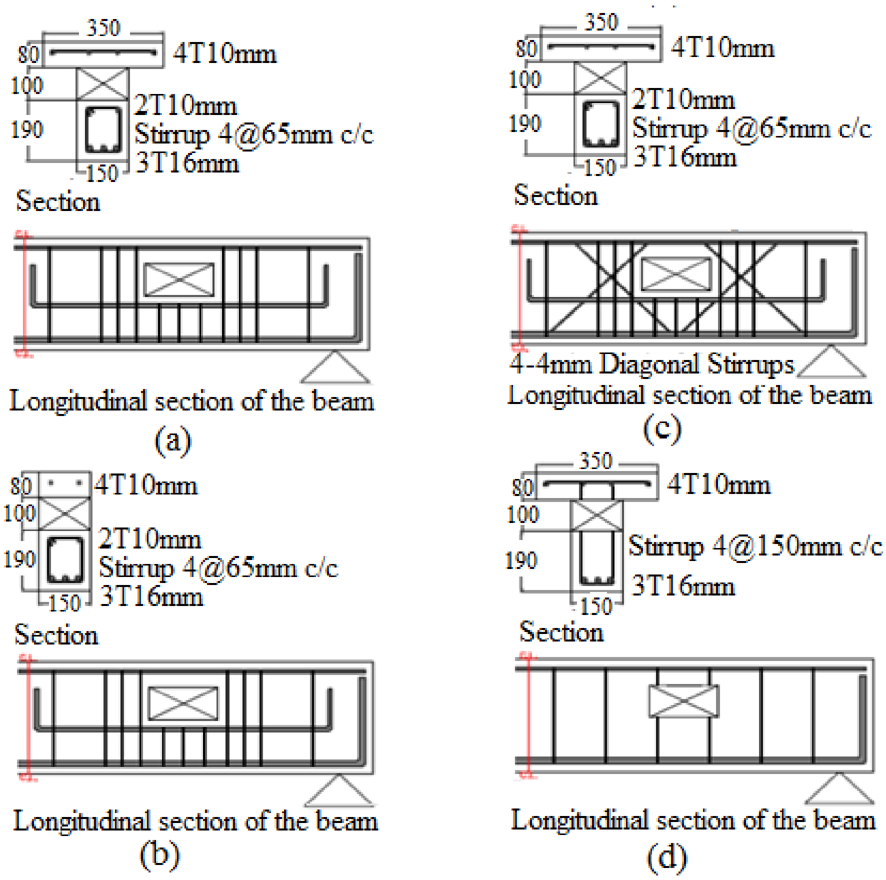


Fig.2: Detail of; (a) T1, TS1, and TP1 beams (b) R1 beam (c) TX1 beam (d) AS1 beam

