Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (41) No. (3) July, 2019

Comparative Study of Flexural Behaviour of Post-Tensioned Normal and Lightweight Concrete Beams

Eng. Samir Mohammed [1], Prof. Dr. Ata El-kareim Shoeib[2], Dr. Mostafa Abd El-Megied [2]

1El Shrouk Academy, Al Shorouk, Cairo, Egypt
2Mataria Faculty of Engineering, Helwan University, Helwan, Egypt

المخلص:

هذا البحث يهدف الي عمل مقارنة بين سلوك الكمرات الخرسانية سابقة الاجهاد ذات الوزن العادي و الوزن المخفض عمليا من خلال استخدام حبيبات البوليسترين كحل بديل جزئي لخفض وزن وحدة الخرسانة الجافة من ٢٣ كيلو نيوتن/ متر٣ إلى 18.2 كيلو نيوتن / متر٣ وتحقيق مقاومة ضغط 35 MPa ومقاومة شد 3.48 MPa. البرنامج العملي يتكون من خمس كمرات مقسمة الي ثلاثة مجموعات من الكمرات سابقة الاجهاد بابعاد ثابتة 150*350*4000 مم (عرض * ارتفاع* طول)علي التوالي .المجموعة الاولي تحتوي علي كمرتين الاولي ذات خرسانة عادية الوزن والاخري ذات خرسانة منخفضة الوزن و تحتوي كل منها علي كابل سبق الاجهاد ناحية الشد مع وجود حديد تسليح قطر 12 مم اي بمحتوي سبق اجهاد 70 % . اما المجموعة الثانية تحتوي علي كمرتين الاولي ذات خرسانة عادية الوزن والاخري ذات خرسانة منخفضة الوزن و تحتوي كل منها علي كابل سبق الاجهاد ناحية الشد فقط بدون حديد تسليح اي بمحتوي سبق اجهاد 100%. المجموعة الثالثة تحتوي علي كمرة واحدة ذات خرسانة منخفضة الوزن و تحتوي علي كابل سبق الاجهاد ناحية الشد مع وجود حديد تسليح قطر 16 مم اي بمحتوي سبق اجهاد 56 % جميع الكمرات تحتوي علي كانات قطر 10 مم بمسافة توزيع 100 مم لاول واخر 1000 مم وبمسافة 200مم للجزء المتبقي من الكمرة المختبرة. قطر الكابلات المستخدمة لتطبيق قوس سبق الاجهاد 12.70مم. تم اختبار الكمرات تحت تاتير اربعة نقاط للتحميل لدراسة تاثير اختلاف نوع الخرسانة المستخدمة (عادية الوزن و منخفضة الوزن) ووجود حديد التسليح ناحية الشد من عدمه (محتوي سبق الاجهاد 100% , 56% ,0.0%).

Abstract:

This paper presents an experimental program conducted to comparative study of flexural behavior of prestressed normal weight concrete (NWC) and reduced weight concrete (LWC) beams by partial aggregate replacement with polystyrene foam achieve cubic compressive strength 35 MPa, tensile strength 3.48 MPa, and density 18.2 kN/m3. The experimental program consists of five concrete tested beams divided to three groups of pre-stressed concrete beams; the overall dimensions of the beams are (150*350*4000) mm. The first group consist of two beams specimen's with NWC and LWC, this group reinforced by unbonded tendon and non-pre-stressed steel with diameter 2T12 mm as bottom reinforcement with prestressing index 70%, the second group consist of two beams specimen's with NWC and LWC, this group reinforced by unbonded tendon with prestressing index 100% and The thrid group consist of one beam specimen's with LWC, this group reinforced by unbonded tendon and non-pre-stressed steel with diameter 2T16 mm as bottom reinforcement with prestressing index 70%. All beams were reinforced using closed stirrups of 10 mm diameter with spacing 100mm for the first 1000 mm in the two ends and 200 mm for the rest of the beam. All the beams were also reinforced with two ordinary longitudinal reinforcements of 10mm diameter as a top reinforcement with 25 mm clear cover. The dimeter of used prestressing tendons was 12.7 mm. The beams were tested under four-point loading condition with constant moment zone up to failure to examine its flexural behavior. The main variables in this experimental program are type of concrete (NWC and LWC) and prestressing index (56.0%, 70% and 100%).

Keywords: Foamed concrete, Reduced weight concrete, Lightweight Concrete and prestressed concrete.

