

Punching Shear Resistance of High Strength GFRP Reinforced Concrete Flat Slabs

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Abstract

This study program has been arranged to test the behavior of punching shear for concrete slabs reinforced by an embedded glass fiber reinforced polymer (GFRP) reinforcements. However, the shear resistance of concrete members in general and especially punching shear of two-way RC slabs, reinforced by GFRP bars has not yet been fully investigated. Seven decades ago, many researches have been carried out on punching shear resistance of slabs reinforced by conventional steel and several design methods were created. However, these methods can be not easily applied to FRP-reinforced concrete slabs due to the difference in mechanical properties between (FRP) and steel reinforcement. sixteen specimens are to be cast in lab within two categories of reinforcements such as GFRP and equivalent steel reinforcements. In addition, based on experimental data obtained from the author's study and ACI model, the paper performed an evaluation of accuracy of proposed model. The results from the evaluation show that the ACI-formula gave inaccurate results with a large scatter in comparison with the test results of this study. A new design formula can be proposed for more accurate estimation of punching shear resistance of (GFRP) specimens.

Key Words: Punching shear, Two-way slabs, GFRP, Design of RC slabs, and High strength concrete

مقاومة القص الثاقب في السقوف الخرسانية عالية المقاومة المسلحة بقضبان اليااف الزجاجية البوليميرية

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الخلاصة

قد تم ترتيب البرنامج الخاص بهذه الدراسة للتحري عن سلوك القص الثاقب في السقوف الخرسانية المسلحة بقضبان تسليح من اليااف الزجاج البوليميرية. بصورة عامة فإن مقاومة القص في الاعضاء الخرسانية وخصوصا مقاومة القص الثاقب في السقوف الخرسانية المسلحة بقضبان اليااف الزجاج البوليميرية لم يتم فحصها وتدقيقها بصورة كاملة. حيث على مر سبع عقود ماضية تم اقتراح ووضع العديد من طرق تصميم السقوف الخرسانية المسلحة بقضبان حديد التسليح الاعتيادية. ولكن لا يمكن اعتمادها مباشرة على السقوف المسلحة بقضبان البوليمير وذلك لوجود اختلاف في الخواص الميكانيكية بين التسليح بالحديد الاعتيادي والتسليح بالاليااف البوليمير. ستة عشر عينة تمصها في المختبر قُسمت الى مجموعتين وحسب نوع التسليح ولكن بنسب مكافئة للحديد الاعتيادي. وبالإضافة الى الجزء المختبر فقد تم اقتراح نموذج لحساب مقاومة القص وهكذا سقوف ومقارنتها مع نموذج مدونة المعهد الامريكي للخرسانة ، ووجد ان نموذج المدونة غير دقيق وله قيم خطأ كبيرة اذا ما قورنت مع نتائج الموديل المستنبط من التجارب في هذه الدراسة في حساب دقيق لحمل الفشل لعينات السقوف الخرسانية عالية المقاومة ومسلحة بقضبان الزجاج البوليميرية. يمكن توسيع النموذج الى عتبات واقعة تحت تأثير حركات ثلاثية الأبعاد.

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1. Introduction

The durability and long time term serviceability of reinforced concrete members has become a most concern in the building industry. One of the main factors decreasing durability and serviceability life of the reinforced concrete structures is the corrosion of steel reinforcement. Many -reinforced steel concrete structure's elements exposed to de-icing salts and marine environment conditions require extensive and expensive maintenance. Recently, the use of fiber-reinforced polymer (FRP) as alternative reinforcing material in reinforced concrete structures has omitted as innovative solution to the effect of corrosion problem. In addition to a non-corrosive response of FRP materials, they also have higher than strength-to-weight ratios which makes them attractive as reinforcement for concrete elements.

The shear behavior of concrete members in general and especially punching shear of two-way slabs, reinforced with FRP bars has not yet been fully explored. Many studies have been carried out on punching shear behavior of slabs reinforced with conventional steel and several design models were proposed. However, these models cannot be directly worked to FRP bars reinforced concrete slabs due to the variances in mechanical textured properties between (FRP and steel) materials . The modulus of elasticity for the commercially available glass(G) and aramid (A)FRP bars is 20–25% that of steel compared to 60–75% for carbon(C) FRP bars. Due to the specific low modulus of elasticity of FRP bars reinforcement, concrete members reinforced with FRP bars experience reduced shear strength compared to the punching shear strength of those reinforced with the same amount of steel reinforcement (Banthia et al. (1995); El-Gamal et al. 2005; El-Ghandour et al. 1997; El-Ghandour 2003; Matthys and Taerwe 2000).

The concrete members reinforced by FRP bars experience reduced shear strength compared to the shear strength of those reinforced with the same amounts of steel reinforcement. This results in the development of wider and deeper cracks. Deeper cracks decrease the contribution to shear strength from the uncracked concrete due to the lower depth of concrete in compression. Wider cracks, in turn, decrease the contributions from aggregate interlock and residual tensile stresses. Additionally, due to the relatively small transverse strength of FRP bars and relatively wider cracks, the contribution of dowel action may be negligible.

2. Experimental Procedure

Test results from steel bars reinforced simply edges supported slab specimens do not usually provide an accurate estimations of the ultimate punching carrying capacity of a GFRP bars reinforced slabs as a flexural reinforcements. When the slab is reinforced with GFRP bars, many factors may be affected on the punching shear strength of that slabs because GFRP bars have different mechanical properties of steel bars. The improved the punching shear carrying capacity can be contributed to the compressive strength of concrete, amount of flexural reinforcement ratio, and slab thickness. Under the circumstances, the present study comprised of a planned series of tests on GFRP bars slabs as well as steel bars (reference) slabs, variation of compressive strength of concrete, flexural reinforcement and slab thickness. The test results obtained from this study will be useful to evaluate an insight on the punching behavior of GFRP concrete slabs.

2.1. Specimen Details

A total of sixteen squared reinforced concrete slabs (Steel & GFRP) were cast and tested in this study. Twelve of these slabs had GFRP bar reinforcements, whereas the other four samples were steel bars reinforcement slabs. All specimens have squared dimensions with 1100mm side length. Details of the tested (Steel & GFRP) slab samples are given in Table 1. Also a typical cross-

sectional and dimension's detail of specimens are shown in Figure 1. A palte of slab specimen within reinforcement bars can be seen in Figure 2.

Table 1. Description of Steel & GFRP reinforced concrete tested specimens

Symbol	Thickness (h) mm	Reinforcement Ratio (ρ)	Reinforcement Bar Type	Concrete Type
SN125-75	75	0.01674	Steel	Normal
SN250-75	75	0.0083	Steel	Normal
SH125-100	100	0.01144	Steel	High
SH250-100	100	0.0057	Steel	High
GN125-75	75	0.01674	GFRP	Normal
GN250-75	75	0.0083	GFRP	Normal
GN375-75	75	0.0055	GFRP	Normal
GH125-75	75	0.01674	GFRP	High
GH250-75	75	0.0083	GFRP	High
GH375-75	75	0.0055	GFRP	High
GN125-100	100	0.01144	GFRP	Normal
GN250-100	100	0.0057	GFRP	Normal
GN375-100	100	0.0038	GFRP	Normal
GH125-100	100	0.01144	GFRP	High
GH250-100	100	0.0057	GFRP	High
GH375-100	100	0.0038	GFRP	High

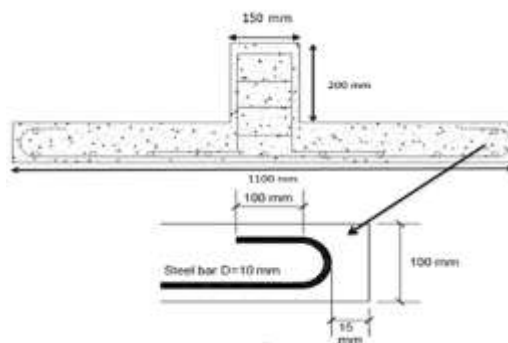
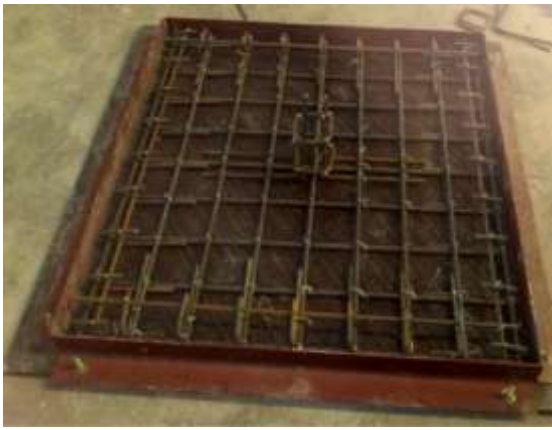
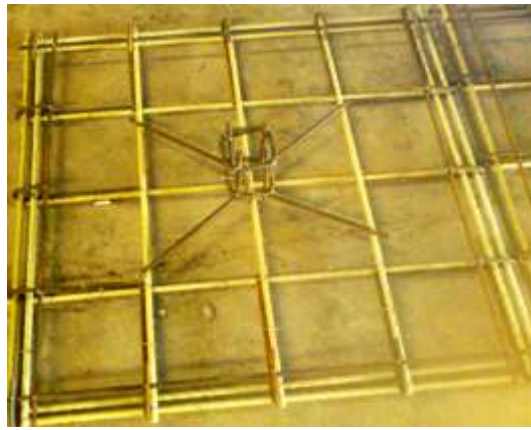


Figure1. Details of a typical model tested specimen of GFRP slab



(a)



(b)

Figure 2. Plate of typical model slab reinforcement , (a). steel reinforced ($\text{Ø}12@125\text{mm}$), and (b). GFRP reinforced ($\text{Ø}12@250\text{mm}$)

2.2. Material Properties

The concrete used in the specimens consisted of ordinary Portland cement, natural sand and crushed stone aggregate with maximum size 10 mm. The water cement ratio (w/c) for normal concrete was (0.4), and for high strength concrete was(0.3) . Both (10 mm and 12 mm) diameter deformed steel bars having average yield strength of (560 MPa) were used in the slab panels. An average cylinder compressive strength of normal concrete of 33.5 MPa, and 54 MPa for high strength concrete, which are tested at the age of 28 days.

