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BEHAVIOR OF HIGH STRENGTH SELF COMPACTING CONCRETE HSSCC SHALLOW BEAMS IN SHAEAR

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ملخص البحث:

مع التطور المذهل فى مجال البناء و الإبداعات المتجددة فب الاشكال المعمارية المعقدة تظهر الحاجة جلية لخرسانة قادرة علي ملأ الشدات الخشبية و الفراغات بين أسياخ التسليح المتشابكة تحت تأثير وزنها بدون الحاجة لدمك ميكانيكي هذا و مع أنتشار الخرسانة عالية المقاومة و شيوعها تم عمل برنامج بحثي وضع لدراسة صلاحية معادلات الأكواد الحالية للكمرات الضحلة المصبوبة بأستخدام خرسانة عالية المقاومة ذاتية الدمك و دراسة تأثير نسبة تسليح القص و مسافات الكانات و قطر الكانات المستخدمة.

ستة كمرات ضحلة تم صبها بأستخدام خرسانة عالية المقاومة ذلتية الدمك(ذات مقاومة مميزة 82.1 نيوتن/مم2) بأبعاد (400 مم عرض و 200 مم سمك و 1800 مم طول بحر) صممت لكي تنهار فقط تحت إجهادات القص مع دراسة المتغيرات التالية : إختلاف نسب التسليح المقاوم للقص, مسافات الكانات و قطرالكانات و احدة من العينات تم صبها بدون كانات كعينة مرجعية و لتوضيح تأثير التسليح الطولي (المقاوم للإنحناء) على مقاومة القطاع في القص و تهدف الورقة البحثية لدراسة سلوك الكمرات الخرسانية الضحلة المصبوبة بأستخدام خرسانة عالية للمقاومة مع الأخذ في الإعتبار تاثير زيادة حديد القص و المسافات بين الكانات و قطر الكانات المستخدمة و مقارنة القيم الفعلية بقيم الأكواد المختلفة مع تقديم تعديل مقترح على معادلة الكود المصري لحساب مقاومة القص للكمرات الضلحة.

ABSTRACT:

This paper presents an experimental study to better understand the Behavior of high strength Self compacting concrete Hidden beams failure in shear with and without web reinforcement. The experimental study presents the results of testing six high strength concrete hidden (shallow) casted with self- compacting concrete. Beams were specially reinforced to ensure a shear failure one of the beams were casted without any shear reinforcement for comparison purpose. The concrete cube compressive strength at the age of 28 days (fcu) reached 82.1 Mpa. The main variables in this study were the amount of shear reinforcement, shear reinforcement diameter, stirrups spacing and number of stirrups branches. The details of the beam specimens, material properties, concrete mixes, instrumentation and the testing procedure are presented in this paper. The loading with cross ponding deflection values and strain in both flexure and shear reinforcement were recorded all along with crack patterns, the effect of the studied variables was presented and discussed. And compared with codes limits and a modification was proposed to Codes equations

Keywords: Shear strength, Shallow beams, Self compacting concrete SCC, High strength concrete HSC, Stirrups spacing.

1. INTRODUCTION:

The SCC appear for the first time in Japan in the year 1988, Scene thin it has been the subject to numerous investigations in order to adapt it to modern concrete production. At the same time the producers of additives have developed more and more sophisticated plasticizers and super-plasticizer designed especially for the precast and the ready-mix industry. Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. 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 but with minimum works in the shortest pouring time.

According to (ECP 203-2007) [1] the shear stress in shallow beams must not exceed the concrete shear strength without any shear reinforcement. Also the code limit of the shear strength provided by concrete for hidden beams about two thirds of the regular dropped beams. ECP also enforce the use of min shear reinforcement. Which leads to a wider section to be reinforced as a hidden beam and with high flexure reinforcement in section to fulfil beam requirements. Which leads to extremely conservative design. Also for the Shear design of hidden wide beams, the code enforce arrangement of the stirrups so that the distance between branches of stirrups less than 250 mm.

