Experimental Evaluation of Effect of Flange Dimensions on Shear Behavior of NSC and SCC Double Tee Beams

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ABSTRACT

This study deals with, experimentally, the effect of flange dimensions on shear behavior of normal strength concrete (NSC) and self-compacting concrete (SCC) double Tee beams.

Twelve beam specimens as well as a series of control specimens are tested. The beam specimens were divided into two groups (based on concrete type) and each group are divided into five subgroups (based on flange dimensions).The webs dimensions, beam depth, beam length, spacing between webs, longitudinal (tension) reinforcement and transverse reinforcement (stirrups) were kept constant in all beam specimens.

Experimental results showed that the ultimate capacity increased about (6%-12) and (9%-20) when the flange width (dimensions) increased from (320mm) to (450mm) for NSC and SCC respectively. Presence of large compression flange lead to increase the stiffness of tested beams due to contribution of additional concrete parts, and this leads to increase in carrying capacity.

Keywords: Flange, Shear, Self-Compacting, Concrete, Double Tee

تقييم عملي لتأثير أبعاد الشفة(Flange) على سلوك القص للعتبات ذات المقطع π والمصنوعة من الخرسانة الاعتيادية والخرسانة ذاتية الرص

الخلاصة

تتناول هذه الدراسة العملية تأثير أبعاد الشفة (Flange)على سلوك القص للعتبات ذات المقطع π والمصنوعة من الخرسانة الاعتيادية والخرسانة ذاتية الرص. تم في هذه الدراسة فحص اثنا عشرة عتبه خرسانية بالإضافة الى مجموعة من نماذج السيطرة. تم تصنيف العتبات المفحوصة الى مجموعتين رئيسيتين (اعتمادا على نوع الخرسانة) وكل مجموعة تم تقسيمها الى خمسة مجاميع ثانوية (اعتمادا على أبعاد الشفة (Flange)). لكافة العتبات المفحوصة, تم الإبقاء على أبعاد الوترات (Webs),العمق الكلي, فضاء العتبة, حديد التسليح الطولي و العرضي بدون أي تغيير.

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أظهرت النتائج أن مقاومة القص تعتمد على مقاومة انضغاط الخرسانة وشكل مقطع العتبة, حيث ازداد الحمل الأقصى بحدود (6%-12%) وبحدود (9%-20%) عندما ازدادت أبعاد الشفة (Flange) من (320mm) الى (450mm) للعتبات المصنوعة من الخرسانة الاعتيادية و الخرسانة ذاتية الرص على التوالي.

INTRODUCTION

Double tee beams are suitable for structural suspended floors in most buildings especially in larger commercial building, car parks and supermarkets were large column free spaces are required. Generally, the double tee is a large component, prestressed precast concrete unit and suitable for use in most types of buildings and can be made with NSC, HSC, SCC and other types of concrete.

Self-compacting concrete (SCC) was developed in Japan in the late 1980's and allows concrete to be placed fully compacted without segregation and with no additional energy (vibration)(1,2). It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

When the double Tee or single Tee beams (T-section beams) subjected to shear stresses, the thin vertical part of beam (i. e. webs) will resist these stresses.

Generally, shear mode of failures are divided into four categories of failure and depends mainly on shear span to effective depth ratio (3). The possible modes of failure are (1) Shear-tension failure; (2) Shear-compression failure; (3) Flexural failure; (4) Arch-rib failure.

New researches on T-section beams show that the concrete flanges provide a certain level of shear resistance above a certain width (4,5). But the current codes of practice such as ACI 318-08(6), do not include an increase in shear strength resulting from the inclusion of a flange.

In the present research, shear behavior of reinforced concrete double Tee Beams which contains different flanges dimensions will be studied as will as the effect of concrete type.

