

RESEARCH PAPER

Shear Strength of Reinforced High-Performance Concrete Wide Beams

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ABSTRACT:

Wide shallow beams have become more common among structural designers since having more space for utility services under the floor. However, the provisions of codes of practice need to be evaluated against an experimental data to evaluate their margin of safety for this type of structural element. This paper is an experimental and theoretical investigations on the shear behavior and capacity of wide shallow beams. A total of seven beam specimens were tested to assess the effect of beam width to height ratio (b/h) which ranged from 0.67 to 3; shear reinforcement ratio ranging from 0 to 0.222%; and carbon fiber content ranging from 0 to 0.53%. The results show that with increasing width to height ratio, the shear strength of the beam decreased and the provisions of codes of practice (ACI318-14 and EC2) might not lead to accurate results when they are used to predict the shear capacity of wide shallow beams.

KEY WORDS: Shear strength; wide shallow beam; web reinforcements; high strength concrete; width to height ratio; fibers.

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1. INTRODUCTION:

Although the utilization of wide shallow beams in structural buildings is not new, in recent years its use is more common. The main idea of using this type of structural member is to have more space for utility services such as ventilation ducts, sewage pipes, and water supply pipes. Flat slab is also useful for these purposes, but it has punching shear problems when encounter for heavy loadings. For heavily loaded slab, beams are normally used between columns to control bending and deflection. However, for normal depth beams, sometimes, the utility services need to pass through the section due to height limitations. These holes could weaken the beam in

shear or bending. Therefore, the answer is to use wide shallow beams to compensate for all aforementioned problems. Additionally, using wide shallow beams means decreasing story height, which in turns decreases the overall height of the building.

In the literature, different researchers tried to investigate the behavior of wide beams experimentally and theoretically. Based on the experimental results of wide beams, Sherwood et al (Sherwood et al., 2006) concluded that member width has no significant effect on shear stress at failure. Depending on their experimental works on wide beam, Lubell et al (Lubell et al., 2009) concluded that stirrup efficiency decreased significantly as the stirrup legs spacing across the width is increased. They also concluded that, the capacity of the members with well distributed shear reinforcement could be safely predicted by ACI shear model. Shuraim and Al-Negheimish

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(Shuraim & Al-Negheimish, 2011) concluded that the distribution of the moments in wide beam was found to not match what is usually assumed in the design practice, as indicated in ACI-318 and EC-2. Therefore, a new evaluation of the moment distribution is needed to satisfy strength and serviceability criteria. Working on the high strength concrete were the efforts of many researchers that concluded and gave advantages on this type of material (Yousif *et al.*, 2004; Saeed *et al.*, 2007). The contribution of web reinforcement in shear strength of wide beam using normal and high strength concrete was studied by Hanafy *et al.* (Hanafy *et al.*, 2012), the results showed that, the effect of web reinforcement on the shear strength is more pronounced in beams with normal concrete compressive strength than beams made from high strength concrete. Lubell *et al.* (Lubell *et al.*, 2009), Shuraim and Al-Negheimis (Shuraim & Al-Negheimish, 2011) and Lotfy *et al.* (Lotfy *et al.*, 2014) found that the configuration of the stirrups (beams with constant stirrups ratio) has an influence on the shear strength, four legs configuration showed high increase in its efficiency to resist shear force over stirrups with two legs configurations.

Conforti and Plizzari (Conforti *et al.*, 2013) demonstrated experimentally that, the effect of wide beam with relatively low steel fiber content increase significantly the shear capacity and ductility. So, the fibers were more prominent in wide shallow beams than in deep beams. Conforti *et al.* (Conforti *et al.*, 2015; Conforti *et al.*, 2017) conducted an experimental investigation on wide and deep beams examining the effect of shear reinforcement and polypropylene fibers. The result showed that the polypropylene fiber can be used to totally replace the shear reinforcement in wide beams.

Self-compacting concrete (SCC) is a special type of concrete which consolidate (i.e., compacting) under its own weight, has a high flowability property during freshen stage, eliminating external mechanical vibration process during filling of forms, which in turns reducing labors cost. This type of concrete is very suitable for areas with congestion reinforcements (like beam-columns joints), permit the concrete to fill complex formwork. The additional works can be faced during casting is induced of voids that occur

in the normal concrete especially in columns; this can be reduced or eliminated by SCC.

For design and analysis purposes, structural engineers and designers follow the procedure and provisions of building codes of practice such as ACI 318-14 (ACI Committee 318, 2014) and EC2 (Eurocode-2, 2004). However, the shear provisions of these codes are based on experimental and theoretical investigations that conducted primarily on beams with normal depth to height ratio. These provisions need to be evaluated to examine their margin of safety when applied to wide shallow beams made with high strength concrete. Thus, the current research is to provide an experimental investigation of the shear behavior of wide shallow beams made with high performance concrete (HSC and SCC). Additionally, it tries to assess the aforementioned codes provisions experimentally for wide shallow beams based on experimental results from this and other researches.

2. SPECIMENS PREPARATION AND TEST SETUP

A total of seven beam specimens were cast using ready mix concrete. Five of these specimens were cast with targeted compressive strength of 90 MPa and without discrete fibers. The other two specimens were cast with discrete fibers (low and medium content), more details, can be found in Table 1.

The investigated parameters are: width to overall height ratio (b/h) of the beams; shear reinforcement ratio and ration of discrete fibers. The reinforcements were positioned so that the beams tested as propped cantilever beams as shown in Fig.1. The main flexural reinforcement $\varnothing 20$ mm was used at the top of the cross section and cross bars were welded to the end of the longitudinal bars to prevent bond failure prematurely at end the test. All the specimens were cast without shear reinforcement except WB-4 and WB5 which they reinforced with $\varnothing 8@200$ mm and $\varnothing 8@100$ mm, respectively. The steel properties are given in Table 2. The beams were designed to fail in shear; therefore, the flexural reinforcement ratios used were higher than the maximum permissible ratio (i.e., ε_t less than 0.004) according to ACI 318-14 to prevent flexural failure.

