Flexural Behavior of Rectangular Concrete Beams with Lap Splices between Deformed and Smooth Reinforcement Bars

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Abstract

The aim of this research is to study flexural behaviour rectangular concrete beams with lap splice between deformed and smooth bars. An experimental program has been performed to investigate the research point, where sixteen rectangular concrete beams were tested in a four point bend configuration. Specimens were grouped into four groups to investigate influences of lap splice length, stirrups intensity and location, end shape, and concrete characteristic strength (N.S.C and H.S.C). It was concluded that distributing stirrups along the splice length increase failure load more than concentrating them at splice ends; end shaping of splices increases failure load; Increasing splice length compared with that required for transmission of tensile stresses through bond decreases ductility; linearity of strain distribution along reinforcement bars increase by the increase and uniformity of stirrups confinement; increasing splice length decreases the difference between strain in deformed and smooth bars.

1. Introduction

When reinforcement is spliced within a concrete beam, it is necessary to overlap bars by a sufficient length for transmission of tensile stresses between bars, through concrete without bond failure.

Most of the previous research works showed that the lap length has a significant effect on the behaviour of reinforced concrete elements. Reynolds and beeby [1] concluded that most of the pervious formulae, concerning bond stresses in R.C elements, mentioned that the lap splice performance is greatly affected by anchorage length. They took concrete strength, concrete cover and transverse steel as main factors affecting splice length.

Hamad et B.S. and Fakhran[2] investigated eighteen full-scale beam specimens. In this study, the amount of transverse reinforcement, bar size, and the bar type (black or galvanized) were considered. They concluded that in beams without transverse reinforcement in the splice region, surfaces of black and galvanized bars were relatively clean with limited signs of concrete crushing in the vicinity of very few bar lugs. In beams with transverse reinforcement in the splice region, however, there were relatively more signs of concrete crushing adjacent to the bar lugs indicating the positive role of confinement by transverse reinforcement in mobilizing more bar lugs in the stress transfer mechanism between the steel bars and the surrounding concrete.

Reynolds and Beedy [1] considered stirrups as main factor which affects lap splice length and stated that the presence of transverse steel increases the bond strength. Their interesting conclusion was that, where the lap is in a constant moment zone bond is only able to mobilize relatively small force in the stirrups and that the increase in the bond strength produced by the stirrups is thus small. However, if the lap is situated in an area of high shear where diagonal cracking has developed and stirrups are highly stressed by the shear, then the presence of transverse steel can lead to a very large increase in bond capacity.

H. Allam [3] concluded that using Concentration of stirrups at the lap ends, or using closely spaced stirrups increase the ductility of the beam, increase the ultimate load and make the failure more ductile closely spaced stirrups are more effective than using stirrups with the volume of lateral steel but with wider spacing and higher cross section.. To eliminate the cracks at the lap ends stirrups must be concentrated with spacing (5-10cm) before and after lap ends with minimum of 3 stirrups at each end.

H. M. Salem [5] recommended using the simplest splice regarding manufacturing which are the U, V and L- shaped splices. He found that better ductility of tension splices can be achieved by using the new developed splices, the goal of the bent splice is to avoid the effect of splitting cracks and cover splitting on the splice resisting mechanisms as in the case of straight lap splice even with end hooks, ones the splitting cracks occur the strength of the member is dramatically decrease. This will be helpful for splicing reinforcement in members that are not provided with web reinforcement such as slabs and footing.

2. Research parameters

The main objectives of this research are to study influences of: splice length, stirrups intensity and location, splice end shape, concrete compressive strength on flexural behaviour of lap spliced concrete beams.

3. Experimental program

Sixteen simply supported reinforced concrete beams of dimensions 120 mm × 200 mm × 1600 mm were tested. All the specimens had the same longitudinal reinforcement. All the spliced bars were casted with 15mm concrete cover along all sides of the specimens. Flexure span was 700mm and shear span was 400mm. All specimens were reinforced by 2Φ10 main reinforcement, 2ϕ6 secondary reinforcement and ϕ8mm stirrups. Beam design was based on concrete compressive strength of 30, 60 MPa and reinforcement yield stress of 240,400 MPa for stirrups and main reinforcement respectively. Test specimens were grouped in four groups to investigate the pre-stated parameters.