3. Testing Procedure

The tests were designed to simulate conditions in actual structures. Each tested specimen was subjected to concentrate at mid span loading at center of universal testing machine. A Four hardened steel supports were used at each corner of the specimen as support. These supports confirmed the clear span of 1100mm for all samples. During testing, corner sides of each sample were properly anchored by means of heavy joist, which was connected to structural floor. Loading was applied to specimen at an approximately constant rate up to the peak load; at the same time deflections were measured. Failure occurred abruptly in all specimens and loading was stopped after failure. The testing apparatus, consisting of steel stiffened girder and 500 kN capacity hydraulic loading jack was used for the purpose of loading the specimens till failure. The load transferred by jack was applied to center of specimen through a stub RC concrete column 200 mm height, whereas cross section of 150x150mm, simulating a concentrated applied load. Loading rate was applied to the specimens by 4.45 kN increments up to failure with measurements of deflections when each increment of loading was reached. The testing rigs are shown in Figures 3 and 4. There was transducer (LVDT) at the mid-span of slab to measure the central slab deflection.

4. Test Results

All tested specimens having a punching type of failure with their true brittle characteristics and failed in a punching shear mode. Most of the slab specimens failed at a tested load much higher than those calculated from the codes. The cracking pattern modes at the bottom surface of slab

having low amounts of reinforcement were more severe than those having higher amounts of reinforced steel. It has been seen for all the specimens that the deflection at support was ignored; pointing out to the viewpoint that support anti-classic curvature was omitted, during the testing of the models. A typical crack pattern after failure on the bottom surface of slab model is shown in Figure 5.

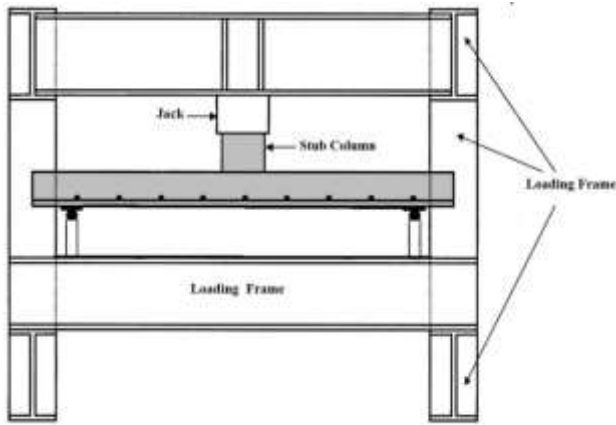


Figure 3. Testing set - up



Figure 4. Test rig equipment



Figure 5. A Typical cracks patterns on the bottom face of tested specimens

5. Discussions

Test results obtained from this study have been analyzed and shown in Table 2. It has been found that ultimate punching shear capacity and behavior of slab samples are dependent on flexural reinforcement ratio, slab thickness and concrete strength of slab.

5.1. Deflection

The differences of RC slab deflection subjected to punching load are shown in Figure 6 for all tested specimens. It may be seen that a true load-deflection exponential curves of the RC slabs tested could be illustrated. It is, however, clear from Figure 6 that mid-span deflections were larger for the slabs have less GFRP reinforcement bars ratios. In general, the value of deflection decreased when the GFRP reinforcement become higher. Although the higher the reinforcement, the smaller the deflection was observed for same loading.

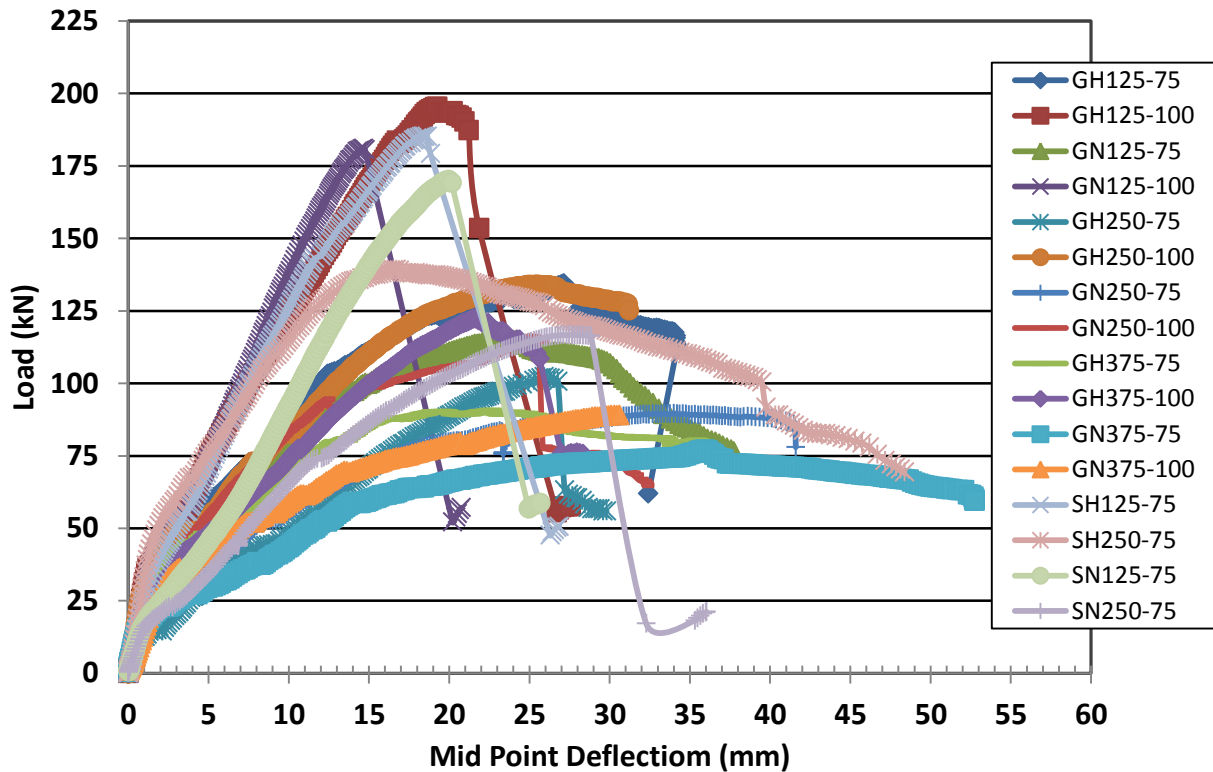


Figure 6. Deflection slab center of all slabs subjected to different conditions

5.2. Ultimate Load Carrying Capacity

The table (2) illustrates a theoretical analysis of test results. The non-dimensional punching shear strength ($P_u/f'_c b_o d$) is estimated, where d = effective depth of slab, $b_o = 4(120 + d)$ and normalized punching shear strength ($P_u/\sqrt{f'_c} b_o d$) of each specimen have been given. There is a general trend to increase the load carrying capacity of slabs with the increase of slab thickness as well as amount of flexural reinforcement in their slabs.

Table 2. Test results of non-dimensional and normalized uniform punching shear Strengths

Slab Sample	Slab thickness (h) (mm)	Reinforcement Ratio (ρ) (%)	Experimental failure load (P_u) (kN)	Cylinder concrete strength (MPa)	Non-dimensional strength ($P_u/f'_c b_o d$)	Normalized punching shear strength ($P_u/\sqrt{f'_c} b_o d$)
SN125-75	75	1.674	170	33.42	0.11	0.65
SN250-75	75	0.83	116.7	32.2	0.08	0.46
SH125-100	100	1.144	185.16	52.82	0.05	0.35
SH250-100	100	0.57	139.3	55.53	0.03	0.25
GN125-75	75	1.674	115.18	35.6	0.07	0.43
GN250-75	75	0.83	89.55	33.69	0.06	0.34
GN375-75	75	0.55	90.45	34.82	0.06	0.34
GH125-75	75	1.674	134.37	53.85	0.06	0.41
GH250-75	75	0.83	102.24	55.2	0.04	0.31
GH375-75	75	0.55	77.12	53.82	0.03	0.23
GN125-100	100	1.144	180.95	31.7	0.08	0.44
GN250-100	100	0.57	116.1	33.52	0.05	0.27
GN375-100	100	0.38	89.06	32.73	0.04	0.21
GH125-100	100	1.144	195.4	53.89	0.05	0.36
GH250-100	100	0.57	133.89	52.67	0.03	0.25
GH375-100	100	0.38	122.24	53.96	0.03	0.23

6. Variables Effecting On Load Deflection Relationship

6.1 The effect of concrete strength

a. For slab thickness 75mm and 125 mm GFRP spacing :

Figure(7) shows that the effect of compressive strength on the same slab thickness and GFRP spacing. The ultimate load increased with increasing compressive strength. In this case the difference in ultimate load was increasing (16) % when using high compressive strength than using normal compressive strength (increasing in concrete strength about (60 %)), because the increasing in concrete strength may be increase in the flexural strength for these slabs and produced punching shear failure at higher ultimate load. However, the compressive strength of concrete has a strong influence on the punching shear strength and behavior of flat slabs.