EXPERIMENTAL STUDY

Experimental Program

Tests were carried out on twelve double Tee (π-Shaped) beams, simply supported under the effect of single point loading at mid span. All beam specimens were reinforced with (2ϕ8mm) deformed bars as a main reinforcement (flexural reinforcement) at bottom of the webs. While, slightly reinforcement of (4ϕ3mm) mild steel, smooth bars at the top flange were used. To eliminate the shear resisting contribution of stirrups and to ensure the specimens to fail in shear mode of failure, the tested beams were made with minimum shear reinforcement (stirrups) and maximum spacing. Therefore, (ϕ3mm@150mm) mild steel, smooth bars were used as shear reinforcement. It may be noted that, the main function of stirrups is to hold in place the top and bottom longitudinal reinforcement.

The variables were the dimensions of slab (flange) and concrete type. The span, webs dimensions, beam depth, beam length, spacing between webs, longitudinal (tension) reinforcement and transverse reinforcement (stirrups) were kept constant for all tested specimens.

SPECIMEN DETAILS

Description and details of beam specimens are summarized and presented in Table (1) and Figures (1) and (2). Each beam is designated in a way to indicate the double tee shaped beam, the type of used concrete and the beam number in its group. Therefore, the beam (DT-N-4) is a double tee beam made with normal strength concrete.

Based on the classification presented by (**Wang, C. K. and Salmon, C. G.**) [(3)], all tested beams are classified as short beams (1< a/d <2.5).

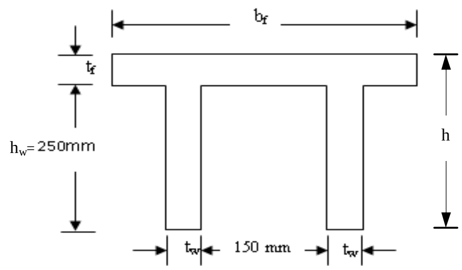

Figure (1) Cross-Section of π –Beams

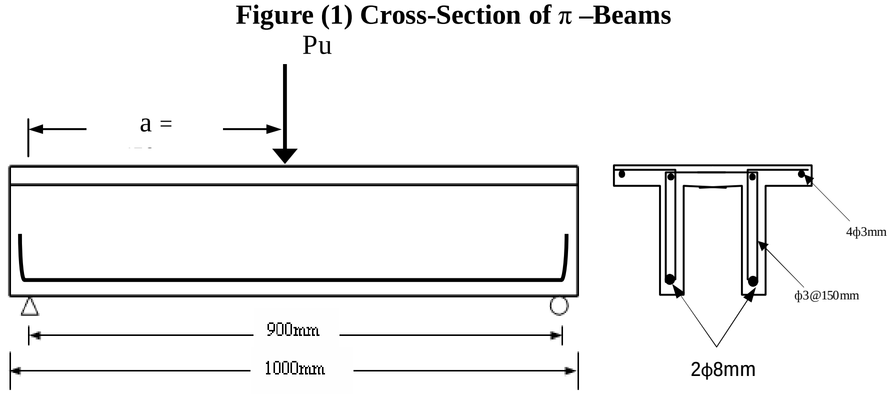

Figure (2) Dimensions and Details of Tested π –Beams

Table (1) Properties of Test Beams

Group	Mix Designation	Beam Designation	Dimensions (mm)				
			b_f	t_f	t_w	h_w	h
Group-1	NSC	DT-N-1*	450	50	50	250	300
		DT-N-2*	450				
		DT-N-3	400				
		DT-N-4	360				
		DT-N-5	340				
		DT-N-6	320				
Group-2	SCC	DT-S-1*	450	50	50	250	300
		DT-S-2*	450				
		DT-S-3	400				
		DT-S-4	360				
		DT-S-5	340				
		DT-S-6	320				

* Reference Beams

MATERIALS

In manufacturing the test specimens, the properties and description of used materials are reported and presented in Table (2); and the concrete mix proportions are reported and presented in Table (3).