Table 1: specimens' General details

Specimen code	Groups	Lap length	Bottom RFT	Fcu (MPa)	FY (MPa)	Remarks
N-R-S	Group 1	No splice	2ϕ10	30	240	reference
N-R-D		No splice	2Φ10	30	400	reference
N-20		20φ	1ϕ10-1Φ10	30	240/400	Increasing Lap length
N-30		30φ	1ϕ10-1Φ10	30	240/400	
N-40		40φ	1ϕ10-1Φ10	30	240/400	
N-50		50φ	1ϕ10-1Φ10	30	240/400	
N-Mid	Group 2	30φ	1ϕ10-1Φ10	30	240/400	Increaseing intensity at lapsplice zone 6φ8
N-End		30φ	1ϕ10-1Φ10	30	240/400	Add 6φ8 at lap end
N-L-U	Group 3	30φ	1ϕ10-1Φ10	30	240/400	smooth (L) deformed(U)
N-L-L		30φ	1ϕ10-1Φ10	30	240/400	L-L
N-V-V		30φ	1ϕ10-1Φ10	30	240/400	V-V
H-R-S	Group4	No splice	2ϕ10	60	240	reference
H-R-D		No splice	2Φ10	60	400	reference
H-20-S		20φ	1ϕ10-1Φ10	60	240/400	Increasing Lap length
H-30-S		30φ	1ϕ10-1Φ10	60	240/400	
H-40-S		40φ	1ϕ10-1Φ10	60	240/400	
ϕ(smooth) Φ(deformed)						

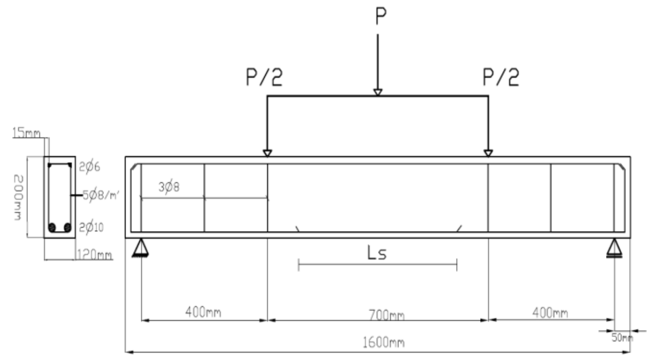


Figure 1: specimens' General details

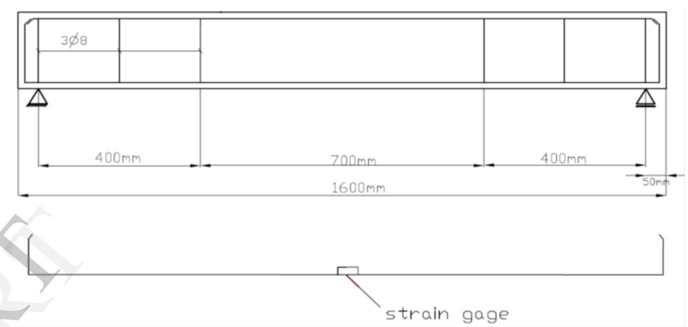


Figure 2: Reinforcement details for specimens [N-R-D,

N-R-S, H-R-D, and H-R-S]