Generally, the ultimate punching shear capacity increased with the increasing of concrete strength. The ultimate load increased (5% to 16%) when the concrete compressive strength changed from (30 to 50)MPa, increasing (66) %. Results show that the deflection of slab casting with normal concrete at ultimate load was (23.68) mm, but at the same load in high compressive strength was (16.2) mm. the effect of concrete strength on deflection is decreasing the deflection at the same load about (31.5) % when increasing the concrete strength (60 %)

b. For slab thickness 100 mm and 125 mm GFRP spacing:

Figure(8) shows that the effect of compressive strength on the same slab thickness and GFRP spacing. The ultimate load increased with increasing compressive strength, in this case the difference in ultimate load was increasing (8)% when using high compressive strength than using

normal compressive strength. Results show that the deflection of slab casting with normal concrete at ultimate load was (14.6)mm, but at the same load in high compressive strength was (16.1) mm. The effect of concrete strength on deflection is so little, it is less than about (10) %when increasing the concrete strength (60%).

c. For slab thickness 75 mm and 250 mm GFRP spacing:

Figure (9) shows that the effect of compressive strength on the same slab thickness and GFRP spacing. The ultimate load increased with increasing compressive strength. In this case the difference in ultimate load was increasing (14) % when using high compressive strength than using normal compressive strength. Results observed that the deflection of slab casting with normal concrete at ultimate load was (33.9) mm, but at the same load in high compressive strength was (21.6) mm. The effect of concrete strength on deflection is decreasing the deflection at the same load about (36.2) % when increasing the concrete strength from (60) %.

d. For slab thickness 100 mm and 250 mm GFRP spacing :

Figure (10) shows the effect of compressive strength on the same slab thickness and GFRP spacing. The ultimate load increased with increasing compressive strength, in this case the difference in ultimate load was increasing (15) % when using high compressive strength than using normal compressive strength. From result observed that the deflection of slab casting with normal concrete at ultimate load was (24.87) mm, but at the same load in high compressive strength was (17.4) mm. The effect of concrete strength on deflection is decreasing the deflection at the same load about (30) % when increasing the concrete strength from (60) %.

e. For slab thickness 75 mm and 375 mm GFRP spacing:

Figure (11) shows the effect of compressive strength on the same slab thickness and GFRP spacing. The ultimate load increased (17) % with increasing compressive strength. Results show that the deflection of slab casting with normal concrete at ultimate load was (35.27) mm, but at the same load in high compressive strength was (12.5) mm. The effect of concrete strength on deflection is decreasing the deflection at the same load about (64.55) % when increasing the concrete strength from (60%).

f. For slab thickness 100 mm and 375 mm GFRP spacing :

Figure (12) shows the effect of compressive strength on the same slab thickness and GFRP bar spacing. The ultimate load increased (35) % with increasing compressive strength. Results show that the deflection of slab casting with normal concrete at ultimate load was (30.28) mm, but at the same load in high compressive strength was (12.9) mm. The effect of concrete strength on deflection is decreasing the deflection at the same load about (57.4) % when increasing the concrete strength from (60%).

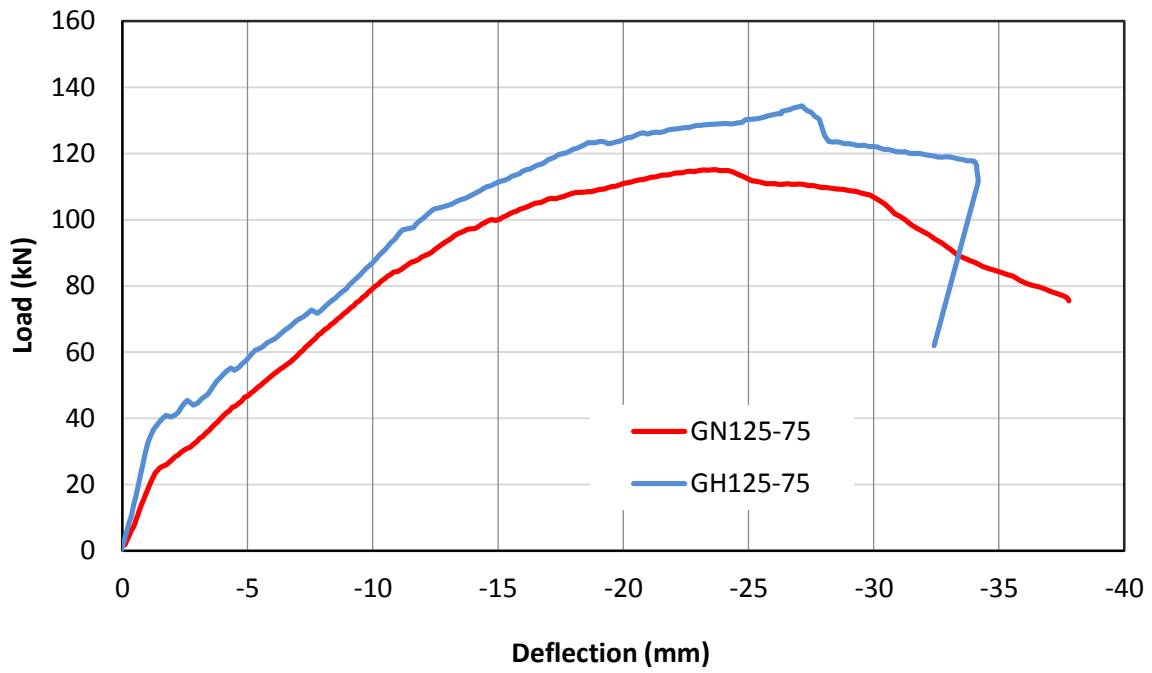


Figure (7) the effecting of concrete strength on load deflection relationship for slab thickness 75 mm and 125 mm GFRP spacing.

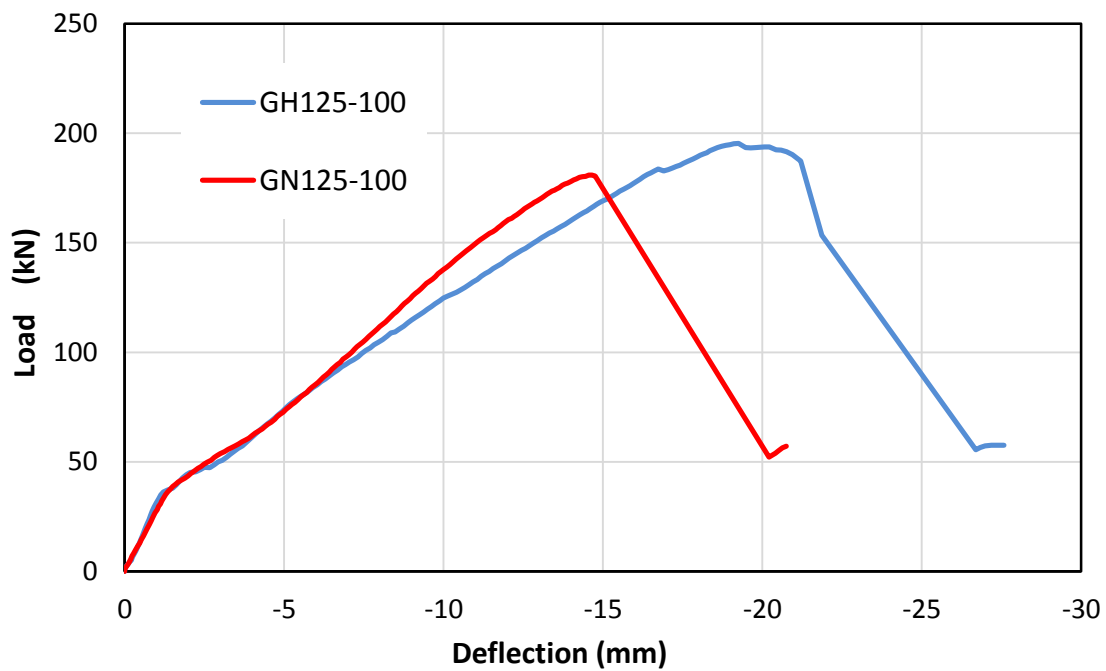


Figure (8) the effecting of concrete strength on load deflection relationship for 125 mm GFRP bar spacing and slab thickness 100 mm.

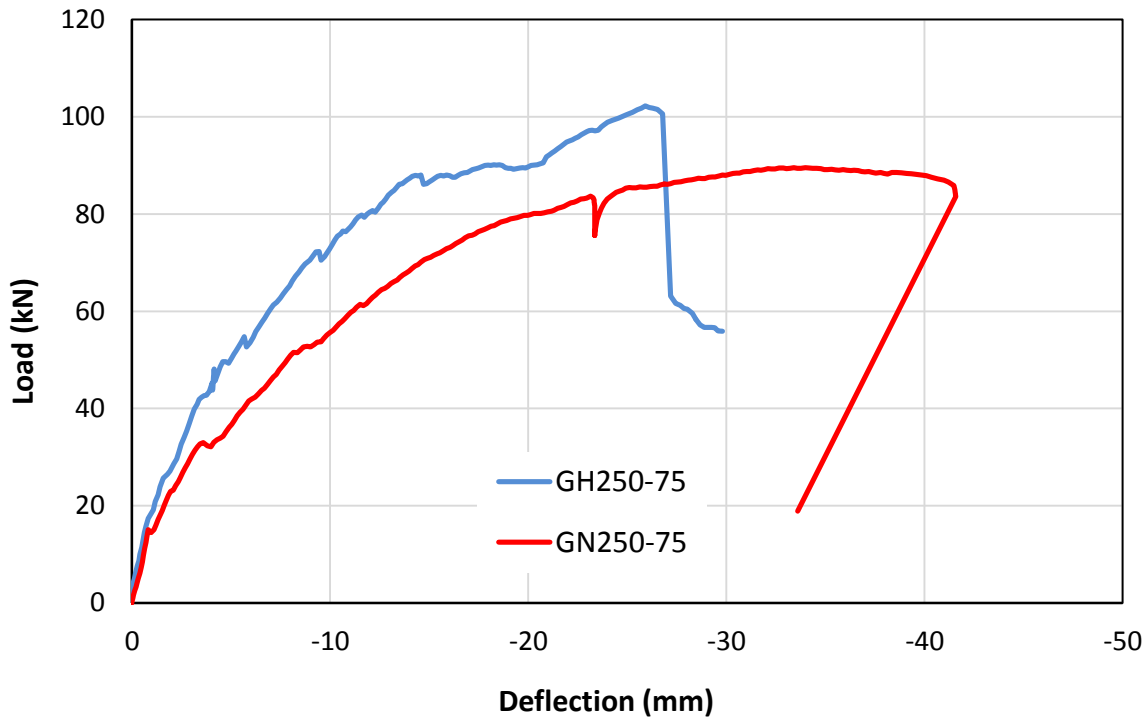


Figure (9) the effecting of concrete strength on load deflection relationship for 250 mm GFRP bar spacing and slab thickness 75 mm