Table (1) Beam properties with variable included in experimental works.

Specimen No.	<i>b</i> (mm)	<i>b/h</i>	Stirrups	<i>V_f</i> (%)	Top longitudinal bars	<i>ρ_w</i> (%)
WB-1	100	0.67	0	0	2-Ø20mm	5.50
WB-2	300	2	0	0	4-Ø20mm	3.67
WB-3	450	3	0	0	6-Ø20mm	3.67
WB-4	450	3	Ø8@200mm	0	6-Ø20mm	3.67
WB-5	450	3	Ø8@100mm	0	6-Ø20mm	3.67
WB-6	450	3	0	0.254	6-Ø20mm	3.67
WB-7	450	3	0	0.53	6-Ø20mm	3.67

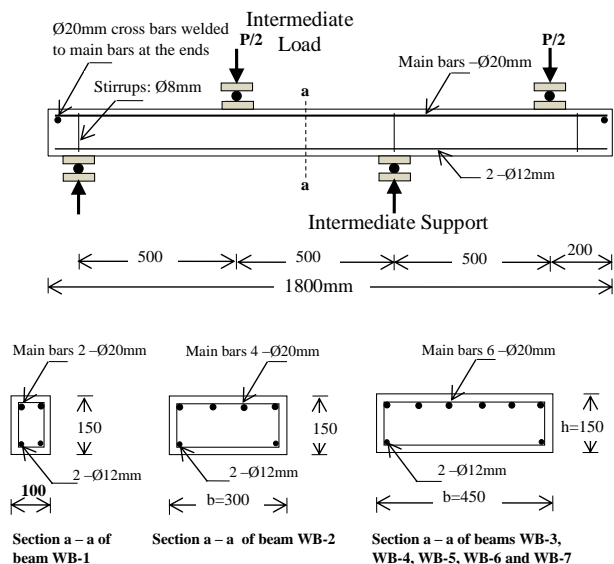


Figure 1: Reinforced details of WB beams.

The reinforcement cages were put in its location inside the wooden mold and the covers were guaranteed by using 20 mm plastic clear covers. All the beams and control specimen with and without fibers were cast at the same time using ready mix concrete.

Before casting WB-6, WB-7 and their control specimens, the specified amount of chopped carbon fibers (length 20 mm, fiber diameter 7 to 8 μm, with tensile strength 2840 MPa, modulus of elasticity 235 GPa, and density 1780 kg/m³) were added to the concrete, mixed for three minutes after fiber addition.

Table (2) Properties of steel used.

Nominal diameter (mm)	Area (mm ²)	Yield strength (MPa)	Ultimate Strength (MPa)
Ø8	50	485	587
Ø12	110	390	562
Ø20	308	478	780

The specimens were cured for about 56 days, then they were air dried in the laboratory.

Before testing they were painted with white paint for crack tracing during the loading stages. The free end deflection; mid-span (the point load between the two supports) deflection, strain of the concrete above the support were recorded (Fig. 2) every 5 kN throughout loading history.

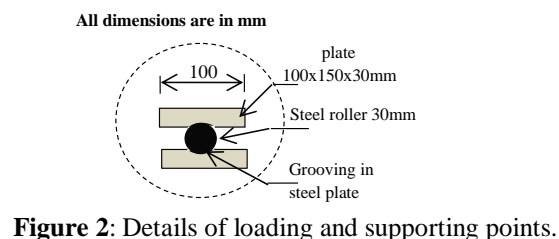
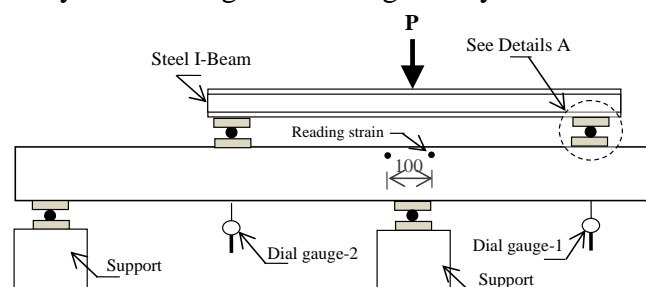


Figure 2: Details of loading and supporting points.

A universal testing machine with maximum capacity of 2500 kN were used to test the beams. The control specimens which are six cubes 150x150x150 mm for compressive strength, three prisms 75x75x380 mm for flexural strength, and two cylinders 100x200 mm for splitting tensile strength were tested at the same day of the beam tests. The failure load of beam specimens and control specimens are presented in Table 3.

3. TEST RESULTS

The failure load of tested beams and control specimens are presented in Table 3. Discussion of test results is given in the sections to follow:

Table (3) The failure load of beam specimens and control specimens.

Specimen No.	f'_{cu}	f'_c (MPa)	f'_r	f'_{ct}	V_u , EXP (kN)	Change** (%)	Deflection at Free end (mm)
WB-1					80	-71.3	9.50
WB-2					195	-30.1	9.59
WB-3	107.6	91.5*	5.8	9.14	279	0.0	11.30
WB-4					320	14.7	13.71
WB-5					372	33.3	17.70
WB-6	62.6	53.2	6.89	6.77	212.5	-23.8	11.05
WB-7	42.5	36.1	3.79	6.73	181	-35.1	9.03

*Cylindrical compressive (f'_c) test result taken as equivalent to 0.85 cubes (f'_{cu}) test results.

