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STUDYING THE BEHAVIOR OF THE PILE CAP FOR SHEAR REINFORCEMENT WHICH IS SIMULATED AS A CONTINUOUS DEEP BEAM USING SELF COMPACTING CONCRETE

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Abstract: This paper is focused on the effect of shear reinforcement on the structural behavior of continuous reinforced concrete deep beams to employ the results on the piles caps works. Experimental study using self-compacting concrete with constant compressive strength nominally equals 60 MPa were frequently used with three groups of shear span-to-depth ratios 0.95, 1.08 and 1.25 to produce twelve continuous beams. Each group of shear span-to-depth ratios has one unreinforced beam against shear stresses and three shear reinforced beams; the first is consist of horizontal stirrups only, the second has vertical stirrups only while the third from combined with horizontal and vertical stirrups to act together against shear stresses .The results revealed that the configuration of the combined shear reinforcement (horizontal and vertical) is an effective factor on the behavior of the deep beam and when it is increased in one category the ultimate strength and the serviceability of specimen can be improved. The percentage of the obtained improvement for a specimen can be increased by decreasing its shear span-to-depth ratio.

Keywords: *Deep beam, pile cap, combined stirrups, depth ratio and self-compacting concrete*

دراسة سلوك قبعة الركائز مع تسليح القص والمتمثلة بعتب عميق مستمر باستخدام خرسانة ذاتية الرص

الخلاصة: تركز هذه الورقة البحثية على تأثير تسليح القص على السلوك الإنشائي للعتبات الخرسانية المسلحة العميقة المستمرة لغرض الاستفادة من النتائج في أعمال قبعات الركائز. وقد استخدمت الدراسة العملية الخرسانة ذاتية الرص ذات مقاومة انضغاط ثابتة المقدار وقيمتها الإسمية تساوي 60 ميكا باسكال وتم تكرارها في ثلاث مجموعات من نسب فضاء القص-إلى-العمق وهي 0.95، 1.08 و 1.25 لغرض إنتاج اثنى عشر عتبة مستمرة. كل مجموعة من نسب فضاء القص-إلى-العمق تتكون من عتبة غير مسلحة تجاه إجهادات القص وثلاث عتبات مسلحة تجاه القص؛ الأولى مزودة بأطواق أفقية فقط والثانية مزودة بأطواق عمودية فقط أما الثالثة فزودت بكلا الحلقات الأفقية والعمودية لتعمل سوية تجاه إجهادات القص.كشفت النتائج عن كون ترتيب تسليح القص بزيادة التسليح إلى خليط من الحلقات الأفقية والعمودية هو عامل مؤثر على سلوك العتبات العميقة كما ويمكن تحسين المقاومة القصوى وقابلية الخدمية للنموذج. أن نسبة التحسن المئوية المستحصلة لنموذج معين يمكن زيادتها بتقليل قيمة نسبة فضاء القص-إلى-العمق لذلك النموذج.

1. Introduction

A pile cap as shown in Figure 1 is a stocky reinforced structure which transforms and distributes the load from columns or bridge pier downward into supporting piles

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[1]. However, the deep beam is a structural member dominant by shear deformations behavior. In practice, engineers typically encounter deep beams when designing transfer girders, bridge bents, or pile supported foundations as well [2, 3]. Continuous deep beams occur as transfer girders in multi-story frames, as foundation wall structures and as pile caps etc. The usual design practice for continuous deep beams has been to utilize empirical equations, which are invariably based on simple span deep beam tests. Given the unique behavioral pattern of continuous deep beams, his practice is unreliable [4].

Figure 1: Pile Caps Behave as Continuous Deep Beams

Some conditions are adopted to determine if beam is deep or shallow (slender). If the beam behaves as shallow, its failure mode can be transformed to flexural deformations, however, force transfer in continuous deep and shallow beam is cleared in Figure 2. When the following expressions achieve, lead to deep beam behavior:

$$a/d < 2 – 2.5 \quad \text{… (1) [2]}$$

$$a/h < 2 \quad \text{… (2) [5] , [6]}$$

$$lc/h \leq 4 \quad \text{… (3) [5] , [8]}$$

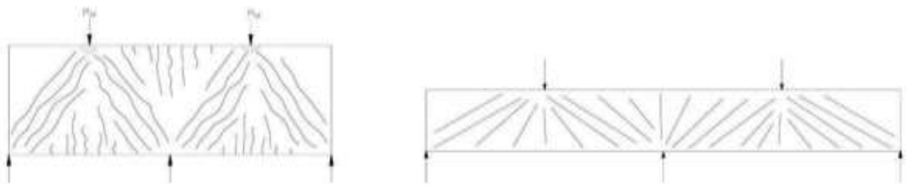
Where:

a: Shear span of a beam.

d: Distance between the extreme compression fiber and centroid of tension reinforcement.

h: Overall depth or height of the beam.

l_c: Face-to-face distance between the two supports of the beam.