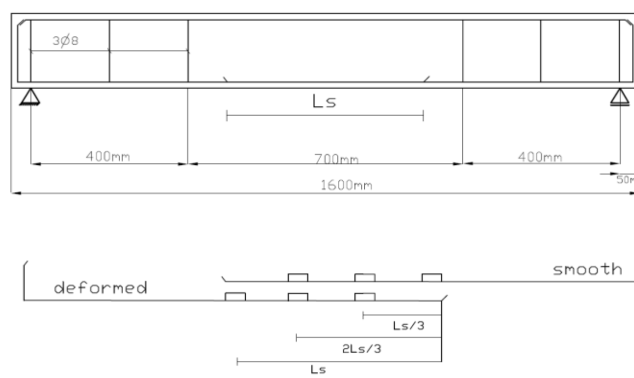


Figure 3: Reinforcement details for specimens [N-20, N-30, N-40, N-50, H-20, H-30, and H-40]

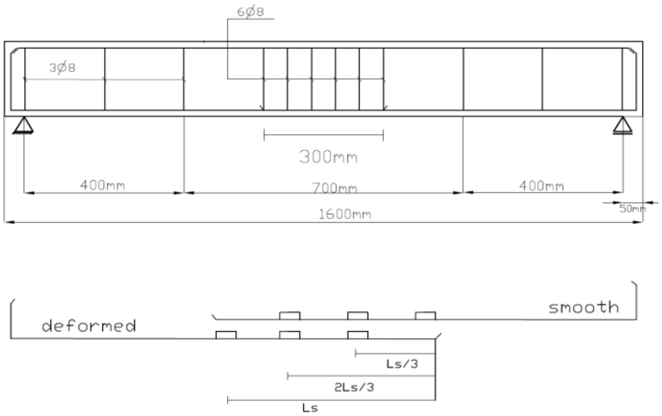


Figure 4: Reinforcement details for specimen [N-Mid]

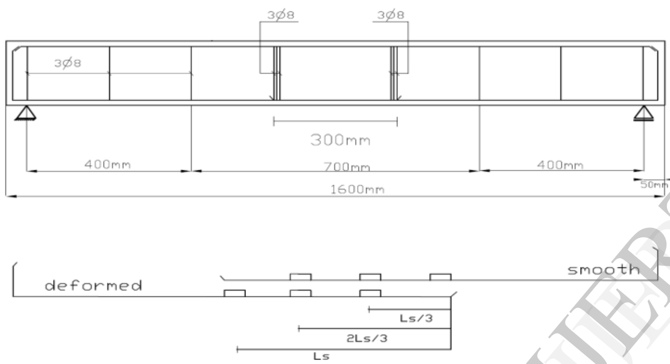


Figure 5: Reinforcement details for specimen [N-End]

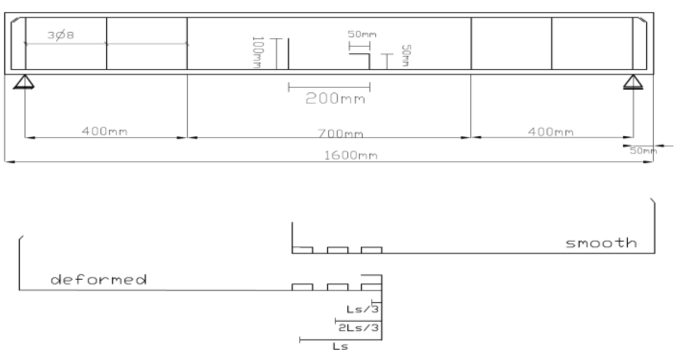


Figure 6: Reinforcement details for specimen [N-U-L]

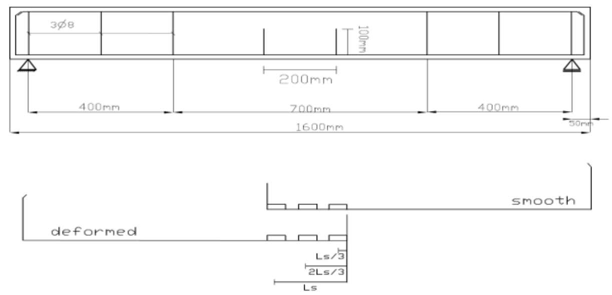


Figure 7: Reinforcement details for specimen [N-L-L]

