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SIZE EFFECT ON SHEAR STRENGTH OF NORMAL AND WIDE BEAMS EXPERIMENTAL INVESTIGATION

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ملخص البحث

الهدف من هذا البحث هو دراسة تأثير العمق والعرض الفعال للكمرات الخرسانية العادية والعريضة ونسبة التسليح الطولى فى الكمرات ومقاومة الخرسانة فى الضغط على أقصى مقاومة للقص فى الكمرات الخرسانية المسلحة. أُجرِيَ برنامج عملي لدراسة هذه العوامل المؤثرة فى مقاومة الكمرات الخرسانية فى القص وتقييم المعادلة التى يتم حساب مقاومة الكمرات الخرسانية فى القص فى الكود المصري لتصميم وتنفيذ المنشآت الخرسانية. يتكون البرنامج العملي من ثمان عشرة كمرات خرسانية مختلفة العمق الفعال من 125 مم, 250 مم, 350 مم, 600 مم. ومقاومة الخرسانة فى الضغط من 25 ميجاباسكال و 87.5 ميجاباسكال, ونسبة التسليح الطولى من 0.8 % و 1.2 %. الكمرات المختبرة لها نفس نسبة البحر الحر إلى العمق الفعال 6. من خلال الدراسة أظهرت النتائج أن مقاومة الكمرات الخرسانية المسلحة تقل بزيادة العمق الفعال وتقليل نسبة التسليح الطولى. ومعادلة الكود المصري لتصميم وتنفيذ المنشآت الخرسانية التى يتم بها حساب مقاومة الكمرات الخرسانية فى القص تقدم قيم غير متحفظة.

1. ABSTRACT

The main objective of this research was to investigate to what extent the beam depth, width, longitudinal reinforcement ratio and concrete compressive strength, influence the ultimate shear capacity of reinforced concrete beams without transverse reinforcement. An experimental program was undertaken to study these parameters and to evaluate the Egyptian Code of practice (ECP 203-2017)[1] empirical formula presented by code for calculating shear strength of concrete beams. The experimental program consisted of eighteen beams with variables heights from 125, 250, 350, and 600 mm. Two concrete compressive strengths, 25 MPa. and 87.5 MPa. were considered. The longitudinal reinforcement ratio varied from .8 % to 1.2%. The tested beams had constant clear span to effective depth (*l/d*=6). It was found that the shear strength of beams decrease as the beam effective depth increase, and longitudinal reinforcement ratio decrease. The Egyptian Code of practice (ECP 203-2017), show un conservative prediction values of shear strength of beams.

Key Words: shear strength, size effect, concrete beams.

2. INTRODUCTION

The diagonal shear failure of reinforced concrete beams has long been known to be a brittle type of failure. There is still considerable disagreement among researchers and practicing engineers regarding a rational way of modeling the shear behavior of reinforced concrete members. On the other hand, analytical methods for flexure that are based on the "plane sections" theory, have been established for many years and are capable of predicting not only the strength but also the load -deformation response of reinforced concrete members subjected to moment with very good accuracy.

Most of the design codes have adopted empirical methods with several different expressions that aim to express shear strength for concrete sections.
The current the previous Egyptian Code of practice (ECP 203-2017)[1], (ECP 203-2007)[2] depends on an empirical formula function only in concrete characteristic compressive strength and do not even account for some basic and proven factors affecting the shear strength capacity of concrete members. Of these factors, the effect of member size[3] and the percentage of longitudinal reinforcement[4] on the shear capacity of beam elements.
The first aspect is concerned with the observation that under certain circumstances as the size of a reinforced concrete member increases the shear strength decreases. This is called "size effect" in shear[3].
The second aspect is concerned with the amount and distribution of longitudinal reinforcement in concrete members.

3. LITERATURE REVIEW

KANI[3] tested four series of beams with depth of (152,305,610 and 1220 mm), the width was constant 152 mm, the percentage of longitudinal reinforcement approximately was 2.8, the concrete strength $f_c{}'$= 27 N/mm^2.The results showed that increasing the beam depth must results in reduction of relative strength r_u . Kani chose relative strength rather than the shear stress as the indicator of failure and obtain semi empirical equation which includes the three major parameters affecting beams shear strength: ρ_w ,a/d and the absolute beam-depth ;d. , where :

$$r_u = \left(\sqrt{\frac{.215}{100p\sqrt{\frac{d}{in.}}}}\right) * \frac{a}{d} \qquad (1)$$

r_u: Relative beam strength $r_u = \frac{M_u}{M_{fl}}$
M_u: Ultimate moment in mid span cross section at failure.
M_{fl}: calculated flexural moment capacity of mid span cross section.
a: Shear span.
d: depth of the beam.
Bazant and Kazemi[5] performed tests on geometrically similar beams with two series. Series I with unanchored bars with a size range of 1: 8. Series II with anchored bars. The beams having a constant a/d ratio of 3.0 and a constant longitudinal steel ratio 1.65, maximum aggregate size of 4.8 mm. The results showed that the diagonal shear failure exhibit a big size effect due to the variation in stored energy that can be released to drive the failure propagation.
Bazant and Kim[6] derived a shear strength equation based on the theory of fracture mechanics. This equation accounts for the size effect phenomenon as well as the longitudinal steel ratio and incorporates the effect of aggregate size. This equation was calibrated using 296 previous tests obtained from the literature and was compared with the ACI Code equations. It was noted that the practice used in the ACI Code of designing for diagonal shear crack initiation rather than ultimate strength does not yield a uniform safety margin when different beam sizes are considered. It was also found according to the new equation that for very large specimen depths the factor of safety in the AC1 Code almost disappears. The new equation derived was as follow:

$$v_u = \frac{10\sqrt[3]{\rho}}{\sqrt{1+d/25d_a}}\left[\sqrt{f_c'} + 3000\sqrt{\rho/(a/d)^5}\right] \qquad (2)$$