(a): Continuous Deep Beam (b): Continuous Shallow Beam

Figure 2: Comparison of Force Transfer between the Two Continuous Beams [4]

Recently, the structural design standards such as ACI 318-08, adopted the use of strut-and-tie modeling (STM) for the design of deep beams. Based on the theory of plasticity, STM is a design method that idealizes stress fields as axial members of a truss. The primary advantage of STM is its versatility. It is valid for any given loading or geometry. However, the primary weakness of STM is also its versatility [2, 9- 11]. The freedom associated with the method results in a vague and inconsistently defined set of guidelines. Because of the lack of a well-ordered design process, many practitioners are reluctant to use STM and it is essential that the designer should have a minimum level of experience to develop the appropriate truss. Further, STM can only be used to determine the limiting capacity and it cannot be used to predict the response of the structure. Hence it is not possible to check whether the structure designed using STM performs satisfactorily in the service stage [2, 12].

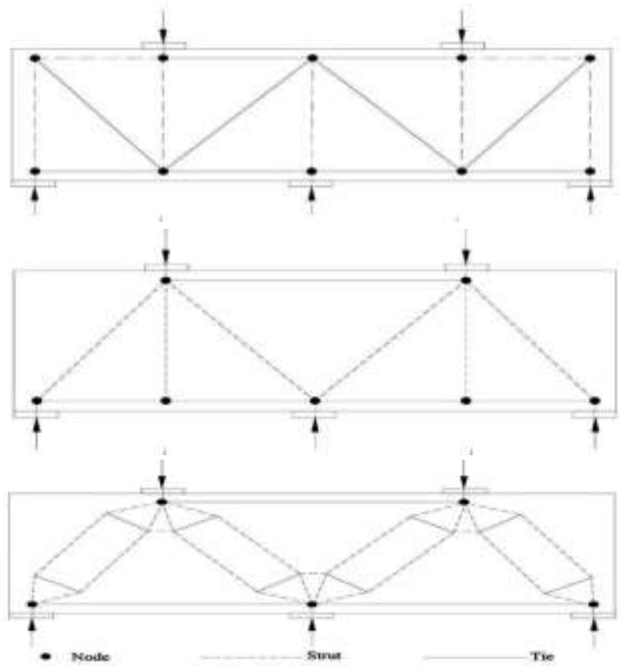


Figure 3: Strut-and-Tie Models for a Continuous Deep Beam [4]

According to ACI 318-08, there are two minimum reinforcement provisions to deep beam design with STM of 0.0025 and 0.0015 are required in the vertical and the horizontal directions, respectively. Maximum spacing of the reinforcement in both cases shall not exceed d/5 or 300mm.

2. Research Significance

This paper investigates the effect of horizontal and vertical shear reinforcements (ρ_h and ρ_v) with different shear span-to-depth ration (a/d) and constant concrete compressive strength (f'_c) on the behavior of continuous reinforced concrete deep beams in order to reflect the results into reinforced concrete pile caps functions. The ultimate load (P_u), flexural deflection (Δ), cracking load (P_{cr}) and crack pattern of tested continuous deep beam are considered.

3. Test Program

Twelve reinforced concrete deep beams with different variables are conducted for the experimental work. Table 1 below contains the differences among the beams in terms of compressive strength (f'_c), span-to-depth ratio (a/d), flexure reinforcement ratio (ρ), horizontal web reinforcement ratio (ρ_h) and horizontal web reinforcement ratio (ρ_v). All tested beams which have the same compressive strength (f'_c = 60 MPa) and same shear span (a = 400 mm).

Table 1: Configurations of the Tested Beams

Symbol	*d* *mm*	*a/d*	*ρ* *%*	ρ_h *%*	ρ_v *%*
B1	320	1.25	0.491	-	-
B2				0.236	-
B3				-	0.267
B4				0.236	0.267
B5	370	1.08	0.425	-	-
B6				0.236	-
B7				-	0.267
B8				0.236	0.267
B9	420	0.95	0.374	-	-
B10				0.236	-
B11				-	0.267
B12				0.236	0.267

3.1. *Concrete*

Self-compacting concrete (SCC) is utilized in this study due to its regarding homogeneity and compaction within multipart structures and to improve the overall strength, durability and quality of concrete [13]. Ordinary Portland cement type I was used. The coarse aggregate was a 14-mm maximum size crushed gravel with specific gravity and absorption of 2.64 and 0.57%, respectively and the fine aggregate was natural river sand with a 3.18 fineness modulus with specific gravity and absorption of 2.7 and 1.5% respectively. For SCC production, A fine limestone powder (LSP) with fineness (3100cm²/gm) is used to avert excessive heat generation, enhance fluidity and cohesiveness and the water content of the mix is reduced by using a superplasticizer (SP) complies with ASTM C 469–86 [14]. The mix proportions and the average results of cylinder strength f'c for all beams are given in Table 2.