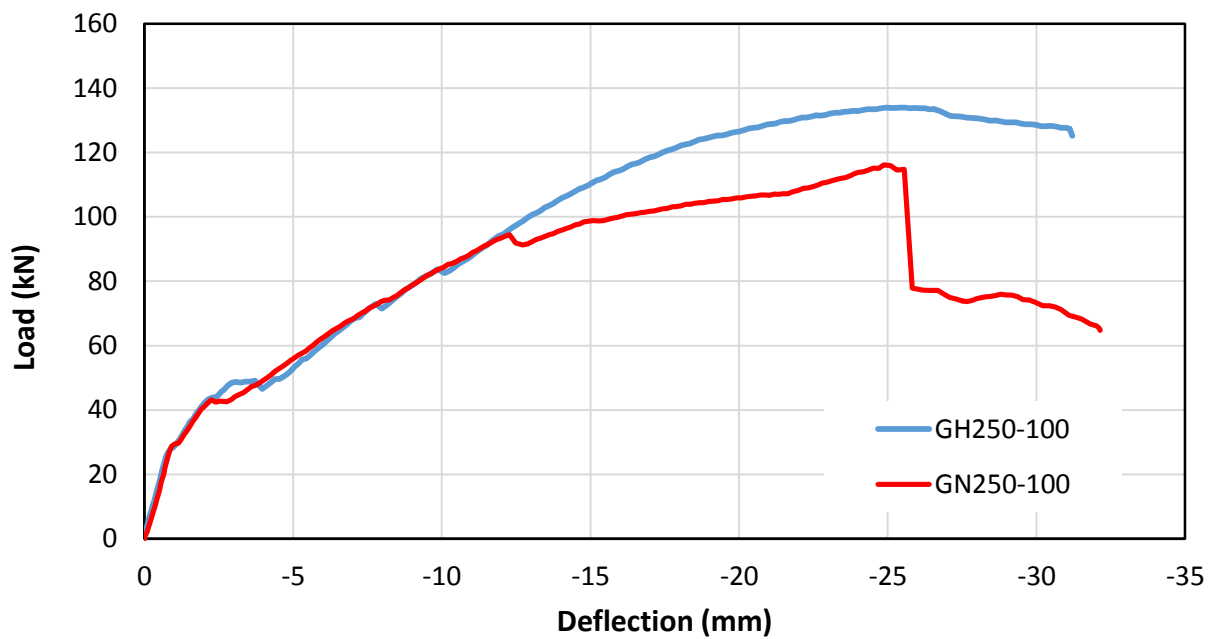


Figure (10) the effecting of concrete strength on load deflection relationship for 250 mm GFRP bar spacing and slab thickness 100 mm.

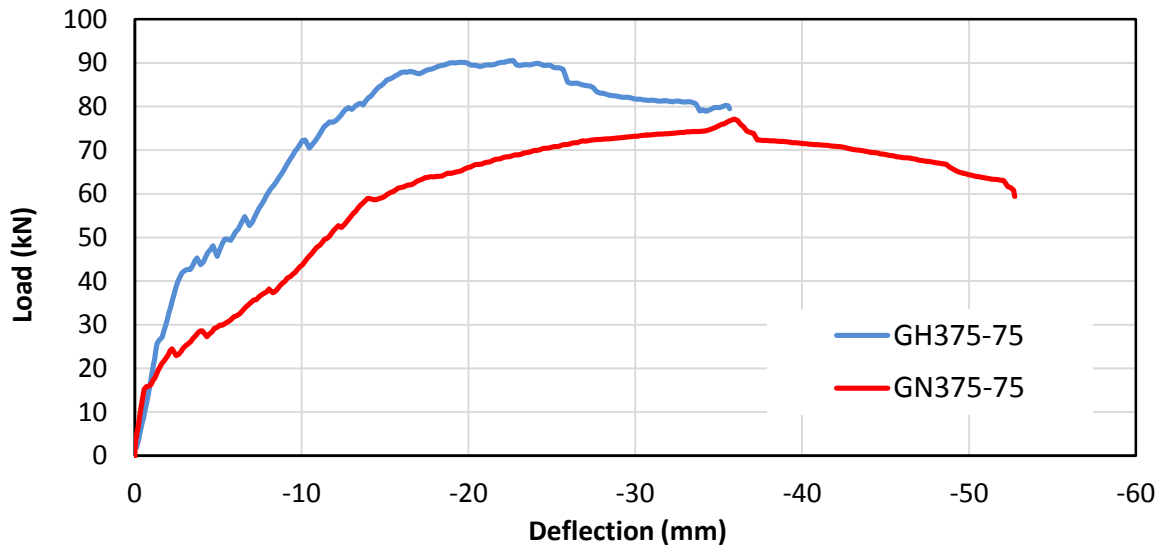


Figure (11) the effecting of concrete strength on load deflection relationship for 375 mm GFRP spacing and slab thickness 75 mm.

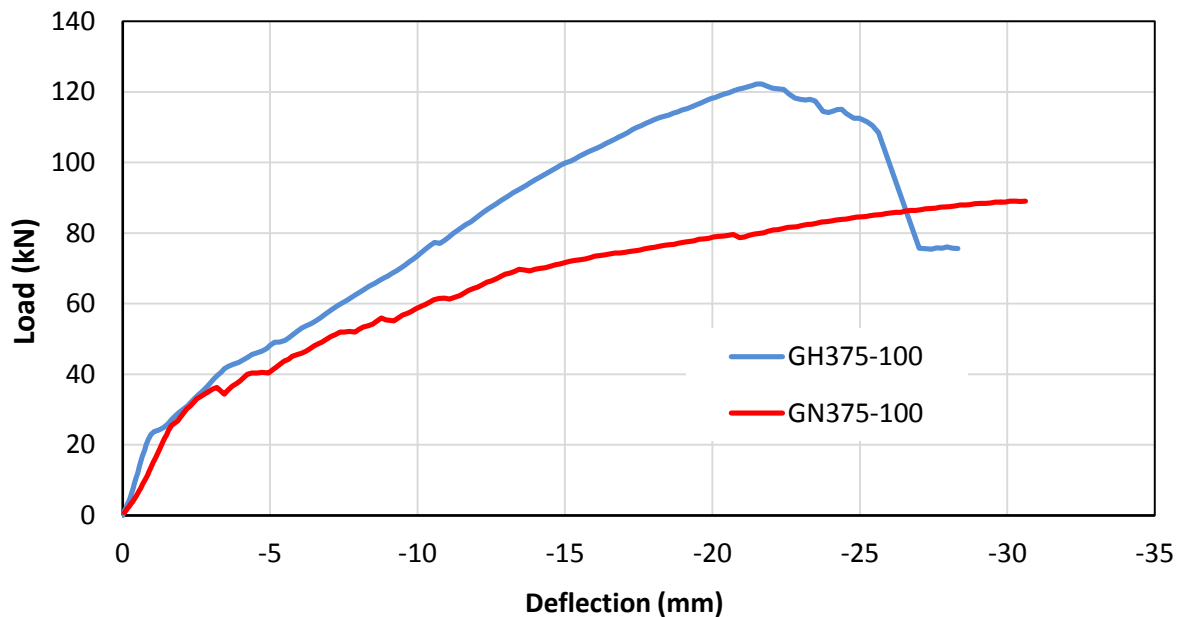


Figure (12) the effecting of concrete strength on load deflection relationship for 375 mm GFRP spacing and slab thickness 100 mm.

