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ORIGINAL ARTICLE

Performance of R.C. slabs with lap splices using headed bars

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Abstract This paper presents an experimental investigation on the behavior and strength of reinforced concrete slabs with lap splice of tension reinforcement using headed bars. Nine simply supported reinforced concrete one-way slabs were tested to study the effect of lap splices length, confinement at the splice zone, debonding of bars in the splice zone, and applying repeated gradually increasing cyclic loading. It was concluded that implementation of lap splice length as stated by ACI 318-14 for headed bars, but without adding confinement in the splice zone, and using cut-off ratio equal to 100%, led to brittle failure of the slab and the ductility was reduced. When the tested slabs were provided with confinement in the splice zone, the strength of slabs was improved and ductility of these slabs was remarkably increased. Additionally, the integrity of the lap joint was preserved when subjected to repeated gradually increasing cyclic loading.

1. Introduction

The use of bar splices in reinforced concrete members is inevitable in many cases because of the limited available length of the steel bars and the existence of construction joints. Steel reinforcement can be spliced by several means such as welding, mechanical couplers or by achieving overlap splices with a minimum length specified by design codes. Bars with heads at their ends are a recent shape of steel reinforcement that are not commercially available in Egypt till now. The use of headed bars shortens the lap splice length when compared with straight or hooked bars because of the mechanism of the load transfer in this case. For lap splice joints using headed bars, the force in the bar is transmitted to surrounding concrete by bearing at the head and bond stresses along the bar surface area in the splice zone. The use of headed bars in lap splice joints is promising because they can enhance the structural performance including anchorage strength and ductility. Also, they can save bar length and reduce congestion of steel reinforcement.

There is no provision in the Egyptian code ECP 203-2007 [1], Eurocode 2-2004 [2], and BS 8110-1997 [3] for the splice requirements of this type of bars with heads. However, ACI 318-14 [4] and Canadian Standards CSA A23.3-04 [5] have provided some specifications for using headed bars.

According to ACI 318-14 [4], the minimum tension development length for headed deformed bars, l_{dt}, shall be calculated by Eq. (1) as follows:

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$$l_{dt} = \left[\frac{0.19\Psi_e f_y}{\sqrt{f_c'}}\right] d_b \geqslant \text{Max of } (8\, d_b, 150\,\text{mm}) \quad (1)$$

where f_c' is concrete compressive cylinder strength, f_y is the yield strength of reinforcement, Ψ_e is a modification factor to account for the coated reinforcement and shall be taken as 1.0 for uncoated bars, and d_b is the bar diameter. Also, the ACI code, permits to use heads to develop deformed bars in tension depending on fulfilling several conditions concerning bottom and side concrete cover, spacing between bars, yield strength of bars, the area of the head (not to be less than four times the nominal bar area) and the nominal diameter of the bar.

Canadian code CSA A23.3-04, allows to use headed bars if the head area is not less than ten times the bar area and they shall be deemed capable of developing the tensile strength of the headed bar if some conditions concerning strength of concrete as well as yield stress of steel are existing.

Several researchers [6–8] investigated the use of headed bars for reinforcing concrete structural members. They concluded that the anchorage capacity of headed bars can be enhanced by the increase of side concrete cover, and that using confining reinforcement in the head zone improved the behavior of these members.

Thompson et al. [9] tested 27 slab specimens with lap splices in the mid-span to study the anchorage of headed bars arranged in one row. The studied parameters were the length of lap joint, the shape and dimensions of the head, the spacing between bars, contact and non-contact lap arrangements, and the use of confinement in the lap area. These experiments led to the conclusion that, a minimum lap splice length of 6 d_b was required to properly develop the bearing capacity of the head. On the other hand, head dimensions and shape had a minor influence on the efficiency of the lap joint. Furthermore, adding transverse confining bars in the same direction of the plane of the lap splice proved to be the best confinement arrangement for the headed bars with lap splice joints.

Li et al. [10] tested eight reinforced concrete specimens to study the performance of continuous longitudinal joint details for decked precast prestressed concrete girder bridge systems. Two types of lap splice joints were assessed. 16 mm diameter epoxy coated Lapped headed bars and lapped welded wire reinforcement were tested to find a better detail of the lap joint. The primary variable was the lap length and the spacing of the reinforcement of the headed bar detail. From the obtained test results, it was concluded that lapped headed bars can transfer force through the lap joint of the tested specimens. It was recommended that the minimum lap length for the headed bars detail was 152 mm (about 9.5 bar diameter). This lap length was able to develop the full anchorage strength of the bars and significantly improved ductility. Also, it was observed that the use of smaller spacing increased the ultimate strength of the specimen but reduced its ductility because of the increase of the area of main steel in the section.

Chun et al. [11] tested 12 beams reinforced with lap-spliced headed bars to study the behavior of high-strength headed bars. The main studied parameters were lap splice length, bar spacing, and transverse reinforcement details. It was concluded that the existing codes provisions were not conservative for the lap splice joints of high-strength headed bars, particularly, if confinement was not provided. It was observed that in this case, the bearing at the head could not be fully obtained because of the prying movement of headed bars at the lap joint. However, when the lap splice joint was confined with transverse reinforcement throughout the splice length, the end bearing contributions to the force transfer were remarkably enhanced.

Yassin [12] tested eight reinforced concrete wide beams to investigate the behavior and strength of these beams when provided with tension reinforcement using headed bars with lap splice joints in the mid-span of the beams. The study focused on studying the effect of lap splices length, spacing of the confining vertical stirrups in the splice zone, and the cut-off ratio of the spliced bars on the strength and ductility of the tested beams. From the results of these experiments, it was concluded that the use of the lap splice length as specified by ACI 318-08, but without the use of transverse reinforcement in the splice zone, and with 100% cut-off resulted in a brittle failure. Also, it was reported that when vertical stirrups were provided in the lap zone to confine the lap joint, the strength of beams was maintained and there was a significant gain in ductility and strain energy of these beams.

Li et al. [13] recently reported the results of testing precast concrete panels connection using lap splice of headed bars. The specimens were subjected to bending and a combination of bending and shear loading. The length of lap joint and spacing between headed bars were the main studied parameters and no confinement was used. A strut and tie model was proposed and validated for the lap splice of headed bars and the ultimate capacity of the joint could be reasonably estimated.