Where:

v_u: The ultimate shear strength.
ρ : Steel ratio.
a: Shear span.
d: depth of the beam.
d_a: maximum aggregates size.

Bentz[7] repeated a classic tests made by Bazant[5] .The tested beam thickness ;t, was 102, 203, and 375 mm and a constant width of 100 mm and maximum aggregate size of 10 mm. The results showed that all beams failed in shear at stresses 31 to 71 % higher the Bazant[4] results.

Ghannoum[8] tested 12 specimens with depths varying from 90 to 960 mm, the maximum coarse aggregates size was 16mm. The percentage of longitudinal reinforcement was 1.2 and 2 %, the width of all specimens are 400 mm. The test results showed considerable size effect in both normal and high strength concrete.

Tompos[4] performed tests with two series. Series I consist of two specimens of width of 457 mm, thickness of 914 mm, and percentage of longitudinal reinforcement of 1.0. Series II consist of four specimens of width of 228 mm, thickness of 457 mm, and percentage of longitudinal reinforcement of 1.0. The results showed that as the longitudinal reinforcement ratio decreased there is an observed reduction in concrete shear strength.

Sneed[9] tested two series comprising eight specimens with depths of 305, 610, 762, and 914 mm. The beams having a constant a/d ratio of 3.0 and a constant longitudinal steel ratio 1.25, maximum aggregate size of 9.5 mm, the concrete strength f_c'= 70 N/mm^2. Series I had constant width of 305 mm, series II had constant b/t ratio of (2/3). The test results showed that all of the specimens failed in shear, and a reduction in shear strength with increasing depth.

Kuchma[10] tested twenty-two Simple beams; twelve continuous beams, and one long frame. The simple beam series had a/d ratio of 3, maximum aggregate size of 10 mm. The test results showed that all simple beam specimens failed in shear prior to flexural yielding of the longitudinal steel reinforcement. The results showed that as the member size increase the shear stress at failure decrease.

Korol[11] tested slender specimens with four point bending, shear span to depth ratio a/d =3, the maximum aggregate size was 16mm, the reinforcement ratio was 1 %, the steel yielding strength was 500 MPa. The slender RC beams failed due to the diagonal-shear failure. A strong size effect on the nominal shear strength of RC beams was obtained.

4. Review of Codes Provisions for Shear in Beams without Shear Reinforcement

4.1 ECP 203-2017 Provisions[1]

The design shear strength capacity provided by concrete for normal beams is as follows:

$$q_{cu} = 0.16\sqrt{\frac{f_{cu}}{\gamma_c}} \quad ,V_c=0.16\sqrt{\frac{f_{cu}}{\gamma_c}}\ b_w d \qquad (3)$$

Where: q_{cu} is the concrete shear capacity (N/mm^2),
f_{cu} is the concrete characteristic cube strength (N/mm^2),
γ_c is concrete partial safety factor equals 1.50.
V_c nominal shear strength provided by concrete (N).
b_w is the web width of section (mm).

4.2 ECP 203-2007 Provisions[2]

The design shear strength capacity provided by concrete for slender normal beams is as follows:

$$q_{cu} = 0.24\sqrt{\frac{f_{cu}}{\gamma_c}} \quad ,V_c=0.24\sqrt{\frac{f_{cu}}{\gamma_c}}\ b_w \text{d} \qquad (4)$$

Where: q_{cu} is the concrete shear capacity (N/mm^2),
f_{cu} is the concrete characteristic cube strength (N/mm^2),
γ_c is concrete partial safety factor equals 1.50.
V_c nominal shear strength provided by concrete (N).
b_w is the web width of section (mm).
The shear strength capacity provided by concrete for wide beams is as follows:

$$q_{cu} = 0.16\sqrt{\frac{f_{cu}}{\gamma_c}} \quad ,V_c=0.16\sqrt{\frac{f_{cu}}{\gamma_c}}\ b_w \text{d} \qquad (5)$$

A beam is considered wide beam if the width is equal or more than double the thickness ($b \geq 2t$).