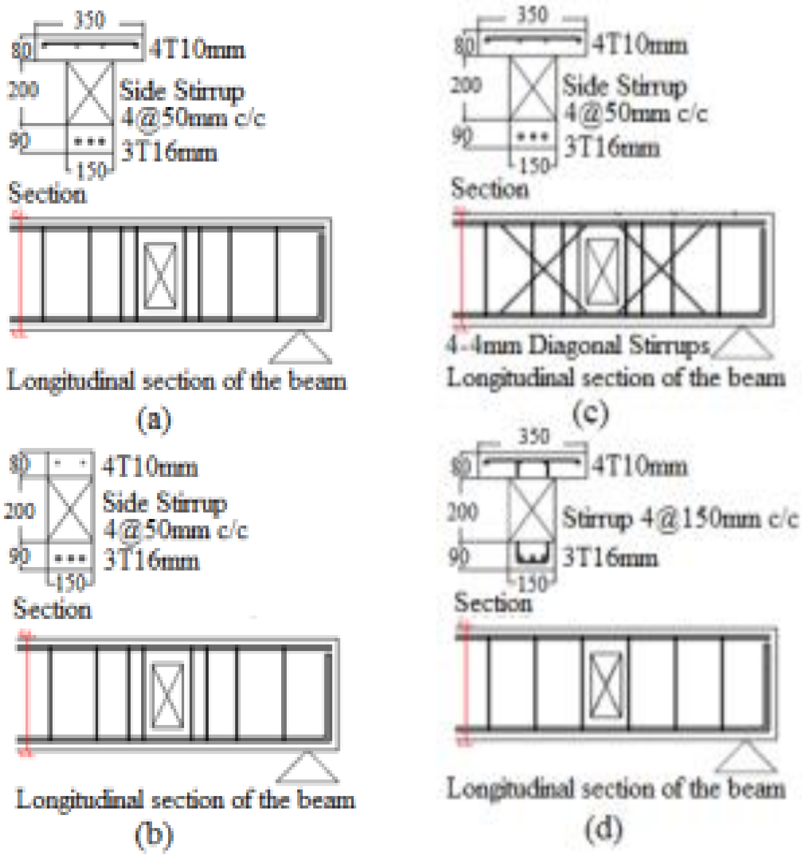


Fig.3: Detail of; (a) T2, TS2, and TP2 beams (b) R2 beam (c) TX2 beam (d) AS2 beam.

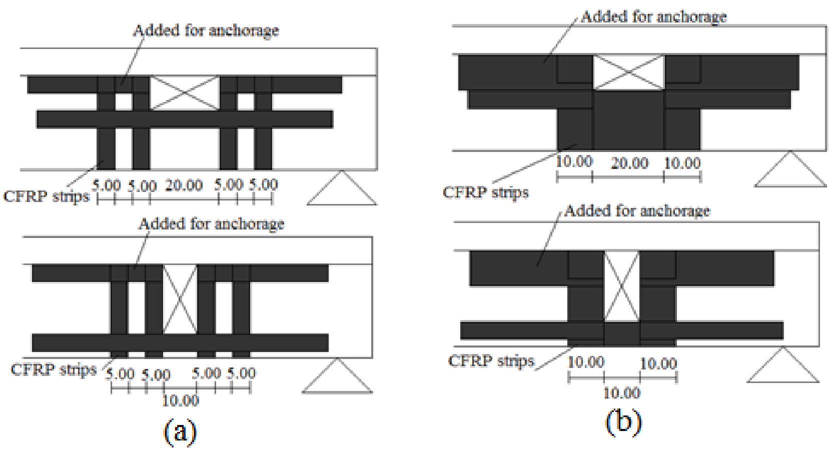
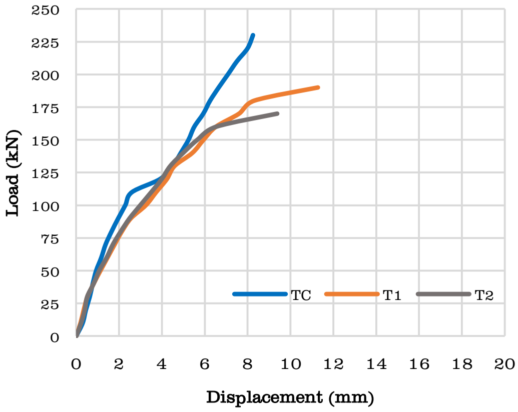
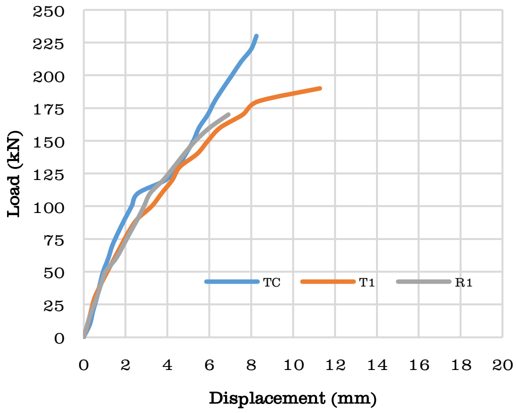


Fig.4: Strengthening techniques; (a) CFRP strengthening for TS1, TS2, AS1, and AS2 beams, and (b) CFRP strengthening for TP1, and TP2 beams.

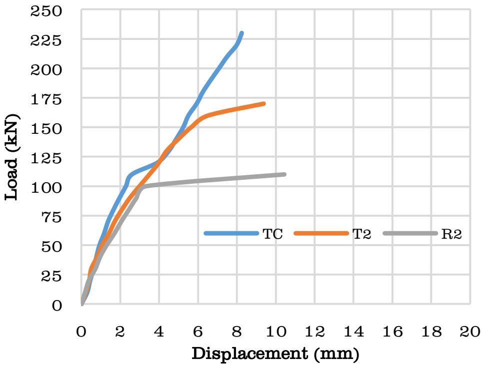
Fig.5: Failure pattern for; (A) TC, (B) T1, (C) T2, (D) R1, (E) R2, (F) TX1, (G) TX2, (H) AS1, (I) AS2, (J) TS1, (K) TS2, (L) TP1, and (M) TP2