Table 2: Mix Proportions and Compressive Strength of SCC Concrete

Mix.	Nominal f'_c (MPa)	Tested f'_c (MPa)	Cement (kg/m^3)	LSP (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (liter/m)	SP (liter/m)
1	50	49.6	300	200	780	870	200	7.0
2	60	62.4	400	150	770	870	198	6.0
3	70	71.8	450	100	756	870	165	10.0

3.2. *Reinforcement*

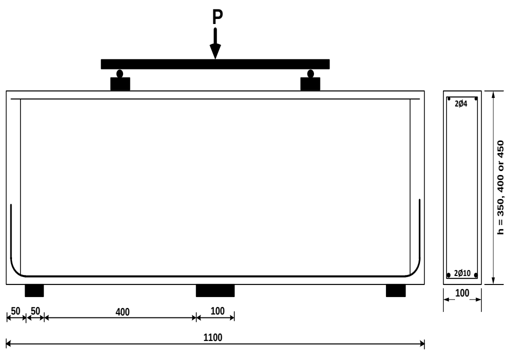
Deformed steel bars of diameter 10 mm were used for the main reinforcement and plain steel bars of diameter 4 mm were used for engaging the main reinforcement and as vertical and horizontal web reinforcements. Properties of the steel bars are shown in Table 3. The spacing of web and main reinforcements were adopted according to ACI Code 318–08 [5] and designed to be near its minimum limits.

Table 3: Properties of Reinforcing Steel

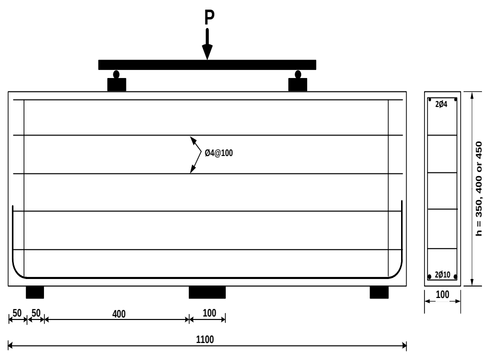
Diameter of Bar Ø (mm)	Yield Stress f_y MPa	Ultimate Stress f_u MPa	Modulus of Elasticity E_s GPa
4	317.1	418.3	200
10	494.7	589.8	200

3.3. *Specimens Details*

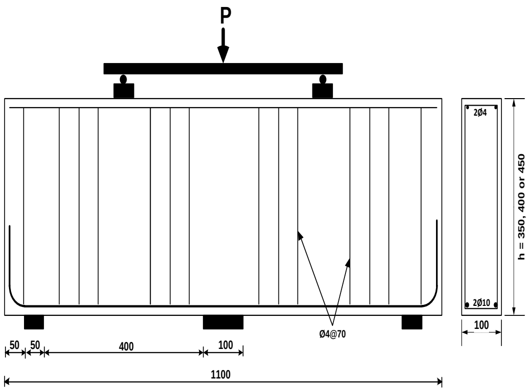
The beams have the same length of 1100 mm, width of 100 mm, the main tension bars of 2Ø10 mm and loading with supporting, as shown in Figure 4 below. The main difference among the beams is the presence of web reinforcement or not to resist the shear stresses, three beams are free from shear reinforcement and nine beams are provided with web reinforcement consists of Ø4mm stirrups divided into 4 horizontal stirrups in three beams, 12 vertical stirrups in other three beams and combination of 4 horizontal and 12 vertical stirrups in the rest beams. Other difference between the beams is the overall depth (h) which governs ratio of beam deepness through a/d ratio; there are three values of h which were 350, 400 or 450mm.



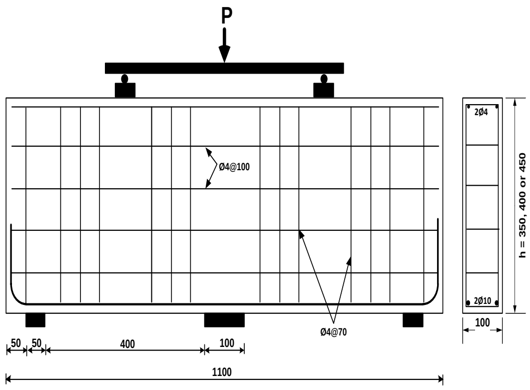
(a): B1, B5 and B9



(b): B2, B6 and B10



(c): B3, B7 and B11



(d): B4, B8 and B12

Figure 4: Details of the Beams (all dimensions are in mm)

3.4. *Test Procedure*

Before testing, a thin layer of white emulsion paint was applied onto the surface of the specimen to aid the cracks detection. The dial gages were positioned at the bottom of midspan of each span of the beam. All the beams were tested by loading at midspan as in Figures 4 and 5. Loading was applied in increments of 5 kN to record the deflection and detect the cracking. Testing was continued until the beam showed a drop in load carrying capacity.

