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Performance of Tension Lap-Splice in Lightweight Concrete

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Abstract**:** ***The use of Light-Weight Concrete (LWC) in modern construction has resulted in efficient designs and considerable cost savings by reducing structural own weight and supporting footings sections. The purpose of this paper is to investigate the Lap-Splice behavior between LWC and steel reinforcement (RFT). The tested specimens were divided into four groups to study the effect of main variables: steel reinforcement bar size, internal confinement (stirrups), splice length and concrete cover thickness. Four-point bending tests were carried out on test specimens to evaluate the performance of lap splices under pure bending. Bond behavior and failure modes were noted to be similar in the normal concrete and in the LWC. In tested beams, it was observed that the bar size has a significant influence on the mean bond stress in the splice. Improving radial tensile strength by using increasing stirrups number improves the bond behavior. The splice length up to 35 times bar diameter decreased the moment capacity of beam. The splice length of 55 times bar diameter results in the same capacity of the beam without any splice.***

Keywords: LWC, RC Beams, Splice length, Bond Behavior.

I. INTRODUCTION

In the last ten years, the interest in lightweight concrete “LWC” grows rapidly and now it is widely used in building construction. Due to the advantage of its low density, this results in a significant benefit in terms of load bearing elements of smaller cross section [1], [2], [3]. Adequate bond between lightweight concrete and reinforcing bars in a splice is an essential requirement in the design of reinforced concrete structure. Many researches were reported on bond strength between concrete and deformed bars for both normal strength and high strength concrete [4], [5], [6]. Experimental tests were done and analytical equations were proposed by some researchers. But more knowledge on the mechanical interaction “bond” between reinforcing bars and lightweight concrete is need [7], [8]. However, it is well known that there are only few experimental investigations about the performance of tension lap-splice in LWC [9], [10]. Twelve full-scale beam specimens (2000x300x200 mm) were tested in positive bending. The specimens of lap-splice series were tested with lap-spliced bars centred on the mid span in a region of constant positive bending. The main variables were, steel reinforcement bar size, internal confinement (stirrups), lap splice length and concrete cover. Thus, the lap splice is considered the most economic and the easiest way for splicing the reinforcing steel bars. Therefore, a research program has been started aiming on a better experimentally supported database for generating performance of tension lap-splice in LWC for future codes.

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II. EXPERIMENTAL PROGRAM

A. Experimental program matrix

The experimental program matrix consists of 12 reinforced concrete beams as show in Table I. The reinforced concrete beams are divided into four groups, a control group without Lap-Splice and three groups with Lap-Splice. The beam study having a total length (L = 2000 mm), overall depth (h= 300 mm) and width (b = 200 mm). The RC beams are reinforced with 2 Ø 10 as top reinforcement and 2 Ø 10 as bottom reinforcement as show in figure (1).

Table- I: Experimental program matrix

Group	Beam	Concrete Type	Spliced Length mm	Stirrups n/m'	Cover mm
G1	B1	NWC	550	7Ø8	20
	B2	LWC	550	7Ø8	20
	B3	NWC	550	7Ø8	20
	B4	LWC	550	7Ø8	20
G2	B5	LWC	880	7Ø8	20
	B6		1210	7Ø8	20
	B7		550	7Ø8	20
G3	B8		550	7Ø8	20
	B9		350	10Ø8	20
	B10		450	7Ø8	20
G4	B11		550	7Ø8	10
	B12		550	7Ø8	40

Group	Beam	Concrete Type	Top RFT	Bottom RFT	Spliced Length mm
G1 Control	B1	NWC	2Ø10	2Ø10	non
	B2	LWC		2Ø10	non
	B3	NWC		2Ø10	550
	B4	LWC		2Ø10	550
G2 Lap Splice	B4	LWC		2Ø10	550
	B5			2Ø10	450
	B6			2Ø10	350
G3 Bar size	B4			2Ø10	550
	B7			2Ø16	880
	B8			2Ø22	1210
G4 Stirrups Spacing	B4			2Ø10	550
	B9			2Ø10	550
	B10			2Ø10	550
G5 Concrete Cover	B4			2Ø10	550
	B11			2Ø10	550
	B12			2Ø10	550

B. Material Properties

The average compressive strength of the concrete based on ACI - 318 [1] is 25MPa and the average tensile strength is 2.50 MPa. The average yield strength of steel reinforcement is 400 MPa with a modulus of elasticity of 200 GPa (DIN 50145) [4] and the ultimate strength is 600 MPa.