High-strength concrete is new trend in reinforced concrete structures in last decades as it generally leads to the design of thin sections. and reduces the own weight, which leads to wider spans and smaller mass (smaller seismic effect).,duo to the usage of high strength mortar close to the strength of the aggregate the shear strength of High strength Concrete require further attention since the concrete shear strength formed partially of the aggregate interlock. According to “High-Strength Concrete: A Practical Guide” by Michael A. Caldarone [11] HSC is the concrete made with normal weight aggregate with a compressive strength higher than 50 MPa; There is a very few researches focused on the shear in Hidden beams specially the one cased with High strength concrete or self-compacting concrete SCC the following section summarize some of the previous research submitted in this subject:

"Shear Behavior of Self-Consolidating Concrete Beams"by Chien-Hung Lin and Jiunn-Hung Chen-ACI Structural Journal-May-June 2012[7]
"Shear Behavior of High-Workability Concrete Beams" by Chien-Hung Lin and Wen-Chih Lee-ACI Structural Journal-September-October 2003[8]
“On the Contribution of Shear Reinforcement in Shear Strength of Shallow Wide Beams” by Mohamed M. Hanafy, Hatem M. Mohamed and Nabil A.B. Yehia Life Science Journal 2012;9 [3]
"Shear Behavior and Performance of deep beams made with Self-Compaction Concrete" by Y.W. Choi, H. K. Lee, S.B. Chu, S.H. Cheong and W.Y. Jung ,ACADEMIC JOURNAL International Journal of Concrete Structures and Materials 2012[9]
“Shear Behavior of Self-Compacting High Strength Concrete I-beams” (Omer A. EL-Nawawy, Ahmed H. Ghallab, and Mohamed A. El-Alfy, 2013)Al-Azhar Magazine[4]

"Effect of tension lap splice on the behavior
of high strength self-compacted concrete beams"by Mahmoud A. El-Azab, Hatem M. Mohamed, Ahmed Farahat,Alexandria Engineering Journal (2014) 53, 319–328[10]

2. CODES’ REVIEW FOR SHEAR OF SHALLOW (HIDDEN) BEAMS

Egyptian Code of practice (ECP 203-2007) [1]

The current Egyptian Code of practice (ECP 203-2007) Calculate the shear Strength of shallow beams as following:

$$q_u \leq q_{cu} \tag{1}$$

$q_{cu} = 0.16 \, (f_{cu} / \gamma_c)^{0.5} * b_w * d$ (2)

Where q_{cu} is the concrete shear capacity (N/mm^2), f_{cu} is the concrete cube strength (N/mm^2), γ_c is concrete strength reduction factor =1.50, d is the effective depth of the section (mm).and b_w is the width of the beam (mm). The code neglects the web reinforcement contribution in shear strength of shallow beams, while insist in provide a minimum web reinforcement.

American Concrete Institute (ACI 318-14) [2]

V_n nominal shear strength, = V_c concrete contribution + V_s. shear reinforcement contribution;

$\phi V_n \geq V_u$ (3)

$V_n = V_c + V_s$ (4)

Where V_u is the ultimate shear force at section, the concrete contribution term, ϕ strength reduction factor =0.75 in shear

V_c can be calculated by either simple equation (5) or the least of equations(6),(7) &(8):

$V_c = 0.17 \, (f_c{}')^{0.5} * b_w * d$ (5)

$V_c = [0.16 \, (f_c{}')^{0.5} + 17 \, \rho_w * (V_u*d/M_u)]*b_w*d$ (6)

$V_c = [0.16 \, (f_c{}')^{0.5} + 17 \, \rho_w \,]*b_w*d$ (7)

$V_c = 0.29 \, (f_c{}')^{0.5}*b_w*d$ (8)

If $V_u > \phi V_c$, shear reinforcement must be provided to sustain extra shear:

$V_s = A_v*f_y*d / S <= 0.66(f'_c)^{0.5} *b_w*d$ (9)

Where: V_u = factored ultimate shear force at the section(N), V_c = nominal shear strength provided by concrete (N), V_s = nominal shear strength provided by shear reinforcement (N), V_n = nominal shear strength (N), M_u = factored flexural moment at section (N.mm), ϕ = strength reduction factor = 0.75, $\rho_w = A_s/b_w d$, As = area of longitudinal reinforcement (mm^2), A_v = area of shear reinforcement (mm^2), b_w= web width of section (mm), d= distance from top of section to the longitudinal reinforcement (mm), s = spacing of the transverse reinforcement (mm), $f_c{}'$= concrete compressive cylinder strength (MPa), f_y = yield strength of stirrups reinforcement (MPa).