4.3 ACI 318-14 Provisions[12]

In a member without shear reinforcement, shear is assumed to be resisted by the concrete. For non prestressed members without axial force the design shear strength capacity provided by concrete, V_c shall be calculated by:

$$\Phi V_n \geq V_u \qquad (6)$$

$$V_n = V_c + V_s \qquad (7)$$

$$V_c = 0.17\lambda\sqrt{f'_c}\ b_w d \qquad (8)$$

Where : V_u = the factored shear force at the section, V_n = nominal shear strength (N), V_c = nominal shear strength provided by concrete (N), V_s= nominal shear strength provided by shear reinforcement (N), Φ = a strength reduction factor.
λ = the modified factor reflecting the reduced mechanical properties of lightweight concrete, and is taken λ=1 for normal weight concrete.
b_w= web width of section (mm),
d= distance from the extreme compression fiber to the centroidal axis of the longitudinal reinforcement (mm),
$f'_c =$ Concrete compressive cylinder strength (MPa) = 0.8 f_{cu}

4.3 Concrete Committee of Japan Society of Civil Engineers (JSCE) Guidelines for Concrete Provisions[13]

The design shear capacity of linear members without shear reinforcing steel, V_{cd} is as follows:

$$V_{cd} = \beta_d \beta_p \beta_n f_{vcd} b_w\, d/\gamma_b \qquad \text{(N)} \qquad (9)$$

Where:

$$f_{vcd} = 0.20\sqrt[3]{f'_{cd}} \qquad \text{(N/mm2)} \quad \text{Where } f_{vcd} \leq 0.72 \text{ (N/mm}^2\text{)} \qquad (10)$$

$$f'_{cd} = f_k / \gamma_m \qquad (11)$$

$$\beta_d = \sqrt[4]{1000/d} \qquad \text{(d: mm)} \qquad \text{When } \beta_d > 1.5,\ \beta_d \text{ is taken as 1.5.} \qquad (12)$$

$$\beta_p = \sqrt[3]{100 p_v} \qquad \text{When } \beta_p > 1.5,\ \beta_p \text{ is taken as 1.5.} \qquad (13)$$

When β_p >2, β_p is taken as 2.

When β_p <0, β_p is taken as 0.

$$\beta_n = 1 + 2M_0/M_{ud} \quad (N'_d \geq 0) \text{ (i.e. tension force)} \qquad (14)$$
$$= 1 + 4M_0/M_{ud} \quad (N'_d < 0) \text{ (i.e. compression force)}$$

N'_d : Design axial force
M_{ud}: Pure flexural capacity without consideration of axial force
M_0: Flexural moment necessary to cancel stress due to axial force at extreme tension fiber corresponding to design flexural moment M_d. For the case considered, M_0=zero, and $\beta_n = 1.0$.
b_w : Web width.
d : Effective depth and was taken 0.95 of the thickness.
$p_v = A_s/(b_w*d)$.
A_s: Area of tension reinforcement (mm^2)
f'_{cd} : Design compressive cylinder strength of concrete (N/mm^2)
f'_k : Characteristic compressive cylinder strength of concrete (N/mm^2) = $0.8f_{cu}$
γ_b : Member factor which may generally be taken as 1.3.
γ_m : Material factor.

It is important to note that JSCE consider member effective depth and longitudinal reinforcement ratio in predicting shear capacity of beams.

5. EXPERIMENTAL PROGRAM

The objective of the experimental program prepared for this research is to investigate the size effect on the concrete shear strength of beams in terms of the concrete dimensions (width and depth), longitudinal reinforcing steel, and concrete compressive strength. All specimens of the experimental program are tested in the Concrete Construction Testing Laboratory (CCTL) of The National Housing and Building Research Center (HBRC). Details of the specimens' geometry, materials, casting, and testing methodology are described.

5.1 Test Program

Eighteen beams were tested under seven main groups as shown in Table 1. The specimens groups are as follows: Group (I): represent the variation in width of wide beams. Group (II): represent the variation in depth of wide beams. Group (III): represent the variation in depth of normal beams. Group (IV): represent the variation in percentage of longitudinal reinforcement of wide beams. Group (V): represent the variation in percentage of longitudinal reinforcement and depth of wide beams. Group (VI): represent the variation in percentage of longitudinal reinforcement and depth of normal beams. Group (VII): represent the variation in characteristic compressive strength and depth of normal and wide beams.

Table 1: Details of the Specimens

Group	Beam Type	Nominal f_{cu}, N/mm^2	Specimen	Dimensions			Longitudinal reinforcement	reinforcement ratio; ρ%
				b, **mm**	***t***,**mm**	l_{eff},**mm**		
Group (I)	Wide Beams	25	B1	500	250	1350	7Y16	1.25
		25	B2	700	250	1350	10Y16	1.28
Group (II)		25	B3	700	150	750	10Y12	1.29
		25	B2	700	250	1350	10Y16	1.28
		25	B4	700	350	1950	14Y16	1.24
Group (III)	Normal Beams	25	B5	125	250	1350	3Y12	1.21
		25	B6	125	350	1950	2Y18	1.25
		25	B7	125	600	3368	2Y18+2Y16	1.30
Group (IV)	Wide Beams	25	B8	500	250	1350	8Y12	0.80
		25	B9	700	250	1350	11Y12	0.79
Group (V)		25	B10	700	150	750	9Y10	0.81
		25	B9	700	250	1350	11Y12	0.79
		25	B11	700	350	1950	9Y16	0.80
Group (VI)	Normal Beams	25	B12	125	250	1350	3Y10	0.84
		25	B13	125	350	1950	3Y12	0.83
		25	B14	125	600	3368	3Y16	0.84
Group (VII)	Wide Beams	87.5	B15	700	250	1350	10Y16	1.28
		87.5	B16	700	350	1950	14Y16	1.24
	Normal Beams	87.5	B17	125	250	1350	3Y12	1.21
		87.5	B18	125	600	3368	2Y18+2Y16	1.25

5.2 Specimens details

The test specimens are varying in height, width, the percentage of longitudinal reinforcement and characteristic compressive strength.

