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Experimental Study for Shear Behavior of Hybrid Self-Compacting Concrete Beams

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Abstract:

This paper discusses shear behavior of hybrid reinforced concrete beams that consist of two different concrete layers: the tension layer is made of normal strength concrete with compressive strength of 25 MPa and the compression layer is made of self-compacting concrete with two values for compressive strength of 25 and 50 MPa. These hybrid beams have been compared with corresponding homogenous beams made with one type of concrete to assess their structural behavior. Fifteen simply supported beams have been used and distributed into five groups to investigate the effect of some important variables on the shear strength for each group, (the concrete compressive strengths and the tensile steel ratio). The hybrid beams failed in shear in similar linear behavior to the homogenous beams and the results show that, the ultimate average shear strength of the hybrid beams with self compacting concrete having a compressive strength of 50 MPa [BHY(50)] is higher than the normal beams by 5.2 % and lower than the self compacting concrete beams having a compressive strength of 50 MPa [BSC(50)] by 12 % , while the ultimate average shear strength of the hybrid beams with normal strength self compacting concrete BHY(25) give approximately close shear strength values of normal beams. Also, from the results obtained, the shear strength of the hybrid beams BHY(50) and BHY(25) increase with the increase of the tensile steel ratio from 1.3 % to 1.94 % by 48 % and 53 % respectively compared to 51% for the normal strength beams. Some published shear strength equation where used for normal concrete have been used to predicate the shear strength values for hybrid concrete, finally these shear strength values have been compared with the shear strength results obtained from

the experimental work presented in this paper in order to check the adequacy of using these equations in the shear strength calculation for hybrid concrete.

Key Word: Shear strength, concrete beams, hybrid, self-compacting concrete

دراسة عملية لسلوك القص في العتبات الخرسانية المسلحة المهجنة بخرسانة ذاتية الرص

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الخلاصة:

تم في هذا البحث دراسة سلوك القص في العتبات الخرسانية الإنشائية المهجنة والتي تتكون من طبقتين:الأولى مكونة من خرسانة اعتيادية (بمقاومة انضغاط مساوية إلى ٢٥ ميكاباسكال) في منطقة الشد والثانية من الخرسانة ذاتية الرص (بمقاومة انضغاط مساوية إلى ٢٥ و ٥٠ ميكاباسكال)في منطقة الانضغاط الهدف منها زيادة مقاومة القص للعتبات ذات الخرسانة الاعتيادية ومحاولة التعرف إلى السلوك الإنشائي لهذا النوع من العتبات ومقارنتها مع العتبات المتجانسة المكونة من نوع واحد من الخرسانة. تم عمل خمسة عشر عتبة خرسانية مسلحة بسيطة الإسناد موزعة على (5) مجاميع مختلفة .تم تحري تأثير بعض المتغيرات المهمة على مقاومة القص لكل مجموعة وهي كل من: مقاومة انضغاط الخرسانة ونسبة حديد التسليح الشد، وبعد فحص العتبات بطريقة (one-point load) لحين الفشل كان فشل العتبات المهجنة بشكل خطي مشابه للعتبات المتجانسة وقد أظهرت النتائج بان مقاومة القص للعتبات المهجنة بخرسانة ذاتية الرص عالية المقاومة BHY(50) كانت أعلى من مقاومة القص للعتبات ذات المقاومة الاعتيادية بنسبة (٥,٢ %) واقل من مقاومة القص للعتبات المصنوعة من خرسانة ذاتية الرص عالية المقاومة BSC(50) بنسبة (١٢ %) في حين كانت مقاومة القص للعتبات المهجنة بخرسانة ذاتية الرص ذات مقاومة اعتيادية(BHY(25 مقاربة لمقاومة القص للعتبات ذات المقاومة الاعتيادية. كذلك أظهرت النتائج بان مقاومة القص للعتبات المهجنة تزداد بزيادة نسبة حديد التسليح من ١,٣ % إلى ١,٩٤ % وكانت الزيادة في مقاومة القص هي (٤٨ %) للعتبات المهجنة بخرسانة ذاتية الرص عالية المقاومة BHY(50) و (٥٣ %) للعتبات المهجنة بخرسانة ذاتية الرص ذات مقاومة اعتيادية BHY(25) في حين كانت الزيادة في المقاومة للعتبات ذات المقاومة الاعتيادية هي (٥١ %). أخيرا تم استخدام بعض المعادلات المنشورة سابقا الخاصة بمقاومة القص للخرسانة العادية في حساب مقاومة القص للعتبات ذات الخرسانة المهجنة وتمت مقارنة نتائج هذه المعادلات مع النتائج العملية لمعرفة دقة هذه المعادلات في حساب مقاومة القص للخرسانة المهجنة.

1-Introduction:

Reinforced concrete is one of the most widely used modern building materials, and this material need for improving of its properties in order to get the best performance for the formed structure. In this study, the suggested improvement show that the composite concrete construction means using different concrete properties which are arranged in layered system, in the state of concrete the composite construction called ((hybrid concrete)),the main objective for using the hybrid concrete is to increase the load carrying capacity for the member. The concept of hybrid section in steel - concrete structures is not a new idea. Some of researchers[(1)] defined a hybrid girder as one that has either the tension flange or both flanges of steel section made with a higher strength grade of steel than used for the web. Others[(2)] defined hybrid concrete structures as structural elements consisting of new and old concrete layers. When extending the hybrid concept to composite concrete members and due to advances in concrete technology, it is relatively easy to produce composite sections which possess high compressive strength, high ductility, high energy absorption and high tensile strength at the same time, these characteristics can be achieved by placing two or more different types or strengths of concrete layers together so that each layer is used to its best advantage and as a result, the concrete section becomes a "hybrid" section. The present experimental work has been studied the behavior of hybrid reinforced concrete rectangular beam consists of two different concrete layers under shear behavior as an example for the term ((hybrid concrete)) ,the tension layer made of normal concrete while the compression layer made with self compacting concrete taken into account different types of concrete material in the cross section (non- homogenous beams) in order to know the effect of some main variables such as the concrete strength (fc`) and the steel ratio (ρ_w) and to check the adequacy of using the same shear strength equations which derived for normal concrete to calculate the shear strength for hybrid concrete , these equations are listed in **Table(1)**below.