Figure 5: Beam at the Test

4. Results and Discussion

The main results which are listed in Table 4 will be discussed according to presence of shear reinforcement and span-to-depth ratio (a/d) and divided into the topics below.

Table 4: Results of the Tested Beams

Beam	P_{cr} *(kN)*	P_u *(kN)*	P_{cr} / P_u *(%)*	Δ_{max} *(mm)*	*Failure Mode*
B1	105	322.5	33	2.95	shear
B2	107.5	332.5	32	2.86	shear
B3	140	337.5	41	3.18	shear
B4	150	347.5	43	2.81	shear
B5	142.5	330	43	2.84	shear
B6	145	345	42	2.76	shear
B7	160	355	45	2.94	shear
B8	170	360	47	2.69	shear
B9	160	335	48	2.73	shear
B10	167.5	362.5	46	2.63	shear
B11	162.5	432.5	38	2.81	shear
B12	172.5	450	38	2.58	shear

4.1. *Ultimate Strength*

The ultimate load which represents the failure of the tested beam (P_u) mentioned in Table 4 revealed the ultimate strength. Figure 6 shows the gradual increments in the beams ultimate strength through B1 to B12. For the beams without web reinforcements (B1, B5 and B9) which have longitudinal tensions steel bars only (flexural reinforcement) with decreasing reinforcement ratio (ρ), the Pu of the beams can be increased slightly (it was 4% of B9 in comparison with B1) by decreasing a/d ratio and this result confirmed by the results of Bircher et al [2]. So, the deep beam with increased ρ is expectable to achieve more P_u value.

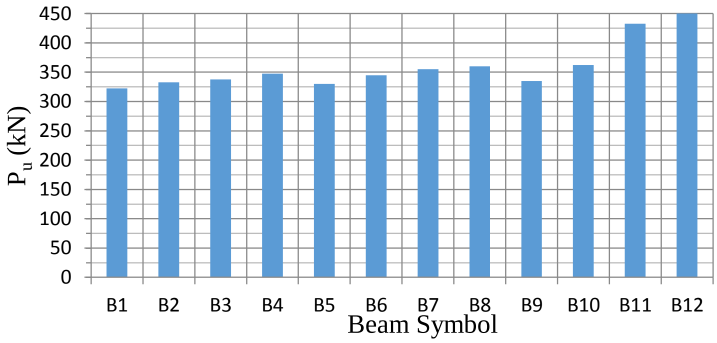


Figure 6: Ultimate Strengths of the Tested Beams

The obtained increment in P_u for tested beams came from using and increasing the shear reinforcements to resist the applied loads in three different groups of a/d ratio. When web reinforcement increase up to both horizontal and vertical stirrups in conjunction with a/d decrease to 0.95, more increase in P_u can be achieved; therefore, B12 has the optimum strength and its Pu achieved enhancement of 40% in comparison with P_u of B1 (645 kN). For comparison between the beams of horizontal stirrups (B2, B6 and B10) and their corresponding beams in the same a/d ratio but without stirrups (B1, B5 and B9), the results revealed little enhancement in P_u which was about 3% for each group of a/d ratio. On the other hand, the beams of vertical stirrups (B3, B7 and B11), the P_u enhanced steadily to reach 7.5% for the same group of a/d ratio and 34% in comparison with B1. The results revealed the minor effect of horizontal or vertical stirrups each one alone on Pu of the deep beam in comparison with its flexural reinforcement, but the vertical stirrups are more effective than horizontal stirrups and the results is compatible with previous work [9].

Figure 7 is graphed to determine the activity of presence of the horizontal, vertical or combined horizontal and vertical stirrups on enhancing P_u of deep beams through a/d decreasing ratios. The graph revealed that a/d is very effective for raising the activity of shear reinforcements on enhancing Pu of continuous deep beams, thereby, the percent increment of P_u according to less a/d (0.95) reaches about 12, 34 and 40% for shear reinforcements varied from horizontal stirrups up to horizontal and vertical stirrups respectively, while the maximum increment of Pu according to greater a/d ratio (1.25) is less than and about 8%.