6.2. The effect of GFRP bars spacing (flexural reinforcement):

Generally, ultimate shear punching capacity of slabs increases with the addition of steel reinforcement (**Marzouk and Hussein 1991**), the existing of flexural reinforcement increased the flexural strength for these slabs and produced punching shear failure at higher ultimate load. The flexural reinforcement ratio increases the depth of the compression zone, and thus, the punching shear strength increases (**Park et al. 2011**).

a. For normal compressive strength and slab thickness 75mm :

From figure (13) observe the effect of GFRP flexural reinforcement ratio (GFRP bar with diameter 12mm). The ultimate load increased with decreasing GFRP spacing. The ultimate load increasing (28%) from decreasing GFRP bar spacing (250 to 125) mm, and (49) % from decreasing GFRP bar spacing (375 to 125) mm, and (16) % from decreasing GFRP bar spacing (250 to 375)mm. Results indicate that the deflection decreased when increasing flexural reinforcement ratio, the existing of flexural reinforcement increased the flexural strength for these slabs and produced punching shear failure at higher ultimate load than less ratio reinforced slabs. At GFRP spacing 375mm, the deflection at ultimate load was (35.27)mm, but at the same load when GFRP spacing is 250 and 125mm the deflection was (18.78) mm and (9.97) mm respectively, that mean the deflection decrease about (87) %, (250) %, (88) % when GFRP bar spacing decreased from (375 to 250) mm, (375 to 125) mm, and (250 to 125)mm respectively.

b. For normal compressive strength and slab thickness 100 mm :

Figure (14) indicates that the effect of GFRP bar spacing for the same concrete strength and slab thickness (100)mm. The ultimate load increased with decreasing GFRP spacing. The ultimate load increasing (56) % when decreasing GFRP bar spacing (250 to 125), and (100) % when decreasing GFRP bar spacing (375 to 125), and (30) % from decreasing GFRP bar spacing (250 to 375), the normalized punching shear strength increased with increasing reinforcement ratio (6) and this result agrees with our results. From the results we observe that the deflection decreased when increasing flexural reinforcement ratio (increasing GFRP spacing). At GFRP spacing 375mm, the deflection at ultimate load was (30.28) mm, but at the same load when GFRP spacing is 250 and 125mm the deflection was (11.17) mm and (6.42) mm respectively, that mean the deflection decrease about (63) %, (78) %, (42.52) % when GFRP bar spacing decreased from (375 to 250) mm, (375 to 125) mm, and (250 to 125), respectively.

c. For high compressive strength and slab thickness 75 mm:

From figure (15) can be observed the effect of GFRP bar spacing, and the ultimate load increased with decreasing GFRP spacing. The ultimate load increasing (31) % from decreasing GFRP bar spacing (250 to 125), and (48) % when decreasing GFRP bar spacing (375 to 125), and (13) % when decreasing GFRP bar spacing (250 to 375). Results show that the deflection decreased when increasing flexural reinforcement ratio (increasing GFRP spacing). At GFRP spacing 375mm, the deflection at ultimate load was (23.07) mm, but at the same load when GFRP spacing is 250 and 125mm the deflection was (20.2) mm and (10.37) mm respectively. This means the deflection decrease about (12) %, (55) %, (48.66) % when GFRP bar spacing decreased from (375 to 250) mm, (375 to 125) mm, and (250 to 125)mm respectively.

d. For high compressive strength and slab thickness 100 mm :

From figure (16) we observe the effect of GFRP bar spacing, and the ultimate load increased with decreasing GFRP spacing. The ultimate load increasing (46) % when decreasing GFRP bar spacing (250 to 125), and (60) % from decreasing GFRP bar spacing (375 to 125), and (10) % from decreasing GFRP bar spacing (250 to 375), the normalized punching shear strength increased with increasing reinforcement ratio (6) and this result agrees with our results. Results show that the deflection decreased when increasing flexural reinforcement ratio (increasing GFRP spacing). At GFRP spacing 375mm, the deflection at ultimate load was (21.67) mm, but at the same load when GFRP spacing is 250 and 125mm the deflection was (18.05) mm and (9.74) mm respectively, that mean the deflection decrease about (16.7) %, (55) %, (46) % when GFRP bar spacing decreased from (375 to 250) mm, (375 to 125) mm, and (250 to 125)mm respectively.

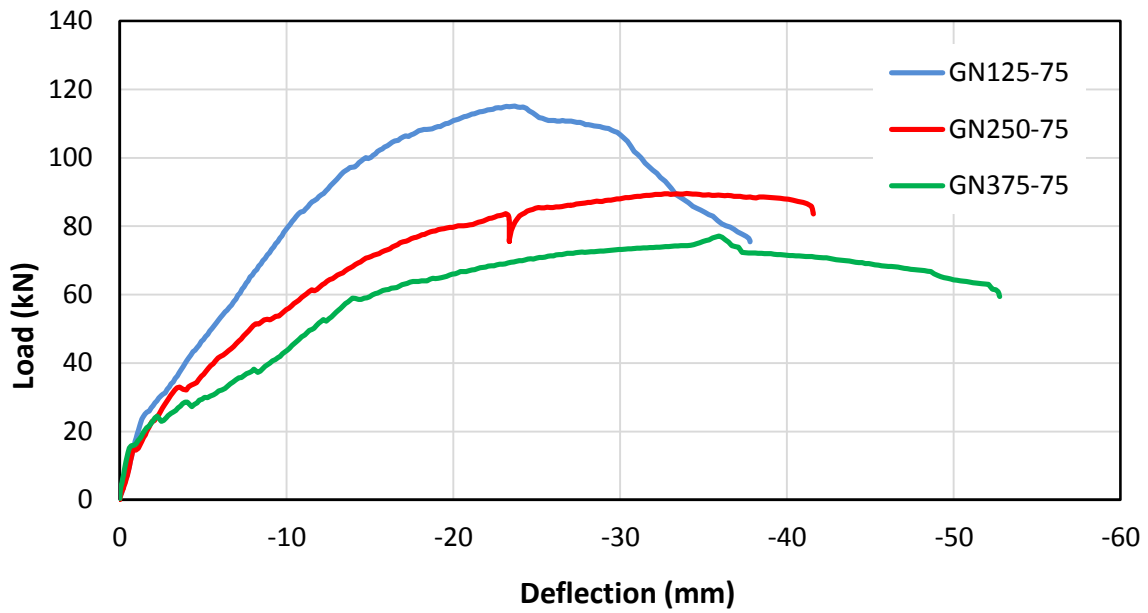


Figure (13) the effecting of GFRP spacing on load deflection relationship for normal concrete and slab thickness 75 mm.

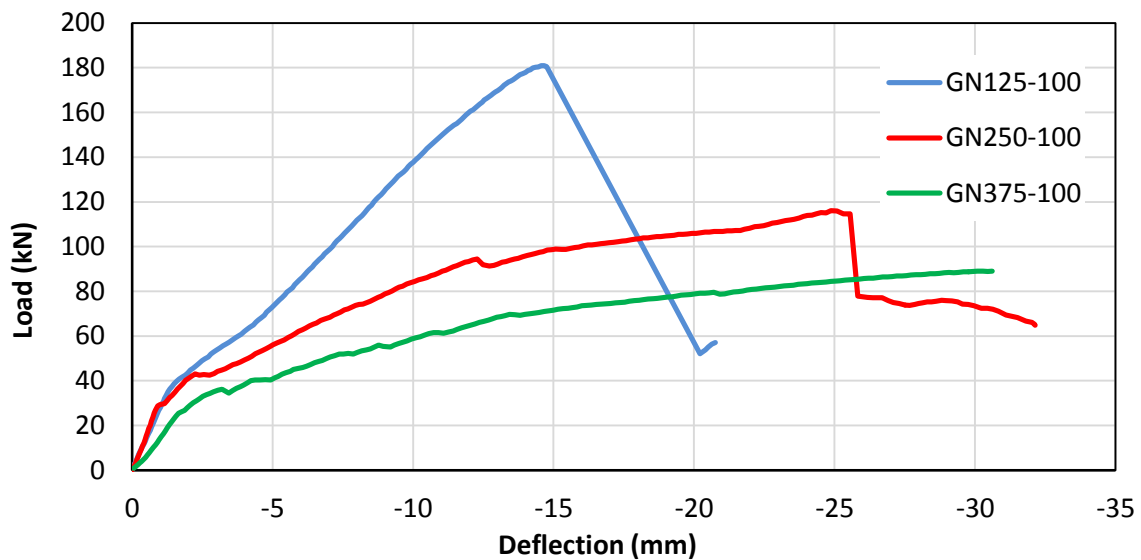


Figure (14) the effecting of GFRP spacing on load deflection relationship for normal concrete and slab thickness 100 mm.

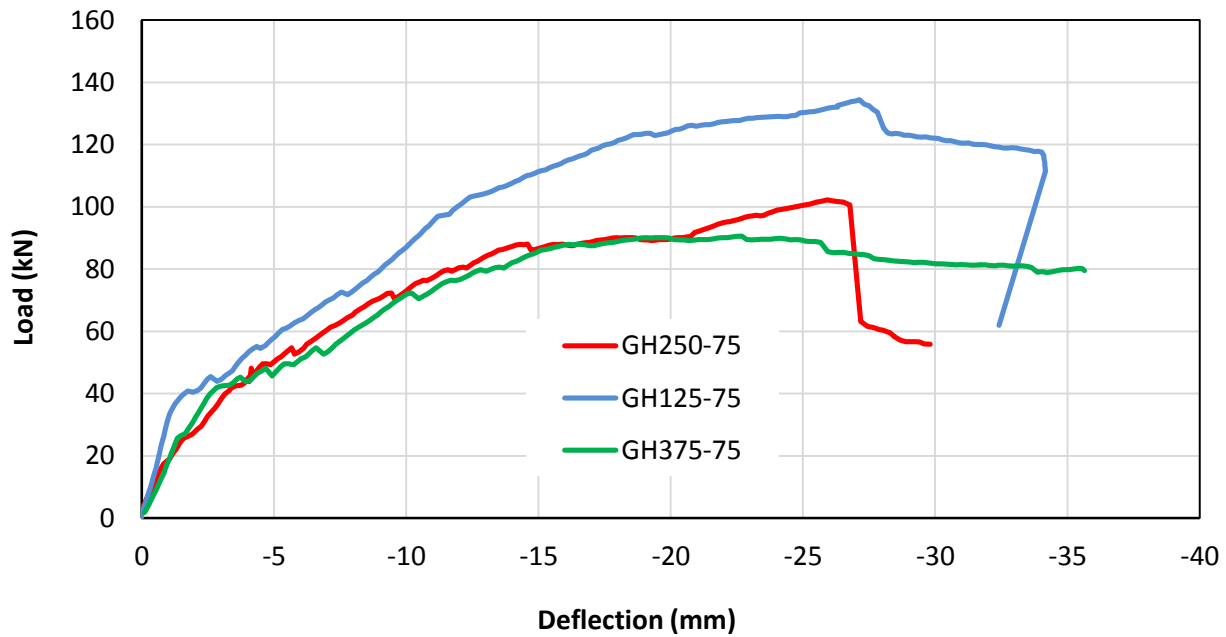


Figure (15) the effecting of GFRP spacing on load deflection relationship for high concrete and slab thickness 75 mm.