Concrete dimensions and steel reinforcement detailing of specimens are as shown in Figure (1).

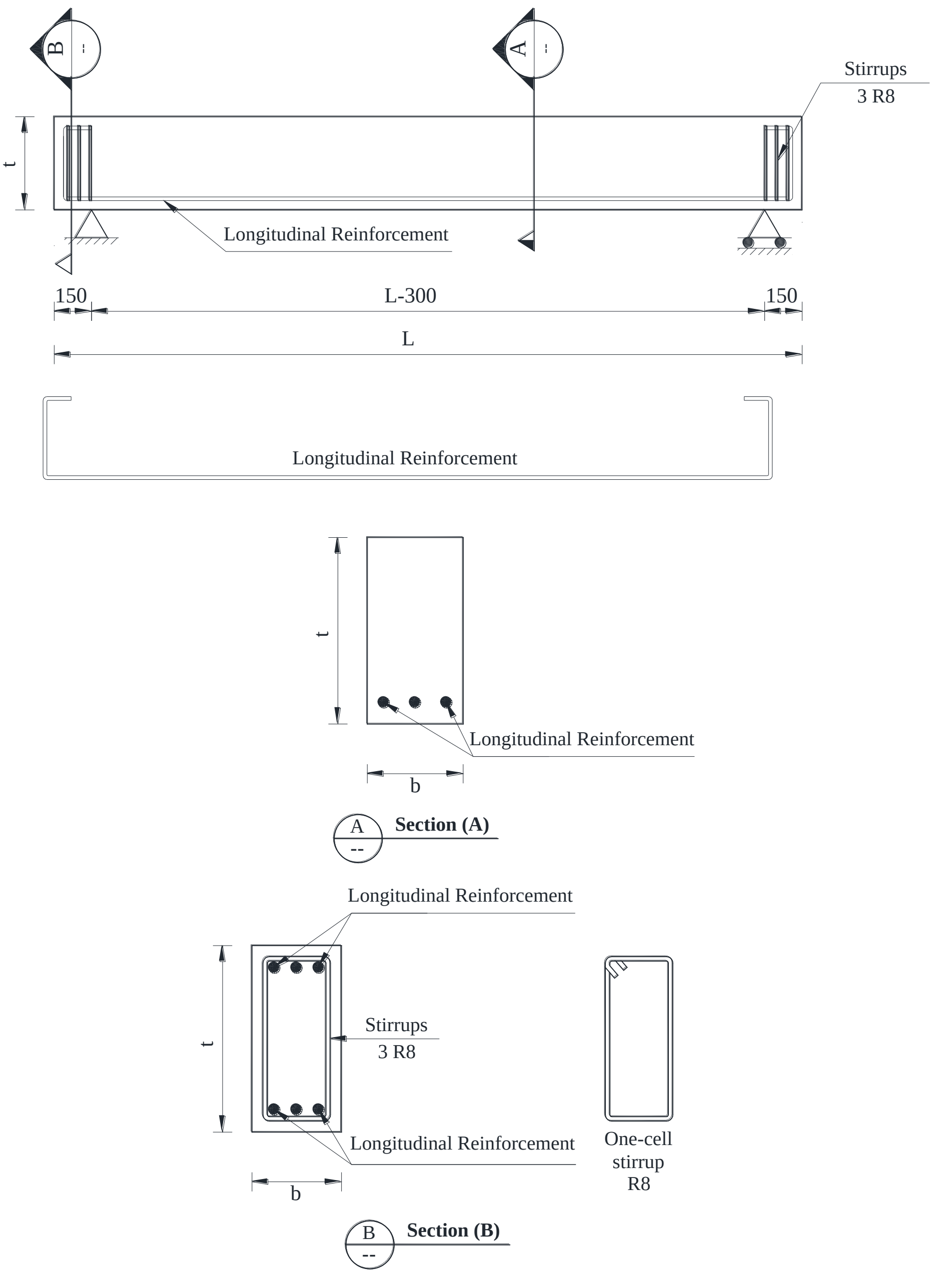

Figure 1: Details of specimens

5.3 Properties of the Material Used

The tested specimens in this investigation were made from locally available materials. (Fine aggregate, coarse aggregate, cement, steel, silica fume, Super-plasticizer steel and water). The coarse aggregate used was crushed hard dolomite from Attaka Mountain, Suez. Batches used were all of good quality and free from injurious materials. The surface texture is relatively rough. The maximum nominal size of coarse aggregate was 10mm.

The Fine aggregate used in this work is Pyramids sand. It was clean and relatively free from impurities. The cement used in this research was the CEMI 42.5N complied with

Egyptian standard specifications. Clean drinking fresh water free from impurities was used for mixing. High-grade steel bars of diameters 10, 12, 16 and 18 mm were used in reinforcing the specimens with Nominal yield strength of 400 MPa High tensile steel. For stirrups, the steel used was mild steel with nominal diameter of 8mm and nominal yield strength of 240 MPa. Silica fume was used as addition for the cement to produce workable concrete with high cubic compressive strength. Super-plasticizer was used to produce self-leveling concrete with only the water necessary to fully hydrate the cement particles.