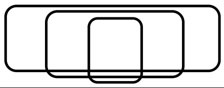
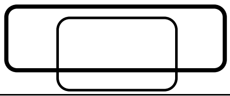
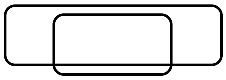
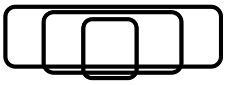
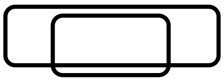
3. EXPERIMENTAL PROGRAM:

The experimental program was carried out to test six simply-supported reinforced concrete beams, the six beams were casted using high strength self compacting concrete HSSCC with compressive strength of f_{cu} =82.1 N/mm^2, Detailed description of the specimens, the material properties, test set-up, equipment, test procedure, and measurements are presented in the below section.

Test Specimens:

In the experimental program, tests were carried out on six concrete beams named (SCC1 to SCC6) where “SCC” refers to Slef compacted high strength concrete; The width/depth ratio was 2.42 in all specimens. All specimen were 400mm x 200mm section Dimension with length = 1800 mm, 1600mm clear span and the same Top flexural reinforcement (6T12) and bottom reinforcement (6T16+6T20). The beams were simply supported and subjected four point loading the details of the tested beams are shown in Table.1 and Figure.1

Table.1 Specimens reinforcement details.

Specimen	Longitudinal RFT		Web Shear RFT.	
	Bottom	Top	Stirrups	Stirrups configuration
SCC1	6T20 + 6T16	6T12	---	---
SCC2			6Y6@200	
SCC3			2Y8+2Y6@200	
SCC4			4Y6@135	
SCC5			6YT8@200	
SCC6			4T8@135	

The test specimens were divided into 4 groups.

Group No. (1): This group consists of four specimens (SCC2) Vs (SCC4) and (SCC5) Vs (SCC6) to study the effect of stirrups spacing and number of branches.

Groups No. (2): This group consists of four specimens (SCC2) Vs (SCC5) and (SCC4) Vs (SCC6) to study the effect of variation in shear reinforcement ratio.

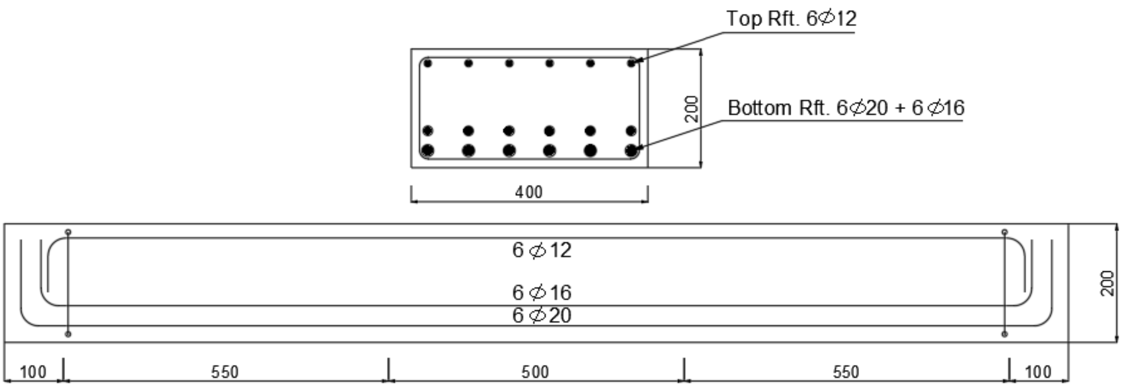


Figure.1 Flexure Reinforcement Configuration of All beams

Groups No. (3): This group consists of two specimens (SCC1) Vs (SCC2) to study the effect of absence shear reinforcement.

Groups No. (4): This group consists of two specimens (SCC2) Vs (SCC3) to study the effect of variation in shear reinforcement diameter.

Materials:

Seven Trial mixes were tried in the Concrete Research Laboratory at Cairo University to reach the target cubic compressive strength Fcu = 80 N/mm^2 The Final used mix tried at 28 days from the batch used in casting the actual samples the acquired Avg. Fcu = 82.1 N/mm^2 Table.2 shows mix Design by weight of the quantities needed for one cubic meter of concrete as one used in the experiment

Table.2 Mix Design of Self Compacting High Strength Concrete HSSCC

Fcu Target (N/mm^2)	Fcu Actual (N/mm^2)	Cement (Kg)	Silica Fume (Kg)	Crushed Dolomite (Kg)	Sand (Kg)	Water (liter)	Super-plasticizer (liter)
75	82	425	50	750	750	160	10

Test Procedure:

Static load hydraulic loading jack with an electrical load cell was used to apply the vertical load. A digital load indicator with 1 KN accuracy was used to measure the applied load.