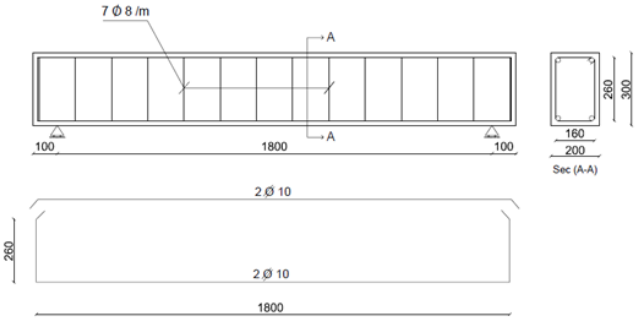


Fig. 1. Specimen dimensions and reinforcement details.

C. Test Set-up

The beams were tested at their age of 28 days. One day before testing, two sides of each beam were painted to facilitate the tracing of cracks and its propagation during loading. At the day of testing, the beams were mounted and adjusted, one by one, in the testing frame in which the beams were tested using four point bending configuration to develop a constant moment region along the middle third of the span at which the spliced length of the bars locates. In order to ease the construction of the beams; their length had been kept constant as 2000 mm which led to use the same test setup for all the beams as shown in figure (2).The test setup allowed a constant moment region of 600 mm along the middle third where the splice length is located and two shear spans at the terminal thirds 600 mm each. The beams were supported at 100 mm apart from the both ends using two metal beams restrained to a horizontal flat surface of the testing frame.

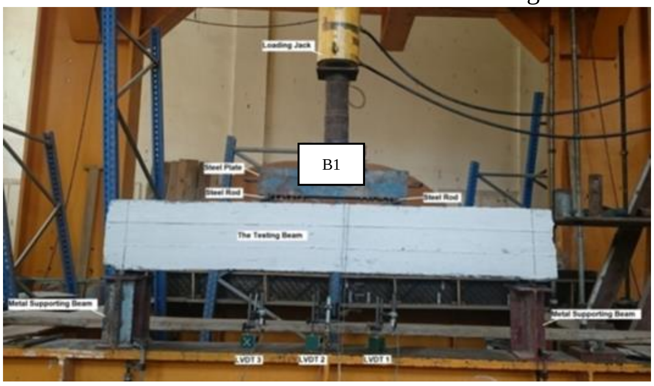


Fig. 2.Test Set-up.

D. Instrumentation

In order to record the beams vertical deflection, three vertical LVDT gages of 0.001mm accuracy were used under beams at the mid span as well as the two thirds of the span between the two supports as shown in figure (3). The LVDTs were connected to the data acquisition system. The mid-span tensile steel strain (S1) was measured by one electrical strain gauge of 20-mm length and 120-Ohm resistance.

Fig. 3.LVDT and Strain gauges positions.

III. TEST RESULTS AND DISCUSSION

This experimental program is conducted in order to study the behaviour of reinforced polystyrene lightweight concrete beams (LWC) with overlapped splices in the region of max positive tension and comparing them with similar normal weight concrete beams (NWC). The program included the testing of ten LWC beams and two NWC beams as a reference. Failure mode, load deflection and failure loads of the tested specimens are obtained from the experimental study and presented comparatively. The study focused on the influence of 5 parameters on the lapped splices within LWC beams. Those studied parameters can be summarized as follows:

1. The type of concrete, by comparing the behaviour of splices in LWC beams with those in NWC beams having the same value of compressive strength of 25MPa.
2. The size of the spliced reinforcement bars, by comparing spliced bars with three different sizes of {10mm, 16mm and 22mm}.
3. The spacing between stirrups, by comparing three uniform stirrups spacing {100mm, 150mm and 200mm}.
4. The spliced length, by comparing three splicing lengths {35Ø, 45Ø and 55Ø}.
5. The bottom concrete cover depth, by comparing three concrete cover depths {10mm, 20mm and 40mm}.

The test results were presented in Table II and will be described in the following.