5.4 Concrete mix

Two mix proportions were used to cast the specimens and they were designed for cube compressive strength 25 and 87.5 MPa at 28 days. These mixes were developed through trial batches. The proportions of the concrete mixes by weight for 1 m3 were as follows:
For the 25 MPa concrete: 300 kg (Portland cement): 1095 kg (coarse aggregate): 729.6 kg (fine aggregate): 195 kg (water).
For the 87.5 MPa concrete: 500 kg (Portland cement): 1002.284 kg (coarse aggregate): 668.189 kg (fine aggregate): 150 kg (water): 60 kg (silika fume): 12.5 kg (Super-plasticizer)

5.5 Test Setup, Procedure and Measurements

All specimens were tested as simply supported in a three point bend test. The specimens was aligned horizontally and rested on the full width on two supports. One support was equipped with a hinged bearing to permit rotation. The other support was roller. The load was applied using 100-ton double acting hydraulic jack attached to the laboratory 400-ton reaction test rig through a hinged base as shown in Figure (2). The data for the beams was collected using a data acquisition system and “lab view" software to collect the data at a rate of 1 sample per second.
The deflections were measured at the mid span using ± 100 mm linear variable differential tranceduser LVDT’s supported on the laboratory floor and attached to the beam bottom surface as shown in Figure (2).
Four electrical strain gages were glued to the longitudinal reinforcement of each specimen. The location of the strain gauges is as shown in Figure (3).
The load was applied gradually through the hydraulic jack using an electrical hydraulic power supply. The load value, deflections, and strains were recorded continuously during the load application. The recorded data were saved on the computer system.

Figure 2: Test set-up for specimens

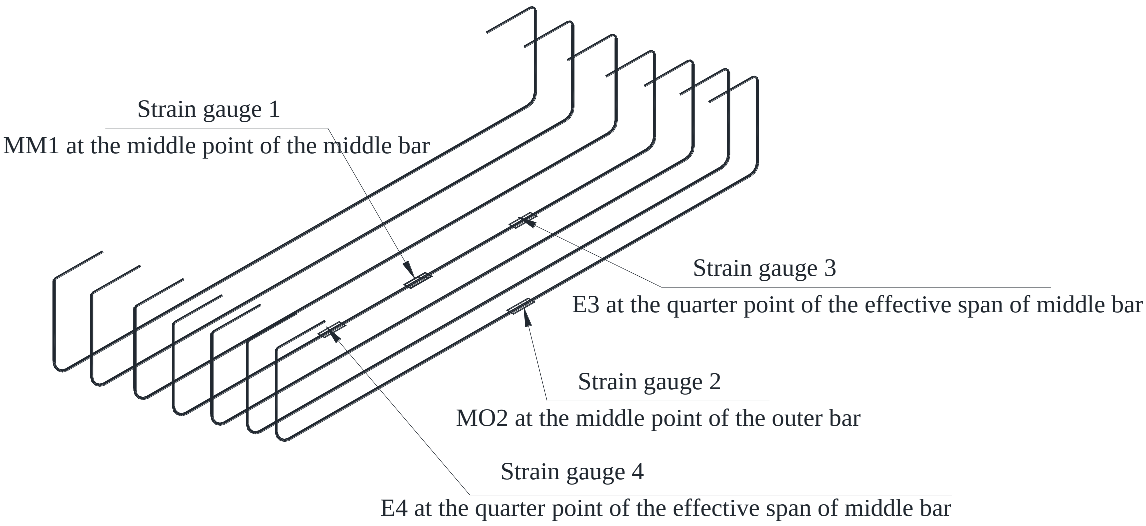

Figure 3: Strain gauge locations for the specimens

6. TEST RESULTS AND DISCUSSION

6.1 Cracking Patterns and Mode of Failure

All tested specimens failed in one-way shear. Electrical resistance strain gauges at mid and quarter span showed no indications of steel yielding. Figure (4) shows sample of specimens at failure. All specimens failed in shear as diagnosed by a main diagonal shear crack.

a) B1

b) B4

c) B7

Figure 4: Specimens at failure

6.2 Failure Shear Load of Tested Specimens versus Codes Prediction

Table 2 shows the normalized shear strength for the tested beams; ($q_{test}/\sqrt{f_{cu}}$). Table 3 shows the normalized shear strength for the tested beams versus the normalized codes predicting shear strength; ($q_{code}/\sqrt{f_{cu}}$), for the comparison the material strength reduction factors in all codes tacked equal one. Figure (5) through Figure (8) shows the normalized shear strength for the tested beams and the normalized codes predicting shear strength versus the depth of beams. The prediction of ECP and ACI codes was constant for all depths of beams. The prediction of JSCE code decreases as the depth of beam increase. Where q_{test} (shear strength) = Q (shear force)/ [b(width) * d(depth)], and $\underline{q_{code}} / (f_{cu})^{0.5}$ is as follows:

For ECP1; $\underline{q_{code}} / (f_{cu})^{0.5} = 0.16$

For ECP2; $\underline{q_{code}} / (f_{cu})^{0.5} = 0.24$ for normal beams, and = 0.16 for wide beams

For ACI; $\underline{q_{code}} / (f_{cu})^{0.5} = 0.152$

For JSCE; $\underline{q_{code}} / (f_{cu})^{0.5} = [0.1538\beta_d\beta_p f_{vcd}]/[f_{cu}]^{1/6}$

It is obvious that only the JSCE code which predicts shear strength dependent on: f_{cu}, d, $\boldsymbol{\rho}$.