In general, most of these studies concentrated on the study of lap splice of headed bars in beams and confinement was applied using stirrups and hoops. This type of confinement is not practical for slabs and there is a need to try other appropriate means and details of confinement arrangement for the lap splice joint.

2. Research significance and objectives

As mentioned above in the introduction section, the available code provisions for the design and detailing of lap splice joints of headed bars in concrete members are limited. The main goal of this paper was to study the behavior of reinforced concrete simply supported one-way slabs reinforced by lapped-spliced headed bar provided with different confinement arrangements in the lap zone. These confinement details were selected to be practical and easy to implement in slabs. Also, the current study aimed at obtaining a slab with lap spliced headed bars that has a strength and ductility not less than those of the same slab without splice joints. Moreover, the integrity of the lap splice with two alternative practical confining arrangements, was monitored when subjected to repeated gradually increasing cyclic loading.

3. Experimental study

3.1. Preparing headed bars

Headed bars were fabricated using the method suggested by Yassin [12]. This suggested bar head detail was obtained by fixing a square steel plate with size (25 × 25 × 10 mm) with a hole

Figure 1 Shape of the prepared headed bar after welding.

in the middle to the main reinforcement bar by passing the bar through the hole and welding the bar from the two sides of the plate as shown in Fig. 1. Three specimens were tested by direct tension to ensure that the welded connection between the bar and the head did not fail before the ultimate strength. Results of these trials are given in Table 1. Failure occurred in the bar after reaching yielding of the bar outside the welded connection.

3.2. Details of the test specimens

Nine simply supported one-way reinforced concrete slabs with dimensions 2400 mm × 1000 mm × 120 mm were tested in the reinforced concrete laboratory, Alexandria University [14]. For all specimens, five 10 mm-diameter (grade 400/600) deformed bars were used as tension bottom reinforcement and plain bars of 8 mm diameter (grade 280/450) were used for the transverse bottom reinforcement. Plain bars of 6 mm diameter (grade 280/450) were used in the case of confining the splice zone. The test setup is demonstrated in Fig. 2. Also, the studied variables are given in Table 2 and discussed in the next sections. Fig. 3 shows reinforcement details for some of the tested slabs. It should be noted that Slab AS-1 with no spliced bars was considered as the reference slab.

3.3. Test groups

The tested slabs were divided into four groups. The main studied variables were as follows.

3.3.1. Group 1: lap splice length

In this study, three different values of lap splice length were examined: 45 d_b without headed bars (Slab AS-2), 15 d_b with headed bars (Slab AS-3), and 27 d_b with headed bars (Slab AS-7). All slabs in *Group 1* were not provided with confinement details in the lap splice zone and all bars were spliced (cut-off ratio = 100%).

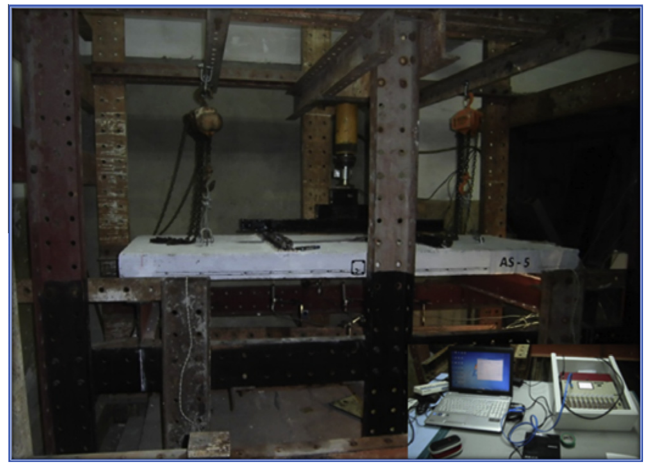


Figure 2 Test setup.

3.3.2. Group 2: confinement arrangement in the lap zone

Two confinement arrangements were used. The first arrangement was of a set of two transverse embedded beams placed at each end of the lap joint perpendicular to the lap splice direction (Slab AS-5). Each embedded beam consisted of four 10 mm longitudinal bars and 6 mm square stirrups (70 mm × 70 mm) spaced at 50 mm apart. The second confinement arrangement was circular spiral 6 mm stirrups with a pitch equal to about 50 mm and diameter of 50 mm placed around each spliced joint (Slab AS-6) in the splice zone and extended 50 mm behind each head. The lap splice length in *Group 2* was 15 d_b and the cut-off ratio was 100%. The details of the reinforcement of these slabs are also given in Fig. 3.

3.3.3. Group 3: debonding of headed bars in the lap zone

Only one slab was tested to evaluate the efficiency of the head to transfer the load through the lap joint (Slab AS-4) without the existence of bond between the bar and concrete in lap joint. Bond between concrete and bars in the splice zone was eliminated by wrapping a plastic tape around the bars in this zone. The lap splice length was 15 d_b and the cut-off ratio was 100%.

3.3.4. Group 4: applying repeated cyclic increasing loading

Two slabs with different stirrups arrangement in the lap splice zone were tested to evaluate the integrity of the lap joint: Slab (AS-8) with the same details of Slab (AS-5), and Slab (AS-9) similar to Slab (AS-6) in all confinement details. The lap splice length in *Group 4* was 15 d_b and the cut-off ratio was 100%. The load was increased in small steps then, this load was released until zero loading. After monitoring cracks, another load cycle was applied with an increase in the load step value. This procedure continued till the failure of the slab.

Table 1 Direct tension test results of headed bars specimens.