Table (2) Description of Construction Materials

Material	Descriptions
Cement	Ordinary Portland Cement (Type I)
Sand	Natural sand from Al-Ukhaider region with maximum size of (4.75mm)
Gravel	Crushed gravel with maximum size of (12mm)
Superplasticizer	High water reducer super plasticizer **Glenium 51**
Lime Stone Powder	Lime stone powder (L. S. P.) with fineness (3100 cm^2/gm)
Reinforcing Bars	(ϕ8 mm) deformed steel bars, having (424 MPa) yield strength (f_y)
Water	Clean tap water

For each beam specimen, only one sample was manufactured. While, for control specimens (cubes and prisms), an average of three samples (per mix) by using (100x100x100mm) cubes were used for compressive strength test and an average of two samples (per mix) by using (100x100x500mm) prisms were used for modulus of rupture test. Both, beam specimens and control specimens were cured under the same conditions for (28 days).

Table (3) Proportions of Concrete Mix

Parameter	Concrete Type	
	SCC	NSC
Water/cement ratio	0.47	0.38
Water (L)	180	158
Cement (kg/m^3)	385	420
Fine Aggregate (kg/m^3)	805	584
Coarse Aggregate (kg/m^3)	860	1166
Lime Stone Powder (L.S.P) (kg/m^3)	165	-
Superplasticizer (L/m^3)	5.8	4.2

TEST MEASUREMENTS AND INSTRUMENTATION

Hydraulic universal testing machine (MFL system) was used to test the beam specimens as well as control specimens. The testing machine has three scale loads (0 to 600 kN), (0 to 1500 kN) and (0 to 3000 kN) and capacity of (3000 kN). Central deflection has been measured by means of (0.01mm) accuracy dial gauges (ELE type) and (30mm) capacity. The dial gauges were placed underneath the bottom face of each span at mid, Figure (3). The beam specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations.

Figure (3) Beam Setup

TEST RESULTS OF SPECIMENS

Properties of the SCC in the fresh state were measured and presented in Table (4). Also, test results of mechanical properties of hardened concrete specimens are summarized in Table (5). Compressive strength was carried out on (100x150mm) cylinders accordance with ASTM C39-96[7]. While, tensile strength in flexural (modulus of rupture) and indirect tensile strength (splitting tensile strength) were carried out in accordance with ASTM-C78[8] and ASTM C496-79 [9] respectively.

Table (4) Properties of the SCC in the Fresh State

Mix Designation	Slump Flow (mm/sec)	L-Box	T20 (Sec.)	T40 (Sec.)	T50 (Sec.)
SCC	780	1.0	1.4	2.1	3.4

Table (5) Mechanical Properties of Concrete After (28) day of Curing

Property (MPa)	Mix Designation	
	NSC	SCC
Cylinder Compressive Strength (f_c')*	33	32
Modulus of Rupture (f_r)**	3.3	3.0
Split Tensile Test (f_t)***	5.3	5.2

*Average of three samples (per mix) by using (150x100mm) Cylinders.
** Average of three samples (per mix) by using (100x100x500mm) Prisms.
***Average of three samples (per mix) by using (150x100mm) Cylinders.

TEST PROCEDURE

All beam specimens were tested using universal testing machine (MFL system) with monotonic loading to ultimate states. The tested beams were simply supported over an effective span of (900mm) and loaded with a single-point load; Figures (2) and (3) shows the setup of beam specimens.

The beams have been tested at ages of (28) days. The beam specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations.

Loading was applied slowly in successive increments. At the end of each load increment, observations and measurements were recorded for the mid-span deflection and crack development and propagation on the beam surface.

When the beams reached advanced stage of loading, smaller increments were applied until failure. They fail abruptly without warning (sudden failure) and the diagonal cracks that develop becomes wider and as a result, the load indicator stopped recording any more and the deflections increased very fast without any increase in applied load.

The developments of cracks (crack pattern) were marked with a pencil at each load increment.

RESULTS AND DISCUSSION

As mentioned before, the main objectives of this study are to examine or assess the shear behavior of reinforced concrete double Tee shaped beams which made of normal or self compacting concrete.During the experimental work, ultimate loads, load versus deflection at mid-span for each beam were recorded. Photographs for the tested beams are taken to show the crack pattern and some other details. The recorded data, general behavior and test observations are reported as well as recognizing the effects of various parameters on the shear behavior.