Each specimen was centered on the loading machine. Loads were applied of specimens with load increment of 0.5 ton. Figure.3 shows a photograph for the General test arrangement, and Figure.2 shows a schematic view of the test setup. At every load increment, the cracks were observed and marked and continuous recording for deflection and steel strain in longitudinal reinforcement and stirrups, and load value from the loading cell using data accusation system. Failure was considered to occur when the load could not be increased further.

The deflections were measured at the mid-span and under loads of the beam by a dial gauge of 0.01mm accuracy (LVDT instrument). The crack propagation was monitored and drown on the beams during loading. The strain in reinforcement were measured using 100 mm gauge length for one deformed bar in the constant moment region and outer stirrups.

All test records were automatically saved on computer file for further data refining and plotting

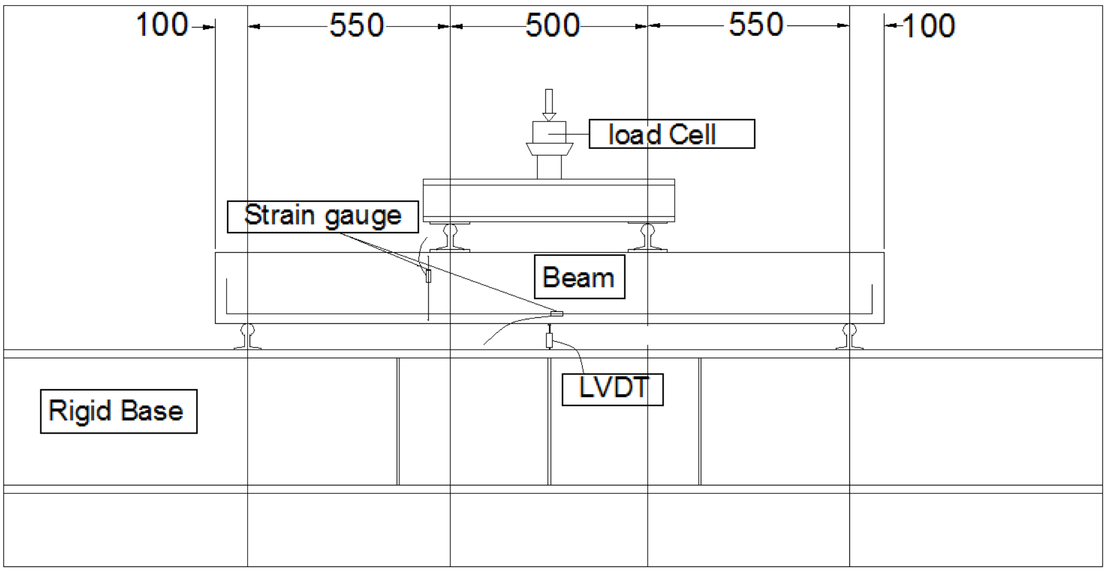


Figure.2, Schematic Test Setup

Figure.3 Test Arrangement

4. TEST RESULT:

For the six specimens the following changes were monitored: Cracking propagation and final Crack pattern, load – deflection was plotted, (First crack in Binding and shear first fully diagonal crack and Final failure load). A comparison between test results of shear strength according to ECP 203-2007 [1], ACI 318-14 [1] values is also presented in this section.

Cracking Pattern and Mode of Failure:

In all the six specimens, the first crack was a Flexure crack; thin shear cracks starts to appear and the flexure crack reached static case. The shear crack starts to develop to a full diagonal crack thin the beam still sustain load until failure in shear. The following recorded values were monitored.

First binding crack load and crossbonding deflection, First shear crack load and crossbonding deflection, load at First Full diagonal Crack and crossbonding deflection and Failure load with crossbonding final deflection.

Table 3 Illustrate the results of all tested specimens. The table gives the recorded loads at different stages for each beam.

Table.3 Summary of experimental results.

Sample Name	First Binding Crack (Ton)	First Shear Crack (Ton)	First Diagonal Crack (Ton)	Failure load (Ton)	Max Shear Force (Ton)	Max. deflection (mm)	stirrups configuration
SCC1	25	27.5	33.5	69.1	34.55	12.5	---
SCC2	19	30	39	72.1	36.05	11.75	6Y6@200
SCC3	15	35	50	71.4	35.7	8.25	2Y8+2Y6@200
SCC4	19	35	40	73.7	36.85	11.5	4Y6@135
SCC5	22.5	30	42	72.7	36.35	8.5	6YT8@200
SCC6	20	35	40	77.1	38.55	12.5	4T8@135

PS. Cracking load values rounded to the nearest 0.25 ton

Figures.4 shows the experimental results, failure & cracking patterns for all specimens.