1-Introouduction

In the last few decades, pre-cast pre-stressed concrete has been rapidly used in bridge engineering due to the enormous development in the construction techniques and the increasing needed for long span beams .A significant portion of the load carried by Pre-stressed concrete beams is the self-weight of the beams. Therefore, the used of reduced weight concrete (LWC) in this paper, which combines the advantages of normal density concrete by achieving the same strength and reduced self-weight by partially replacing the normal weight aggregates with polystyrene foam. The latter material can therefore be produced using standard methods familiar to the construction industry with a dry unit weight of 18.20 kN/m3, which in turn leads to dead load reduction by 15 – 20 % which additional benefits can then be realized in the form reduced crane capacity requirements, and lower shipping costs. Lightweight Concrete (LWC) has been used in construction since the eighteenth century. It is very important in decreasing the cost of Reinforced Concrete (RC) structures. The weight and type of coarse aggregate and the ratio between fine and coarse aggregate are the main parameters used to reduce the density of concrete (less than 1800 kg/m3) [1 - 4]. Foam with different forms is used in the construction field and can be used in the mixed material of concrete.

Youssef, et. Al. 2018[5], presented the experimental result on the performance of structurally reinforced foam concrete flat slab exposed to fire under eccentric and concentric loads. results showed by comparing the performance of structural lightweight polystyrene foam concrete flat slabs and normal-weight concrete flat slabs, the ultimate load decreased in the foam concrete flat slab by approximately 7.0% for concentric load and 4% for eccentric load compared with those of normal-weight concrete. The number of cracks decreased and the crack width increased in foam concrete.

Jee hock, et al., 2017[6], presented the experimental results on flexural behavior of reinforced concrete beams and slabs made of lightweight foamed mortar with density ranged from 1700 to 1800 kg/m^3. Beam specimens consist of seven lightweight foamed mortar beams and three normal weight concrete beams acted as the control sample. Whereas, slab specimens contain two lightweight foamed mortar slabs and two normal weight concrete slabs. The results showed that reinforced lightweight foamed mortar beams sustained about 8% to 34% lower ultimate load as compared to normal weight reinforced concrete with same reinforcement configuration. However, lightweight foamed mortar slab sustained higher ultimate load, averagely 18% as compared to normal weight slab.

2-Experimental Program

The experimental program consists of five prestressed beams with overall depth, width and length of 350, 150 and 4000-mm, respectively, as shown in Fig. 1. The beams were simply supported with a clear span of 3800-mm. The flexural non-prestressed steel and steel stirrups were made of deformed high tensile steel with yield stress of 360 MPa and ultimate strength of 520 MPa. The top and bottom longitudinal reinforcement of the specimens was two 10mm and two 12- or 16-mm diameter bars respectively. The stirrups were 10mm diameter bars every 200 and 100-mm at mid span and beam ends, respectively. The concrete cover of the stirrups was 25mm. The selection of mixture properties for normal and reduced weight concrete was based on several trail mixes and their dry cured28-day compressive strength. The average dry cured 28-day compressive strengths of the selected mixes were 35 MPa. The main reinforcement of the specimens changed according to the prestressing index(ip), which was defined as the ratio of the yield strength of the prestressing reinforcement to the sum of the yield strength of the prestressing and non-prestressing reinforcement, as given by the following equation [1]:

$$. \ ip = \frac{Aps*Fpy}{Aps*Fpy+As*Fy}$$

One strand with diameter 12.70mm was used to reinforce the fully prestressed beams, one strand with diameter 12.7mm in addition to two 12 mm diameter non-prestressed bars were used to reinforce the partially prestressed beams, as shown in Figs.2, Fig.3 and Fig.4. The yield and ultimate stress of the prestressing steel strands were 1674 and 1860 MPa, respectively. The prestressing steel strand had a profile similar to the bending moment induced from the concentrated loads. Additional horizontal stirrups were added at the anchor zone to resist the splitting force; these stirrups were calculated according to the recommendation of the ACI code [9]. The prestressing force was applied at both ends of each beam using 250 kN jack capacity after the concrete reached an age of 28 days on four steps up to 1395 MPa stress level, which is equal to 75% of the ultimate stress for unbonded strands, as shown in Fig. 5.