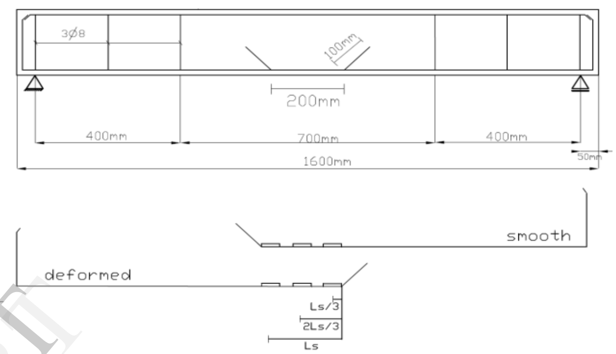


Figure 8: Reinforcement details for specimen [N-V-V]

4. Test procedures and instrumentation

All test specimens were subjected to a four points bend setup, so loads were applied through two loading points facing two supports. Loads were generated from a hydraulic machine of 5000 kN capacity applying its load directly to the mid-span of an I beam that distributes the load equally on the two loading plates. A load cell was installed beneath the machine upper head, so it measured double the load of each loading point.

5. Test results and discussion

5.1 Failure load

Figure 9 (shown below) shows that first group failure loads are linearly proportional to splice length; in addition failure load of the longest splice length (50Φ) was intermediate between those of the two reference specimens. The second group shows that stirrups confinement has a significant effect on failure load; this could be attributed to that confinement increases bond between concrete and reinforcement. Specimen [N-mid] showed a higher failure load than specimen [N-end], this reflects that distributing stirrups along the splice length results in a higher failure load than concentrating it at the splice ends. The third group shows that shaping the bar end increases the failure load, in addition it also shows that U shaping results in the highest increase in failure load, than L shaping, than V shaping. This could be attributed to the higher effect of bearing in U shaping than L than V.

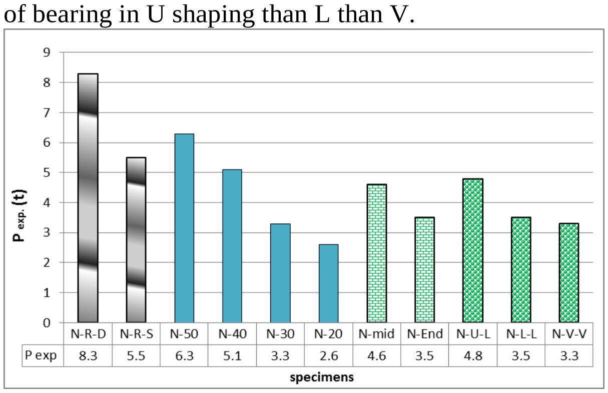


Figure 9: Failure Loads of Tested Specimens (N.S.C)

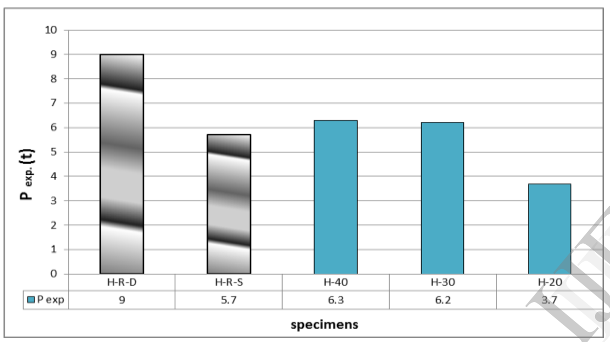


Figure 10: Failure Loads of Tested Specimens (H.S.C)

Figure 10 shows the recorded failure loads for tested specimens of the fourth group. It shows that an increase in failure load for longer splice length between specimens [H-20] and [H-30], while for specimen [H-40] no significant increase could be noticed. This reflects that the increase of lap length over that required for transmission of tensile stress through shear along the bar circumference is insignificant.