**The negative sign (-) indicates reduction of the shear strength of WB relative to reference beam (WB-3).

3.1 Cracks and Cracks Propagations

Cracks occurrence, distribution, and propagation present the respond of reinforced concrete beams under the loads, cracks happen when the internal tensile strength due to applied external load reached tensile strength of the material at that position. After the specimen was loaded, the first visible cracks were observed at location 1 (Fig. 3). In this stage the beams have one or two major cracks that have limited length which is less than quarter of the beam depth, these flexural cracks are mostly vertical and straight, started at top toward bottom, at maximum negative moment (i.e., the intermediate support). The loading procedure was continued during which no cracks were appeared in the web of the section, until the loading reached to about more than 90% of failure load, the shear cracks were appeared at location 2 (Fig. 3), mid-height of the beam. These cracks are almost horizontal, with increasing load, they extended diagonally towards location 3 and 4 (Fig. 3). Further increasing of loads produced semi-parallel crack 5 around path 3-2-4 at the top and bottom of first shear cracks.

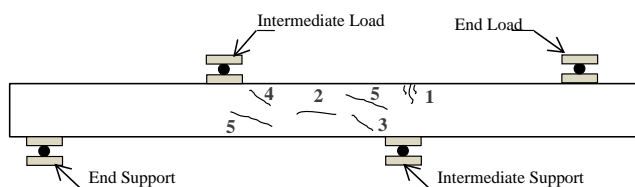


Figure 3: Sequence of cracking appearance.

The majority of the main shear cracks were observed between intermediate loading (see Fig. 1) and intermediate support, while the cracks on other side of intermediate support were observed to be less critical as shown in Fig. 4. With the test progress the cracks width and length increased and final failure were triggered due to splitting shear failure of the cracks.

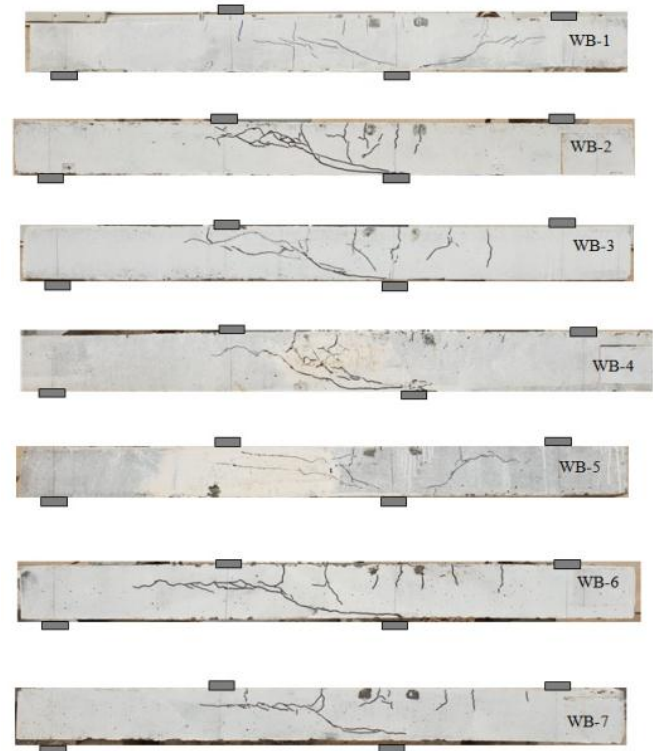


Figure 4: Crack patterns of the specimens at failure.

The appearance of shear cracks was delayed significantly by the presence of stirrups ($\varnothing 8@200$ and $\varnothing 8@100$ mm c/c). The same thing is also noticed in beams with fibers especially the beams with higher fiber content. The specimen with 0.53% fiber content failed in more ductile manner compared to other beams without fibers.

3.2 Control Specimens

High strength self-compacted concrete prepared by truck mixer from central batch plant under the authors' order. The average cubes compressive strength (150x150x150 mm) of the concrete reached to 107.6 MPa, while adding of wet carbon fiber polymer (microfiber) by 0.254% and 0.530%, led to strength reduction by 42% and 61%, respectively, these results may be attributed due to the mix design was just done for HS SCC,

but at the practical work, we added two specimens with fiber without mix design (HS SCC with fiber) The same trend was observed for tensile strength of the concrete. The reason behind this reduction may be that high strength self-compacted concrete is more sensitive to addition of micro fiber than high strength concrete with steel fiber (Wafa & Ashour, 1992); this means that it's required a new mix design for using microfiber with SCC. The tensile strength of the concrete was obtained using indirect tensile test on prisms (modulus of rupture) and cylinders (splitting test).

The results indicated that adding 0.254% fiber led to an increase of the flexural tensile strength by 18.8%, while adding 0.53% of fiber led to reduction of the flexural tensile strength by 34.7%. The same conclusion as discussed earlier for compressive strength is also true for the tensile strength. The other indirect test (Splitting strength) undergoes 25.9% and 26.4% reduction on strength for both fiber contents, respectively. The reasons may be, adding fibers led to increase the friction between the ingredients of fresh concrete, so less workability obtained and during the cast, the balling of fiber observed at 0.53% fiber content, as a result, influenced on the final strength.

4. INVESTIGATED PARAMETERS

4.1 Beam Width to Height Ratio

The effect of width to height ratio (b/h) on the shear strength of the beams is shown in Fig. 5. As the beam (b/h) ratio increases from 0.67 to 2 and 3, the area of concrete contribution (of the beam section) in shear strength are increased 3 and 4.5 times with respect to control specimen WB-3. While the reduction of shear strength of beam reached 30.1% and 71.3% respectively. It can be seen that with increasing b/h the shear strength decreased. This could be attributed to the fact that the area of the cross-section becomes larger with increasing width of the beam, and the probability of encounter for weak point is higher when the area is larger. This eventually leads to lower shear strength due to releasing more fracture energy throughout loading history.

4.2 Stirrups

As the shear reinforcement increase from 0 to $\text{Ø}8$ at 200 mm c/c and $\text{Ø}8$ at 100 mm c/c , the shear strength increased by 14.7% and 33.3%, respectively, relative to WB-3, as shown in Fig. 6.