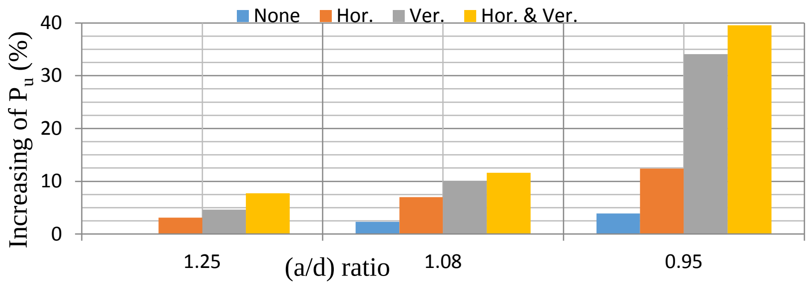


Figure 7: Ultimate Strengths Enhancement of the Tested Deep Beams

4.2. *Load-Deflection Behavior*

It is obvious from Figure 8, the similarity in behavior among the curves of all beams and characterized by a nearly bilinear response. After flexural cracking appearance, a second, softer linear region was observed in all of deep beams curves up to the failure; this behavior observed in previous researches [15, 16]. Other important matter is the homogeneity of curves with absence of scattered or many singular points and that reflects the reliability of behavior obtained from using SCC in casting the tested beam .

Figure 8 clarifies two notes; the first is that the presence of horizontal shear reinforcement has a considerable contribution in reducing the deflections of the deep beams in all stages of loading to reflect expected highest stiffness of the deep beams due to their high moment of inertia comes from the tall depth; and this contribution can be magnified by using combined horizontal with vertical stirrups and reducing the a/d ratio of the beam through increasing its overall depth; therefore, B12 is the less deflection specimen in all stage of loading due its large stiffness. The second note is that the beams with vertical stirrups only (B3, B7 and B11) exhibit deflections greater than the ones of beams with horizontal stirrups only (B2, B6 and B10), that revealed the effective of the horizontal stirrups in stiffening the deep beams more than the vertical stirrups where maximum deflections were observed in each group of constant a/d ratio; in spite of the effect of vertical stirrups in enhancing the ultimate strength of the deep beam better than the horizontal stirrups.

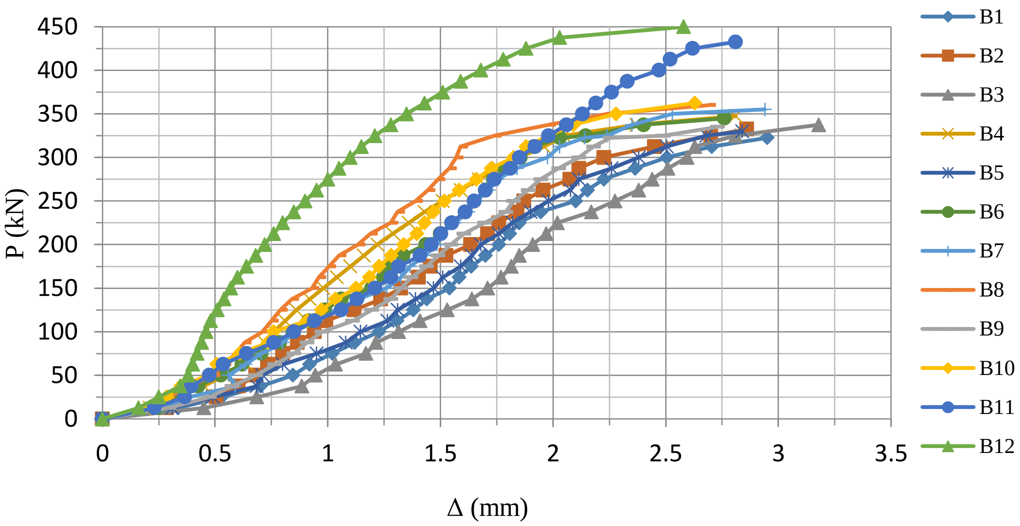


Figure 8: Load-Deflection Behavior of the Tested Beams

The investigation of shear reinforcements presence activity according to a/d decrease on the load-deflection behavior of the deep beams is shown in Figure 9 which confirms effect of shear reinforcements on the general load-deflection behavior of all tested deep beams. The graphic curves according to shear reinforcement's presence confirm expected increase of stiffness with the shear reinforcement's types (vertical stirrups only, horizontal stirrups only or combined horizontal with vertical stirrups) for each a/d ratio. Also, Figure 9 shows decrease in deflections and increase in the beam stiffness according to a/d decrease for each type of shear reinforcements.

The results lead to conclude that decreasing a/d ratio is very effective for the activity of shear reinforcement's presence on moment of inertia value and increase the stiffness to govern deflections and flexural serviceability. From ultimate strength and load-deflection behavior topics; the results indicate the advantages of using SCC and increasing its shear reinforcements in design and working with piles cap, but increasing the depth of the section to decrease a/d ratio is more preferable option to achieve these advantages in high percentage.