Table- II: Experimental results

Beam	*L* splice (mm)	P_{Crack} (kN)	$P_{Ultimate}$ (kN)	Failure Mode	f_b Avg. {ACI} (MPa)
B1	-	42	95	*Flexural Mode*	-
B2	-	46	94		-
B3	550	47	94		1.34
B4		52	93		1.41
B5	880	74	173	*Shear Mode*	1.30
B6	1210	129	242		1.18
B7	550	53	96	*Flexural*	1.57

B8		51.4	92	*Mode*	1.12
B9	350	50	82		1.99
B10	450	50	91		1.57
B11	550	47	92		1.26
B12		55	91		1.48

A. Failure Mode

The failure modes were depending on the test variables: size of the spliced reinforcement bars, spliced length and concrete cover depth Fig.4. It's observed that the failure mode for the two non-spliced beams (B1 & B2) were almost similar, the flexure failure was happened at the maximum positive moment zone at load 87 and 88 kN respectively. The flexural cracks at the mid span expanded gradually until they caused the flexural failure. For B3 and B4, the loading increasing up to the ultimate load, the flexural failure occurred for spliced beam NWRC (B3) outside the splicing zone at load level of 85 kN. Similarly for the spliced beam LWRC (B4), the flexure failure was occurred at the load level of 86 kN, also outside the splicing zone. The spliced NWC beam and LWC beam had almost the same failure load which reflects that the splicing was sufficient to transfer loads.

However, the failure mode for B5 (Ø= 16mm) was started as flexural, then it changed to be shear-tension due to expanding the flexural-shear cracks near the ends of the splice upward. The failure occurred at load level 172 kN accompanied by a little bottom concrete cover loss. Also, the beam B6 (Ø= 22mm) exhibited a shear-compression failure mode near the support at load level 237 kN. The failure occurred outside the splicing zone and not far from the splice ends which was located far from the supports by 290 mm where the critical shear zone. Thus, it's observed that, increasing the bar size (reinforcing steel area) had enhanced the flexural capacity of the beam, while the shear capacity remained at the same level. Consequently, the shear failure was predicted.

The beam B7 with (stirrups spacing = 100mm) has the narrow cracks and flexural failure, while to the beam B8 with (stirrups spacing = 200mm) has wide cracks and shear failure. it's observed that increasing the transverse reinforcement enhances the shear capacity of the beam, but doesn't affect considerably its flexural capacity, as decreasing the stirrups spacing from (200mm) to (150mm) and from (150mm) to (100mm) was increased its flexural strength by (1. %) up to (4.0%) only. Regarding the beam B9 with (Ls = 35Ø), was failed outside the splicing zone at 66 kN. Similarly, the beam the beam B10 with (Ls = 45Ø), the splitting failure was occurred outside the splicing zone at load level of 84 kN. In addition the failure mode was flexural failure for both beams. The beam B11 with (bottom concrete cover 10 mm) was failed by the splitting failure at load level 92 kN with crushing of its thin concrete cover. And beam B12 with (bottom concrete cover 40 mm) was failed at load level 91 kN without crushing of its concrete cover.