It is clear from the figure, that the stirrups have limited effect on the shear strength of the beams as most of the applied stress is resisted by concrete. However, during the test, it was observed that the presence of stirrups is very essential for restricting width and length of shear cracks at final stages of loading.

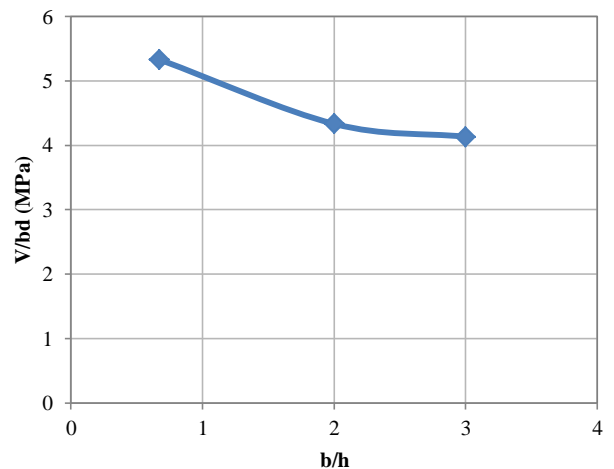


Figure 5: Effect of (b/h) on the shear strength of the specimens.

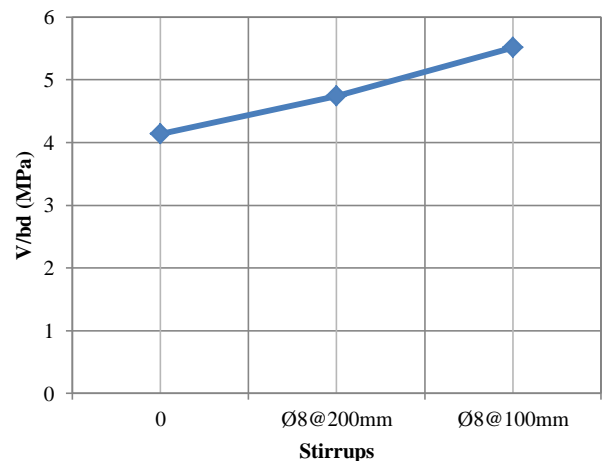


Figure 6: Effect of shear reinforcement on the shear strength of the specimens.

4.3 Fiber Content

Adding microfiber to fresh mix led to significant decrease in the compressive strength of the concrete. The reductions were 42% and 61% for 0.254% and 0.53% fibers contents, respectively. This reduction in strength reflected on all properties of concrete, including shear strength. This is probably the reason that only slight increases in shear strength can be seen in Fig. 7, which shows the effect of fiber content on

the normalized shear strength ($V/\sqrt{f'_c} bd$) of the beams.

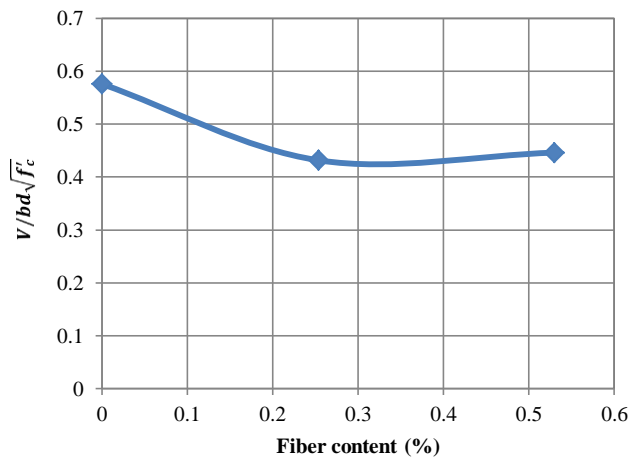


Figure 7: Effect of fiber content on the normalized shear strength of the specimens.

4.4 Load-Displacement Relationship

The vertical displacements were recorded at mid-span between the supports (under intermediate load) and at free end (under the end load). The intermediate load displacement is very small compared to the free end displacement, therefore, the main focus here is the displacement of the free end. Fig. 8-10 show the load deflection relationship of the beams which grouped based on different investigated parameters. Fig. 8 shows the relationship for beams with different (b/h). As can be seen in the figure, by decreasing beam width, the final deflection decreased by 15.9% and 15.1% for (b/h) 0.67 and 2, respectively. In addition, the stiffness of the beam (slope of the curve) is decreased clearly as the width decreased.

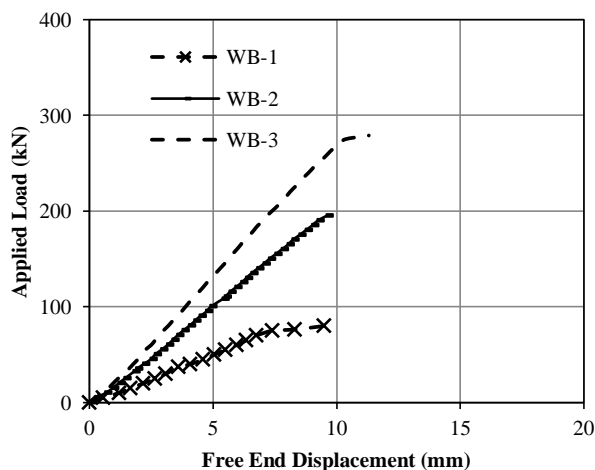


Figure 8: Load-displacement relationship (effect of b/h).