Figure.4a, Crack pattern for Specimen SCC1.

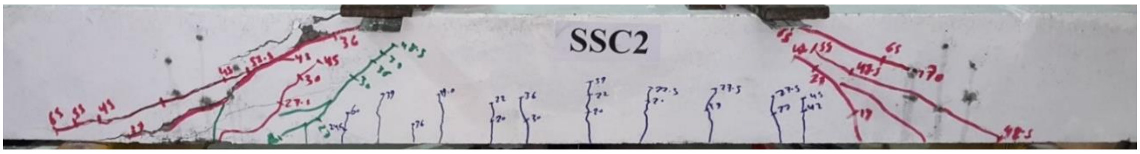


Figure.4b, Crack pattern for Specimen SCC2.

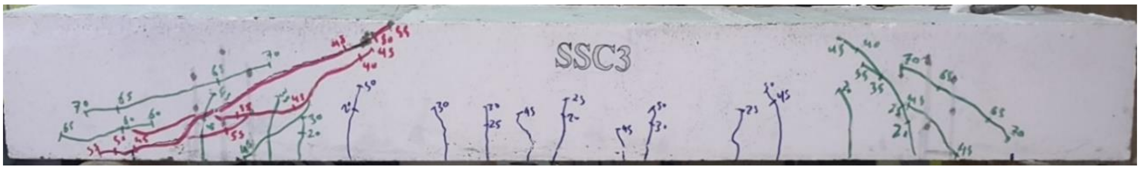


Figure.4c, Crack pattern for Specimen SCC3

Figure.4d, Crack pattern for Specimen SCC4.

Figure.4e, Crack pattern for Specimen SCC5.

Figure.4f, Crack pattern for Specimen SCC6.

Load-Deflection Relationship:

For each sample the deflection value was recorded at mid span and as previously shown in the test set up. Values recoded using data accusation system DAS during loading till failure; the deflection values used for comparison purpose between beams. Generally, two stages were observed;

- The linear stage; the curves shows linear behavior associated with un-cracked sections. All curves were almost linear up to the cracking load and the extend of this stage is function of the tensile strength of concrete. the curves shows almost linear behavior associated with cracked propagation and widening. curves were almost linear up to stage of forming a full diagonal crack.
- The semi-linear stage; the curves shows Semi-linear behavior associated with failure crack widening. curves fluctuate till failure.

Figure.5 shows the load VS deflection curves for each sample also Table.4 Shows deflection values associated with each stage:

Table.4 Summary of recorded deflection values

Specimen	Δ Binding cracking (mm)	Δ Shear cracking (mm)	Δ Diagonal crack (mm)	Δ failure (mm)
SCC1	4.25	4.75	5.50	12.5
SCC2	3.75	5.0	6.50	11.75
SCC3	2.0	4.0	5.50	8.25
SCC4	3.50	5.25	6.25	11.5
SCC5	2.25	3.0	4.0	8.5
SCC6	4.25	6.25	6.75	12.5