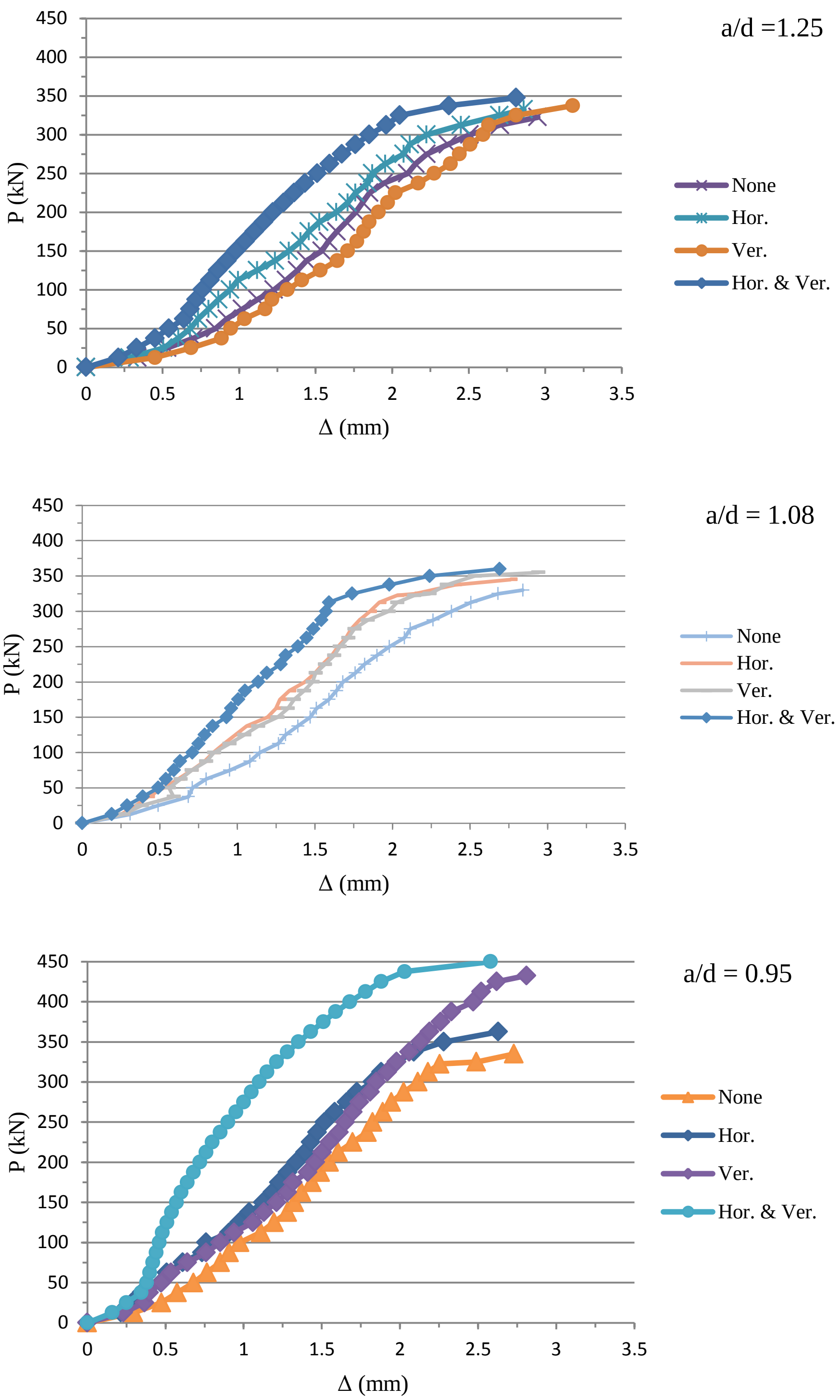


Figure 9: Load-Deflection Behavior of the Tested Deep Beams

4.3. *Cracking and Failure Mode*

All the deep beams showed the same response of cracking patterns up to failure. In the early steps of loading, few vertical flexural cracks formed in the mid span regions at P_{cr} / P_u = 32 – 48%. As the load increased diagonal cracks appeared and propagated rapidly toward the outside edge of the loaded point and the inside edge of the support. While the diagonal cracks were developing across length, their widths were propagating in the center of shear span, as shown in Figure 10.