Fig. 9 shows the load deflection of beams with different shear reinforcement, the final displacement of WB-3 reached to 11.3 mm while

with increasing stirrups reached to 13.7 mm and

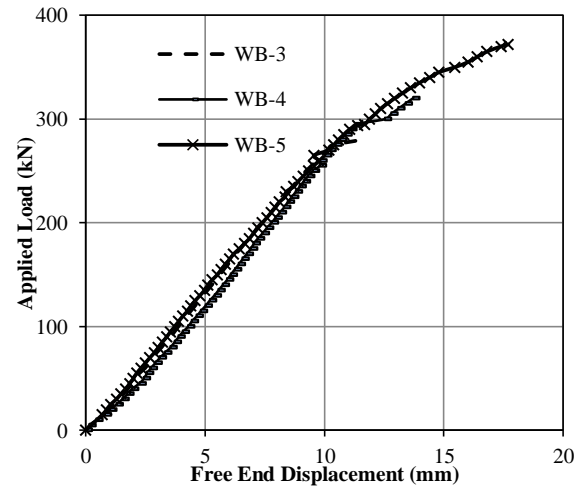


Figure 9: Load-displacement relationship (effect of shear reinforcement).

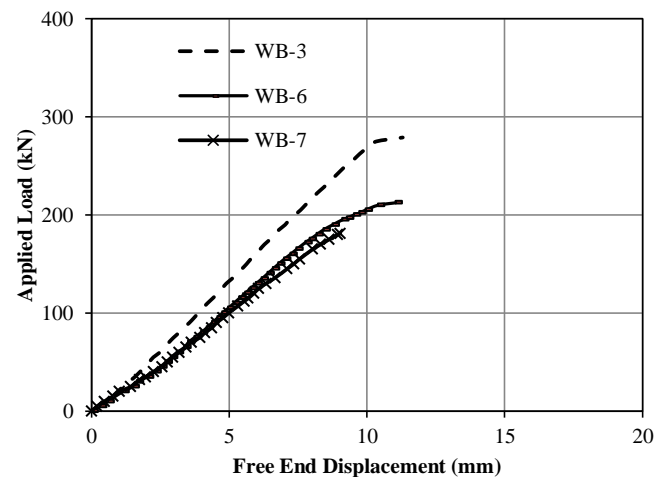


Figure 10: Load-displacement relationship (effect of fiber content).

17.7 mm for WB-4 and WB-5 respectively. It is clear that the shear reinforcement has no influence on the load deflection behavior, except it enhanced the load capacity of the beam. It is also obvious from the figure that the presence of shear reinforcement leads to more ductile behavior (the final displacement) after shear crack development.

The deflection at all loading stages and final deflection were noticed decreased relative to WB-3, as shown in Fig. 10. The reason can be attributed to bad results of existence of fibers relative to control specimens.

5. SHEAR STRENGTH THEORIES

Up until now, there is no unified shear theory among researchers and codes of practice. ACI Code (ACI Committee 318, 2014) divided the shear resistance of a concrete member into two components, concrete resistance, V_c , and shear

reinforcement resistance, V_s ; while EURO Code (Eurocode-2, 2004), shear resistance approach neglects the concrete contribution to the shear resistance in the presence of shear reinforcement.

The nominal shear strength of ACI Code adopted by V_n , when strength done by two contributions as follow:

$$V_n = V_c + V_s \tag{1}$$

Where, V_c is concrete strength contribution and simplified shear strength of concrete equals to

$$V_c = 0.17\sqrt{f'_c}b_wd \quad \text{for } \sqrt{f'_c} \leq 8.33 \text{ MPa} \tag{2a}$$

Additionally, for simplified equation, another case was considered without $\sqrt{f'_c} < 8.33$ restriction to check the equation for concrete compressive strength higher than 70 MPa.

$$V_c = 0.17\sqrt{f'_c}b_wd \tag{2b}$$

ACI also permits to use more accurate equation, include the effect of applied shear and moment and has also effects of dowel action of the longitudinal bars.

$$V_c = \left(0.17\sqrt{f'_c} + 17\rho_w \frac{V_u d}{M_u}\right) b_wd \tag{3}$$

The value of $V_u d/M_u$ in Eq. (3) must be equals or less than 1. Also, V_s is the steel contribution and equals to:

$$V_s = \frac{A_v f_{yv} d}{s} \tag{4}$$

Euro Code (EC-2) adopted variable strut inclination method to find shear strength of a member. This method takes the diagonal strut as a concrete strut, D_c , the ties act as a vertical stirrup V_T , and the longitudinal reinforcement acts as a bottom chord, B_T , where the angle θ , has varying between 22 to 45 degree, shown in Fig. 11.

The EC-2, design shear resistance of a member without shear reinforcement is $V_{Rd,c}$ as given

$$V_{Rd,c} = \left[0.18 \left(1 + \sqrt{200/d}\right) (100\rho_w f_{ck})^{1/3}\right] b_wd \tag{5}$$

But not less than

$$V_{Rd,c} = \left[0.035 \left(1 + \sqrt{200/d}\right)^{3/2} \sqrt{f_{ck}}\right] b_wd \tag{6}$$

Where $1 + \sqrt{200/d} \leq 2$

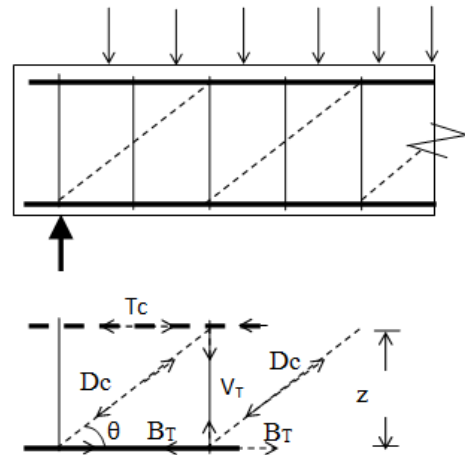


Figure 11: Strut and tie mechanism.