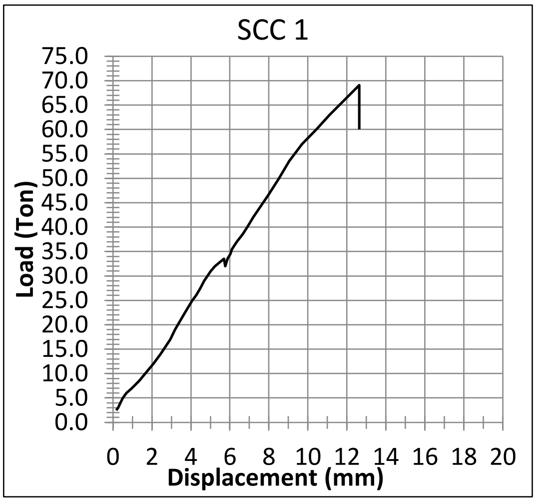


Figure.5a Load-Deflection Beam SCC1

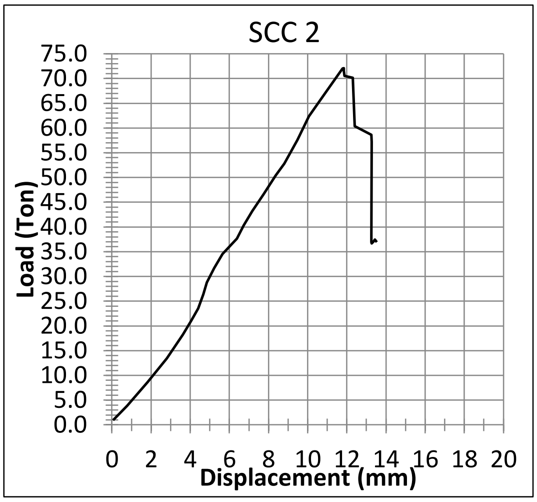


Figure.5b Load-Deflection Beam SCC2

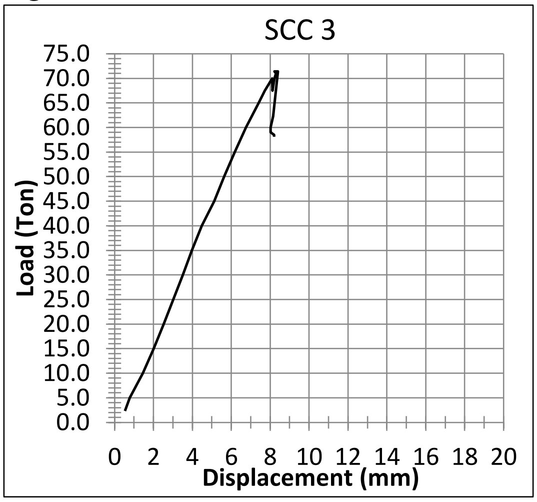


Figure.5c Load-Deflection Beam SCC3

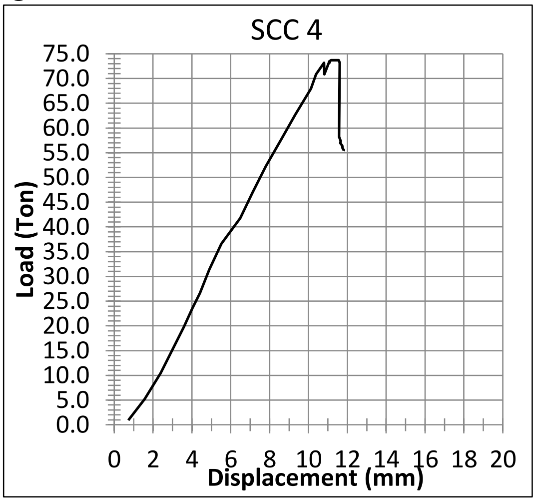


Figure.5d Load-Deflection Beam SCC4

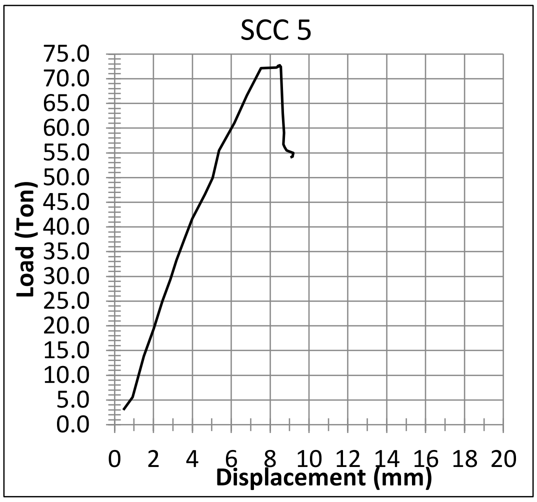


Figure.5e Load-Deflection Beam SCC5

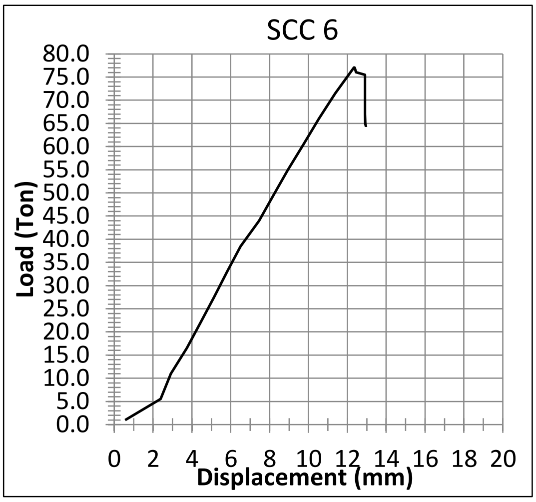


Figure.5f Load-Deflection Beam SCC6

5. DISCUSSION OF RESULTS

Effect of variation in spacing and number of branches of stirrups on beam strength and behavior:

For the hidden wide beams are typically wider and require larger number of branches so it is important to study the effect of of number of branches and spacing to study this point a group consist of four beams forming two pairs of beams each pair formed of two beams with the same Rft. ratio, concrete grade, concrete workability, stirrups diameter, and flexure reinforcement they only difference is in number of branches and stirrups spacing.