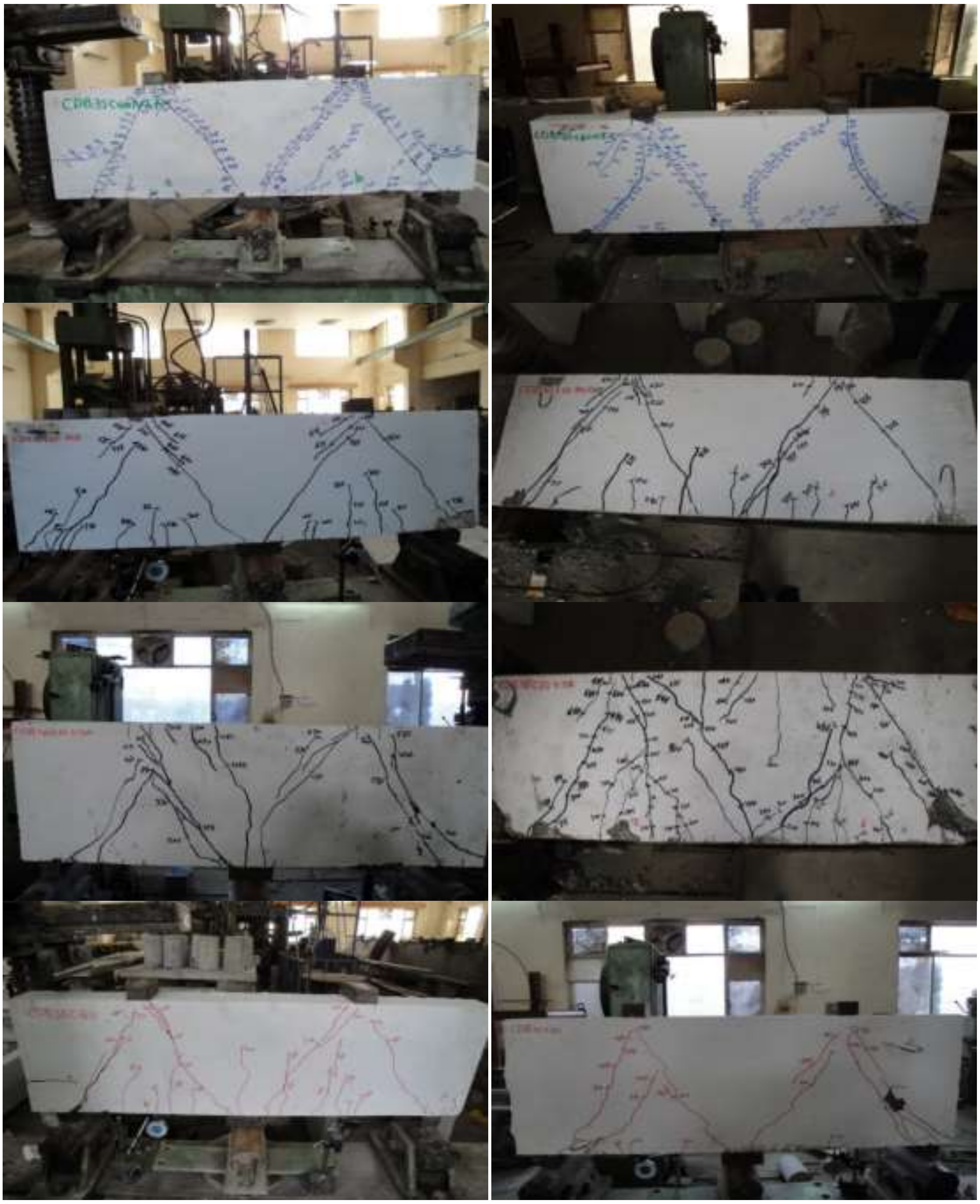


Figure 10: Cracking Patterns of the Tested Beams

The observed number of cracks in the tested beams was increased with their ultimate strengths up to the beams reinforced with vertical stirrups. The cracking

Pattern of the present work complies with previous experimental works [2] except for P_{cr} / P_u = 50% [4], 30 – 50% [9] and 25% [10]. The failure in the present work characterized by widening the web shear cracks that extended between the outside edge of the loaded point and the inside edge of the support.

However, the increment achieved at P_{cr} in deep beams with shear reinforcement depends on reinforcement type (horizontal, vertical or combined horizontal and vertical stirrups) with three different a/d ratios. When combined horizontal and vertical stirrups are used and the a/d ratio decreased to 0.95, increment at P_{cr} can be gained for all the beams and especially for beams with combined stirrups; therefore, B12 was last cracked beam and its P_{cr} increased about 64% as shown in Figure 11. Generally, at the same value of a/d ratio for one group, the P_{cr} of the beams can be increased by transfer the shear reinforcement from horizontal stirrups to vertical stirrups and to obtain the highest P_{cr}, combined stirrups must be adopted.