GENERAL BEHAVIOR

Photographs of the tested beams are shown in Figure (4) and test results are given in Table (6). All beams of this category were designed to fail in shear, which was characterized by sudden failure and diagonal wide cracks which extended from the supports towards the load or flange. The general behavior of the tested beams can be described as follows:

At early stages of loading, several cracks initiated in the mid span of tested beams (flexural cracks), with further loading, these cracks extended upwards and became wider in shear span. One or more cracks propagated faster than the others and reached the compression flange (near applied load), where crushing of the concrete near the positions of applied loads had occurred due to high concentrated stresses under load. As expected, the main cracks (diagonal cracks) for all tested beams commenced at the shear span and all beams exhibited sudden failure. It is may be noted that, at advanced stage of loading, some parts of tested double Tee Beams were crushed and subjected to defragmentation , this is may be due to high concentrated of stresses and absents of steel reinforcement to hold these parts in the transverse direction.

FAILURE MODE

The experimental evidences show that the diagonal cracks extended horizontally along the tension reinforcement and eventually, the failure take place due to crushing failure in the concrete near the compression face (near applied load) and this mode of failure called “Shear-Compression” failure.

Figure (5) Crack Patterns for double Tee Beams.

ULTIMATE LOADS

Ultimate load capacity of tested specimens are reported and presented in Table (6). Generally, the experimental results show that the ultimate capacity increased with increasing of concrete strength.

For the first group, the ultimate load were decreased (6%), (8%), (11%) and (12%) when the flange width decreased to (400mm), (360mm), (340mm) and (320mm) respectively. While, for the second group, the ultimate load were decreased (9%), (11%), (16%) and (20%) when the flange width decreased to (400mm), (360mm), (340mm) and (320mm) respectively. This means, the increasing in flange dimensions leads to increase the ultimate load capacity and as a result, the shear capacity increased.

Another notes which can be seen, the use of self compacting concrete (SCC) improves the shear resistance and allowing higher forces to be transferred through the section, this may be due to high density of (SCC) in comparison with (NSC). As a result, the ultimate capacity depends on both, concrete strength and shape of slab.

Table (6) Ultimate Load Capacity

Group	Beam Designation	Ultimate Load (P_u) (kN)	Ultimate Shear Force(V_u) (kN)	(P_u/P_{ur}) %
Group-1	DT-N-1*	155	77.5	1.0
	DT-N-2*	155	77.5	1.0
	DT-N-3	145	72.5	0.94
	DT-N-4	142	71.0	0.92
	DT-N-5	138	69.0	0.89
	DT-N-6	137	68.5	0.88
Group-2	DT-S-1*	160	80	1.0
	DT-S-2*	160	80	1.0
	DT-S-3	146	73	0.91
	DT-S-4	142	71	0.89
	DT-S-5	134	67	0.84
	DT-S-6	128	64	0.80

* Reference Beams

LOAD – DEFLECTION BEHAVIOR

Load-deflection curves of the tested beams at mid-span (for two webs) at all stages of loading up to failure are constructed and shown in Figures (6) and (10).

As shown in Figures, at the beginning, all curves were identical and the tested beams exhibited linear behavior and the initial change of slope of the load-deflection curves occurred between (20 kN to 40kN), which may be indicated the first crack loads (first flexural crack). Beyond the first crack loading, each beam behaved in a certain manner.

For NSC and SCC, behavior of reference double tee beams (DT-N-1 and DT-S-1) exhibited greater loads and deflections in comparison with the other beams. This beams had the greatest stiffness due to presence of large compression flange due to contribution of additional concrete parts.

Load-deflection curves for the tested beams (DT-N-3, DT-N-4, DT-N-5 and DT-N-6) exhibits smooth increase in both applied loads and deflections. Increasing of flange dimensions caused increasing in the load carrying capacity beyond the first cracking and this was reflected on the corresponding deflections.