Where $V_{Rd,c}$ is the design shear strength of a member governed by the yielding of web bars (kN), A_{sw} is the area of web bars (mm^2), f_{ywd} : is the design yield strength of web bars (MPa), θ is the angle between the concrete strut and the longitudinal axis of the beam (rad), and f_{ck} : is the cylinder compressive strength of concrete ($= \sqrt{f'_c}$), (MPa).

The external applied shear V_{ED} is greater than resisting shear of concrete, $V_{Rd,c}$, all the applied shear is resisted by stirrups (neglecting the effect of concrete contribution), so the shear resistance of the web reinforcement $V_{Rd,c}$ is given by (EC-2, Clause (6.2.3))

$$V_{Rd,s} = \frac{A_{sw}}{s} f_{ywd} \cot \theta \tag{7}$$

$$\theta = 0.5 \sin^{-1} \left(\frac{V_{Rd,E}/b_wd}{0.153 f_{ck} (1 - f_{ck}/250)} \right) \tag{8}$$

A shear strength formula is proposed based on the 65 experimental data of the current paper and other six literatures (Sherwood et al., 2006; Lubell et al., 2009; Shuraim, 2012; Hanafy et al., 2012; Lotfy et al., 2014; Mohammadyan-Yasouj et al., 2015) for wide beams. The proposed shear strength equation composed of three parts which are concrete strength contribution (V_c), shear reinforcement contribution (V_{vs}) and longitudinal reinforcement contribution (V_{LS}). The following equations are proposed:

$$V_R = V_c + V_{vs} + V_{Ls} \quad (9)$$

$$V_c = 0.75 \theta f'_c b_w d \quad (10)$$

$$V_{vs} = \frac{A_v z f_{yv}}{20 s \tan \theta} \quad (11)$$

$$V_{Ls} = \left(A_s \rho - \frac{M_u}{z} \right) \tan \theta \quad (12)$$

$$\text{Where: } \theta = 0.5 \sin^{-1} \left(\frac{2 V_u}{b z f'_c} \right) \quad (13)$$

$$19 \leq \theta \leq 60$$

6. THEORETICAL MODEL ASSESSMENT

The efficiency of the proposed model is compared to the provisions of ACI 318-14 and EC2 using 65 wide beams from the literatures (5 wide beams from (Sherwood et al., 2006), 13 from (Lubell et al., 2009), 16 from (Shuraim, 2012), 12 from (Hanafy et al., 2012), 10 from (Lotfy et al., 2014), 4 from (Mohammadyan-Yasouj et al., 2015), and 5 from the authors, the results are shown in Fig. 12, 13 and 14; and statistical details are presented in Table 4. The majority of the considered beams were made from normal strength concrete (NSC) while eleven of them are made from high strength concrete (HSC) (i.e., compressive strength is equal to or higher than 70 MPa). For ACI 318-14 and EC2, no safety factors and material partial safety factors were used.

Fig. 12 shows the influence of concrete compressive strength on the shear strength prediction using ACI 318-14, EC2 and proposed equation. It can be seen that ACI 318-14 prediction is more conservative and more scatters compared to EC2; however, EC2 conservatism does not change with increasing concrete compressive strength as the ACI 318-14 becomes extremely conservative and uneconomic when concrete compressive strength is higher than 70 MPa. The proposed equation leads to more accurate results with the least coefficient of variation.

The second considered parameter on the shear strength prediction of wide beams using aforementioned codes of practice and the proposed equation is width to depth ratio (b/h) of the beam as shown in Fig. 13. It is clear from the figure that the degree of conservatism for both

ACI318-14 and EC2 decreases as the width of the beam increases and becomes very unsafe when b/h is higher than 3, this is more pronounced in the EC2 prediction than ACI318-14. This is probably because the provisions of these codes of practice were drawn mainly on beams with normal b/h and could lead to very unsafe results when applying to wide shallow beams.