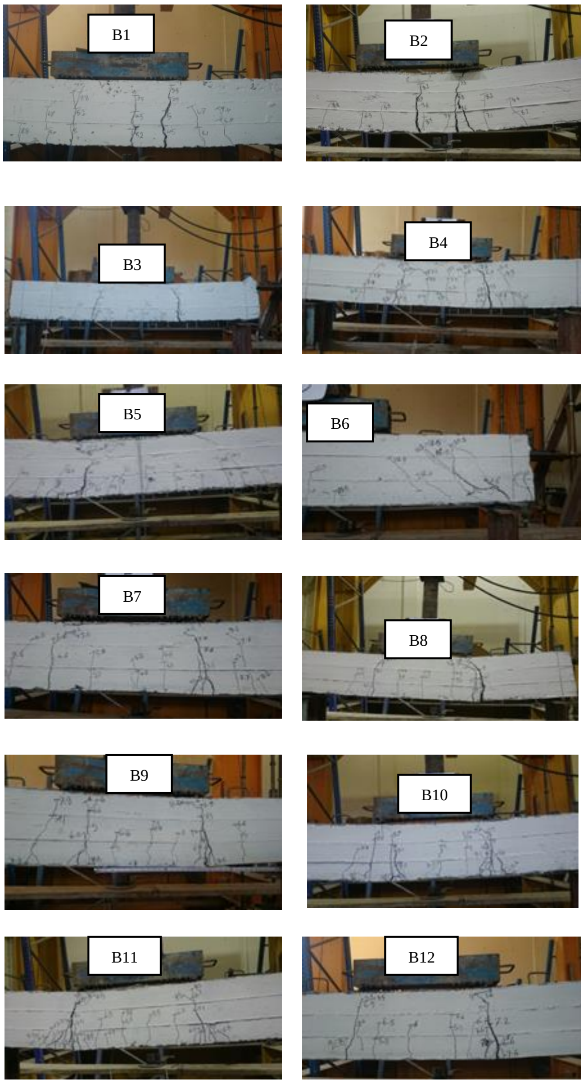
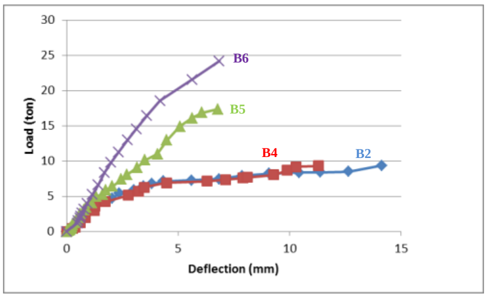


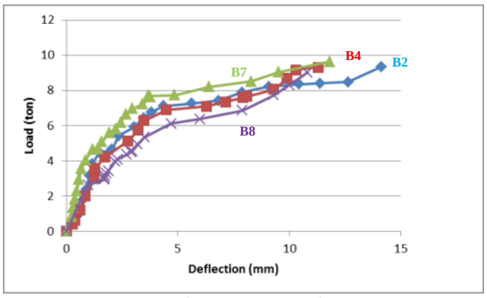
Fig. 4.Failure Mode of all tested beams.

B. Load-Deflection Relationship

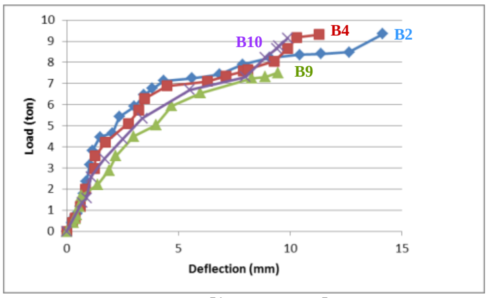
The loads versus mid-span deflection relationships for all beams are shown in Fig 5. In order to study the relation between the applied load and the mid span deflection occurs at the different load stages for LWC beams (B4, B5 & B6) with different longitudinal spliced bottom reinforcement bar sizes inside and comparing them with the reference non-spliced LWC beam (B2), Figure (5-a) was plotted from which it's clearly observed that the beam B6 (Ø= 22mm) sustained the greatest load levels due to its biggest bars' size which enhanced it flexural capacity, where Ø is the diameter of the spliced bar, secondly came the beam B5 (Ø= 16mm), however they exhibited lower deflection values than the beam B4 (Ø= 10mm) which sustained the lowest load levels and greater deflection values due to its small bars' size. It's obvious that the beam (B4) has the greatest value of max deflection. Obviously, the resulted deflection of a beam at the sequent loading stages is inversely proportional to the reinforcement bar size within it, as increasing the spliced bar size within a beam from (10mm) to (22mm) decreased its ductility by (40%).



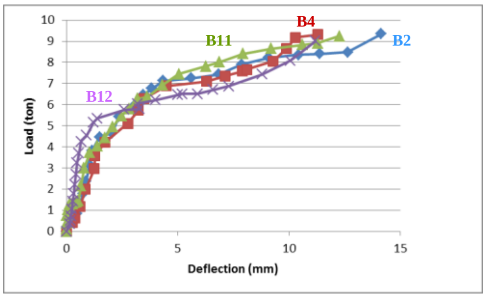
A – Bar Size



B-Stirrups Spacing



C-Splice Length



D-Cover Depth

Fig. 5. Load-Deflection.