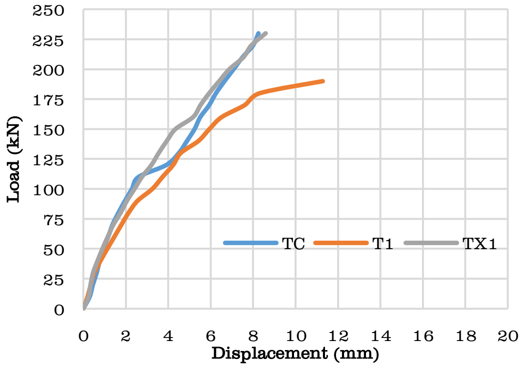
(A)



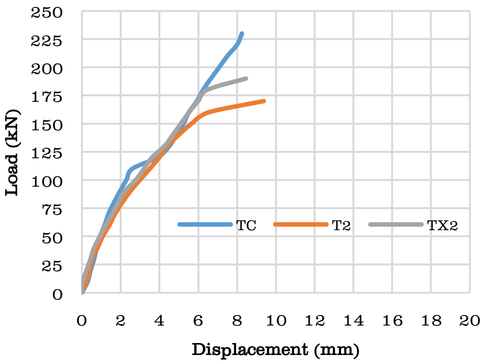
(B)



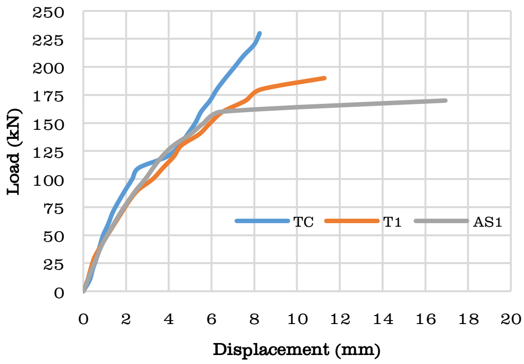
(C)



(D)

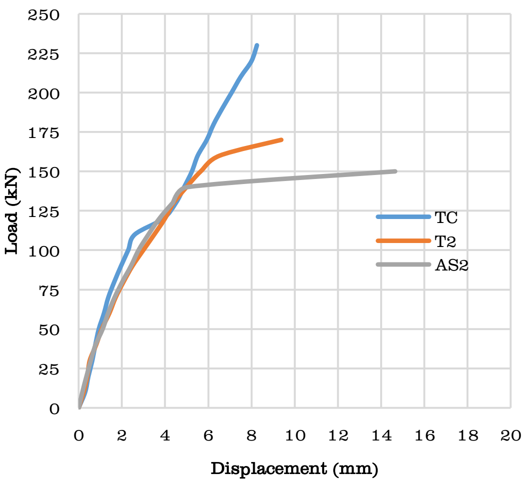


(E)

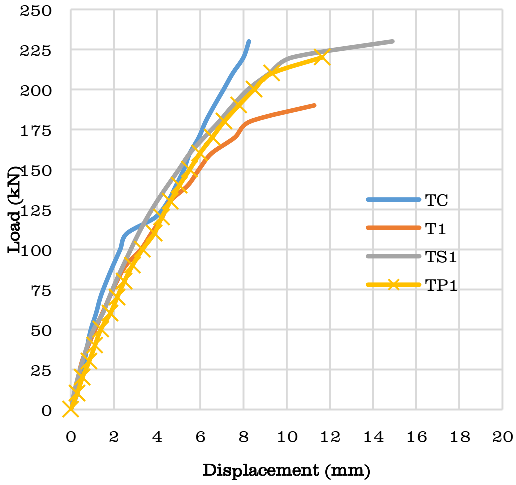


(F)

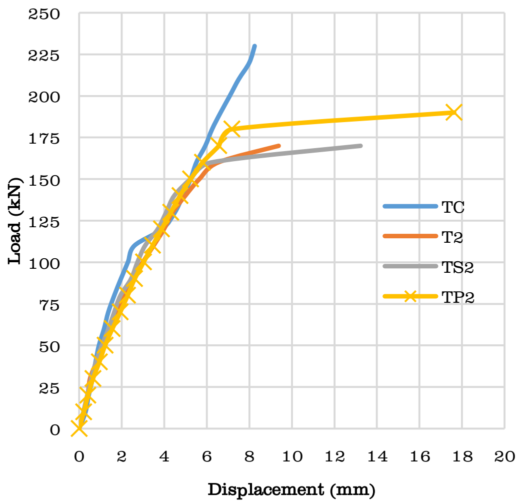
Fig.6 (A,B,C,D,E,F) : Load displacement relationship at mid span of the beams.