For SCC group (DT-S-1, DT-S-3, DT-S-4, DT-S-5 and DT-S-6), slight decrease in ultimate deflection were observed in comparison with NSC group. This is may be due to slightly higher compressive strength of normal concrete, which lead to increasing of beam stiffness and as a result, slight increases in deflection take place.

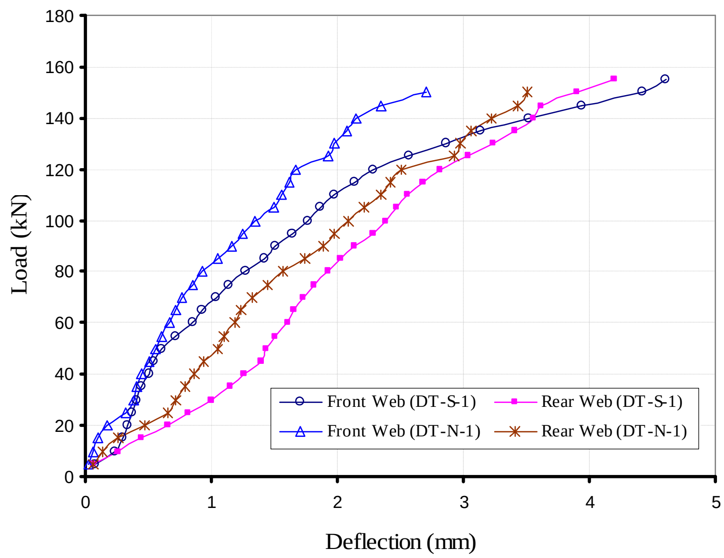

Figure (6) Load-Deflection Curves for Tested Beams (DT-N-1) & (DT-S-1)

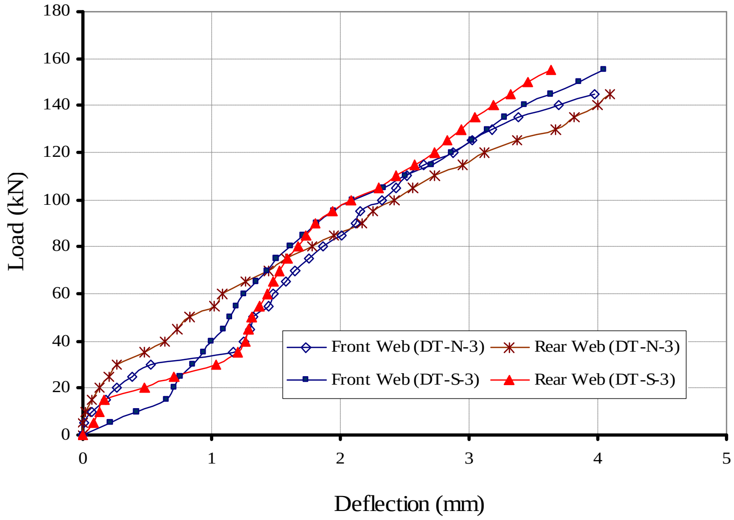

Figure (7) Load-Deflection Curves for Tested Beams(DT-N-3) & (DT-S-3)

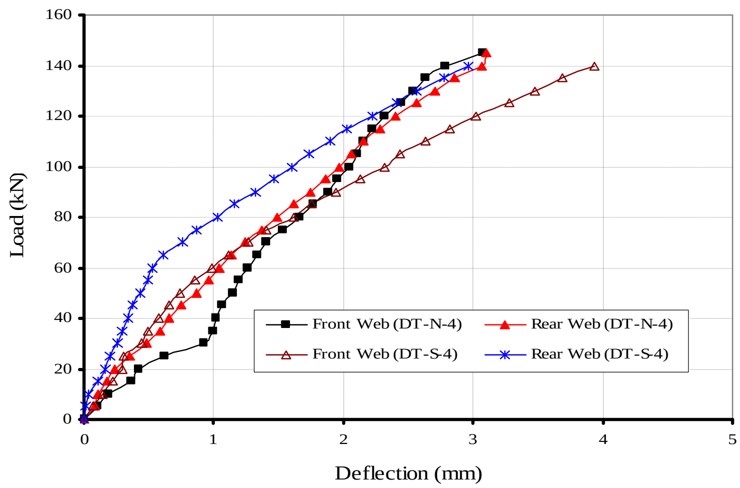

Figure (8) Load-Deflection Curves for Tested Beams(DT-N-4) & (DT-S-4)