Specimen	Failure load (kN)	Yield stress (f_y) (N/mm^2)	Tensile strength (f_u) (N/mm^2)	(f_u/f_y)	Mode of failure
TR1	54.00	437.12	683.54	1.56	Failure occurred in the bar near welding
TR2	53.50	436.21	677.22	1.55	Failure occurred in the bar near welding
TR3	54.50	439.38	689.87	1.57	Failure occurred in the bar near welding

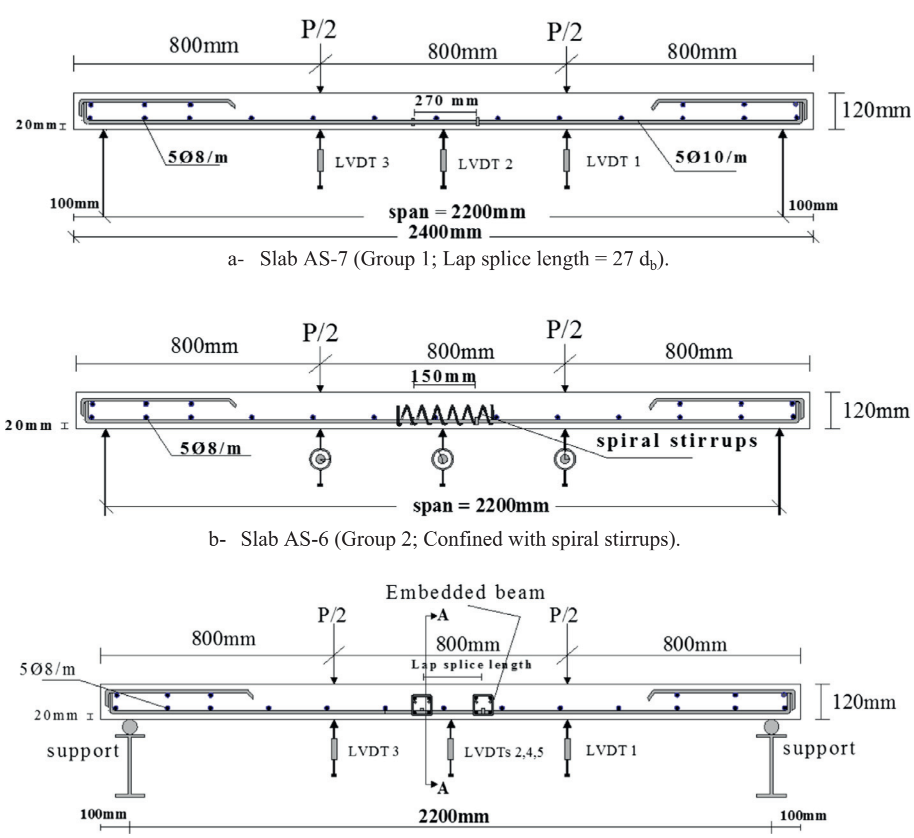
Table 2 Details of the tested slabs (Cut off ratio in slabs with spliced bars was 100%.).

Slab	Group	Average concrete compressive cube strength, f_{cu} (N/mm^2)	Splice length, L_o*	Special reinforcement in the lap zone	Loading	Debonding of lapped bars
AS-1	Reference slab	34.7	No splice	–	Monotonic	Bonded
AS-2	Group 1	36.7	45 d_b (without headed bars)	–	Monotonic	Bonded
AS-3+	Group 1	37.0	15 d_b	–	Monotonic	Bonded
AS-4+	Group 3	34.9	15 d_b	–	Monotonic	Debonded
AS-5+	Group 2	35.9	15 d_b	2 Embedded beams	Monotonic	Bonded
AS-6+	Group 2	31.7	15 d_b	Spiral stirrups	Monotonic	Bonded
AS-7+	Group 1	42.1	27 d_b	–	Monotonic	Bonded
AS-8+	Group 4	30.7	15 d_b	2 Embedded beams	Repeated cyclic loading	Bonded
AS-9+	Group 4	31.0	15 d_b	Spiral stirrups	Repeated cyclic loading	Bonded

* d_b: bar diameter.
+ Slabs with headed bars.

3.4. Test setup and measurements

The details of the setup of the experiment and loading system are shown in Fig. 2. The load was applied using a hydraulic jack of 200 kN capacity and the load value was monitored using a calibrated load cell. A stiff spreader beam was used to transfer the vertical load to the tested slab at two transverse lines 800 mm apart. Three Linear Variable Displacement Transducers (LVDTs) of 0.01 mm accuracy were utilized to measure vertical deformations at the center of the slabs and under the positions of the two applied line loads. For each slab, two electrical strain gauges of 10 mm length were used to measure the strain of the bottom steel reinforcement. Strain gauges were fixed at the end (near the head of the bar if existing) and at the start of the splice joint for all slabs. The vertical load was applied in 2.5 kN increments in a low rate. All measurements of loads, deflections and strains were recorded automatically using data acquisition system.



a- Slab AS-7 (Group 1; Lap splice length = 27 d_b).

b- Slab AS-6 (Group 2; Confined with spiral stirrups).

c- Slab AS-5 (Group 2; confined using two embedded beams).

Figure 3 Reinforcement details of some tested specimens.

Table 3 Main test results.

Slab	Group	Ultimate load, P_u (kN)	Deflection at ultimate load, Δ_u (mm)	Calculated strain energy at ultimate load (kN m)	Strain Energy at ultimate load (%) of reference specimen
AS-1	Reference slab	55.0	38.25	1.748	100%
AS-2	Group 1	55.0	30.91	1.423	81%
AS-3	Group 1	42.5	23.05	0.696	40%
AS-4	Group 3	40.0	13.48	0.412	24%
AS-5	Group 2	62.5	138.56	7.229	414%
AS-6	Group 2	65.0	92.0	4.956	284%
AS-7	Group 1	60.0	83.06	4.255	243%
AS-8	Group 4	60.0	121.45	7.394	423%
AS-9	Group 4	68.0	144.19	8.173	468%

4. Test results and discussion

For each slab, ultimate loads, deflection at failure and the area under the load–deflection curve for each tested slab (strain energy), are presented in Table 3. Figs. 4–10 show cracks at failure of some of the tested slabs. It should be noted that the load values shown on cracks in these figures are given in tons.