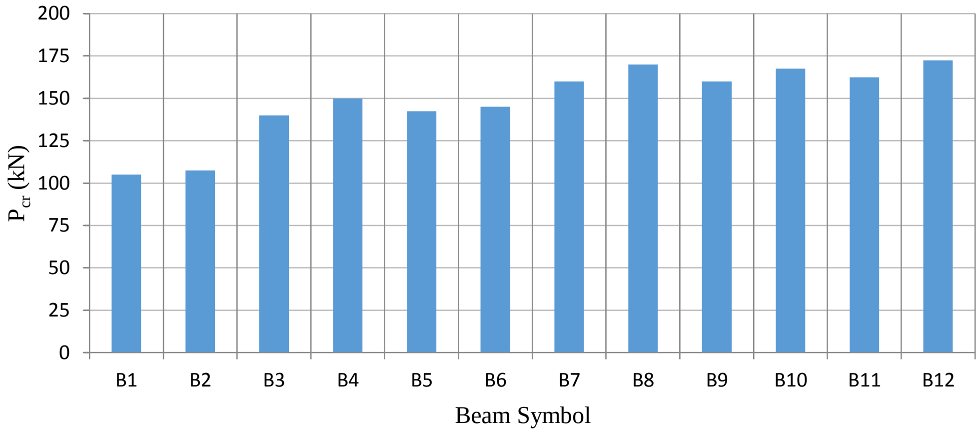


Figure 11: Cracking Loads of the Tested Beams

Furthermore, it can be noticed that adopting on directional shear stirrups only (horizontal or vertical), P_{cr} enhance up to 60% and 55% in the present work which is greater than 52% that enhancement achieved in none shear reinforcement beams and this means improvement in this structural property, as shown in Figure 12.

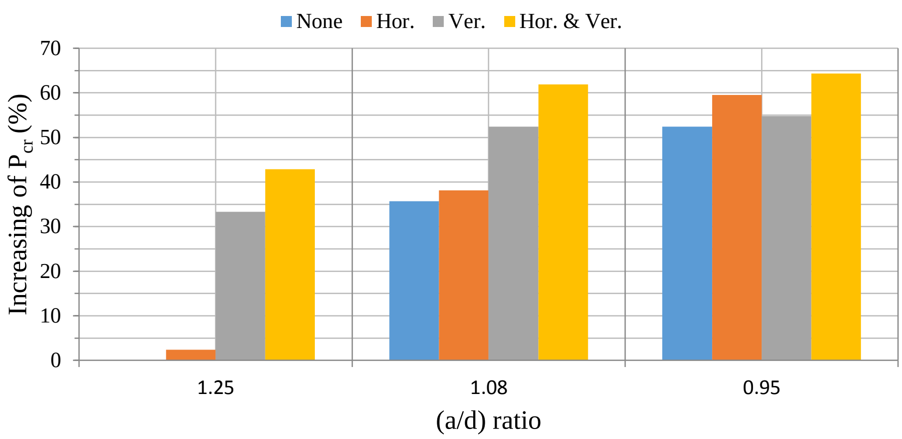


Figure 12: Cracking Loads Enhancement of the Tested Deep Beams

5. Conclusions

- The ultimate strength of the deep beam can be increased depending on the tension bars only with absence of shear reinforcement by decreasing depth ratio (a/d). However, this increment will be proportional with the increment of flexural reinforcement.
- The effect of horizontal or vertical web reinforcement individually on the ultimate strength of deep beam is very little in comparison with its flexural reinforcement effect, but the vertical stirrups is more effective than horizontal reinforcement with enhancement ratios of 3% and 7.5% respectively. While at the same boundaries, dual action for both horizontal and vertical reinforcement together has large effect and can increase the strength up to 40%.
- Decreasing the shear span-to-depth ratio is an effective on enhancing the ultimate strength of the continuous deep beams, thereby, the increase in the ultimate strength is about 12%, 34% and 40% for a/d ratio (0.95), while the maximum increment of the ultimate strength according to greater a/d ratio (1.25) is less than about 8%.
- The presence of the vertical shear reinforcement has not effect on deflection value of the continuous deep beams in all stages of loading, while the horizontal shear reinforcement achieved improvement on stiffness of the deep beams more than the vertical stirrups; whereas the effect of vertical stirrups on enhancing the ultimate strength of the deep beam is better than the horizontal stirrups.
- For ultimate strength and flexural stiffness of continuous deep beams; the results indicate the advantages of using the self-compacting concrete to cast the beam and enhancing its shear reinforcement with horizontal stirrups in design and working with piles cap, but increasing the depth of the section to decrease a/d ratio is more preferable option to achieve these advantages in high percentage.
- The presence of shear reinforcement in continuous deep beam means increment in its cracking load, however the percentage of increment can be increased even when this reinforcement represented by horizontal stirrups and by using horizontal and vertical stirrups together maximum enhancement can be achieved which was 64% in the present work.
- Through the ability of increase the shear reinforcement for reducing deflection due to the increasing stiffness and the ability of this increment for delaying cracking appearance, it is no doubt, the deep beams and piles cap exhibit more serviceability with the combination of horizontal and vertical stirrups in one category.

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