Table.5 illustrate each pair and the difference in stirrups branches and spacing

Table.5 First study group (effect of spacing and number of Branches).

Pair1					
SCC2	3T6@200	Ult. Load=72.1	SCC4	2T6@135	Ult. Load=73.7
Pair 2					
SCC5	3T8@200	Ult. Load=72.7	SCC6	2T8@135	Ult. Load=77.1

As seen from Figure.6 and table. 4 we notice a small increase by about 4 % in beam ultimate strength when decreasing Number of branches and decreasing the spacing. For the max deflection recoded value which indicate the ductility (area under P-Δ) we notice either steady or increase by about 45%.

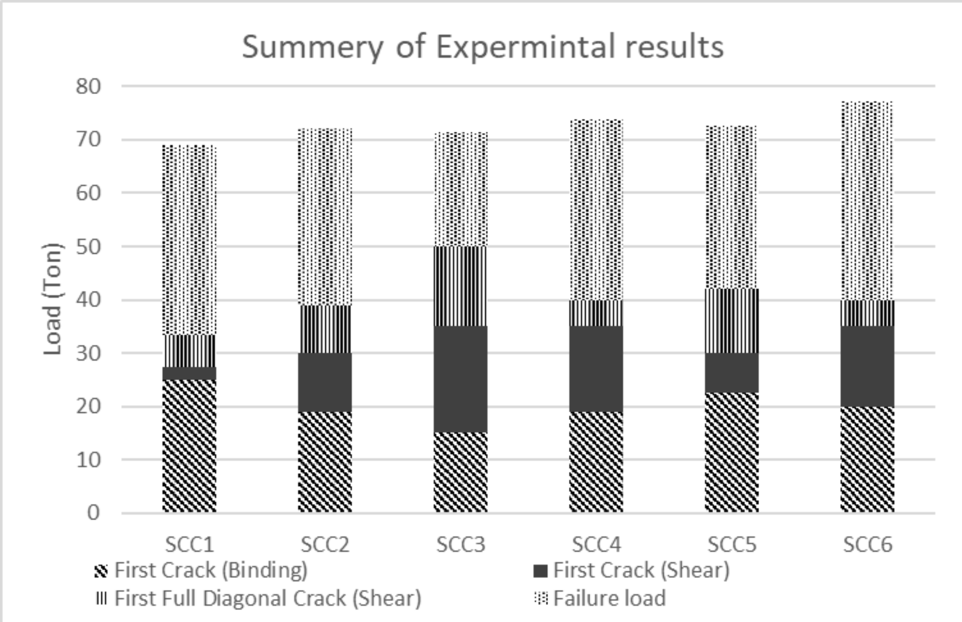


Figure.6 Summery of experimental results

Effect of variance in reinforcement ratio on beam strength and behavior:

to study the effect of change in shear reinforcement ratio a group of two pairs each pair consist of two specimens with the same stirrups spacing, concrete grade, number of branches, and longitudinal reinforcement the only difference is in reinforcement ratio and shear reinforcement stirrups diameter; PS.The contribution of change in stirrups diameter is negligible as shown in the next article.

Table.6 second study group (effect of variation in shear reinforcement)

Pair 1					
SCC2	3T6@200	Ult. Load=72.1	SCC5	3T8@200	Ult. Load=72.7
Pair 2					
SCC4	2T6@135	Ult. Load=73.7	SCC6	2T8@135	Ult. Load=77.1

As seen from Figure.6 and Table.4 we notice positive correlation between reinforcement ratio and ultimate strength in both pairs the strength increased by 1to 5% when shear reinforcement ratio increased. For the max deflection recoded value which indicate the ductility (area under P-Δ) there is no clear relation the values up and down by about 20%. Which indicate that increasing shear reinforcement after a certain limit has no direct effect to beam ductility.