4.1. Test results and general behavior of the tested slabs

All slabs in *Group 1* were with no confinement arrangement in the lap zone and 100% cut-off ratio. For slab AS-1 (reference slab), flexural cracks appeared between the two line loads in the constant bending moment zone at a load of 30.0 kN. With the load increase, flexural cracks propagated to the compression zone and became wider. Bottom main steel yielded at a load of 50.0 kN. Flexural failure of the slab took place at a load of 55.0 kN. For slab AS-2 with lap splice length equal to 45 d_b and without headed bars, flexural cracks appeared at the constant moment zone at a load of 25.0 kN. With the load increase, flexural cracks propagated to the top of the slab, and cracks became wider. Yielding of bottom longitudinal tension steel occurred at a load of 52.5 kN. Failure of the slab occurred by crushing of concrete in top of the slab at a load of 55.0 kN. For slab AS-3, with 15 d_b lap splice length provided with headed bars but without any confinement at the splice zone, flexural cracks initiated at the constant moment zone at a load of 15.0 kN. As the applied load was increased, flexural cracks formed and appeared along the position of the heads at each end of the spliced bars at a load of 20 kN. With load increase, flexural cracks propagated to the compression zone at the top of the slab and became wider. No yield of steel reinforcement was recorded in the bottom longitudinal steel bars up to failure. Failure of this slab was sudden with the loss of bond between concrete and steel which resulted in pushing down the bottom cover. Pullout of bars occurred at a load of 42.5 kN and the failure was brittle as shown in Fig. 4. Slab AS-7 with 27 d_b lap splice length provided with headed bars without confinement, flexural cracks initiated at the constant moment zone at a load of 25.0 kN. With the load increase, cracks appeared at the lap-splice zone at a load of 27.5 kN and started to propagate to the compression zone and the width of cracks became wider. Yielding of main steel occurred at a load of 48.0 kN. At a load of 60.0 kN, flexural ductile collapse of the slab took place.

In *Group 2*, all slabs in this group had a lap splice length = 15 d_b and 100% cut-off ratio. In slab AS-5, confined with two transverse embedded beams perpendicular to the splice zone, first flexural crack appeared at the constant moment zone outside the edge of the embedded beams, and extended to the head of the spliced bar at a load of 32.5 kN. With the load increase, cracks initiated outside of the lap zone at a location close to transverse embedded beams, and these cracks started to extend toward the compression zone at the top of the slab. The first crack inside the lap zone initiated near the heads and at the bottom of the transverse embedded beams at a load of 47.5 kN. During applying the load increase, longitudinal cracks formed outside the end of the lap zone. This type of cracks did not propagate between transverses embedded beams in the lap zone, but cracks propagated and formed

Figure 4 Brittle failure of slab AS-3.

Figure 5 Brittle failure of the lap splice on the bottom of slab AS-4 (debonded bars).

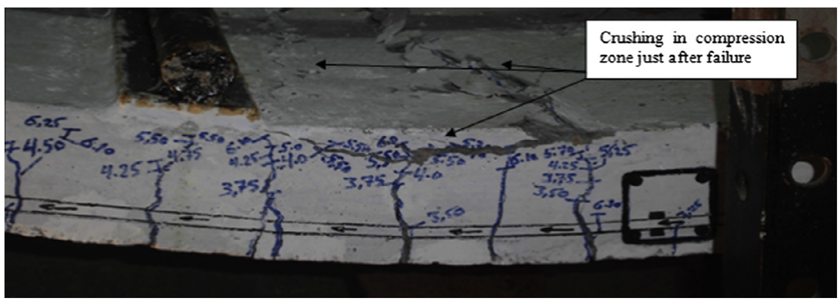


Figure 6 Ductile flexural failure of slab AS-5 (confined with two embedded beams).

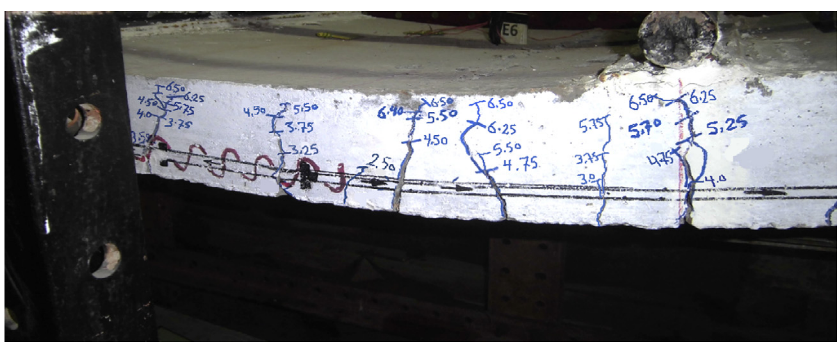


Figure 7 Crack pattern on the side of slab AS-6 at failure (outside lap splice zone).

just outside of the lap zone. These cracks became wider and extended to cover the constant moment zone. Yielding of bottom main steel was noticed at a load of 48.0 kN. Failure of the slab occurred by crushing of concrete in compression zone at a load of 62.5 kN, as shown in Fig. 6. For slab AS-6, confined with circular spiral stirrups around the lap splice joint, flexural cracks appeared in the constant moment zone and near the head of the spliced bar at a load of 32.5 kN. As the load was increased, the first crack in the lap zone initiated near the heads and close to the edge of the spiral stirrup around lap splice. This behavior was also, observed in slab AS-5 confined with two embedded beams. Then, with the gradual increase of the applied load, additional transverse cracks outside of the lap zone were formed. Just before failure, some cracks formed within the lap zone. These cracks became wider and extended in the lap zone. At a load of 57.5 kN, bottom main steel yielded. Failure of the slab occurred by crushing of concrete in compression zone at a load of 65 kN (see Fig. 7).

In *Group 3*, all slabs were not provided with any confinement in the lap zone and the splice length = 15 d_b with headed bars. In slab AS-4, with debonded headed bars in the spliced zone, flexural cracks appeared at the constant moment zone near the head of the spliced bar at a load of 12.5 kN. This value was less than that recorded for the bonded slab AS-3. The width of cracks was wider than that of slab (AS-3). Transverse crack in the slab (AS-4) occurred close to the position of the bar head. Distinct longitudinal cracks formed between the two opposing heads in the lap zone. These cracks appeared at a load of 37.5 kN. In Slab (AS-3) with bonded headed bars, the intensity and number of cracks along the lap joint zone were observed. This behavior was not evident in the debonded slab (AS-4) because there was no contribution from bond in load transfer. As the load was increased, flexural cracks propagated to the compression zone and cracks along the line of heads at each end of the lap became wider and extended to upper face of the slab covering the lap zone. No