Table 2: Normalized Shear Strength for tested Beams

Group	Specimen	P_{test}, KN	Q_{test}, KN	f_{cu}, N/mm^2	q_{test}, N/mm^2	$q_{test}/(f_{cu})^{0.5}$ (N)$^{1/2}$/mm
Group (I)	B1	264.6	132.3	24.582	1.176	0.237
	B2	369.4	184.7	25.213	1.173	0.234
Group (II)	B3	236.3	118.15	21.747	1.35	0.290
	B2	369.4	184.7	25.213	1.173	0.234
	B4	420.2	210.1	22.140	0.924	0.196
Group (III)	B5	59.4	29.7	21.932	1.056	0.225
	B6	76.4	38.2	23.327	0.94	0.195
	B7	119.1	59.55	27.011	0.849	0.163
Group (IV)	B8	218.4	109.2	24.006	0.971	0.198
	B9	289.6	144.8	23.340	0.919	0.190
Group (V)	B10	210.1	105.05	23.731	1.201	0.246
	B9	289.6	144.8	23.340	0.919	0.190
	B11	368.3	184.15	31.620	0.809	0.144
Group (VI)	B12	57.4	28.7	26.462	1.02	0.198
	B13	62.2	31.1	24.128	0.766	0.156
	B14	93.4	46.7	32.010	0.65	0.115
Group (VII)	B15	486.1	243.05	86.657	1.543	0.166
	B16	569.4	284.7	91.284	1.251	0.131
	B17	85.9	42.95	86.024	1.527	0.165
	B18	146.1	73.05	91.640	1.041	0.109

Table 3: Normalized Shear Strength for tested Beams vs. codes prediction of shear strength

Group	Specimen	$q_{test}/f_{cu}^{0.5}$	$q_{ECP1*}/f_{cu}^{0.5}$	$q_{ECP2**}/f_{cu}^{0.5}$	$q_{ACI}/f_{cu}^{0.5}$	$q_{JSCE}/f_{cu}^{0.5}$
Group (I)	B1	0.237	0.16	0.16	0.152	0.170
	B2	0.234	0.16	0.16	0.152	0.171
Group (II)	B3	0.290	0.16	0.16	0.152	0.204
	B2	0.234	0.16	0.16	0.152	0.171
	B4	0.196	0.16	0.16	0.152	0.158
Group (III)	B5	0.225	0.16	0.24	0.152	0.171
	B6	0.195	0.16	0.24	0.152	0.157
	B7	0.163	0.16	0.24	0.152	0.135
Group (IV)	B8	0.198	0.16	0.16	0.152	0.148
	B9	0.190	0.16	0.16	0.152	0.147
Group (V)	B10	0.246	0.16	0.16	0.152	0.172
	B9	0.190	0.16	0.16	0.152	0.147
	B11	0.144	0.16	0.16	0.152	0.128
Group (VI)	B12	0.198	0.16	0.24	0.152	0.147
	B13	0.156	0.16	0.24	0.152	0.136
	B14	0.115	0.16	0.24	0.152	0.104
Group (VII)	B15	0.166	0.16	0.16	0.152	0.139
	B16	0.131	0.16	0.16	0.152	0.124
	B17	0.165	0.16	0.24	0.152	0.137
	B18	0.109	0.16	0.24	0.152	0.109