Effect of shear reinforcement diameter on beam strength and behavior:

Finally to study the effect of stirrups diameter in the beam strength and behavior. A group of two beams with the same reinforcement ratio, same stirrups spacing, concrete grade, concrete workability and flexure reinforcement they only differ in diameter of outer stirrup and number of branches which shows about 4% decrease in beam ultimate strength Table.7 illustrate each pair and the difference in stirrups branches and spacing

Table 7. Third study group (effect of shear reinforcement diameter).

Pair 1					
SCC2	3T6@200	Ult. Load=72.1	SCC3	1T6+1T8@200	Ult. Load=71.4

We notice about 1 % in crease in beam strength in SCC2 than SCC3 from previously studied group 1we noticed reduction by 4% duo to increase in number of branches so the relation between outer stirrups diameter to beam strength is inconclusive.
Comparison between test results and code prediction for shear strength
From results of SCC1 without any shear reinforcement According to the ECP the beam shear strength shall be equal:
Q_{cu} = 0.16 (f_{cu} / ɣc)^0.5* b_w* d = 0.16*(82.1/1)^0.5*400*165= 95.7 KN =9.75 Ton
the ECP multiply loads by factor 1.4 D &1.6 Live lets assume average value = 1.45
the expected experimental load according to ECP = 9.75*1.45 = 14.1 ton
From results of SCC1 without any shear reinforcement According to the ACI the beam shear strength shall be equal:
V_u = 0.17 (f'_c)^0.5* b_w* d = 0.17*(82.1*0.8)^0.5*400*165=90.93 KN = 9.27 Ton
the ACI multiply loads by factor 1.4 D &1.2 Live let's assume value = 1.4
the expected experimental load according to ACI = 9.27*1.4 = 12.97 ton
A seen in Figure.7 the codes underestimate the shallow beams strength
Both ACI and ECP shear strength value are less than half the experimental value

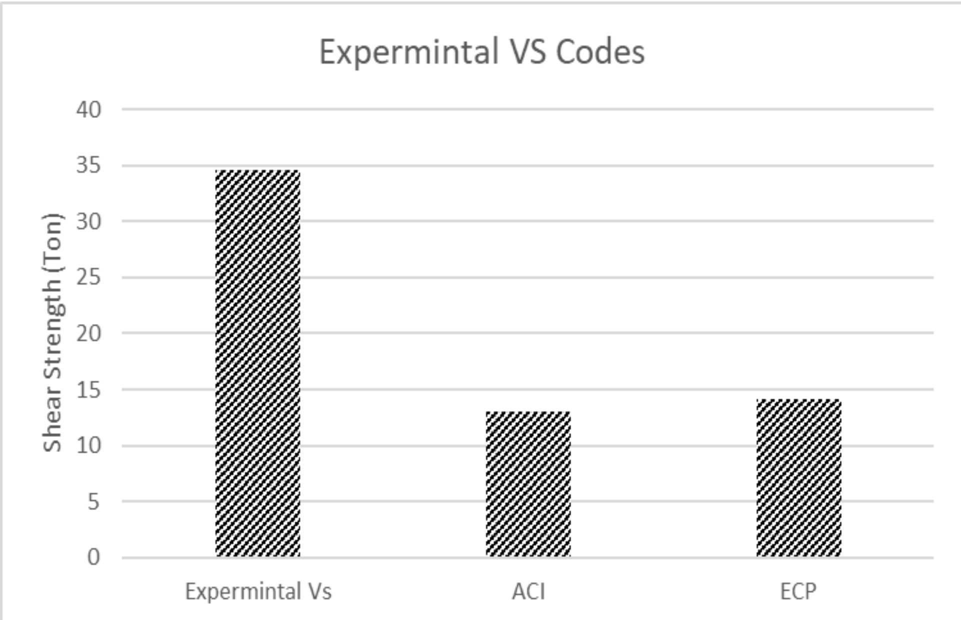


Figure.7 Experimental Vs Code limits.

6. CONCLUSION:

Based on the experimental results and the observed behavior, the following conclusions may be made:
- Both ECP and ACI underestimate the hidden beams strength that we may propose to multiply the equation by magnification factor equal 230 %.
- The ECP recommendation to sustain shear force in Hidden beams by only concrete is more realistic since the contraption of shear reinforcement was from 3% to 11% at maxim cases which can be considered as a factor of safety impeded in code equation in case we added the earlier proposed magnification factor.
- The Spacing of Stirrups has a minor enhance to performance of beam in strength and ductility by about 4%.
- Increase of outer stirrups diameter has insignificant effect to beam strength.

References:

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