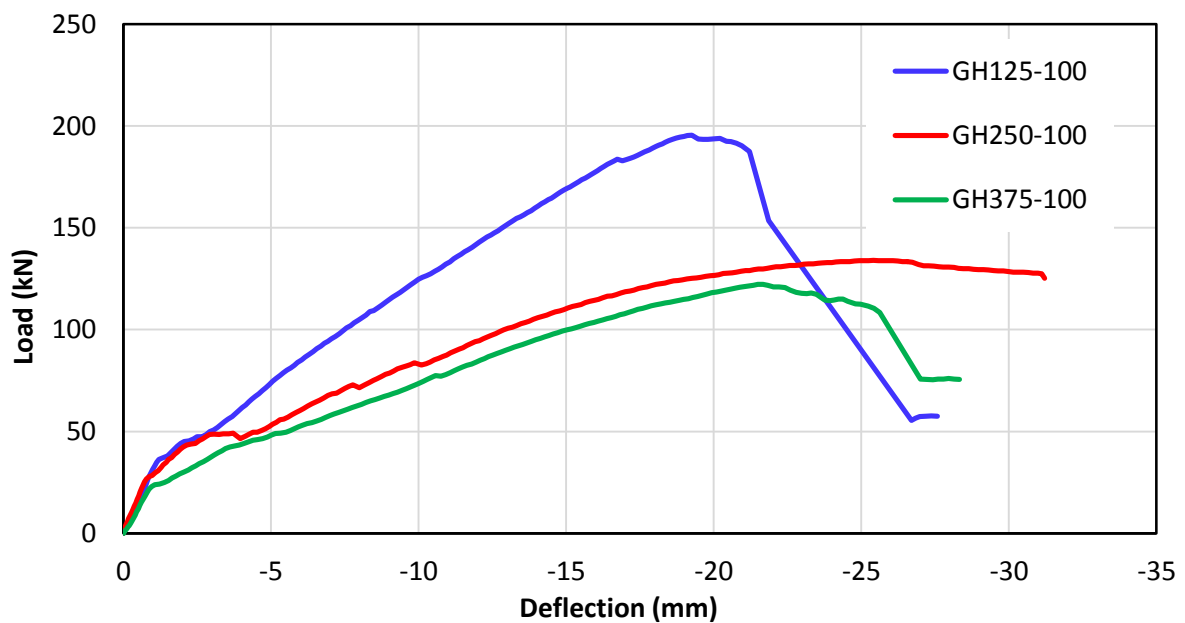


Figure (16) the effecting of GFRP spacing on load deflection relationship for high concrete strength and slab thickness 100 mm.

6.3. The effect of slab thickness:

The slabs thickness has noticeable effect on the punching shear capacity. The size effect characteristics cannot be look as a constant value related to the slab effective depth but it must also be functioned to the adherence properties of concrete. However, size effect is recommended by accounting the thickness of the specimens and fracture crack mechanics macrostructure property

represented in main brittleness factor known as the characteristic length. The punching shear strength of concrete slabs is strongly influenced by the thickness of slab.

a. For normal compressive strength and 125 mm GFRP bar spacing

From figure (17) we observe the effect of slab thickness, the ultimate load increased with increasing slab thickness. The increasing of punching shear was (57) % when increasing the slab thickness from (75 to 100) mm. Results show that the deflection at slab thickness (75) mm at ultimate load was (23.68) mm, but at the same load in slab thickness (100) mm was (8.27) mm. The effect of slab thickness on deflection is decreasing the deflection at the same load about (65) % when increasing the slab thickness from (75 to 100) mm.

b. For high compressive strength and 125 mm GFRP bar spacing and different slab thickness:

From figure (18) observed that the effect of slab thickness. The ultimate load increased with increasing slab thickness, the increasing of punching shear was (45) % by raising the slab thickness from (75 to 100) mm. Result show that the deflection at slab thickness (75) mm at ultimate load was (27.14) mm, but at the same load in slab thickness (100) mm was (11.19) mm. The effect of slab thickness on deflection is decreasing the deflection at the same load about (58) % when increasing the slab thickness from (75 to 100) mm.

c. For normal compressive strength and 250 mm GFRP bar spacing:

From figure (19) can be observed the effect of slab thickness. The ultimate load increased with increasing slab thickness, the increasing of punching shear was (30)% by raising the slab thickness from (75 to 100)mm. Results show that the deflection at slab thickness (75) mm at ultimate load was (24.87) mm, but at the same load in slab thickness (100) mm was (11.2) mm. The effect of slab thickness on deflection is decreasing the deflection at the same load about (54.96) % when increasing the slab thickness from (75 to 100) mm.

d. For high compressive strength and 250 mm GFRP bar:

From figure (20) we observe the effect of slab thickness. The ultimate load increased with increasing slab thickness, the increasing of punching shear was (30)% by raising the slab thickness from (75 to 100)mm. Results show that the deflection at slab thickness (75) mm at ultimate load was (25.91) mm, but at the same load in slab thickness (100) mm was (13.47) mm. The effect of slab thickness on deflection is decreasing the deflection at the same load about (48) % when increasing the slab thickness from (75 to 100) mm.

e. For normal compressive strength and 375 mm GFRP bar spacing:

From figure (21) we observe the effect of slab thickness. The ultimate load increased with increasing slab thickness, the increasing of punching shear was (15) % by raising the slab thickness from (75 to 100) mm. Results show that the deflection at slab thickness (75) mm at ultimate load was (35.27) mm, but at the same load in slab thickness (100) mm was (18.87) mm. The effect of slab thickness on deflection is decreasing the deflection at the same load about (46) % when increasing the slab thickness from (75 to 100) mm.

f. For high compressive strength and 375 mm GFRP bar spacing:

From figure (22) illustrated the effect of slab thickness. The ultimate load increased with increasing slab thickness, the increasing of punching shear was (35) % accounting when raising the

slab thickness from (75 to 100) mm. Result indicate that the deflection at slab thickness (75) mm at ultimate load was (22.68) mm, but at the same load in slab thickness (100) mm was (13.1) mm. The effect of slab thickness on deflection is decreasing the deflection at the same load about (43) % when increasing the slab thickness from (75 to 100) mm.

From previous results, slab thickness is be observed affecting on ultimate load and deflection of GFRP slabs within a limited enhancement percentage. The punching shear capacity of slab enhances with a corresponding when increased in the slab thickness. This can be attributed to the fact that increasing slab thickness lead to increase in the perimeter of the punching shear section as well as an increase in the effective depth of the slab, the followed by decreasing in the shear stresses.

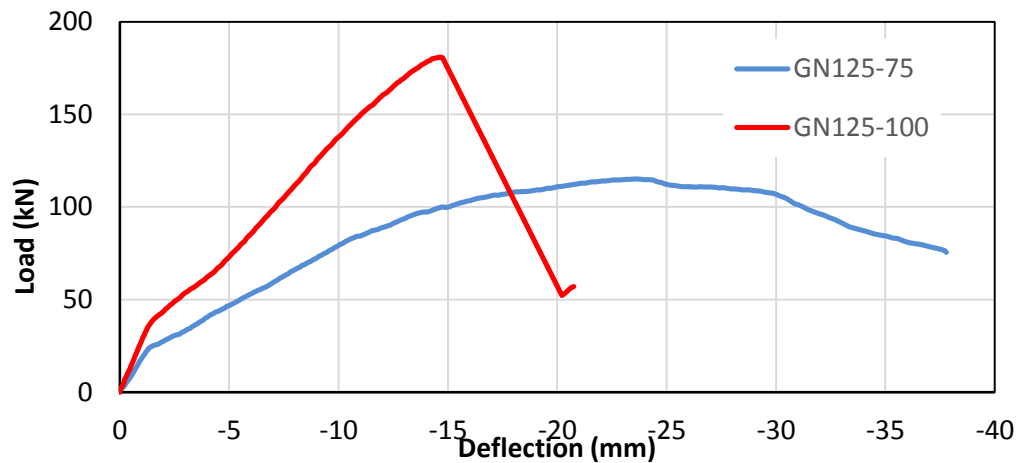


Figure (17) The effecting of slab thickness on load deflection relationship for normal concrete strength and 125 mm GFRP bar spacing

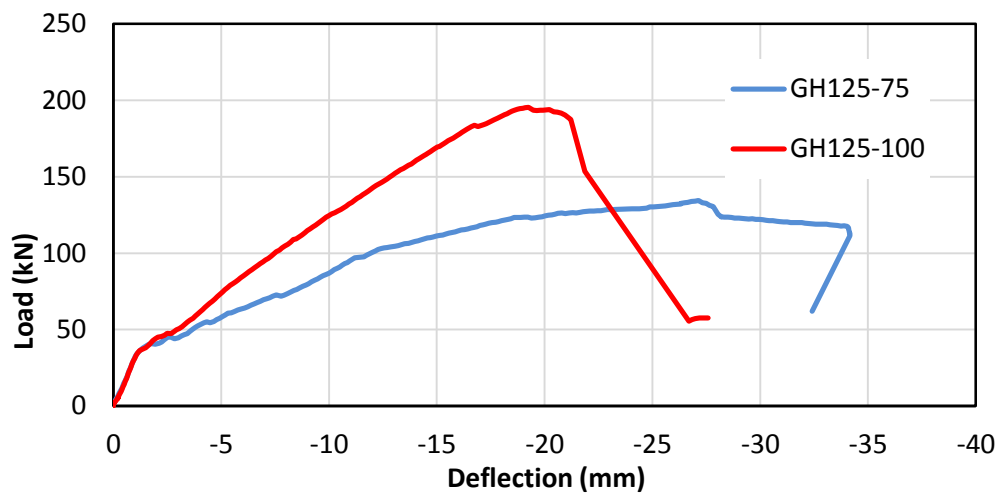


Figure (18) The effecting of slab thickness on load deflection relationship for high concrete strength and 125 mm GFRP bar spacing