(G)

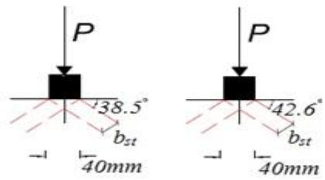


(H)

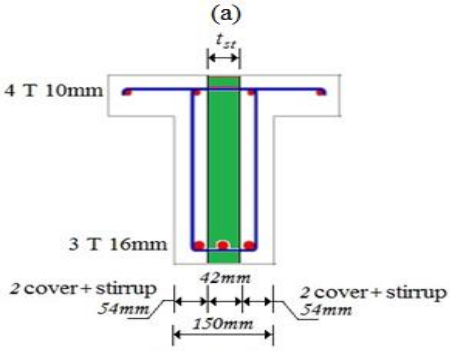


(I)

Fig.6 (G,H,I) : Load displacement relationship at mid span of the beams.



(a)



(b)

Fig.7: (a) Inclination of strut (b) Dimension of Strut.

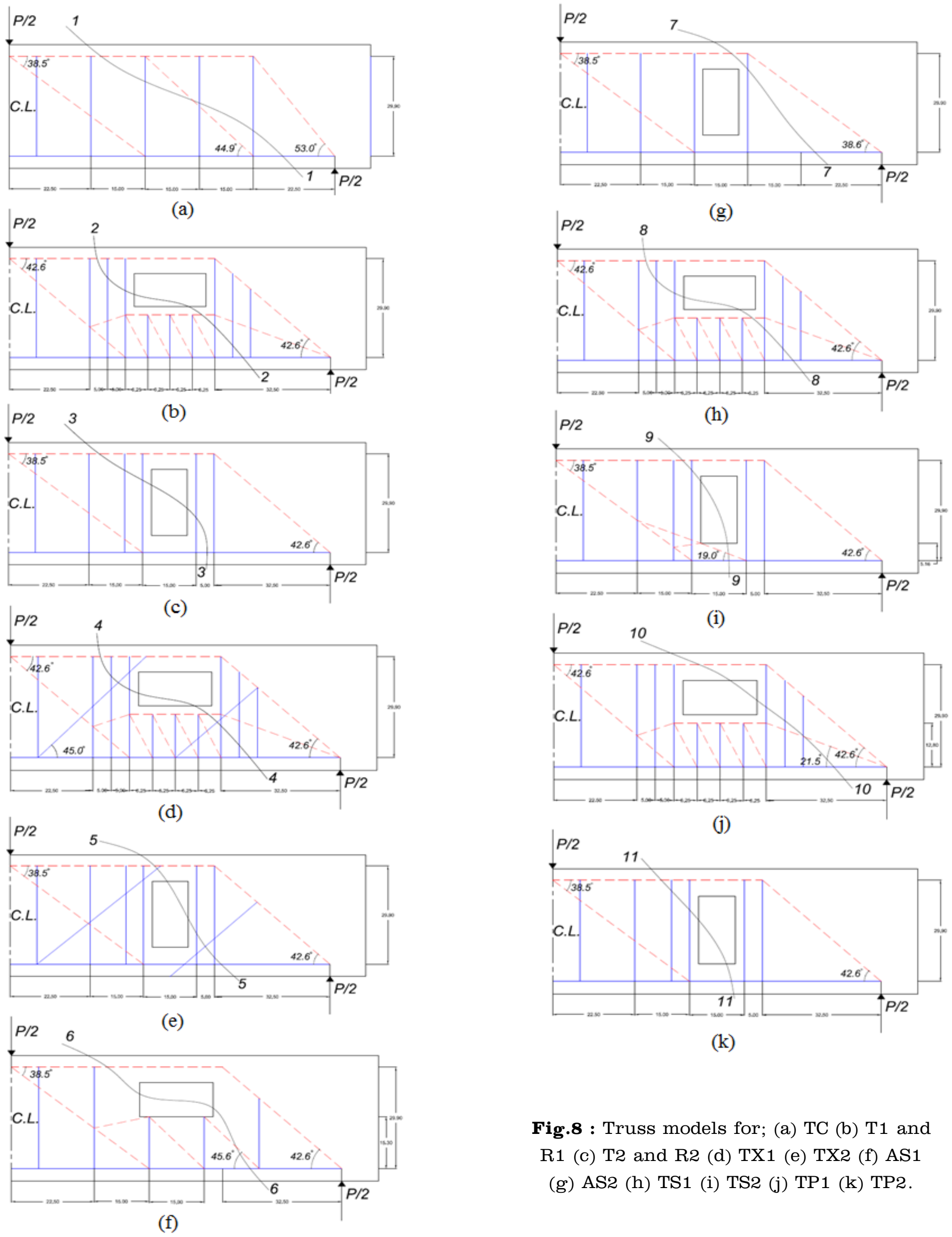


Fig.8 : Truss models for; (a) TC (b) T1 and R1 (c) T2 and R2 (d) TX1 (e) TX2 (f) AS1 (g) AS2 (h) TS1 (i) TS2 (j) TP1 (k) TP2.

Fig.9: Dimensional variables for capacity of the CFRP strips [11]

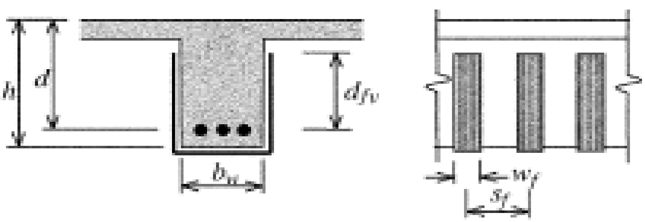


Table 1: Description of beams specimens using in Experimental program**

Groups	Designation	Description
1	TC	Control solid beam
2	T1 T2	Control beams with opening
3	R1 R2	Rectangular beams with opening
4	TX1 TX2	Internal strengthened beams with diagonal stirrups
5	AS1 AS2	Strengthened beam that making opening after construction
6	TS1 TS2	Strengthened beam with CFRP strips
7	TP1 TP2	Strengthened beam with full wrap CFRP sheets

**R: Rectangular section; T: Tee section; X: Internal strengthening; S: Strengthened beam with CFRP; A: Opening after construction; and P: Different CFRP strengthening scheme of T-*section beam*.

Table 2: Properties of ASOFABRIC-C300 and ASODUR-1330

ASOFABRIC-C300		ASODUR-1330	
Description	Value	Description	Value
Thickness (mm)	0.166	Pot life at (23ºC) (minutes)	70