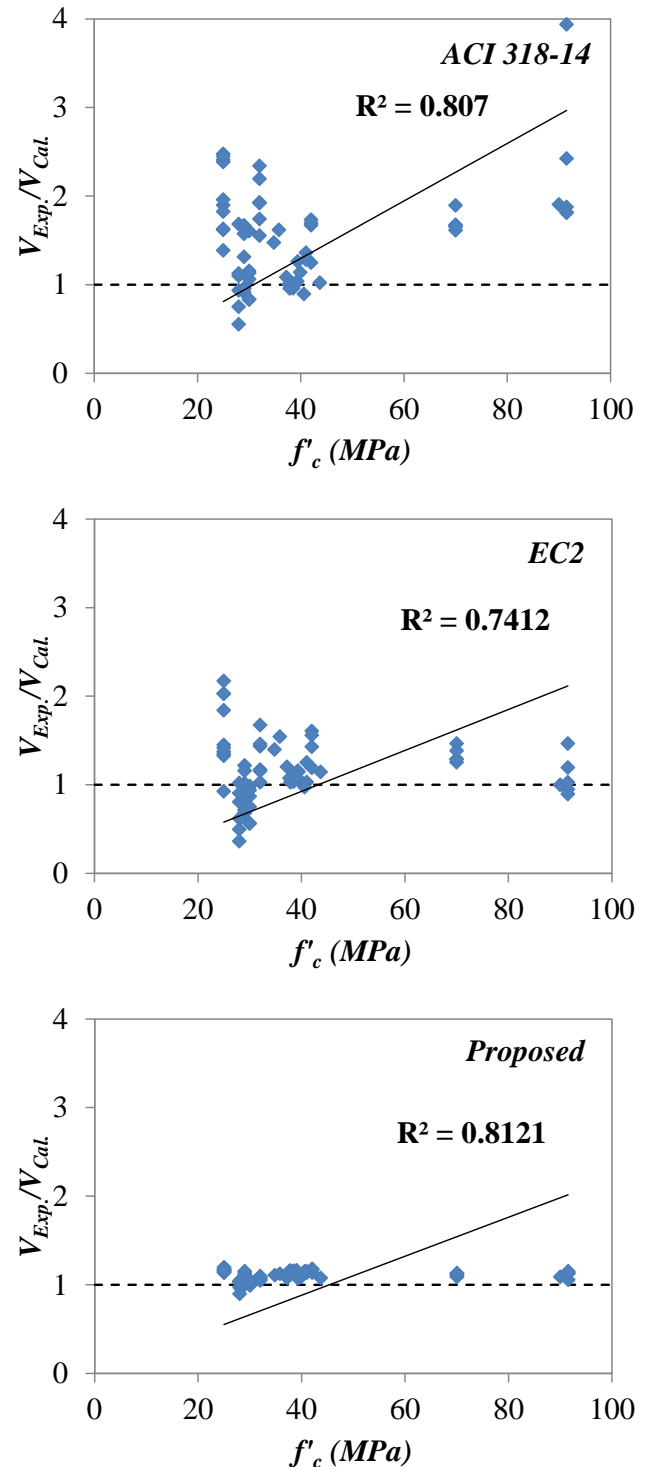


Figure 12: Influence of concrete compressive strength on the predicted shear capacity of wide beams by different approaches.

Table (4) Experimental to theoretical shear strength results for different methods.

Equations	$V_{EXP}/V_{Theor.}$			
	Average	SD	COV	R ²
ACI (1): Eq. (1), (2) and (4)	1.53	0.57	37.01	0.807
ACI (2): Eq. (1), (2) and (4) without $\sqrt{f'_c} < 8.333$	1.5	0.52	34.75	0.788
ACI (3): Eq. (1), (3) and (4)	1.38	0.48	34.50	0.802
Euro (EC-2): Eq. (5), (6), (7) and (4)	1.16	0.36	31.33	0.741
Proposal: Eq. (9), (10), (11), (12) and (13)	1.10	0.06	5.69	0.812

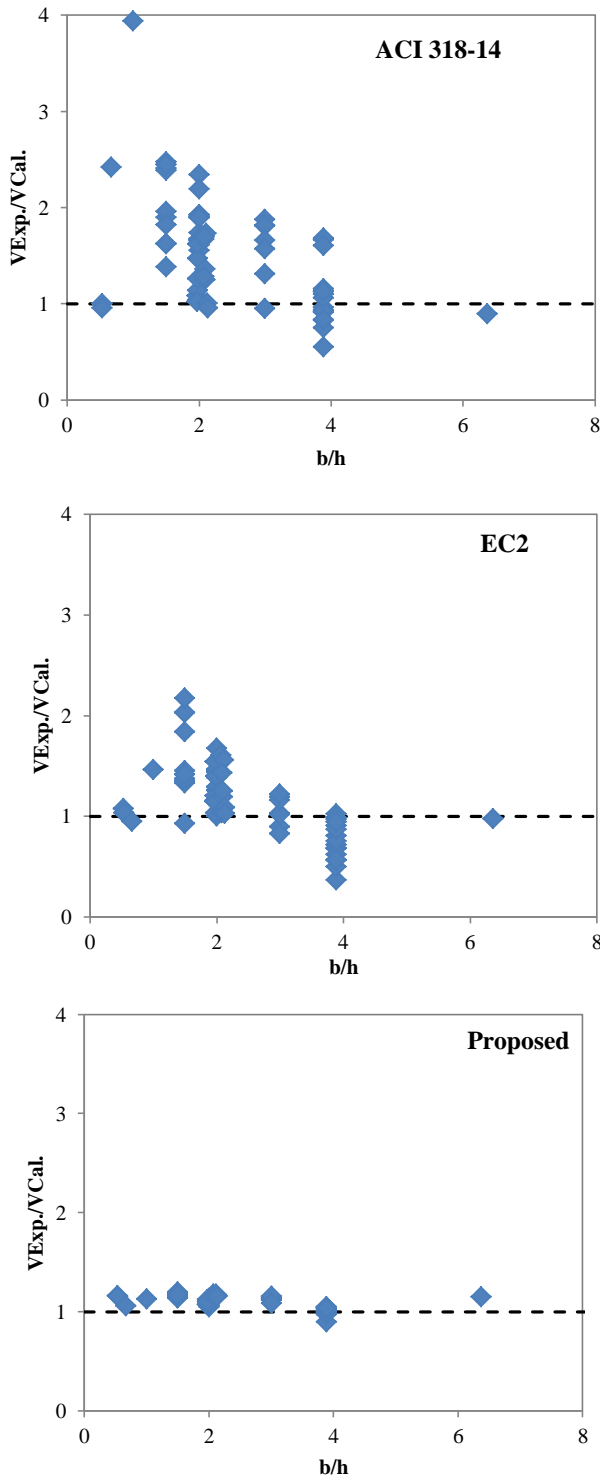


Figure 13: Influence of b/h on the predicted shear capacity

of wide beams by different approaches.

The influence of shear reinforcement index ($\rho_v f_{yv}$) on the shear strength prediction of the considered approaches are shown in Fig. 14. Once more the codes of practice do not have a constant margin of safety for beams with different shear reinforcement ratio. Shear reinforcement ratio has limited effect on the shear capacity of the beam; it could enhance the capacity when shear reinforcement is increased up to a limit, any increase after that has a negligible effect on the shear capacity. This cannot be fulfilled with the provisions of EC2, since it neglects the effect of concrete contribution which in turn could lead to very unsafe results for beams with high shear reinforcement ratio as can be seen in Fig. 14. For beams with shear reinforcement index more than 1.0 MPa, ACI318-14 code is more conservative compared to EC2, since ACI 318-14 accounts for concrete contribution in the shear strength prediction.