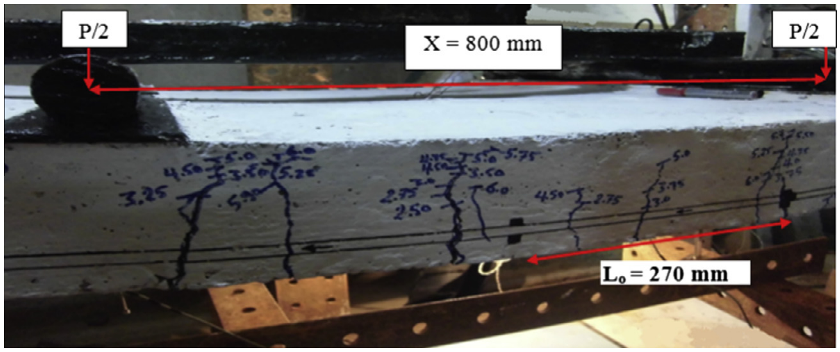


Figure 8 Crack pattern on the side of slab AS-7 at failure.

yield of steel reinforcement was recorded in the tension steel up to failure. Failure of the slab was a brittle failure occurred suddenly as the heads of bars pushed down the bottom cover and cover separated from the slab at a load of 40 kN as shown in Fig. 5. This failure action could be described as a prying action as the ends of the lapped spliced bars moved outside the bottom of the slab, pushing the bottom concrete cover in lap joint zone.

In *Group 4*, slabs were subjected to repeated gradually increasing cyclic loading up to failure. In slab **AS-8** confined with embedded beams around the bar heads, with the same details of slab **AS-5**, flexural crack appeared in the first cycle at a load of 20 kN at the constant moment zone, near the end of the stirrups of the embedded beams. With the applying of loading cycles, the width of cracks parallel to the embedded beams became wider and flexural cracks propagated to the top compression zone of the slab. Failure of the slab AS-8, occurred in the tenth cycle by crushing of concrete in compression zone at load of 60 kN. Fig. 9 shows crack patterns of slab **AS-8 at failure**. Slab **AS-9** was provided with circular spiral stirrups around the lap splice, and had the same reinforcement details of slab **AS-6**. In this slab, flexural crack appeared at the constant moment zone adjacent of the end of circular spiral stirrup in the first cycle at a load of 25 kN. With applying repeated loading cycles, the cracks formed and initiated outside of the lap zone close to the end of the spiral stirrups. Also, some cracks started near the head of the bar. In the fifth loading cycle, yielding of the longitudinal headed bars occurred at a load of 50.7 kN (about 75% of the ultimate load; P_u). The behavior of this specimen was similar to that of slab **AS-8**

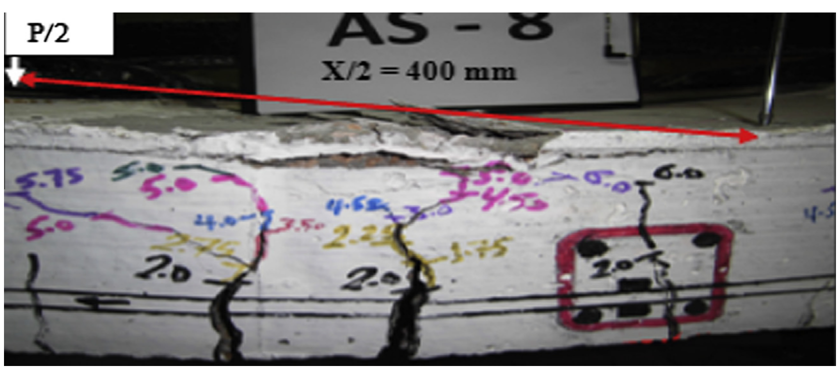


Figure 9 Crack pattern on the side of slab AS-8 at failure.

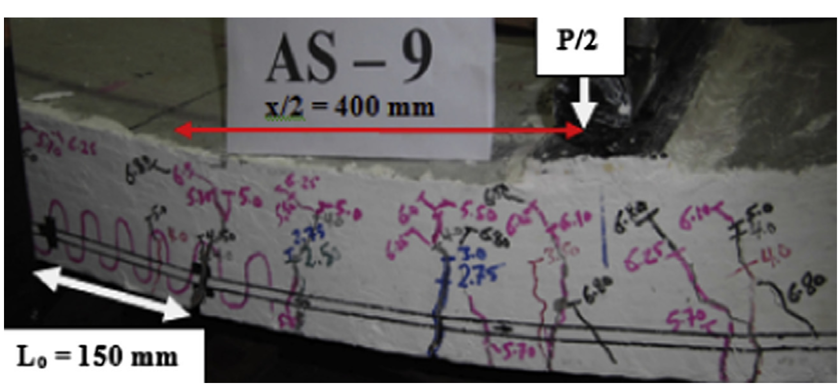


Figure 10 Crack pattern on the side of slab AS-9 at failure.

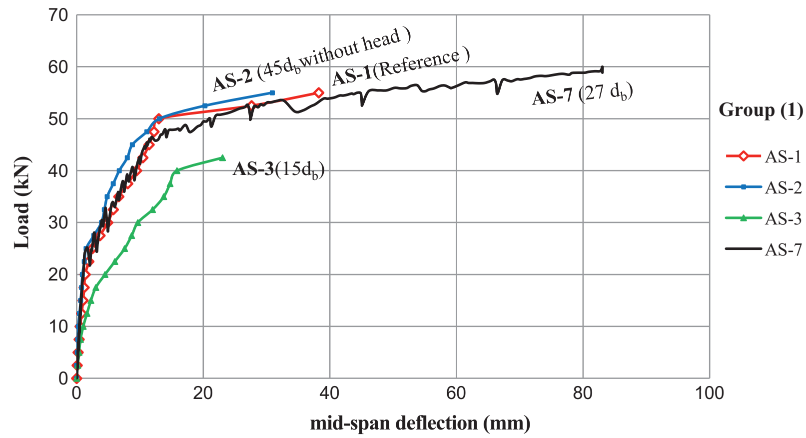


Figure 11 Load–deflection curves for Group 1.