Table (1) the Adopted Methods for Calculating Shear Strength of Beams

METHOD	EQUATION
ACI.318M-08.Code[3]	$\phi V_c=0.75\ [\ 0.16\ \lambda\ \sqrt{fc`}\ +17(\ \rho w\ V_u d/M_u)]\ b_w d + 0.75\ \rho_v f_{yv} b_w.d$
British Standard (B.S.8110)[4]	$\phi V_c=[0.79(100\rho_w)^{1/3}(400/d)^{1/4}(f_c'/20)^{1/3}/1.25]b_w d+0.95\ \rho_v f_{yv} b_w d$
Canadian Code 1984[5]	$\phi V_c= 0.12\sqrt{f_c'}b_w d + 0.85\ \rho_v f_{yv} b_w d$
New Zealand Code[6]	$\phi\ V_c = 0.85[(0.07+10\ \rho_w)\ \sqrt{f_c'}b_w\ d\ ] + 0.85\ \rho_v f_{yv} b_w d$
Zsutty Method[7]	$\phi V_c= 0.75[2.2(\ f_c'\rho_w d/a)^{1/3} b_w d]\ +0.75\ \rho_v f_{yv} b_w d$

2-Experimental Study:

2-1-ExperimentalProgram:

The investigation consists of (15) simply supported beams under the effect of single point load and have been designed with minimum shear reinforcement to ensure shear failure with ductile behavior, the experimental variables are:

1) Compressive strength equal to 25 MPa for normal strength concrete(NSC) and (25, 50) MPa for self-compacting concrete(SCC).

2) The total number of steel bars with (12) mm diameter will be (4, 5 and 6) in the tension zone and the steel reinforcement ratio(ρ_w) will be ranging between 0.013 to 0.0194.

2-2- Beam Specimens Details:

All beams tested in this study, are rectangular beams (b_w=180mm, h=250mm). (The length= 1200mm) have been cast in a steel form and reinforced with two plain of (6) mm diameter in the compression zone just to hold and fix in position the shear reinforcement. Figures (1) and (2) show all beam details. The total numbers of tested beams are (15) and divided into five groups according to the type of concrete and number of bars in the tension zone as shown below:

1-**Group BN:** Three beams made with normal strength concrete having compression strength equal to 25 MPa.

2-**Group BSC(25):**Three beams made with self-compacting concrete having compression strength equal to 25 MPa.

3-**Group BSC(50):** Three beams made with self-compacting concrete havingcompression strength equal to 50 MPa.

4-**Group BHY(25):** Three beams made in two layers:

a) first layer with depth (170)mm casting by normal concrete having compression strength equal to 25 MPa.

b) second layer with depth (80)mm casting by self-compacting concrete having compression strength equal to 25 MPa.

5-**Group BHY(50):** Three beams made in two layers:

a) first layer with depth (170)mm casting by normal concrete having compression strength equal to 25 MPa.

b) second layer with depth (80)mm casting by self-compacting concrete having compression strength equal to 50 MPa.

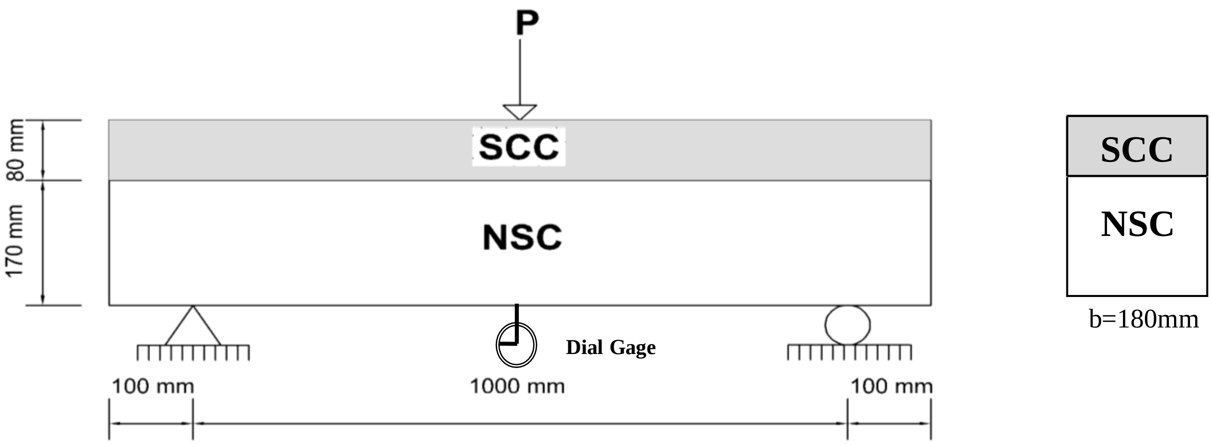
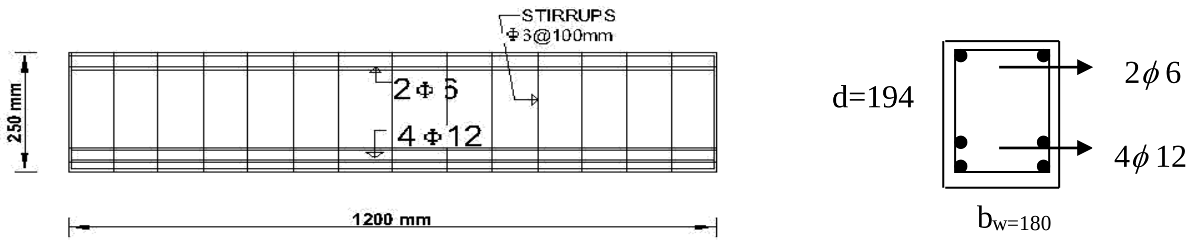
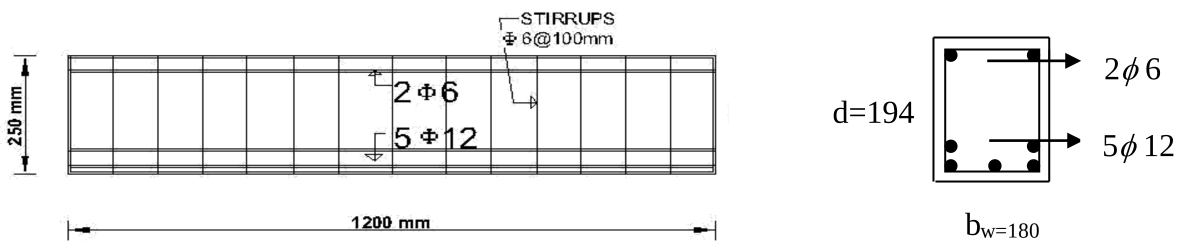