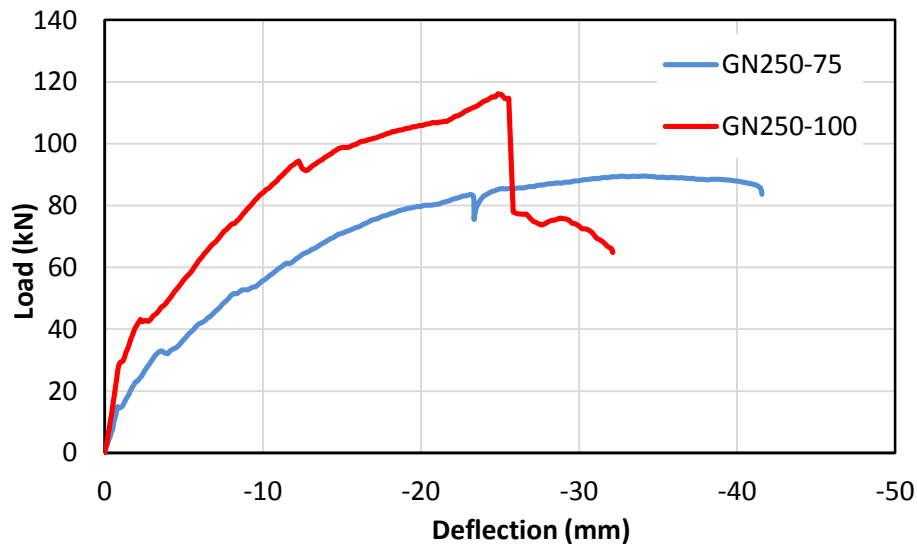


Figure (19) The effecting of slab thickness on load deflection relationship for normal concrete strength and 250 mm GFRP bar spacing

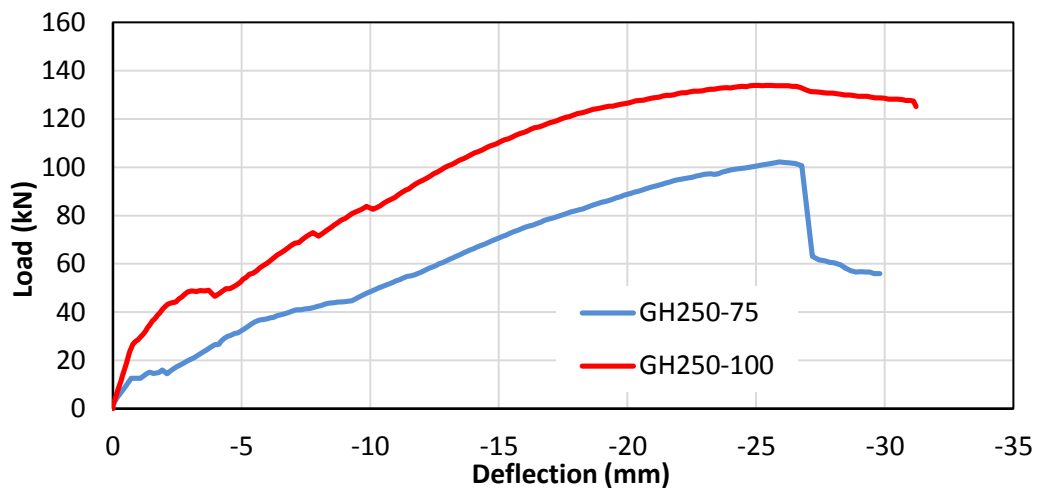


Figure (20) the effecting of slab thickness on load deflection relationship for high concrete strength and 250 mm GFRP bar spacing

7. PROPOSED MODEL

This study deals with proposed a design model can be used for evaluating the punching shear resistance of concrete two way slabs specimens reinforced by (GFRP) bars reinforcements. This proposed model is based on the experimental data collected form lab tested specimens, and theoretical analysis for such slabs, which considers the true behavior of the GFRP slabs under such loads. The effects of pure linear brittle behavior, low level of elastic modulus and the different bond characteristics properties, as compared to mild steel. The GFRP reinforcements are always accounted for in the present study. The suggested model does not merge any fitting parameters to match the theory to the directed the available GFRP slab test results. However,

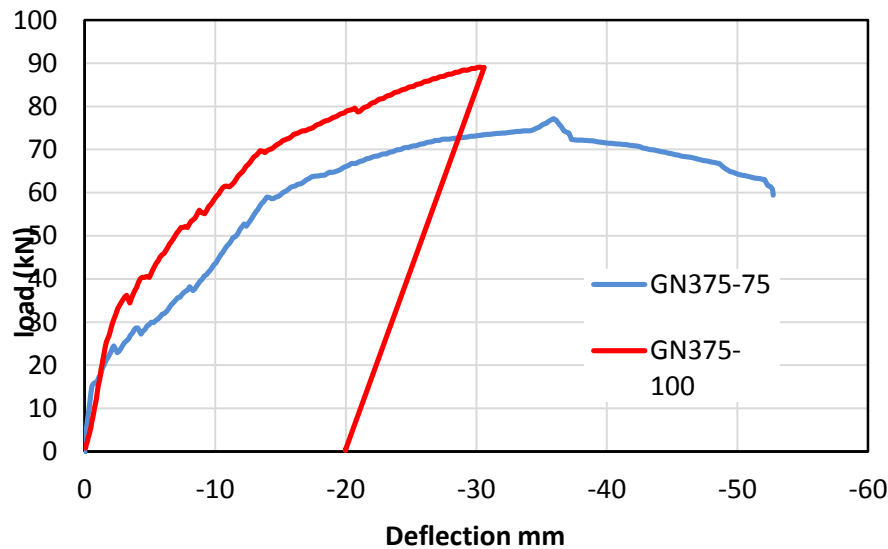


Figure (21) the effecting of slab thickness on load deflection relationship for normal concrete strength and 375 mm GFRP bar spacing

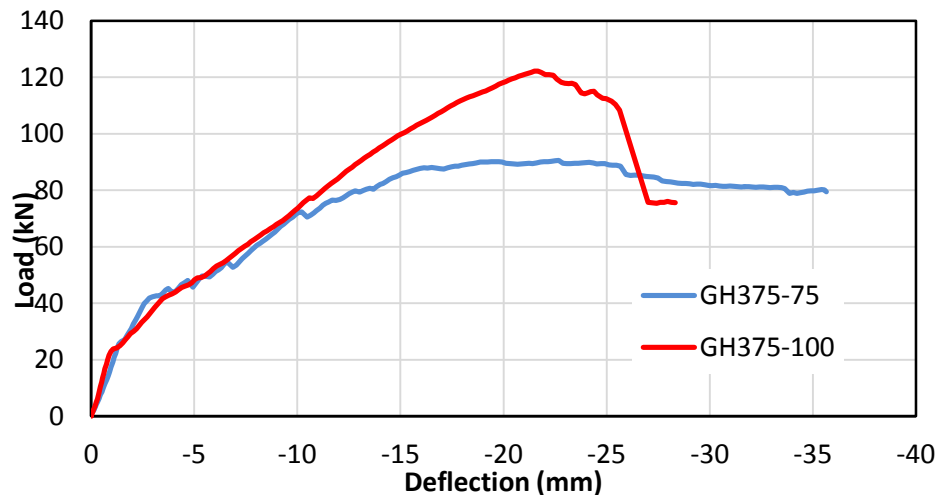


Figure (22) the effecting of slab thickness on load deflection relationship for high concrete strength and 375 mm GFRP bar spacing

very good agreements between the predicted and test results readings should give confidence to designers and engineers in using GFRP as a sound structural reinforcement for RC slab.

Theodorakopoulos and Swamy (2008) have presented a simple computational model to estimate the ultimate punching shear resistance of FRP bars reinforced slab-column joints. This model was based on the typical behavior of the connections under applied loads, and estimates the net depth of the compression zone area to evaluate of the FRP elastic modulus, ultimate tensile strength and bond properties. The calculations of the effective depth of the compression zone are a major hindrance to any acceptable theory for the ultimate of shear strength. This study flowed the contributed boons of a previous researches that deal with obtaining shear strength of GFRP slabs (El-Gamal et al. 2006; El-Ghandour et al. 1999; Theodorakopoulos and Swamy 2008), then issued a design equation for estimating punching shear in flat slab reinforced with GFRP bars as flexural reinforcements.