5.2 Deflection

Figure 11 shows load deflection curves for this group, studying influence of changing splice length on mid-span deflection. It could be noticed that, for all specimens the more the splice length the less the mid span deflection, in addition it could also be noticed that specimens [N-50] and [N-40] showed a stiffer behavior than the smooth reference specimen, while the other specimens [N-20 & N-30] showed less stiffness. This could be attributed to that splice length of [N-40] and [N-50] are sufficient to transmit tensile force in reinforcement through bond with concrete; this exaggerated the effect of reinforcement at the splice zone, to behave as if the specimen is reinforced by double the actual reinforcement.

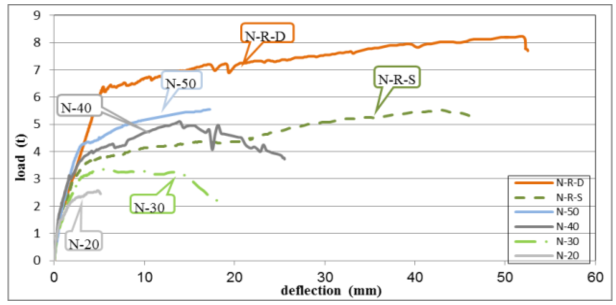


Figure 11: Load-Deflection Group

Figure 12 shows load deflection curves for group II which includes the reference specimens at which no splices were made and specimens [N-Mid & N-End] at which splice length was 30ϕ, in addition to [N-30]. The figure shows the influence of increasing number of stirrups along splices length and at splice ends by 6ϕ 8, on mid span deflection for group II. It could be noticed, that increasing number of stirrups along splices length decreases mid span deflection and increases ductility. In addition it could also be noticed that specimens [N-Mid] and [N-End] showed a stiffer behavior than specimen [N-30].

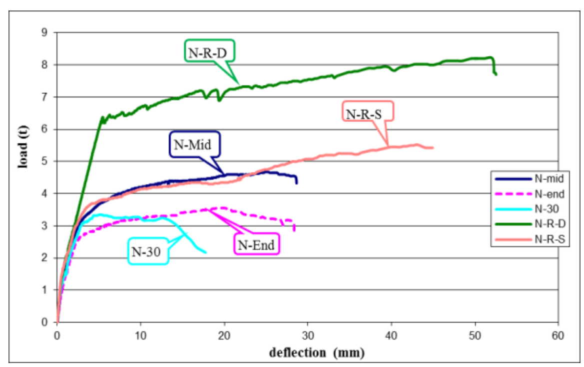


Figure 12: Load-Deflection Group II

Figure 13 shows load deflection curves for this group which includes the reference specimens at which no splice was made and specimens [N-U-L, N-L-L, and N-V-V] at which splice length was 30ϕ and overlap between bars was 20 ϕ .This group studies the influence of changing splice end shape. It could be noticed for all specimens, that changing splice end shape from straight to L or V with splice length 30 ϕ have a small effect on deflection and ultimate loads of the specimens, while the use of U shape ends has a significant effect on decreasing deflection. In addition it could also be noticed that specimens [N-U-L] showed a stiffer behavior than specimen [N-30], this could be attributed the high bearing in the U end shaped splice.

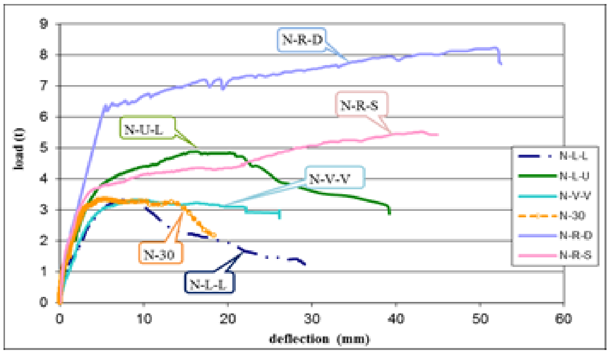


Figure 13: Load-Deflection Group III

Figure 14 shows load-deflection curves for group IV which includes the reference specimens with specimens [H-40], [H-30], and [H-20] at which splice length was changed by a step of 10ϕ. This Figure shows also the influence of increasing splice length and concrete characteristic strength (Fcu=60MPa) on mid span deflection. It could be noticed for all specimens, the more the splice length the less the mid span deflection. The figure shows that H-30 is more ductile than [H-40], but [H-40] is stiffer than H-30. In addition it could also be noticed that specimens [H-40] and [H-30] showed a stiffer behavior than [N-R-S], this could be attributed to the same reason as in group I.