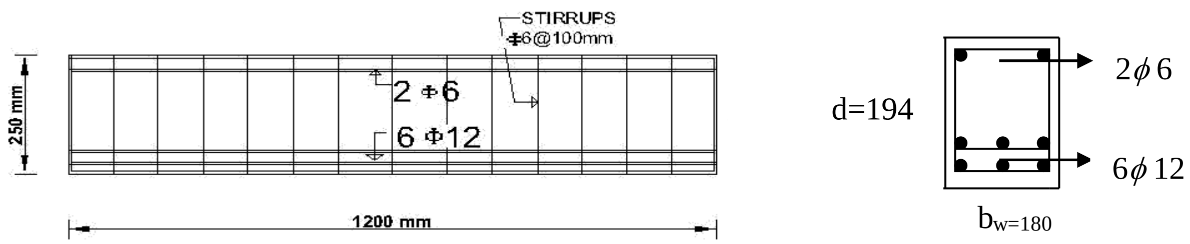
Figure (1) Hybrid Beam Profile and Loading Arrangement.



(a) Beam with 4ϕ12 at Tension Zone (ρ_w=1.3% ,ρ_v=0.00314).



(b) Beam with 5ϕ12 at Tension Zone(ρ_w=1.6%,ρ_v=0.00314).



(c) Beam with 6 ϕ12 at Tension Zone(ρ_w=1.94% ,ρ_v=0.00314).

Figure (2) Beams Profile Showing Flexural and Shear Reinforcement.

2-3-Casting Procedure:

The beams and control specimens have been treated according to the type of concrete in each group as follow:

♦**Group BN**: The beams and control specimens are fully compacted on a vibrating table. The vibration time to reach full compaction is decided upon by the stop of air bubbles migration from fresh concrete. The specimens are then cast into three layers, in which(25 – 30) seconds are required for compaction per layer.

♦**Group BSC (25) and Group BSC(50)**: The beams and control specimens filled with self compacting concrete without compacting.

♦ **Group BHY(25) and Group BHY(50):** The beams have been made from two separate concrete mixes, the bottom layer of 170 mm depth of NSC cast in two layers, and during the initial setting time (30-40) minutes ,the upper layer of SCC with 80 mm has been placed.

2-4-Materails:

In manufacturing test specimens, the following materials have been used: ordinary Portland cement **(Type 1);**rounded gravel with maximum size of (10mm);natural sand from AL-Ukhaider region,Karbala,Iraq, with fineness modulus of (2.6);high water reducer superplasticizer (Glenium 51);limestone powder (LSP) has been used for SCC mix ,clean tap water has been used for both mixing and curing. Three concrete mixes have been designed in this study (NSC25, SCC25and SCC50).The concrete mix properties are reported and presented in **Table (2).**

Table (2) Details of Mixes

Mixture	Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	LSP Kg/m^3	Water(w) L/m^3	Total (cement+LSP) (p)	w/p	Dosage of SP (%) by weight of cement
NSC(25)	300	600	1100	-----	150	300	0.5	------
SCC(25)	280	780	850	240	180	520	0.34	1.4
SCC(50)	500	785	850	85	173	585	0.29	7.5

2-5-Reinforcement Design:

All beam specimens have been designed in accordance with ACI 318M-08[3]. Deformed longitudinal steel bars have been used in this study with a nominal diameter of (12)mm for the longitudinal reinforcement in the tension zone and plain steel of (6)mm diameter used for stirrups and in the compression zone just to hold stirrups, **Table(3)** gives the results of three 400 mm long specimens from each nominal diameter

Table(3) Properties of Steel Reinforcement

Diameter(steel bar)mm	f_y (MPa)	f_u(MPa)
12	412	670.5
6	290	580.4

2-6-Test Measurement and Instrumentation:

All beams specimens as well as control specimens were tested at ages of(30-32) days by using the hydraulic universal testing machine (MFL system) with a maximum rang capacity of (300kN), vertical deflection was measured at mid-span of beam specimens by using a dial gauge of (0.01mm/div.)accuracy at every load stage.

2-7-Experimental Results of control specimens:

2- 7-1-Fresh concrete properties:

For each mix of SCC, the fresh properties are evaluated and compared with the requirements of SCC. The tests include the slump flow and L-box, as summarized in **Table (4)**where (D) represent the maximum spread slump flow final diameter, the (T_{50}) represent the time required for the concrete flow to reach a circle with 50 cm diameter, (H_2/H_1) represent the blocking ratio (BR), while the values of T_{20} and T_{40} represent the time of the concrete flow to 200 and 400 mm respectively

Table (4) Results of Fresh Concrete Properties

Mixture	Slump Flow Test		L-box Test		
	D (mm)	T_{50} (sec)	BR%	T_{20} (sec)	T_{40} (sec)
SCC (25)	670	2.5	0.83	1.3	3.2
SCC (50)	730	4.8	0.92	2.5	6.5

2-7-2Mechanical Properties of Hardened Concrete:

The results of mechanical properties of hardened concrete are summarized in **table (5).**The compressive strength has been carried out in accordance with ASTM C39M [(8)], (150*300mm) cylinders have been used to determine the compressive strength of NSC and SCC respectively. The indirect tensile strength (Splitting tensile strength) has been carried out according with ASTM C496 [(9)]by using of (150*300mm) cylinders for NSC and SCC respectively. Flexural strength (modulus of rupture) test has been carried out on NSC and SCC in accordance with

ASTM–C78 [10] using (100*100*500mm) beam specimens (prisms). The modulus of Elasticity has been carried out on NSC and SCC in accordance with ASTM C469-02a [11]using (150*300mm) cylinders.