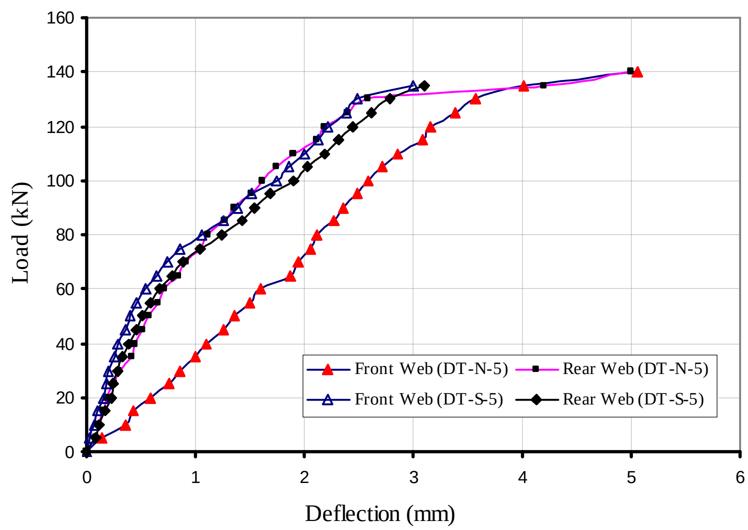

Figure (9) Load-Deflection Curves for Tested Beams (DT-N-5) & (DT-S-5)

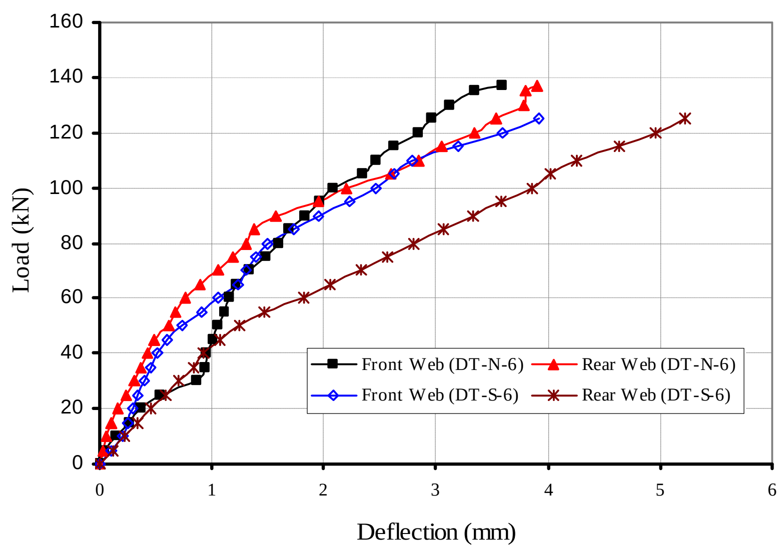

Figure (10) Load-Deflection Curves for Tested Beams(DT-N-6) & (DT-S-6)

EFFECT OF FLANGE DIMENSIONS ON ULTIMATE CAPACITY

As shown in Table (6), when the flange's dimensions increased the ultimate capacity increased. The ultimate capacity increased (6%-12) and (9%-20) when the flange width (dimensions) increased from (320mm) to (450mm) for NSC and SCC respectively. Presence of large compression flange lead to increase the stiffness of tested beams due to contribution of additional concrete parts, and this leads to increase in carrying capacity. This evidence shows the contribution of flanges to increase the ultimate shear capacity.

EFFECT OF CONCRETE TYPE ON ULTIMATE CAPACITY

As shown in Table (6), the beam specimens that have flange widths of (450mm, 400mm, 360mm) shows an increase in ultimate load capacity about (3%) when the concrete type changed from NSC to SCC. While, for beam specimens that have flange widths of (340mm,320 mm), shows an increase in ultimate load capacity about (7%) when the concrete type changed from SCC to NSC. This difference indicated to that the ultimate strength depend mainly on concrete strength (concrete type).