Tensile Strength (MPa)	4900	Tensile Strength (MPa)	55
Modulus of Elasticity (GPa)	230	Tensile modulus (MPa)	1.7
Elongation (%)	2.1	Elongation (%)	3
Area Weight (g/m^2)	300	Flexural Strength (MPa)	79

Table 3: Strength of the beams with cylindrical compressive strength

Group	Designation	Compressive strength (MPa)	Ultimate capacity (kN)	Side of shear Failure
1	TC	35.85	230	Solid
2	T1	35.85	192	Opening
	T2	35.85	168	Opening
3	R1	35.85	171	Solid
	R2	35.85	110	Opening
4	TX1	35.85	234	Solid
	TX2	35.85	188	Opening
5	AS1	32.00	170	Opening
	AS2	32.00	151	Opening
6	TS1	35.36	222	Solid
	TS2	35.36	170	Opening
7	TP1	32.00	218	Solid
	TP2	32.00	190	Opening

Table 4 : Results of theoretical shear strengths

Des.	(kN)		
	V_f	Vc + Vs	Vn
TC	0.0	118.4	118.4
T1	0.0	95.6	95.6
T2	0.0	76.6	76.6
R1	0.0	70.0	70.0
R2	0.0	52.5	52.5
TX1	0.0	120.3	120.3
TX2	0.0	83.8	83.8
AS1	31.2	43.8	74.9
AS2	31.2	40.3	71.5
TS1	32.8	95.2	128.1
TS2	32.8	51.7	84.6
TP1	62.4	86.7	149.1
TP2	62.4	56.5	118.9

Table 5: Comparison of theoretical and experimental shear capacities

Des.	(kN)		
	Experimental	Theoretical	$P_{th.} / P_{exp.}$
TC	230	237	1.03
T1	192	191	0.99
T2	168	153	0.91
R1	171	140	0.82
R2	110	105	0.95
TX1	234	241	1.03
TX2	188	168	0.89
AS1	170	150	0.88
AS2	151	143	0.95
TS1	222	256	1.15
TS2	170	169	0.99
TP1	218	298	1.37
TP2	190	238	1.25
	Average		1.01