Table (5) Mechanical properties of hardened concrete*

MIX		f_c'test (MPa)	$f_t$test (MPa)	$f_r$test (MPa)	$E_c$test (MPa)
NSC (25)		26	3.11	4.18	24300
SCC (25)		24.7	2.95	3.72	23853.33
SCC (50)		48.8	4.33	5.66	33670.65
BHY (25)	NSC	25.7	3.15	4.15	24400.33
	SCC	24.6	2.85	3.8	22329.67
BHY (50)	NSC	25.8	3.35	4.16	24690.22
	SCC	49.5	4.47	5.7	34318.13

*Average of three specimens for each concrete type

2-8- Testing Procedure:

All beams have been tested at ages of (30-32) days. Before the testing day, the beam specimens have been cleaned and painted with white color in order to clarify the crack propagation. The beam specimens have been labeled and placed on the testing machine and adjusted so that the centerline supports and point load in their correct or proper locations. The marked point loading has been covered by (100*50*30 mm) steel plate to avoid stress concentrations on the upper face of the beams during loading. One dial gauge has been mounted in its marked position to touch the bottom of center of beam having an accuracy of (0.01 mm) and a maximum travel distance of (30 mm) has been used to measure deflections of the tested beams at mid span, as shown in **Figure (1)**. Loading has been applied slowly in small increment (5) kN,the positions and extents of the first and the other consequent cracks have been marked on the surface of the beam and the magnitude of the load stage at which these cracks occurred has been written. The failure load has been recorded and the load has been removed to allow taking some photographs for the tested beams.

3-Results and Discussion:

3-1-General Behavior:

Figure (3) shows the crack patterns after the final failure for the hybrid tested beams. The numbers shown beside the cracks indicate the load when the crack has reached that position. For all beams in the groups [BN,BSC(25),BSC(50),BHY(25) and BHY(50)],it can be concluded that these beams have similar linear behavior starts at regions near the supports towards the load causing failure as follows: at the early stages of loading, an inclined tensile crack is formed in the shear span between the applied load and the support increased ,gradually in depth above the tension reinforcement to be inclined towards the applied load, as the load increased, the diagonal crack is formed from the top of this crack and extends in the shear span towards the applied load. For the final stages of loading, the diagonal crack extends quickly in the compression zone towards the applied load and in the horizontal plane towards the longitudinal reinforcement in the tension zone leads to failure that can be regarded as a mode of diagonal tension failure where the cracks developed suddenly and led to destructive shear failure and the ductile behavior have been observed during the period between the early stages and the final stages of loading when inclined cracking occurs during the test due to use of a minimum area of the shear reinforcement. The primary difference between the observed cracking patterns was in beams of group BSC (50) and BHY (50) in the compression zone only, where the diagonal tension crack was wider in comparison with the beams in the other groups, this may be due to brittle behavior of the high compressive strength 50 MPa which makes the failure to arise suddenly.

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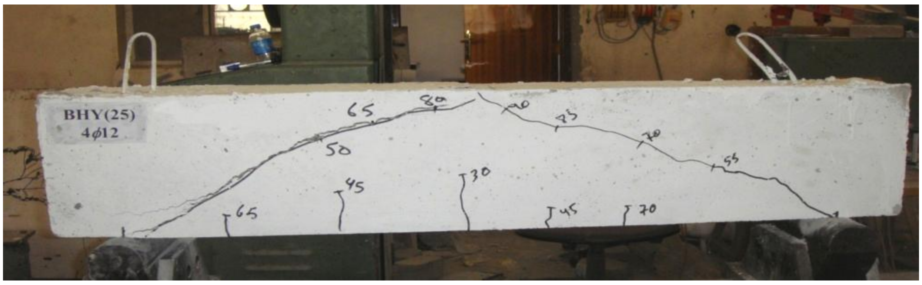

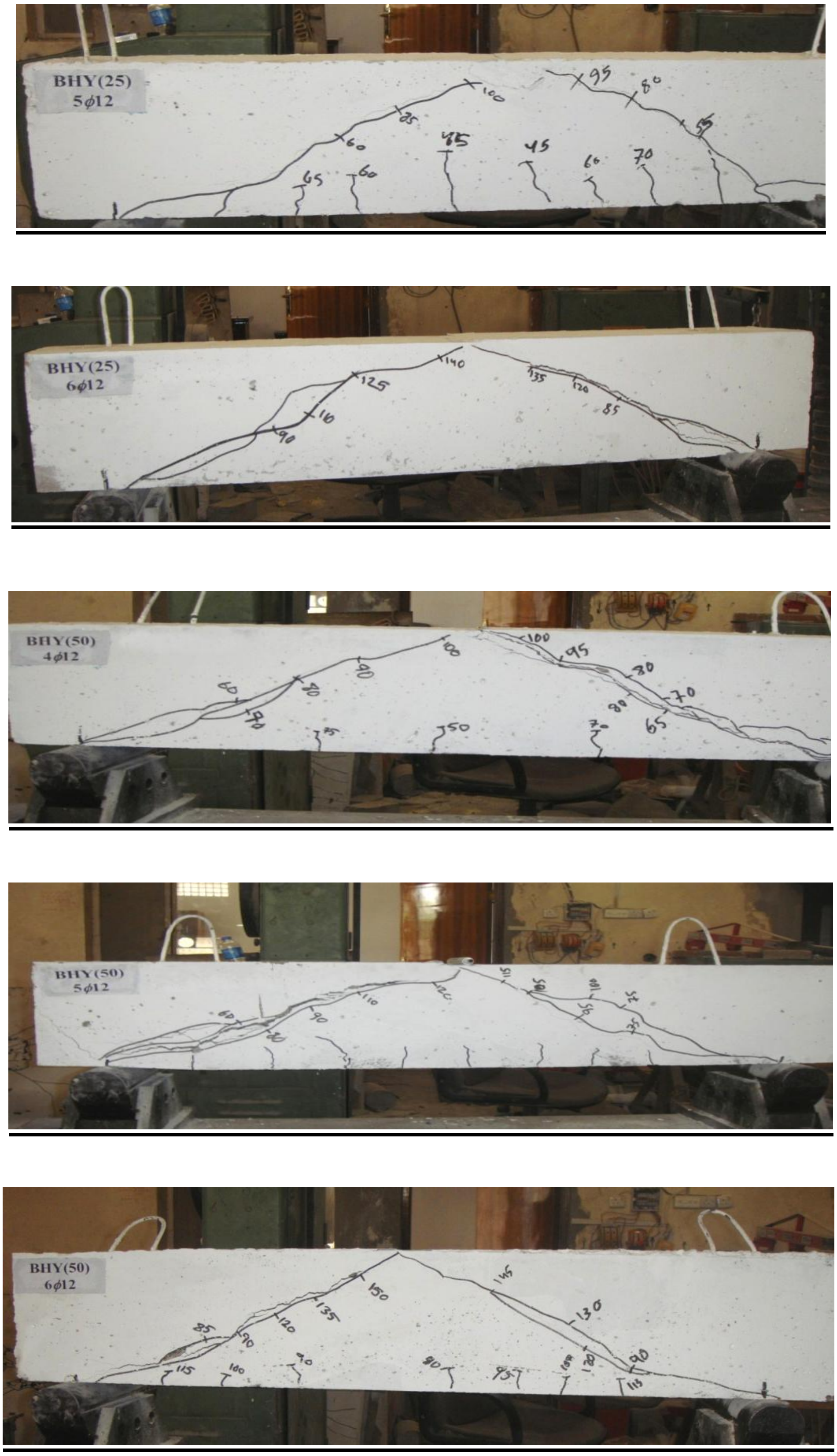

Figure (3) Crack Pattern for Tested Beams

3-2-Results of Beam Specimen:

The discussion of results will be concentrated on the following:

1. Diagonal cracking (V_{cr}) and concrete strength (V_c).
2. Effect of concrete compressive strength (f_c')
3. Effect of tensile steel ratio (ρ_w)

3-2-1-First Diagonal cracking and ultimate shear strength (V_{cr}, V_c) :

The first diagonal cracking load (V_{cr}) represents the shear load at the time when the critical diagonal crack is formed during the early stages of loading within the shear span crossing the mid-depth of the beam, while the concrete strength (V_c) represent the maximum load causing shear failure in the beam, which means the ultimate shear strength for the beam. The values of the diagonal cracking load obtained from tested beams are not very accurate like the ultimate load because they are sensitive to the adjustment by the observer. Table (6) shows the diagonal cracking load and the concrete strength for all beams in the experimental work, these values differ from one beam to another depending on the variation of the type of concrete, concrete compressive strength (f_c'), tensile steel ratio (ρ_w) and the type of beam (homogeneous, hybrid). From Table (6) , the first diagonal cracking load (V_{cr}) and the ultimate shear strength (V_c) for the hybrid beams in group BHY(25) which consists of two concrete layers having the same concrete compressive strength (f_c') are approximately close values of beams in group BN and BSC(25) which made with one type of concrete (f_c'=25 MPa).For the hybrid beams in group BHY(50) which made in two layers with different concrete compressive strength 25 MPa and 50 MPa, the first diagonal cracking loads (V_{cr}) are approximately close values of normal beams BN because the first diagonal crack forms in the lower part of beam which made with normal strength concrete, while the ultimate shear strength (V_c) are higher than beams in group BN and BSC(25) and lower than beams in group BSC(50),this behavior caused by incorporating self-compacting concrete with high compressive strength 50 MPa instead of normal concrete in the compression zone led to increase in beam stiffness and improved the resistance to tensile cracking in the upper part of the beam and a result, the overall strength of the beam is increased. Generally, it can be seen from the test results for the hybrid beams in both groups BHY(25) and BHY(50) that the shear strength for these beams is found to be influenced by the same factors that affect the homogenous beams, however, shear strength increases with the increase in (f_c') and (ρ_w).

Table (6) Diagonal Cracking and Shear Strength for Tested Beams.

Beam Notation		fc' (MPa)	V_{cr} (kN)	V_c (kN)	Vcr /Vc (unit less)
GROUP BN	BN 4 Φ 12	26	52	97.5	0.53
	BN 5 Φ 12	26	57	112.5	0.50
	BN 6 Φ 12	26	65	147.5	0.44
GROUP BSC (25)	BSC(25) 4 Φ 12	24.7	48	94	0.51
	BSC(25) 5 Φ 12	24.7	55	109	0.50
	BSC(25) 6 Φ 12	24.7	60	150	0.40
GROUP BSC (50)	BSC(50) 4 Φ 12	48.8	60	115	0.52
	BSC(50) 5 Φ 12	48.8	73	137.5	0.53
	BSC(50) 6 Φ 12	48.8	79	167.5	0.47
GROUP BHY(25)	BHY(25) 4 Φ 12	25.7 24.6	50	92.5	0.54
	BHY(25) 5 Φ 12	25.7 24.6	52	105	0.49
	BHY(25) 6 Φ 12	25.7 24.6	64	142	0.45
GROUP BHY(50)	BHY(50) 4 Φ 12	25.8 49.5	53	103	0.51
	BHY(50) 5 Φ 12	25.8 49.5	58	120	0.48
	BHY(50) 6 Φ 12	25.8 49.5	66	152.5	0.43

3-2-2-Effect of concrete compressive strength (f_c'):

As shown in **Table (6)** given above, increasing the compressive strength of concrete results in an increase in the first diagonal cracking load and the ultimate shear loads for the beams having the same amount of tensile reinforcement. This fact can be discussed by making a comparison between the groups as follow:

<u>1-**Groups BSC(25) and BSC(50):**</u>the beams in these groups consist of similar type of concrete (SCC) but they are different in the concrete strength (f_c') for example, increasing of (f_c') from 24.7 MPa to 48.8 MPa for the beams with ρ_w qual to 1.3% such as BSC(25)4ϕ12 and BSC(50) 4ϕ12, increases the first diagonal cracking load by 25 % and the ultimate shear load by 22%, for the beams with ρ_w equal to 1.6% such as BSC(25) 5ϕ12 and BSC(50) 5ϕ12, increases the first diagonal cracking load by 32 % and the ultimate shear load by 26 % and for the beams with ρ_w equal to 1.94 % such as BSC(25) 6ϕ12 and BSC(50) 6ϕ12, increases the first diagonal cracking load by 31 % and the ultimate shear load by 11%.As a result of increasing (f_c') from 24.7 MPa to 48.8 MPa,it can be said that the average percent of increment in the first diagonal cracking load and the ultimate shear load are 29 % and 20 % respectively, from these results, it can be noted that the increasing in the first diagonal cracking load is higher than the increasing in the ultimate shear load and this may be caused by using a minimum amount of shear reinforcement in the beams.