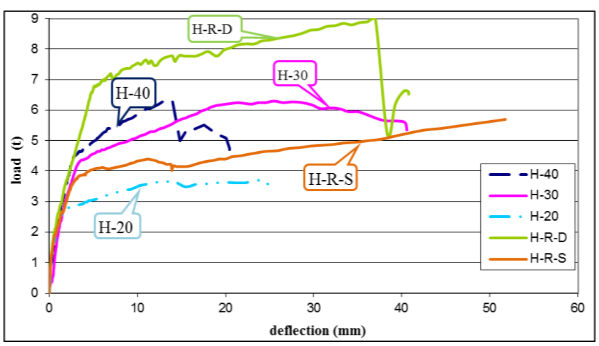


Figure 14: Load-Deflection Group IV

5.3 Crack pattern

Figure 15 shows the crack pattern of reference beams of normal strength concrete. It could be noticed that cracking density is higher in case of using deformed bars than smooth bars; this refers to the difference in bond strength between deformed and smooth bars. In addition crack width, in case of using smooth bars, appear wider than in case of using deformed bars.

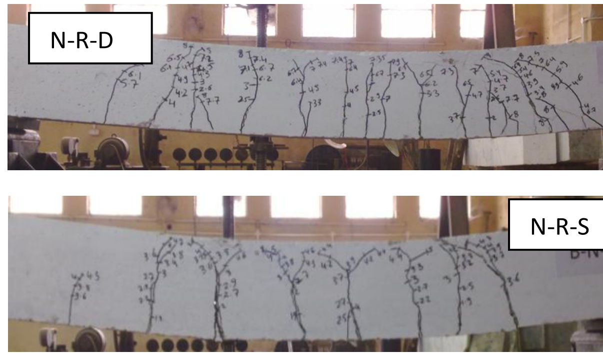


Figure 15: Crack pattern or reference beams

Figures 16 shows the crack pattern of specimens [N-50, N-40, N-30, & N-20] .The initial and widest crack for all specimens in this group appeared inside the tension zone at the end of splice of the smooth bar. N-50 Lap splice length was sufficient to transmit tensile force inside the bar through shear along the bar surface, consequently no slippage cracking appeared. While in case of shorter lap length slippage cracks appeared, in the form of cracks parallel to reinforcement direction. Generally, all specimens with lap between deformed and smooth reinforcement generated cracks of denser intensity appearing at deformed bar side than smooth bar side

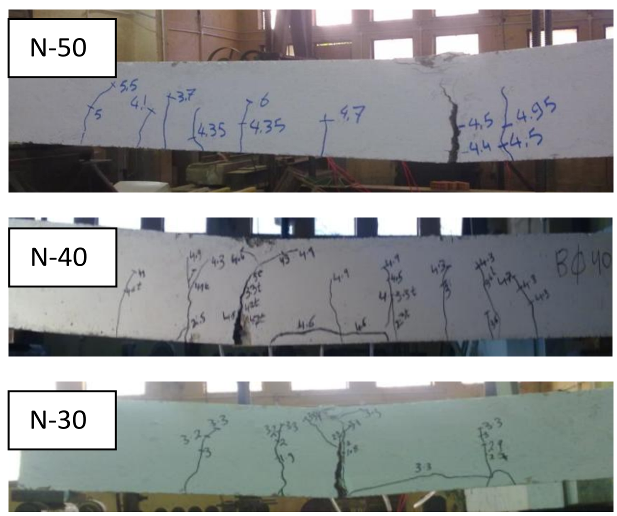


Figure 16: Crack pattern Group I

Figure 17 shows crack pattern for specimen [N-Mid and N-End]. The general notes, as in case of group one, could be adopted. In addition it could be noticed that confinement, using stirrups distributed along the splice length leads to distributing cracks than in case of stirrups at splice ends.