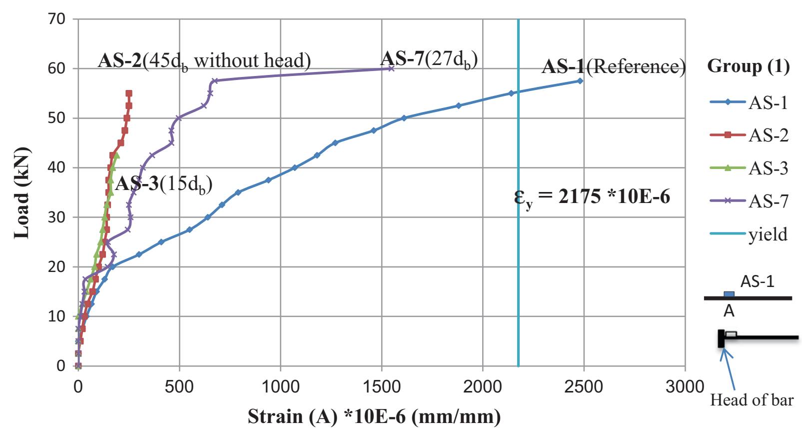


Figure 12 Load–steel strain curves for Group 1.

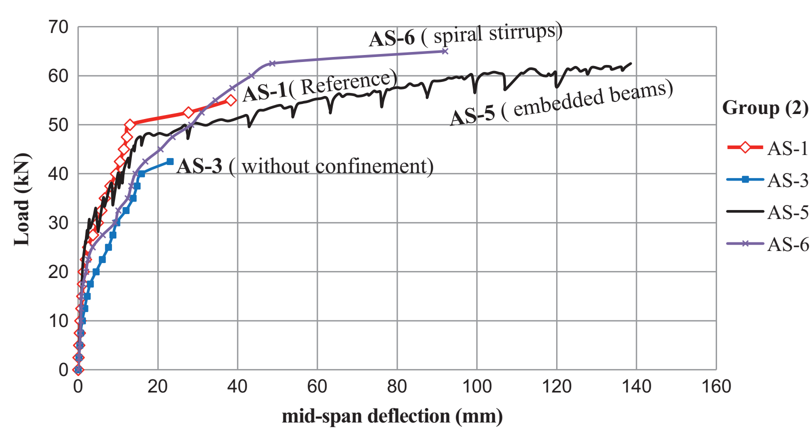


Figure 13 Load–deflection curves for Group 2.

which was also provided with embedded beams around the bar heads. Failure of slab **AS-9** occurred by crushing of concrete in compression zone at load of 68 kN. Crack patterns of slab **AS-9** are demonstrated in Fig. 10 which shows that concrete inside the spiral stirrups zone was not damaged and concrete cover did not split off.

4.2. Effect of lap splice length (Group 1)

Fig. 11 shows the applied load–deflection at mid-span relations for slabs AS-1, AS-2, AS-3, and AS-7. It can be shown that the load–deflection curve for slab AS-1 (reference slab) and slab AS-2 (with 45 d_b lap splice without headed bars) was very close. Slope of load-defection curve of slab AS-3 was less than that of slabs AS-1 and AS-7 after the cracking loads which indicates that AS-3 is less stiff than other slabs in the Group 1 due to the short unconfined lap splice length. The area under the load–deflection curve was calculated to measure the total energy absorbed by the tested slabs which is called strain energy or toughness. The strain energy ratios achieved by the tested slabs were 81%, 40%, and 243% for slabs AS-2, AS-3, and AS-7 respectively, of that of Slab AS-1 (reference slab). The ultimate load values of slabs AS-2, AS-3, and AS-7 of 100%, 77%, and 109%, respectively, of that of Slab AS-1 (reference slab). Fig. 12 shows the relationship between measured steel strain (at point A) near the head of bar and load for slabs of group (1). For all slabs in this group except AS-1, strain data indicated that the steel did not yield until failure. It is clear that without using confinement in the lap zone, the strength and ductility of the reference slab can be maintained if the lap splice length is 27 d_b with headed bars, or 45 d_b with straight bars with no head. On the other hand, slab AS-3 with 15 d_b had less strength and ductility.

4.3. Effect of using confinement arrangements in the lap zone (Group 2)

Fig. 13 presents load-mid-span deflection relations for slabs of this group. The figure indicates that at all load value, the recorded mid-span deflection of slabs provided with confinement at the splice zone was less than that of slab AS-3 provided with no confinement. The strain energies calculated for the slabs of this group were 81%, 414%, and 284% for slabs AS-3, AS-5, and AS-6 respectively, of that of slab AS-1 (reference slab). Slabs AS-3, AS-5, and AS-6 failed at an ultimate load equal to 77%, 114%, and 118%, respectively, of that of slab AS-1 (reference slab). This indicates the enhancement of ductility and energy dissipation of slabs with confined lap splices. Fig. 14 shows load–strain at point A relation for the tested slabs in group (2). Strain readings indicated that steel did not yield until failure of slabs AS-3 (without confinement) and AS-5 (with embedded beams confinement), while for slab AS-6 (confined with spiral stirrups around lap splice) yield was recorded at a load value equal to 62.5 kN just before failure.

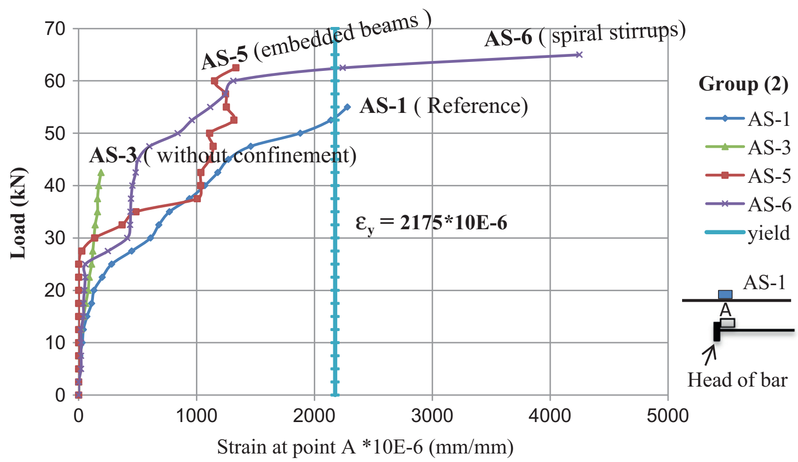


Figure 14 Load–steel strain curves for Group 2.