<u>2-**Groups BHY(25) and BHY(50):**</u>the beams in these groups are hybrid and made with two different layers of concrete, as examples, increasing of (f_c') for the compressive layer from 24.6 MPa to 49.5 MPa ,for the beams with ρ_w equal to 1.3 %such as,BHY(25) 4ϕ12 and BHY(50) 4ϕ12, increases the first diagonal cracking load by 6 % and the ultimate shear loads by 11 %, for the beams with ρ_w equal to 1.6% such as,BHY(25) 5ϕ12 and BHY(50) 5ϕ12, increases the first diagonal cracking load by 11 % and the ultimate shear loads by 14 %, and for the beams with ρ_w equal to 1.94% such as,BHY(25) 6ϕ12 and BHY(50) 6ϕ12, increases the first diagonal cracking load by 3 % and the ultimate shear loads by 7 % .As a result of increasing (f_c') for the compressive layer from 24.6 MPa to 49.5 MPa,it can be said that the average percent of increment in the diagonal cracking load and the ultimate shear load are 6.6 % and 10.6 % respectively.

<u>3-**Groups BN, BSC (50) and BHY (50):**</u> the beams in these groups are different in the type of concrete (Normal, SCC) and in the type of beam (homogeneous, hybrid). As examples on these groups, for the beams with ρ_w equal to 1.3% such as,BN 4ϕ12, BSC(50) 4ϕ12 and BHY(50) 4ϕ12, the first diagonal cracking loads are (52 , 60 and 53)kN respectively and the ultimate shear

loads are (97.5 , 115 and 103)kN respectively, the hybrid beam BHY(50) 4ϕ12 show higher cracking load by 1.92% and ultimate loads by 6% compared to the normal concrete beam BN 4ϕ12, but lower cracking load by 13.2% and ultimate loads by 11.65% compared to the beam BSC(50) 4ϕ12, for the beams with ρ_w equal to 1.6% such as,BN 5ϕ12, BSC(50) 5ϕ12 and BHY(50) 5ϕ12, the diagonal cracking loads are (57, 73 and 58)kN respectively and the ultimate shear loads are (112.5 ,137.5 and 120)kN respectively, the hybrid beam BHY(50) 5ϕ12 show higher cracking load by 1.7% and ultimate loads by 6.6% compared to the normal concrete beam BN 5ϕ12, but lower cracking load by 25.8% and ultimate loads by 14.6% compared to the beam BSC(50) 5ϕ12, for the beams with ρ_w equal to 1.94 %such as,BN 6ϕ12, BSC(50) 6ϕ12 and BHY(50) 6ϕ12, the diagonal cracking loads are (65 , 79 and 66)kN respectively and the ultimate shear loads are (147.5,167.5 and 152.5)kN respectively, the hybrid beam BHY(50) 6ϕ12 show higher cracking load by 1.5% and ultimate loads by 3.4% compared to the normal concrete beam BN 6ϕ12, but lower cracking load by 19.7% and ultimate loads by 9.8% compared to the beam BSC(50) 6ϕ12. As a final result, it can be said that the hybrid beam in group BHY(50) show higher average shear strength by 5.2 % compared to the normal beams in group BN but lower average shear strength by 12 % compared to the beams in group BSC(50).

The previous comparisons show that increasing of the compressive strength of concrete leads to an increase in the shear capacity of beams, this may be for the following reasons: Increasing f_c' increases the inclined cracking load. The interaction between shear stresses and tensile stresses in the tension zone of the beam, may have caused inclined tensile cracking. After an inclined crack occurs, the dowel force in the longitudinal reinforcement begins resisting shearing displacement at the crack, and that resistance tends to raise tensile stresses in the tension steel surrounding concrete. When stresses exceed concrete tensile strength, they produce splitting cracking along the reinforcement and a failure in the tension zone. Therefore, the dowel force increases with the increase of f_c', since increasing f_c' will increase the tensile strength of concrete [12].

3-2-3-Effect of tensile steel ratio (ρ_w):

It can be seen from Table (6) that increasing the amount of reinforcement results in an increase in the shear strength for all tested beams as follows:

Group BN: increasing (ρ_w) from 1.3% to 1.94 % for the normal beams increases the first diagonal cracking load for these beams by 25% and the ultimate shear strength by 51 %.

Group BSC(25): increasing (ρ_w) from 1.3% to 1.94 % for the SCC beams increases the diagonal cracking load for these beams by 24 % and the ultimate shear strength by 59 %.

Group BSC(50): increasing (ρ_w) from 1.3% to 1.94 % for the SCC beams increases the diagonal cracking load for these beams by 31.6 % and the ultimate shear strength by 45.6%.

Group BHY(25): increasing (ρ_w) from1.3% to 1.94 % for the hybrid beams increase the diagonal cracking load for these beams by 28 % and the ultimate shear strength by 53.5 %.

Group BHY(50): increasing (ρ_w) from 1.3% to 1.94 % for the hybrid beams increase the diagonal cracking load for these beams by 24 % and the ultimate shear strength by 48%.

From the test results, it is obvious that the hybrid beams are influenced by the increasing of (ρ_w) as the other homogenous beams but in various ratio,however,the increasing of (V_{cr}) and (V_c) for the hybrid beams in group BHY(25) are 28% and 53.5% respectively, whereas the increasing of(V_{cr})and (V_c) for group BN are 25%and51%respectively, and for beams in group BSC(25) are 24% and 59% respectively. On the other hand , the increasing of (V_{cr}) and (V_c) for the hybrid beams in group BHY(50) are 24% and 48%respectively, whereas the increasing of(V_{cr})and (V_c) for group BN are 25% and 51% respectively and for beams in group BSC(50) are 31.6% and 45.6% respectively, which means that ,these hybrid beams in group BHY(50) show lower shear strength by 1% than normal strength and higher by 2.4% than SCC beams in group BSC(50) as a result of increasing ρ_w from 1.3 % to 1.94%.

The effect of tensile steel ratio may be explained, as follows. ρ_w has an effect on the basic shear transfer mechanism. An important factor that affects the rate at which an inclined tensile crack develops into a diagonal cracking is the magnitude of shear stresses near the tip of that crack. The intensity of principal stresses above the inclined tensile crack depends on the depth of penetration of the crack, the value of (ρ_w) and the applied load. These stresses will result in diagonal tension cracking. Increasing ρ_w increases the dowel capacity of the member by increasing the dowel area and hence decreasing the tensile stresses induced in the surrounding concrete. Also, increasing ρ_w affects the aggregate interlock capacity. Beams with low ρ_w will have wide, long cracks in contrast to the shorter and narrow cracks found in beams with high ρ_w. Since the aggregate interlock mechanism depends on the crack width, an increase in the aggregate interlock force is to be expected with an increase in ρ_w(13).