In Figure (5-b) shows the load-mid span deflection relation for the spliced beams (B4, B7 & B8) with different stirrups spacing and the non-spliced reference beam (B2), it's observed that the beam B7 (stirrups spacing 100mm) exhibited the lowest deflection values at different loading stages, secondly beam B4 (stirrups spacing 150mm) and the greatest deflection values were been recorded by the beam B7 (stirrups spacing 200mm). According to the max deflection value at the ultimate load, it's observed that increasing the transverse reinforcement, i.e. reducing the stirrups spacing, enhances the ductility of the beam, as reducing the stirrups spacing from (200mm) to (100mm) increased beam ductility by (4%).

Figure (5-c) shows load-mid span deflection behaviour for LWRC spliced beams with variable splicing lengths (35Ø, 45Ø and 55Ø) and the reference non-spliced beam (B2) where Ø is the bar size of the spliced bar. It's observed that the beam B9 (with Ls = 35Ø) exhibited the greatest values of deflection at different load stages. At load level of 70 kN, the beam B9 (Ls = 35Ø) exhibited the greatest deflection value, secondly the beam B10 (Ls = 45Ø) and the lowest values were recorded by the beam B4 (Ls = 55Ø), however the max deflections recorded at the ultimate load stage which reflect the ductility decreased and consequently the ductility of the beam decreased by (25 %) and when decreasing the splicing length from (55Ø) to (35Ø).

Figure (5-d), it's observed that, at the linear stage of loading-deflection curve, the beam B12 (cover = 40mm) had exhibited almost the same deflection values. According to the max deflection recorded at ultimate load stage which reflects the ductility of the beam and since the ductility is mainly depends on the longitudinal as well as transversal reinforcement steel, it's observed that the ductility tends to be greater for the deeper stirrups, which is accompanied with the smaller concrete cover.

C. Ductility and Strength

Where the ductility (D) is defined as the ratio of the central deflection at the maximum load of the tested beam to that of the beam without tension lap splice and the strength measure (K) is defined as the ultimate load of the tested specimen to that for the reference specimen without splice, table (IV) shows the summary of the results. The ductility (D) and strength (K) calculated as the following equations:

(D) = max deflection for tested beam / max deflection for the reference beam.

(K) = ultimate load for tested beam / ultimate load for the reference beam.

Table- III: Ductility and Strength

Beam	(D)	(K)
B2	1.00	1.0
B4	0.80	0.99
B5	0.48	1.85
B6	0.48	2.58
B7	0.84	1.02
B8	0.76	0.98
B9	0.67	0.87
B10	0.70	0.97
B11	0.87	0.98
B12	0.80	0.96

According Table (III), it's observed that increasing the diameter of spliced bar improves stiffness and the strength, however decreases the ductility.

D. Bond Failure Mechanism:

For reinforcing bars in tension, two types of bond failure have been observed.The first type is the direct pull-out of the bar, which is expected to occur in case of using relatively small diameter bars with sufficiently large concrete cover distances and bar spacing, as if the bar is sufficient confined by a mass of surrounding concrete; then, increasing the tensile force on the bar leading to overcoming the bonds of friction; hence, the concrete eventually crushes locally ahead of the bar deformations, and finally, the bar pull-out results.

The surrounding concrete remains intact, except the crushed concrete adjacent to the bar interface.The second observed type of failure is splitting of the concrete along the reinforcing bar.

Such splitting comes mainly from wedging action of the bar when the ribs of the deformed bars bear against the concrete. As for the loaded bar for the first time, friction forces are present, however by increasing the load, i.e. increasing the tensile force affecting on the reinforcing bar, these bond transfer mechanisms are quickly lost, leaving the bond to be transferred by bearing in the deformations of the bar and then equal and opposite bearing stresses act on the concrete, these stresses affecting against the concrete having longitudinal and radial components, the later causes circumferential tensile stresses in the concrete around the bar. After a certain stage of loading, cover, confinement and bar spacing become insufficient to resist the lateral concrete tension resulting from the wedging effect of the bar deformations; hence the concrete will split parallel to the bar and the resulting crack will propagate out to the surface of the beam.