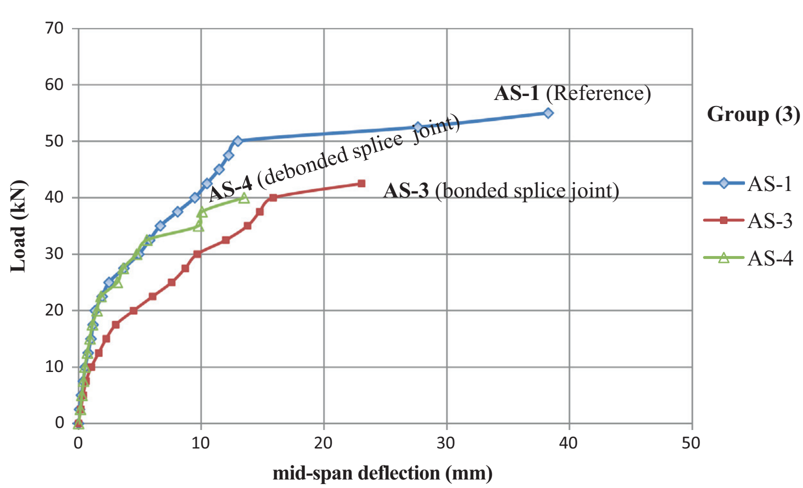


Figure 15 Load–deflection curves for Group 3.

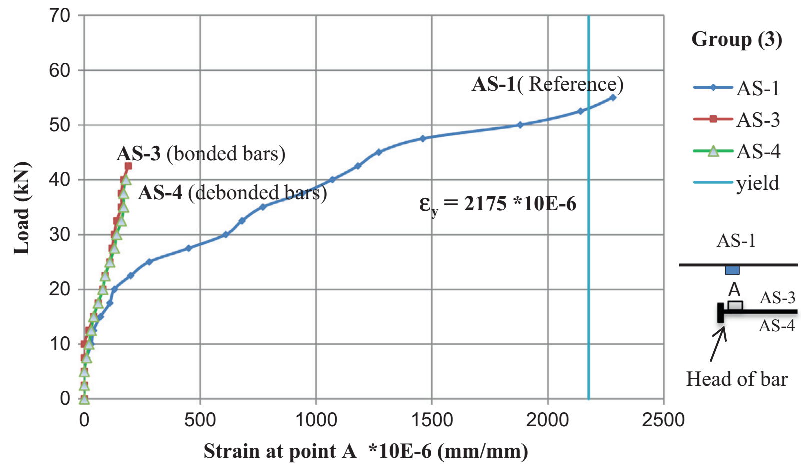


Figure 16 Load–steel strain curves for Group 3.

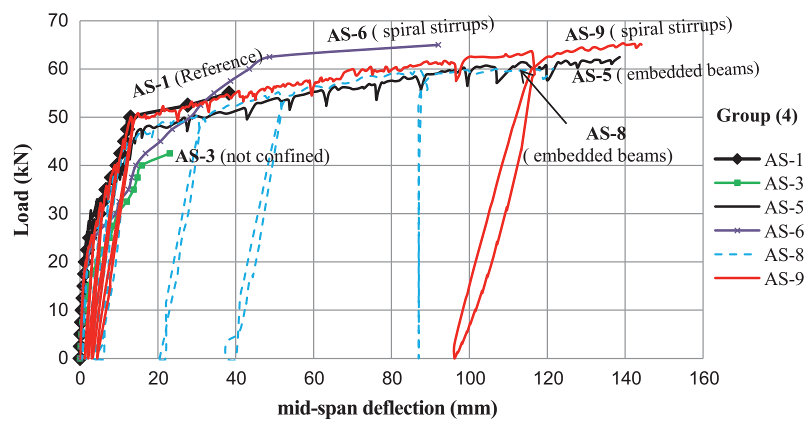


Figure 17 Load–deflection curves for Group 4.

From these results, for slabs with relatively short lap splice equal to 15 d_b, using confinement in the splice zone enabled the slabs to have a strength slightly higher than the reference slab and the calculated strain energy was more than twice that of the reference slab.

4.4. Effect of debonding bars in the lap zone (Group 3)

Fig. 15 displays applied load–deflection at the mid-span relations for the tested slabs AS-1, AS-3, and AS-4. The figure shows that deflection of slab AS-4 (with debonded bars in splice zone) at failure was about 58% of that of slab AS-3 (with bonded bars in splice zone). These results indicated that elimination of bond between steel reinforcement and concrete in the lap splice zone decreased the maximum deflection at failure load and decreased the ductility. The strain energies calculated for the slabs of this group were 40%, and 24% for slabs AS-3, and AS-4 respectively, of that of slab AS-1 (reference slab). Slabs AS-3 and AS-4 failed at an ultimate load of 77%, and 73%, respectively, of that of slab AS-1 (reference slab). Fig. 16 shows the relationship between values of strain (at point A) near the head of bar and load for the tested slabs in group (3). Main steel bars did not yield till failure of the spliced slabs of this group. Although only one slab was tested in this group, the head could not develop the force of the bars through the lap splice joint and the failure was sudden and brittle when compared with the bonded slab AS-3 with the same splice properties.

4.5. Effect of applying repeated gradually increasing loading (Group 4)

Fig. 17 shows load–deflection at mid-span for the tested slabs AS-1, AS-3, AS-5, AS-6 (with monotonic loading), and AS-8, AS-9 (subjected to repeated gradually increasing loading). The figure shows that at any load level, the recorded deflection at mid-span of slabs provided with confinement at the splice zone and subjected to repeated loading was less than that of slab AS-3 without confinement and loaded monotonically. The calculated strain energies for each of the tested slabs were 40%, 414%, 284%, 423%, and 468% for slabs AS-3 (without confinement), AS-5, AS-6, AS-8, and AS-9 respectively, of that of Slab AS-1 (reference slab). Specimens AS-8 and AS-9 were able to properly dissipate energy, exhibited good ductility, and showed almost stable hysteric loops. The ultimate load values for these slabs were of 77%, 114%, 118%, 109%, and 124%, respectively, of that of slab AS-1 (reference slab). Fig. 18 shows the relationship between values of strain (at point A)