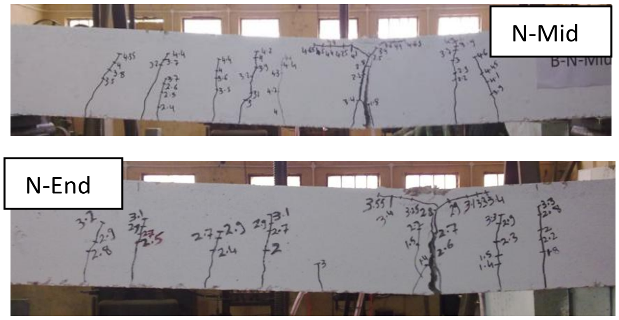


Figure 17: Crack pattern Group II

Figures 18 shows crack pattern for specimen [N-U-L, N-L-L, and N-V-V]. In addition to the previously stated general notes for group I it could be noticed that slippage cracks did not appear for specimens of this group, but a concentration of hazard cracks appeared at the deformed end, especially in case of using a U shaped end. Moreover cracking was denser in case of L-L and V-V specimens than in case of U-L specimens.

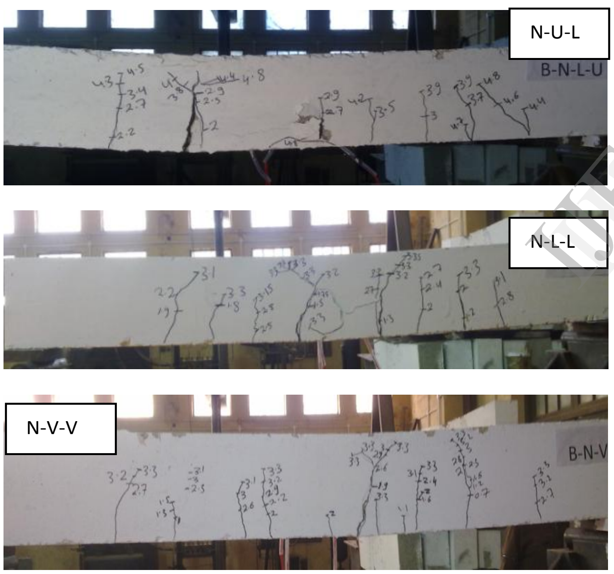
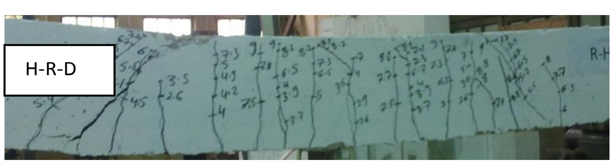


Figure 18: Crack pattern Group III

In addition to general notes, stated for group I. It could be noticed that crack pattern in case of high strength concrete is much more dense than normal strength concrete.



It could also be notice that slippage cracks did not appear in case of using a lap length of 40 Φ for high strength concrete this could be attributed to the higher bond in H.S.C. than N.S.C.