SHEAR STRENGTH ANALYSIS

Shear strength of the tested beams were calculated according to ACI 318-M08 [6] and compared with experimental ultimate shear strength (V_u). The calculated and measured shear strength is reported in Table (7).

Table (7) Calculated Shear Strength of Tested Beams.

Group	Beam Designation	Concrete Type	f'_c (MPa)	Shear Strength (kN)		$\frac{(V_c)_{Cal.}}{(V_u)_{Exp.}}$
				Calculated *	Experimental	
Group-1	DT-N-1*	NSC	33	27	77.5	0.35
	DT-N-2*				77.5	0.35
	DT-N-3				72.5	0.37
	DT-N-4				71.0	0.38
	DT-N-5				69.0	0.39
	DT-N-6				68.5	0.39
Group-2	DT-S-1*	SCC	32	26.7	80	0.33
	DT-S-2*				80	0.33
	DT-S-3				73	0.37
	DT-S-4				71	0.38
	DT-S-5				67	0.40
	DT-S-6				64	0.42

*$V_c = \frac{1}{6}\sqrt{f'_c}.b_w.d$ ……..(Eq. 11-3 ACI-318-08), b_w=2x50=100mm , d=283mm

As shown in Table (7), the adopted empirical equation of ACI-318-08 Code (Equation 11-3 in AC1-318-08) gives underestimation to the shear strength of the tested beam made with (NSC) or (SCC). This indicates that the flanges provide a certain level of shear resistance above a certain width. But the current ACI-318 code of practice, do not include an increase in shear strength resulting from the inclusion of a flange. Therefore, it is necessary to improve the current equation (formula) to satisfy the requirements of Tee or Double Tee beams (take into account the contribution of the flanges).

CONCLUSIONS

Based on the results obtained by the experimental work, the following conclusions are presented:-

1- When the flange's dimensions increased the ultimate capacity increased. The ultimate capacity increased (6%-12) and (9%-20) when the flange width (dimensions) increased from (320mm) to (450mm) for NSC and SCC respectively. Presence of large compression flange lead to increase the stiffness of tested beams due to contribution of additional concrete parts, and this leads to increase in carrying capacity.

2- The beam specimens that have flange widths of (450mm, 400mm, 360mm) shows an increase in ultimate load capacity about (3%) when the concrete type changed from NSC to SCC. While, for beam specimens that have flange widths of (340mm,320 mm), shows an increase in ultimate load capacity about (7%) when the concrete type changed from SCC to NSC.

3-In all tested beams, the diagonal cracks are created in two parallel webs (in one side) and extends from the supports toward the point load. Therefore, in design, special details must be added at these locations.

4- The experimental evidences show that the diagonal cracks extended horizontally along the tension reinforcement and eventually, the failure take place due to crushing failure in the concrete near the compression face (near applied load).

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NOTATION

a =	Shear Span (mm);
b_w=	Web width (mm);
b_f =	Flange width (mm);
d =	Effective depth of Π-Beam (mm);
f_c' =	Cylinder compressive strength of concrete (MPa);
f_t =	Indirect tensile strength (splitting tensile strength) (MPa);
f_r =	Flexural tensile strength of concrete (modulus of rupture) (MPa);
f_y =	Yield strength of steel (MPa);
h =	Total depth of Π-Beam (mm);
L =	Effective Span (mm);
HSC=	High Strength Concrete;
NSC=	Normal Strength Concrete;
SCC=	Self Compacting Concrete;
P_u =	Ultimate load (kN);
P_{ur} =	Ultimate load of Reference Beam (kN);
t_f =	Flange thickness (mm);
t_w=	Web thickness (mm);
V_c=	Shear Srength of Concrete (kN);
V_u=	Ultimate Shear Force (mm);
ϕ =	Reinforced bar diameter (mm)