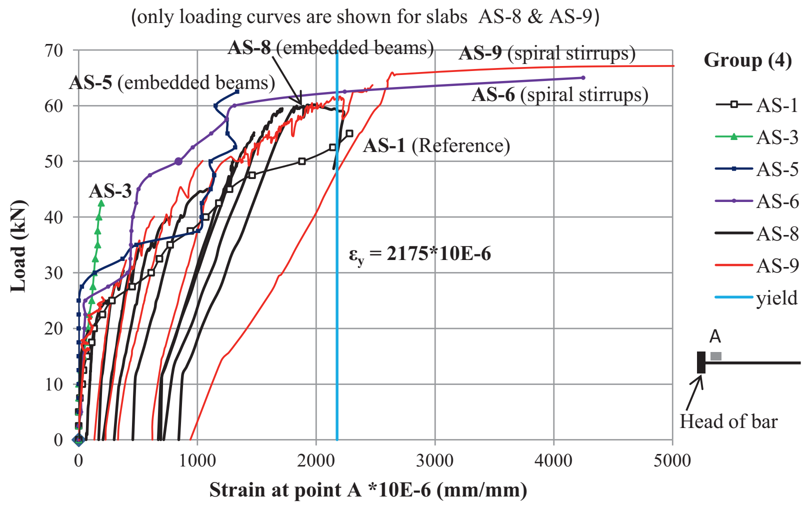


Figure 18 Load–steel strain curves for Group 4 (only loading curves are shown).

near the head of bar and load for the tested slabs of group (4). For Slab AS-8 (confined with embedded beams around the heads of the bars and subjected to repeated loading) yielding was recorded near the head (stain gauge at point A) just before failure at load value = 59 kN (about 98% of the ultimate load) in the last cycle, while for slab AS-9 (confined with circular spiral stirrups around lap splice), yielding was recorded near the head (stain gauge at point A) before failure at 61 kN (about 90% of the ultimate load) in the fifth cycle. This indicates that the confined head was capable of developing the full strength at the lap splice joint.

5. Summary and conclusions

In this paper, the results of testing nine concrete one-way slabs with lap splice using headed bars with 100% cut-off ratio were presented. The main studied variables were the splice length, using confinement details in the lap zone, debonding of bars in the lap splice zone, and applying repeated gradually increasing cyclic loading. From the results of the tested slabs, the following conclusions can be drawn:

1. Flexural and ductile mode of failure of slabs without lap splice can be achieved in slabs with lap splice when: the lap splice length, L_o = 45 d_b without headed bars, and without using any confinement at the splice zone, or L_o = 27 d_b with headed bars, and without using any confinement at the splice zone, or L_o = 15 d_b with headed bars as recommended by ACI, and confinement was provided at splice zone. The failure of these slabs transformed from brittle mode (splitting of bottom cover under main steel) to ductile flexural mode and crushing of concrete in compression zone.
2. Although only one slab was tested to study the effect of debonding of the headed bars in the lap splice zone, it was clear that head was not able to develop the full strength of the bar through the lap joint. When comparing with the behavior of the similar bonded slab, the number of surface cracks was less but with larger crack width. Also this slab showed less ductility than that of the un-spliced slab and the failure was brittle (bottom cover split and pullout of headed bars). This indicates that the head of the bar, without confinement, could not develop the full strength of the bar along the lap splice joint.
3. Slabs provided with different confinement details in the lap zone and subjected to repeated gradually increasing cyclic loading showed that the lap splice joint was stable and the integrity of the joint was preserved. Also, it showed a good energy dissipation, fairly ductile failure, and stable loading loops.

From the results of this present study, it is recommended to investigate the behavior of non-contact spliced headed bars and the usage of bars with large diameter. Also, there is a need to develop a general nonlinear finite element model of lap splice joints with headed bars.

References

[1] ECP 203-2007, Egyptian Code for Design and Construction of Reinforced Concrete Structures, Ministry of Housing, Utilities and Urban Development, 2007.
[2] Eurocode 2 EN 1992-1-1:2004, Design of Concrete Structures – Part 1: General Rules and Rules for Buildings, European Committee for Standardization, December 2004.
[3] BS 8110: Part 1:1997, Structural Use of Concrete, Part 1. Code of Practice for Design and Construction, British Standard Institution, 1997.
[4] ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary, American Concrete Institute, 2014.
[5] CSA A23.3-04, Design of Concrete Structures, Canadian Standards Association, 2004.
[6] R.A. DeVries, Anchorage of Headed Reinforcement in Concrete, Ph.D. Dissertation, The University of Texas at Austin, Austin, Texas, December 1996.
[7] T.R. Bashandy, Application of Headed Bars in Concrete Members, Ph.D. Dissertation, The University of Texas at Austin, Austin, Texas, December 1996.
[8] M.K. Thompson, The anchorage behavior of headed reinforcement in CCT nodes and lap splices, Ph.D. Dissertation, The University of Texas, Austin, Tex., USA.
[9] M.K. Thompson, A.L. Ledesma, J.O. Jirsa, J.E. Breen, R.E. Klingner, Anchorage of Headed Reinforcement in Lap Splices,

Center for Transportation Research Report 1855-3, Austin, Texas, May 2002.
[10] L. Li, Z. Ma, M.E. Griffey, R.G. Oesterle, Improved longitudinal joint details in decked bulb tees for accelerated bridge construction: concept development, J. Bridge Eng. 15 (3) (2010) 327–336.
[11] S.C. Chun, J.G. Lee, Anchorage strengths of lap splices anchored by high-strength headed bars, in: The 8th International Conference on Fracture Mechanics of Concrete and Concrete Structures, Toledo, Spain, 2013.
[12] A.M. Yassin, Behavior of reinforced concrete wide beams provided with lap splices using headed bars, M.Sc. thesis, Faculty of Engineering, Alexandria University, Alexandria, Egypt, February 2013.
[13] L. Li, Z. Jiang, Flexural behavior and strut-and-tie model of joints with headed bar details connecting precast members, Perspect. Sci. 7 (2016) 253–260.
[14] A.A. Abudiena, Behaviour of reinforced concrete slabs using headed bars in lap splices, M.Sc. thesis, Faculty of Engineering, Alexandria University, Alexandria, Egypt, February 2015.