E. Bond Strength

According to the ACI - 318 [1], the bond stress was calculated by using Eq. (1) as shown in table (IV).
Figure 6 presents a comparison between the bond strength of each specimen. The bond strength in the splice region increases as the lap-spliced length increases [10]. Regarding ACI, it takes into account both the concrete and the reinforcing steel properties, thus it's fair to obtain precisely the resulted bond stresses which can be obtained as follows:

- The average splicing bond stress,
  $f_b = d_b * (f_s) / 4l_s$ Eq. (1)
- The maximum bar stress:
  $f_s = E_s * max\ steel\ strain$ Eq. (2)

Where,
(f_s) Maximum bar stress.
- (E_S) Modulus of elasticity.
- (l_s) Spliced length.
- (d_b) is the nominal diameter of the reinforcement.

TABLE- IV: Bond Stress

Beam	Max Steel Strain (μ_{str})	Measured Steel Stress (f_s) (Mpa)	Bond Stress by ACI code f_b (Mpa)
B3	1475	295	1.34
B4	1548	310	1.41
B5	1435	287	1.30
B6	1295	259	1.18
B7	1725	345	1.57
B8	1233	247	1.12
B9	1396	279	1.99
B10	1411	282	1.57
B11	1388	278	1.26
B12	1626	325	1.48

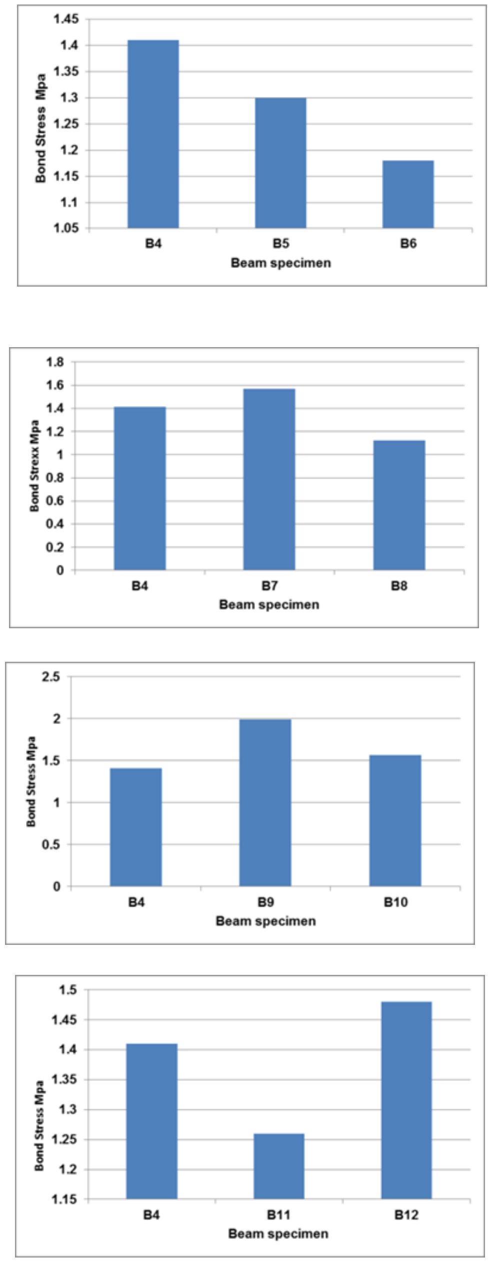


Fig. 1.Bond Stress.

IV. CONCLUSIONS

1. The LWC is more ductile than the NWC.
2. The LWC and NWC spliced beam had almost the same failure load which reflects that the splicing was sufficient to transfer loads.
3. Although light-weight concrete has a good performance for tension lap splice, the splicing decreased the ductility of the LWC beams, as the continuity of the reinforcement bars within the non-spliced beam enables it to be more ductile while bearing loads.
4. The splice bar size is inversely proportional to the ductility, as increasing the splice bar size from (10mm) to (22mm) decreased its ductility by (40%).
5. Increasing the transverse reinforcement, i.e. reducing the stirrups spacing, from (200mm) to (100mm) increased its ductility of the beam by (4 %).

6. Decreasing the splicing length from (55Ø) to (35Ø), decreasing its ductility by (25%) and also decreased the flexure strength by (12 %).
7. The concrete cover (40mm) did not provide more additional bond strength; while the bottom concrete covers depth (20mm) was efficient and preferable to providing the beam with the most accessible strength.

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