The experiment result of 65 WB available in the literatures are divided by calculated result (V_{EXP}/V_{cal}) are showed that, the average values are as follows: from smallest to highest 1.0, 1.16, 1.38, 1.50 and 1.53 for proposal, EC-2, ACI-Eq. (3), ACI-Eq. (2b) without $\sqrt{f'_c}$ restriction, and ACI-Eq.(2a) with $\sqrt{f'_c}$ restriction. The COV has same ascending order are 5.69%, 31.3%, 34.5%, 34.75%, and 37.0%, respectively (Table 4). From these results of average, SD and COV, it can be concluded that ACI (3) accurate is better that ACI-Eq. (2) for wide beam.

This means that $\sqrt{f'_c}$ restriction is conservative, can be worked with HSC, and can be removed from ACI. EC-2 Code depends on struts and tie model but has little difference with ACI (3) in all three statistical assessments. The proposed method depends on strut and tie model but incorporated with some changeable in the

factor and got more close result to unity for (V_{EXP}/V_{cal}) as shown in Table 4.

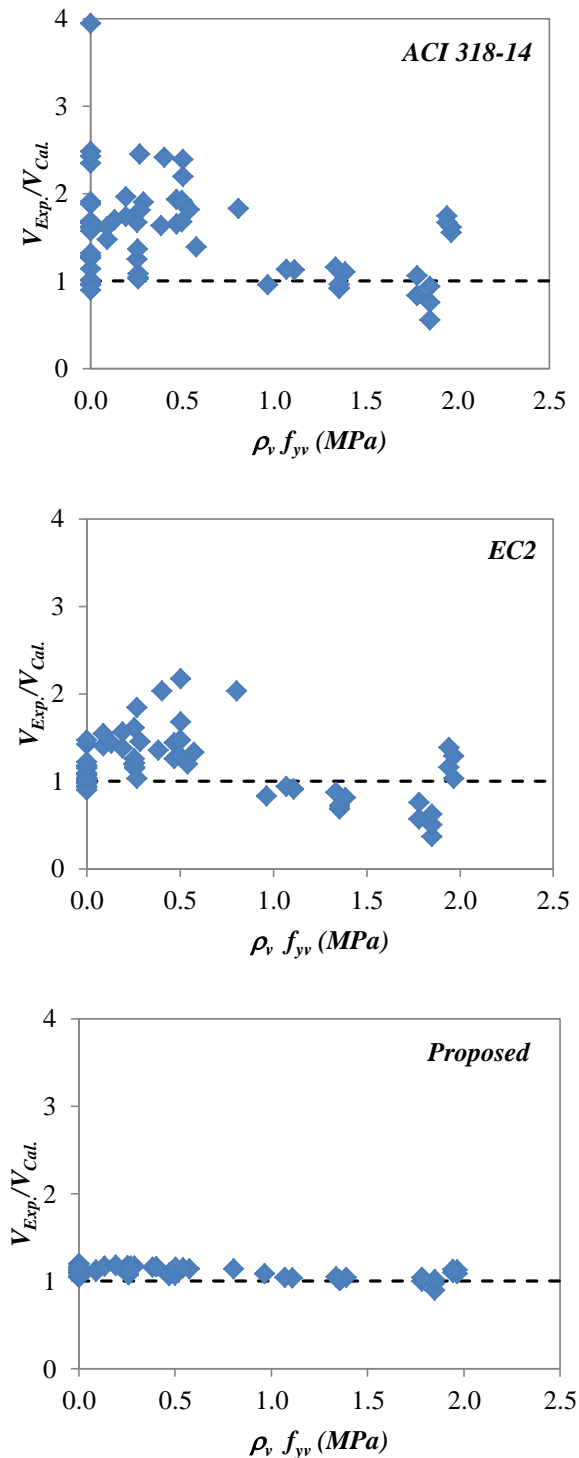


Figure 14: Influence of shear index on the predicted shear capacity of wide beams by different approaches.

The proposed equation could account for all aforementioned parameters and predict the shear behavior of wide shallow beams very accurately. However, it needs further investigation and validations against more experimental data, since the equation was proposed using best fit analysis for the same database. Therefore, the

authors of this paper recommend more experimental investigation on wide shallow beam and validating the proposed approach.

7. CONCLUSION

The following conclusion can be drawn based on the experimental and theoretical work of the current paper:

- For high strength self-compacted concrete, adding of wet carbon fiber polymer (microfiber) could lead to reduction in the compressive strength. This is because high strength self-compacted concrete is more sensitive to add micro fiber than high strength concrete with steel fiber, it's required a new mix design for using microfiber with SCC.
- As the beam (b/h) ratios decrease from 3 to normal depth, the reduction of shear strength of beam reached 30.1% and 71.3% respectively. It is noted that, the relation between (b/h) ratios and the shear strength are somewhat proportion linearly.
- The WB with and without stirrups has no effect on load-displacement relationship during most loading increment. The exitance of the stirrups lets to delay the final failure of the beams, then increased the final deflection. The final deflection increased as the stirrups increased from 0 (WB-3) to 8 \emptyset @200 mm c/c (WB-4) and 8 \emptyset @100 mm c/c (WB-5), changed from 11.3 mm (WB-3) to 13.7 mm and 17.7 mm, respectively.
- ACI equations has a limit in calculation of shear strength with concrete compressive strength (f'_c) up to 70 MPa. This means that the restriction is conservative. The experimental results showed the ACI equation can be worked with HSC with f'_c more than 70 MPa. The restriction can be removed from ACI.
- The experiment results with respect to calculated results (V_{EXP}/V_{cal}) of 65 WB available in the literatures are showed that, the average values are as follows: from smallest to highest 1.0, 1.16, 1.38, 1.50 and 1.53 for proposal, EC-2, ACI-Eq. (3), ACI-Eq. (2b), and ACI-Eq. (2a). From these results, it can be concluded that ACI code equations gave conservative results relative to Euro code for WB.

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Conflict of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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