ECP1*: ECP 203-2017
ECP2**: ECP 203-2007

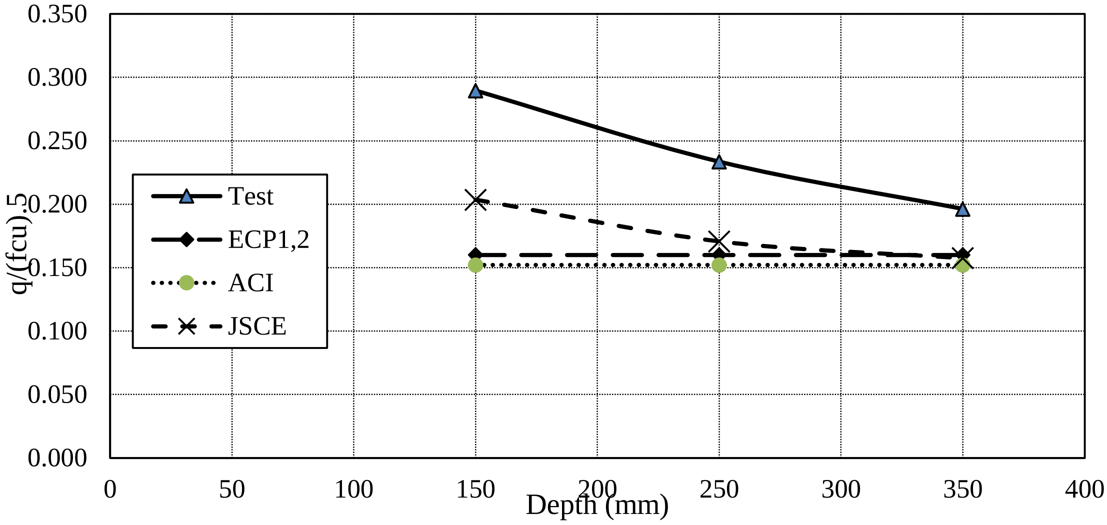

Figure 5: Normalized Shear Strength Vs. Depth for Group II

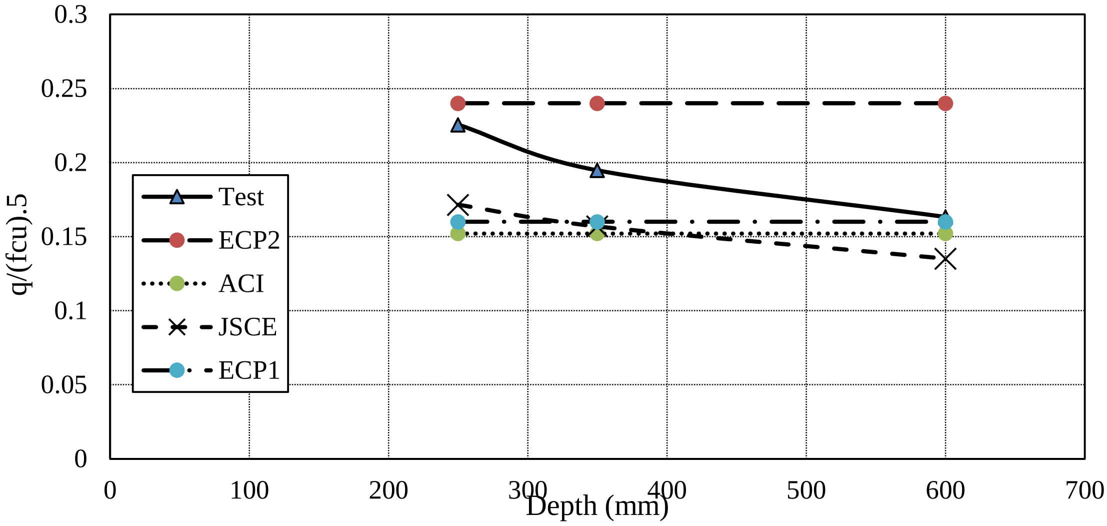

Figure 6: Normalized Shear Strength Vs. Depth for Group III

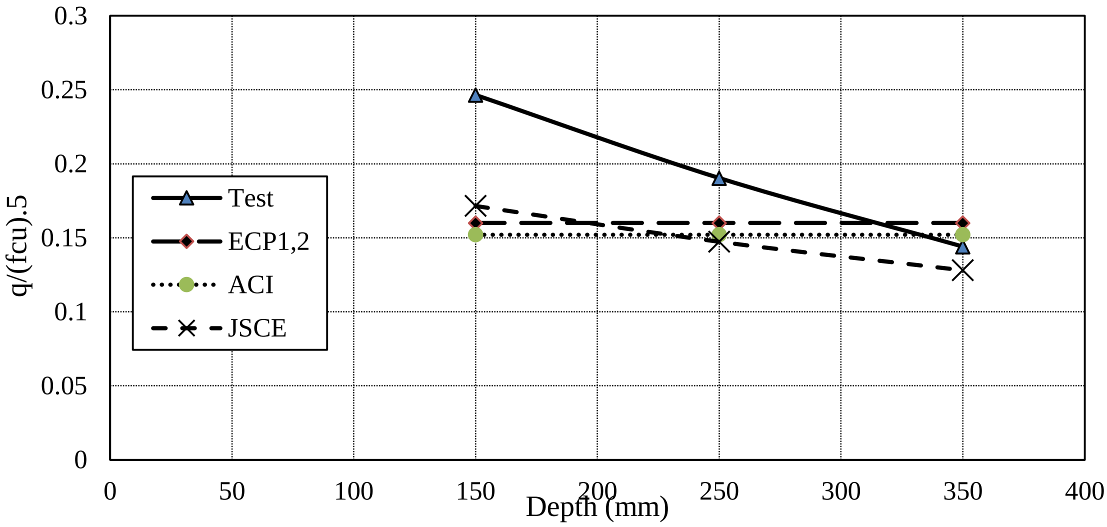

Figure 7: Normalized Shear Strength Vs. Depth for Group V

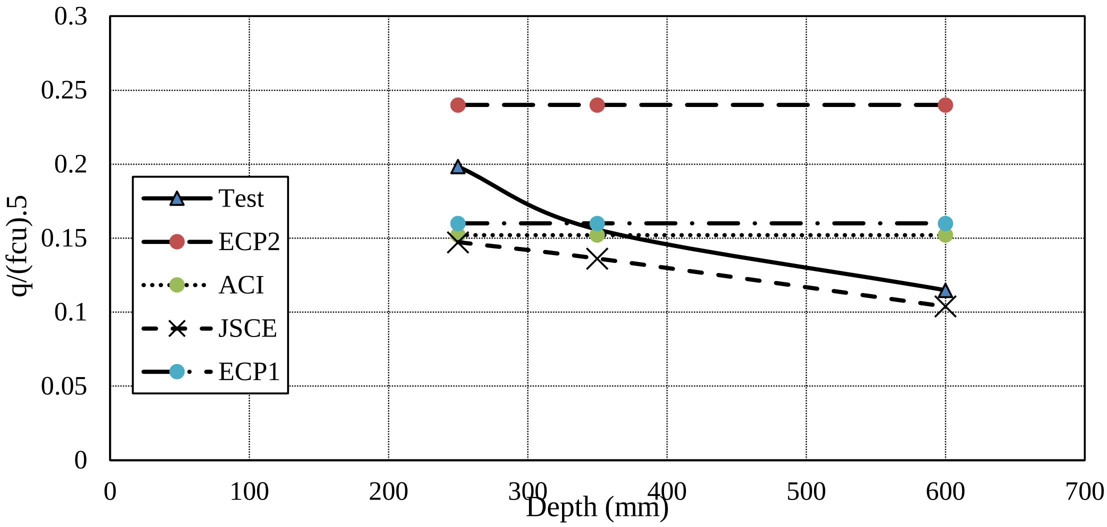

Figure 8: Normalized Shear Strength Vs. Depth for Group VI

6.3 Influence of Width on Shear Stress

For specimens having the same depth and percentage of longitudinal reinforcement, the normalized shear capacity almost the same. The variation of width has minor effect on shear stress, as the shear stress is directly proportional to the width. For specimens in groups I, II, and III the percentage of longitudinal reinforcement was about 1.25%, specimens B1, B2, and B5 has depth of 250 mm the normalized shear capacity for these specimens was 0.237, 0.234, and 0.225. Specimens B4, and B6 has depth of 350 mm the normalized shear capacity for these specimens was 0.196, and 0.195. For specimens in groups IV, V, and VI the percentage of longitudinal reinforcement was about 0.80%, specimens B8, B9, and B12 has depth of 250 mm the normalized shear capacity for these specimens was 0.198, 0.190, and 0.198. Specimens B11, and B13 has depth of 350 mm the normalized shear capacity for these specimens was 0.144, and 0.156. For specimens in groups VII, the percentage of longitudinal reinforcement was about 1.25%. Specimens B15, and B17 has depth of 250 mm the normalized shear capacity for these specimens was 0.166, and 0.165.

6.4 Influence of Characteristic Compressive Strength on Shear Stress

The characteristic compressive strength was the main factor on predicting shear capacity in most of design codes as Egyptian Code of practice (ECP 203-2017). The test result showed that as the characteristic compressive strength increase the shear strength of the tested beam increase. For specimens B2, and B4 has a shear strength of 1.173, and 0.924 MPa. The similar specimens B15, and B16 in Group VII of high strength concrete has a shear strength of 1.543, and 1.251 MPa. For specimens B5, and B7 has a shear strength of 1.056, and 0.849 MPa. The similar specimens B17, and B18 in Group VII of high strength concrete has a shear strength of 1.527, and 1.041 MPa. The normalized shear capacity showed in Table 3 showed that specimens in high strength concrete group has less strength than normal strength group on similar specimens in normalized shear strength, which indicate that in high strength concrete the shear strength is not directly proportional with the square root of characteristic compressive strength.