3-3- Load Deflection Behavior:

Figures (4) to (**6**) show load-deflection curves, depending upon the amount of tensile steel reinforcement and the concrete strength, the maximum deflections at failure are not obtained to avoid dial gage damage. The deflection has been measured at mid-span point. Comparison of load-deflection behavior for the beams inside each group, which have approximately the same concrete strength but different amounts of steel, show that the beams with the higher steel content have a stiffer response in terms of load-deflection, this behavior is applied on the hybrid beams. The reason is primarily due to the large effective moment of inertia due to large amount of tensile reinforcement. Comparison of load-deflection behavior for beams which have the same amount of steel with different concrete strength shows that the deflection decreases with the increase of f_c', this is because deflection is influenced by the beam stiffness. The behavior of the hybrid beams in group BHY(50) was generally similar to the beams in group BSC(50),while the hybrid beams in group BHY(25) and the normal beams BN have approximately the same load-deflection behavior.

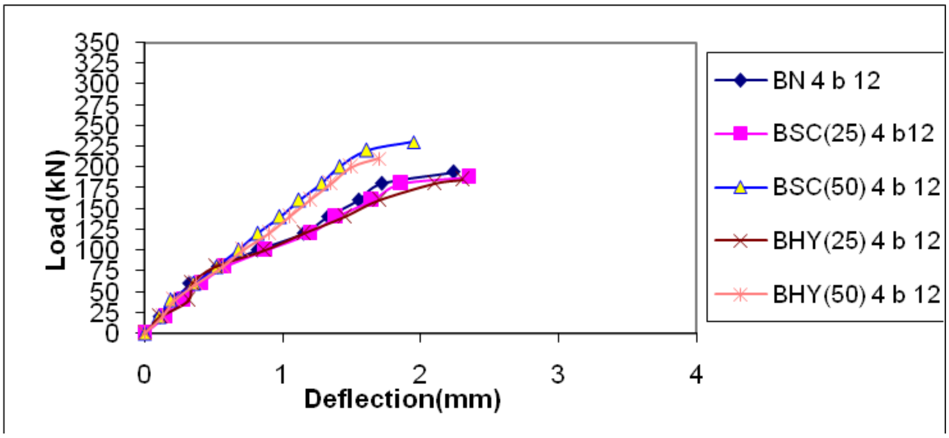

Figure (4) Load-Deflection for Beams with Reinforcement of (4 ϕ 12)

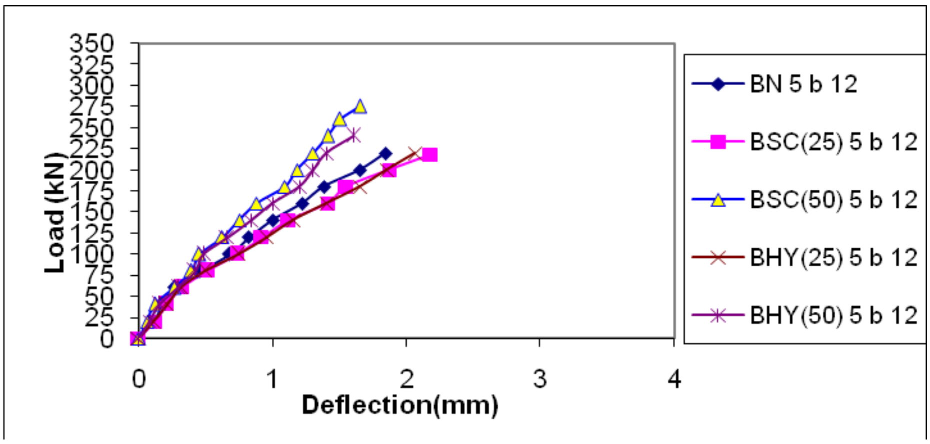

Figure (5) Load-Deflection for Beams with Reinforcement of (5 ϕ 12)

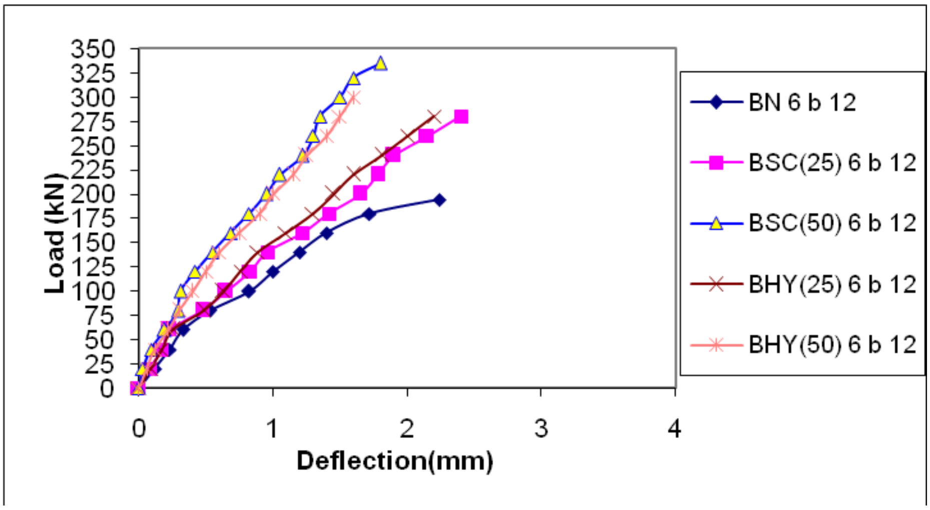

Figure (6) Load-Deflection for Beams with Reinforcement of (6 ϕ 12)

3-4-Comparison of The Tested Results With The Current Design Approaches:

The ultimate design shear for the tested beams are calculated according to the formulas of the standard building code ACI.318M-08,British Standard Code [B.S 8110],Canadian Code 1984(CAN),New Zealand Code 1982(NZ) and Zsutty Method(ZST) by using the equations reported in **Table (1)**. In order to examine the efficiency of these design equations in predicting the ultimate shear of beams, they are applied for each group of beams failing in shear, and the relative shear strength values (RSSV=$V_{TEST}/V_{r\ DES}$) are found using these equations as shown in **Table (7),** then, the value of the coefficient of variation [COV] has been calculated for each equation, and the equation which gives the lowest [COV] values will be the best prediction for the group.