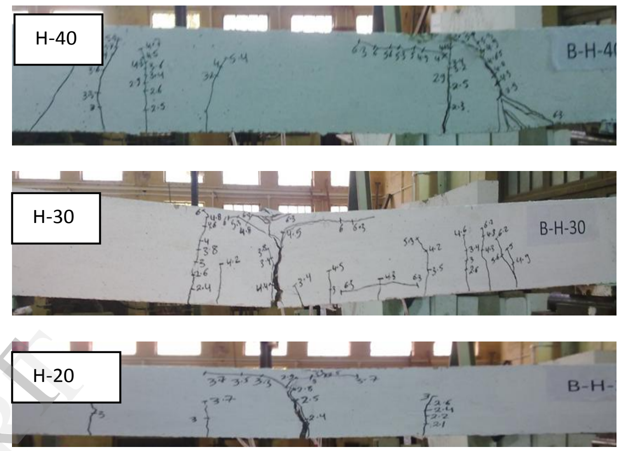


Figure 19: Crack pattern Group IV

5.4 Reinforcement strain

Figure 20 shows steel strain at the end of splice of the deformed bars for specimens [N-50], [N-40], [N-30], and [N-20] with [N-R-D] and [N-R-S]. The study of these curves shows that for specimens with lap length less than 40ϕ steel strain didn't reach yield (0.002) as in specimens [N-30] and [N-20], where steel strain is about 55 % and 35% of their yield respectively. This clarifies the cause of brittle bond failure of these specimens. On the other hand specimens [N-50] and [N-40] nearly reached yield strain, this refers to their sufficient lap length for transferring stress through bond to concrete. Figure 21 shows steel strain at the end of splice of the smooth bars for group I specimens, from these curves it could be noticed that [N-50], [N-40], [N-30] exceeded yield strain (0.0012), where their strains. Studying both figures shows that end strain gauges readings of smooth bars reached yield before deformed bars. This refers to the difference in yield stress between the two types of reinforcement used.

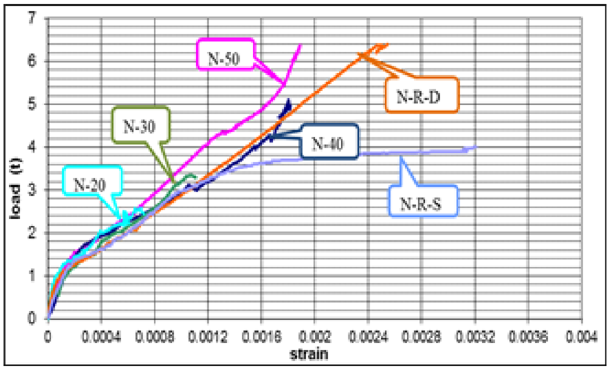


Figure 20: Load-Strain (End deformed) for Group I

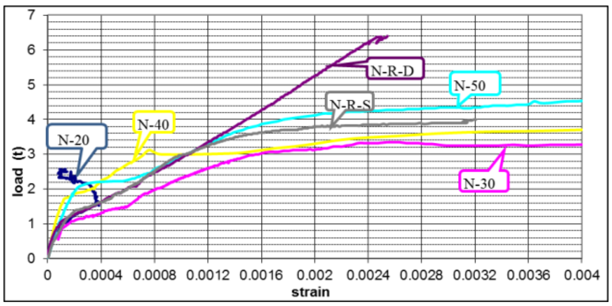


Figure 21: Load-Strain (End Smooth) for Group I

6. Summary and conclusions

The experimental program included sixteen reinforced concrete beams, tested to study the behavior of reinforced concrete beams spliced with steel of different surface texture. This study resulted in valuable conclusions that could be summarized as follows.

1- Increasing splice length leads to increase in failure load, cracking load and ductility, the increase of lap length over that required for transmission of tensile stress through bond along the bar circumference does not increase failure load significantly.
2- Distributing stirrups along splice length with small spacing increases failure load, cracking load and ductility than concentrating stirrups at splice ends.
3- End shaping of splices increase failure load, cracking load, and ductility especially in case of U-shape end than L & V shape ends.
4- Strain hardening increases the experimentally recorded failure loads than calculated ones, for reference beams and beams with lab length exceeding that required for transmission of tensile yield stress through bond along bar circumference.
5- Strain hardening increases failure loads of high strength concrete than normal strength concrete.
6- Flexural cracks in case of using deformed bars appear denser than smooth bars, while cracks in case of using smooth bars appear wider than deformed bars.
7- Linearity of strain distribution along reinforcement bars increase in case of distributing stirrups uniformly with small spacing inside splice zone.
8- Linearity of strain distribution along reinforcement bars decreases in case of end shaping, according to the form of end shape (U shaping affects linearity passively than L shaping than V shaping).

7. References

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