6.5 Influence of Percentage of Longitudinal Reinforcement on Shear Stress

The percentage of longitudinal reinforcement has a strong effect on shear strength of beams as the test result showed. Table 2, shows the normalized shear strength of specimens in groups of normal strength concrete. The normalized shear strength increase as the percentage of longitudinal reinforcement increase.

5.7 Influence of Depth on Shear Stress

The test results showed that as the beam depth increase the shear strength of the beam decrease. For specimens in group II, B3, B2, and B4 has a width of 700 mm the normalized stress for these specimens was 0.290, 0.234, and 0.196. For specimens in group III, B5, B6, and B7 has a width of 125 mm the normalized stress for these specimens was 0.225, 0.195, and 0.163. . For specimens in group V, B10, B9, and B11 has a width of 700 mm the normalized stress for these specimens was 0.246, 0.190, and 0.144. For specimens in group VI, B12, B13, and B14 has a width of 125 mm the normalized stress for these specimens was 0.198, 0.156, and 0.115. For specimens in group VII, B15 and B16 has a width of 700 mm the normalized stress for these specimens was 0.166, and 0.131. B17 and B18 has a width of 125 mm the normalized stress for these specimens was 0.165, and 0.109.

6. CONCLUSIONS

The results of the experimental program can be concluded in the following points:

The shear strength of beam increases as the characteristic concrete compressive strength increase. This result agree well with codes prediction of concrete shear strength of beams.

The beam width have minor effect on concrete shear strength of beam. The shear force of a beam is directly proportional to the beam width.

The shear strength of beam increases as the percentage of longitudinal reinforcement increase.

The shear strength of beam decreases as the beam depth increases if other factors affecting shear strength are kept constant which known as size effect on shear.

Both the Egyptian and the ACI codes do not consider the size effect and the longitudinal reinforcing steel on the concrete shear capacity of beam. Both provisions overestimate concrete shear capacity of beams; hence yield unconservative results.

In opposite to that, the prediction capacity of Japanese code JSCE was less than the ultimate loads of the tested beams in both normal and high strength concrete. This is due to the fact that JSCE takes into consideration the effect of beam depth and the percentage of longitudinal reinforcement.

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