Table (7)Results of Experimental Work and the Relative Shear Strength Values

Beam	V_{TEST} (kN)	V_{DES} (kN)					V_{TEST} / V_{DES}				
		ACI	BS	CAN	NZ	ZST	ACI	BS	CAN	NZ	ZST
BN (4 Φ 12)	97.5	47.45	62.68	48.39	57.3	53	2.05	1.55	2.01	1.7	1.84
BN (5 Φ 12)	112.5	47.98	64.93	48.39	61.84	55.22	2.34	1.73	2.32	1.82	2.03
BN (6 Φ 12)	147.5	48.55	67.17	48.39	66.98	57.28	3.04	2.19	3.05	2.2	2.57
BSC(25)(4 Φ 12)	94	46.85	61.15	47.85	56.53	52.74	2	1.53	1.96	1.66	1.78
BSC(25)(5 Φ 12)	109	47.45	63.36	47.85	60.96	54.69	2.29	1.72	2.27	1.78	1.98
BSC(25)(6 Φ 12)	150	48	65.57	47.85	65.97	56.75	3.125	2.28	3.13	2.27	2.64
BSC(50)(4 Φ 12)	115	55.34	69.03	56.3	68.5	59.87	2.07	1.66	2.04	1.67	1.92
BSC(50)(5 Φ 12)	137.5	55.86	71.8	56.3	74.72	62.54	2.76	1.91	2.44	1.84	2.19
BSC(50)(6 Φ 12)	167.5	56.45	74.57	56.3	81.77	65.07	2.96	2.24	2.97	2.05	2.57
BHY(25)(4 Φ 12)	92.5	47.14	66.96	48.08	56.85	47.02	1.96	1.38	1.92	1.62	1.96
BHY(25)(5 Φ 12)	105	47.66	69.64	48.08	61.32	48.65	2.2	1.5	2.18	1.71	2.15
BHY(25)(6 Φ 12)	142	48.26	72.26	48.08	66.4	50.33	2.94	1.96	2.95	2.14	2.82
BHY(50)(4 Φ 12)	103	50.73	71.21	51.66	61.93	49.34	2.03	1.44	2	1.66	2.08
BHY(50)(5 Φ 12)	120	51.24	74.18	51.66	67.17	51.14	2.34	1.62	2.32	1.78	2.34
BHY(50)(6 Φ 12)	152.5	51.85	77.11	51.66	73.1	52.98	2.94	1.97	2.95	2.08	2.87

The comparison show that, the best predicted formula for all the groups is the New Zealand code as explained below:

1-**Group BN**:the Coefficient of Variation values(%) for the formulas (ACI,BS,CAN,NZand ZST) are (20.56, 18.13, 21.66, 13.68 and 17.66) respectively,itis obvious that the best predicted formula for all the groups is the New Zealand code which gives the lowest [COV] value.

2-**Group BSC(25)**: the Coefficient of Variation values(%) for the formulas (ACI,BS,CAN,NZandZST)are(23.48,21.19,24.48,16.84and21.12)respectively,itis obvious that the best predicted formula for all the groups is the New Zealand code which gives the lowest [COV] value.

3-**Group BSC(50)**: the Coefficient of Variation values(%) for the formulas (ACI,BS,CAN,NZandZST)are(17.67,15.02,18.54,10.27and14.41) respectively,itis obvious that the best predicted formula for all the groups is the New Zealand code which gives the lowest [COV] value.

4-**Group BHY(25):** the Coefficient of Variation values(%) for the formulas (ACI,BS,CAN,NZandZST)are(21.61,18.63,22.55,14.83and19.48)respectively,itis obvious that the best predicted formula for all the groups is the New Zealand code which gives the lowest [COV] value.

5-**Group BHY(25):** the Coefficient of Variation values(%) for the formulas (ACI,BS,CAN,NZandZST)are(18.93,16.16,19.83,11.41and16.32) respectively,itis obvious that the best predicted formula for all the groups is the New Zealand code which gives the lowest [COV] value.

4-Conclusions:

Based on the results obtained from experimental work for (15) rectangular reinforced concrete beams were made from normal strength concrete, self compacting concrete and hybrid concrete besides to their corresponding cylinders and prisms specimens, the following conclusions can be drawn:

1. The hybrid beams as the other tested beams failed in shear in similar linear behavior and the mode of shear failure for all beams was diagonal tension failure.
2. The hybrid beams are influenced by the same factors (fc' and ρ_w) that affect the homogenous beams.
3. The hybrid beams with high strength self compacting concrete BHY (50) give higher average shear strength by 5.2% compared to the normal beams and lower shear strength by 12 % compared to the beams made with high strength self-compacting concrete BSC (50) while the hybrid beams with normal strength self-compacting concrete BHY (25) give approximately close shear strength values of normal beams.
4. Shear strength of the hybrid beams and the other homogenous beams increases with the increase of ρ_w from 1.3 % to 1.94 % as follow:

   a. for normal beams, the diagonal cracking load increases by 25% and the ultimate load by 51 % .

   b. for normal strength SCC beams BSC(25),the diagonal cracking load increases by 24 % and the ultimate load by 59 % .

   c. for high strength SCC beams BSC(50) ,the diagonal cracking load increases by 31.6% and the ultimate load by 45.6 %.

   d. for the hybrid beams BHY(25) ,the diagonal cracking load increases by 28 % and the ultimate load by 53 %.

e. for the hybrid beams BHY(50) ,the diagonal cracking load increases by 24% and the ultimate load by 48 %.

5. A comparison of the load-deflection behavior shows that, the behavior of the hybrid beams in group BHY (50) was generally similar to the beams in group BSC (50), while the hybrid beams in group BHY (25) and the normal beams BN have approximately the same load-deflection behavior.
6. The five different codes of design approaches for prediction of shear strength in beams; ACI.318M-08, British Standard Code [B.S 8110], Canadian Code 1984, New Zealand Code and Zsutty Method give underestimation to the experimental shear strength, therefore; all these formulas are conservative for the beams but the best predicted formula for all the groups was the New ZealandCode equation.

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6-Notations:

a/d	Shear Span to Depth Ratio
b_w	Width of the Beam,mm
d	Effective Depth of the Beam,mm
f_c'	Compressive Strength of Concrete Based on ASTM Specifications,MPa
V_u	Ultimate Shear Force at the section,kN
ρ_w	Tensile Steel Ratio
ρ_v	Shear Reinforcement Ratio
M_u	Ultimate Moment at the Section,kN.mm