From previous researches, that can be noticed that the factors effecting on ultimate punching shear strength as below:

- a) Most research show that the effect of the FRP modulus of elasticity to steel modulus of elasticity ratio (El-Ghandour et al. 1999) as $\left(\frac{E_f}{E_s}\right)^{1/3}$, where; E_f/E_s in this study equal to (0.22) according to the tested elastic modulus for the GRPR and steel bars.
- b) Most research show that the effect of the concrete strength (f'_c) is under square root $\left(\sqrt{f'_c}\right)$ (El-Gamal 2006; Shaaban and Gesund 1994; Ospina et al. 2003).
- c) The effective depth (d) has been significant effect on shear strength (Bažant and Cao 1987). However, in proposed equation has been taken, also do it in recent calculations according to clear concrete cover take 15 mm for all slab specimens.
- d) The flexural reinforcement ratio (ρ_f) was referred in some studies that it affected on punching shear strength. Therefore, it was included in proposed model. And it was depended on effective depth value as ($\rho_f = A_s/b \times d$).
- e) Critical section perimeter (b_o), it was assumed in three values depending on the effective depth and column's dimensions. In recent calculations were calculated b_o at $d/2$, $1.0d$, and $1.5d$, that have the symbols $b_{o,0.5d}$, $b_{o,1.0d}$, and $b_{o,1.5d}$, respectively. For investigating the best parametric values of b_o

However, depending on getting above parameters of proposed equation and worked within mathematical modeling based on experimental results of this study. It can be write in equation a proposed model in two equations. Each equation is depended on the ratio of flexural GRPR reinforcement as shown in equations (1 and 2):

$$V_u = \sqrt[3]{\left(\frac{E_f}{E_s}\right)} \cdot (120 \rho_f)^{-1.15} \cdot \sqrt{f'_c} \cdot b_o \cdot d^{-0.61} \quad \text{for } \rho_f \geq 0.01 \quad (1)$$

$$V_u = \sqrt[3]{\left(\frac{E_f}{E_s}\right)} \cdot (120 \rho_f)^{-0.4} \cdot \sqrt{f'_c} \cdot b_o \cdot d^{-0.88} \quad \text{for } \rho_f < 0.01 \quad (2)$$

Depending on experimental data, the results of proposed equation 1 are summarized in table (3) depend on three values of b_o , in addition experimental and ACI440 model results. The comparison between experimental results and proposed model equation 2 results, also ACI model to predicate punching shear strength listed in table(4). From the results of the proposed model in equations 1. The proposed model is very satisfied the experimental data, when it determined the b_o according to ($d/2$) as specified on ACI model for punching shear failure pattern. However, the COV was found a minimum for $b_{o,0.5d}$ calculations. In otherwise the ACI model has COV equal to 0.264 that is more than proposed model of equation 1.

Also, the results of the proposed model in equations 2. The proposed model is very good convergence with experimental data, it was determined the b_o according to (d) whereas the ACI model used ($d/2$) in estimated punching shear failure strength. However, the COV was found a minimum for $b_{o,1.0d}$ calculations. In otherwise the ACI model has COV equal to 0.27, that is so far than proposed model of equation(2).

Figure(23) shows the comparison of the proposed model which is specified in equation 1 and 2 and the ACI318-14 model verses experimental outcomes for GFRP bars reinforced concrete two-way specimens. The some results from ACI model and most theoretical model results which is depend on $b_o, 1.5d$ are outside the acceptable range. Whereas the proposed model results of equation 1 and 2 which are depend on $b_o, 0.5d$, and $b_o, 1.0d$, respectively, within the mid-point range of comparisons with experimental and prediction results.

Table (3) The details of experimental results and proposed equation (1) punching model

Sample	d (mm)	f_c' (MPa)	ρ_f (%)	Exp. Ultimate load (kN)	$P_{u \text{ pred.}}$ at d/2 (kN)	$P_{u \text{ pred.}}$ at d (kN)	$P_{u \text{ pred.}}$ at 1.5d (kN)	ACI Model (kN)
GN125-75	54	35.6	1.674	115.18	114.93	145.35	175.77	52.0564
GH125-75	54	53.85	1.674	134.37	141.35	178.77	216.18	64.02388
GN125-100	79	31.7	1.144	180.95	149.55	201.14	252.73	80.67099
GH125-100	79	53.89	1.144	195.4	194.98	262.25	329.52	105.1821
Mean ($\bar{X}$)					150.20	196.88	243.55	75.48334
Standard Division (SD)					28.85	42.65	56.61	19.93157
Coefficient of Variance (COV)					0.19205	0.216612	0.23242	0.264053

Table (4) The details of experimental results and proposed equation (2) flexural model

Sample	d (mm)	f_c' (MPa)	ρ_f (%)	Exp. Ultimate load (kN)	$P_{u \text{ pred.}}$ at d/2 (kN)	$P_{u \text{ pred.}}$ at d (kN)	$P_{u \text{ pred.}}$ at 1.5d (kN)	ACI Model (kN)
GN250-75	54	33.69	0.83	89.55	85.07	91.72	110.92	50.64
GN375-75	54	34.82	0.55	90.45	101.96	109.93	132.94	51.48
GH250-75	54	55.2	0.83	102.24	108.89	117.41	141.98	64.82
GH375-75	54	53.82	0.55	77.12	126.76	136.67	165.28	64.00
GN250-100	79	33.52	0.57	116.1	79.21	89.45	112.39	82.95
GN375-100	79	32.73	0.38	89.06	92.05	103.95	130.61	81.97
GH250-100	79	52.67	0.57	133.89	99.29	112.13	140.88	103.98
GH375-100	79	53.96	0.38	122.24	118.19	133.47	167.71	105.25
Mean ($\bar{X}$)					101.43	111.84	137.84	75.64
Standard Division (SD)					15.14	16.15	19.75	20.11
Coefficient of Variance (COV)					0.15	0.14	0.14	0.27

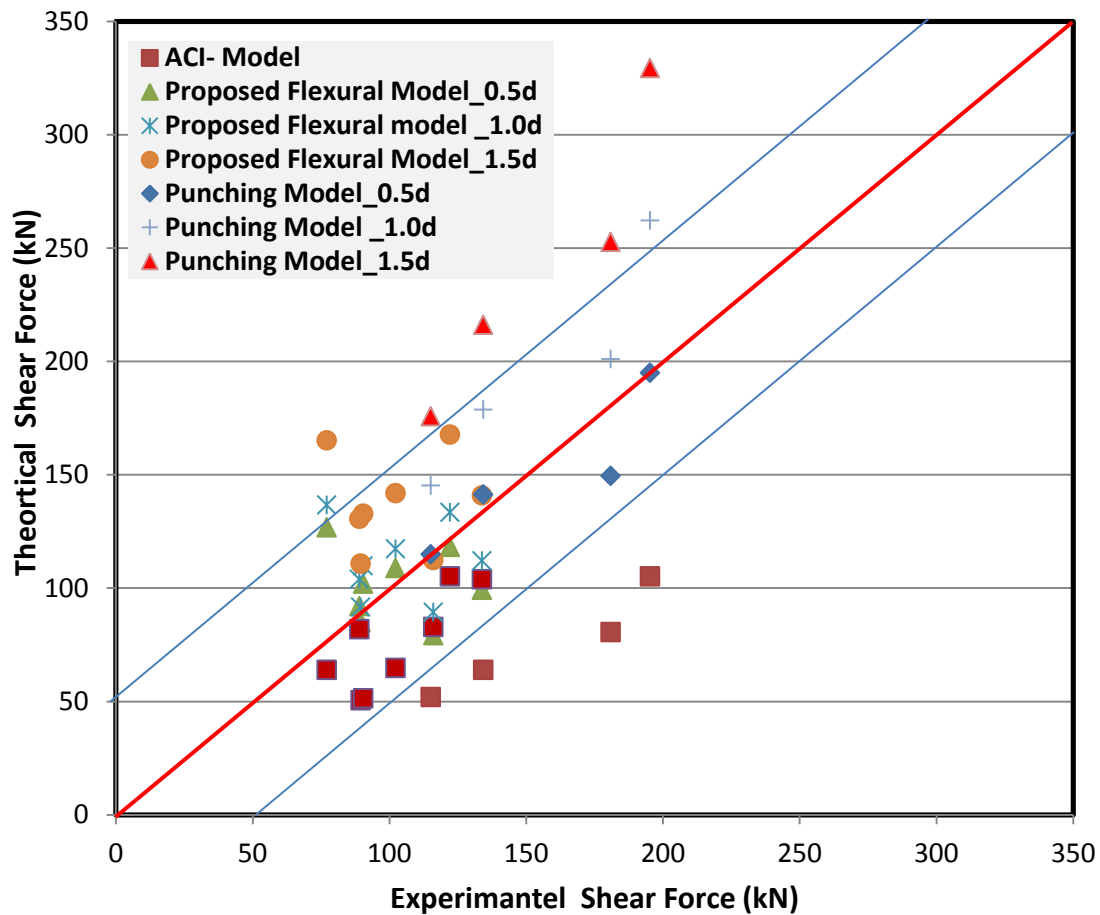


Figure (23) Comparison of the proposed model and the ACI440 -08 model verse exp. results for GFRP-reinforced specimens .

8. Conclusions

1. From recent test results, it was observed that the effect of concrete compressive strength on ultimate load and deflection was less than effected when increasing slab thickness and increasing flexural reinforcement ratio. This is due to greater stiffness of slab specimens.
2. It was observed that the effect of GFRP spacing on ultimate load and deflection was unnoticeable when increasing slab thickness and increasing flexural reinforcement ratio. This may be attributed to the fact that, for high reinforcement ratios, a brittle punching failure can occur, and yield lines can form but these do not necessarily occur.
3. The angles of failure zone for all GFRP slabs failure with punching shear are in the range of (15° -22°).
4. The ultimate loads for slabs which have casting with flexural GFRP bar decrease about (31-45) % than those of slabs which casting with steel bar.
5. The proposed model for prediction the punching shear has been very acceptable results when it is compared with experimental data.
6. The proposed model has been classified the two-way GFRP slabs into two categories according to the provided flexural GFRP reinforcements. First group has ρ_f equal or more than 1%, that means it has punching shear failure. The second group has flexural yield line failure when ρ_f less than 1%.

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NOTATIONS

The following symbols are used in this paper:

A_s	area of steel (mm^2)
b_o	perimeter of critical section computed (mm)
$b_{o,0.5d}$	perimeter of critical section computed at ($d/2$) measured from the column face (mm)
$b_{o,1.0d}$	perimeter of critical section computed at ($1.0d$) away from the column face (mm)
$b_{o,1.5d}$	perimeter of critical section computed at ($1.5d$) away from the column face (mm)
d	effective depth (mm)
E_s	modulus of elasticity of steel (MPa)
E_f	modulus of elasticity of GFRP (MPa)
V_u	shear capacity (kN)
ρ_f	longitudinal of GFRP reinforcement ratio

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