2-1 Test specimens

The variables considered in this study, were type of concrete (NWC and LWC), and prestressing index (56.0%, 70%and 100%), as given in Table 1. The details of the tested specimens are as follows:

specimen’s B1 and B3 with NWC and LWC, respectively reinforced using one strand with diameter 12.7mm in addition to two 12 mm diameter non-prestressed bars with prestressing index 70% while the specimen’s B2 and B4 with NWC and LWC, respectively reinforced using One strand with diameter 12.70mm with prestressing index 100%, in addition specimen B7 with LWC reinforced using one strand with diameter 12.7mm in addition to two 16 mm diameter non-prestressed bars with prestressing index 56%.

2-2 Test set-up

The specimens were tested under four-point loading condition with constant moment zone. This setup has to be achieved using a hydraulic jack with 3000 kN capacity and using 1000 kN load cell as shown in Fig. 6. To achieve the two acting loads, a rigid steel spreader beam of 1.00m length is used to divide the applied load into two-point loads. The rigid steel beam was borne on a 30mm steel plate which is rested on the top of the concrete beam. This 30mm steel plate is attached on the concrete surface using a mortar-based material. Then the steel plat is leveled using spirit level to insure its horizontality. The vertical deflection of the tested beam was recorded using dial gauge with accuracy 0.01 mm and also using linear variable deferential transducers, LVDT, which has length = 200mm. 3 LVDT and two dial gauges were used to measure the vertical deflection with spacing 630mm.

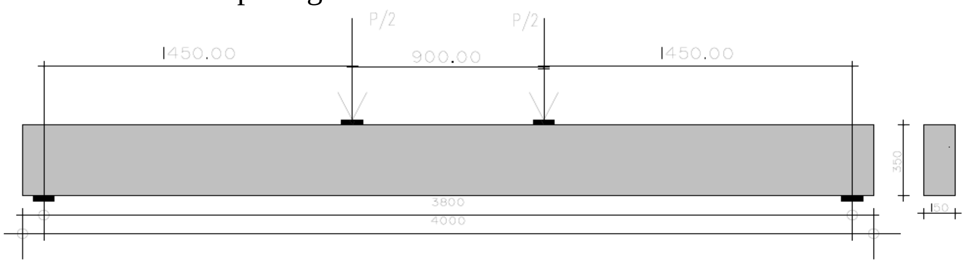

Fig. 1: Concrete dimensions and cable profile of prestressed beams

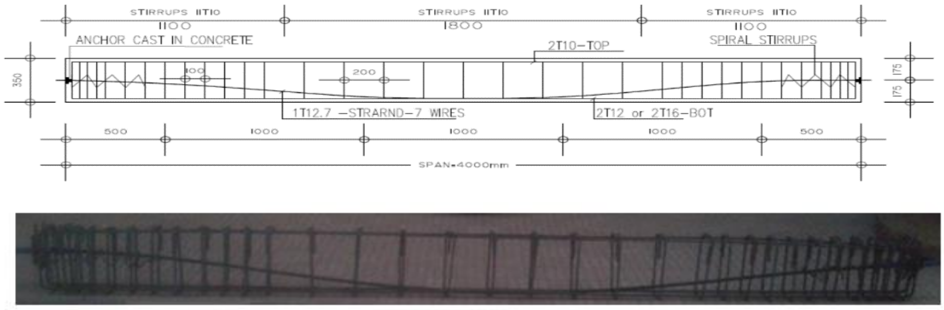

Fig 2: Typical Reinforcement Detailing and Tendon for Specimens (B1, B3 and B7)

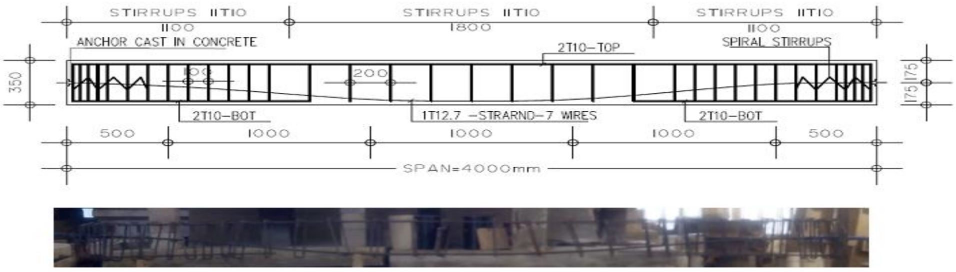

Fig 3: Typical Reinforcement Detailing and Tendon for Specimens (B2 and B4).

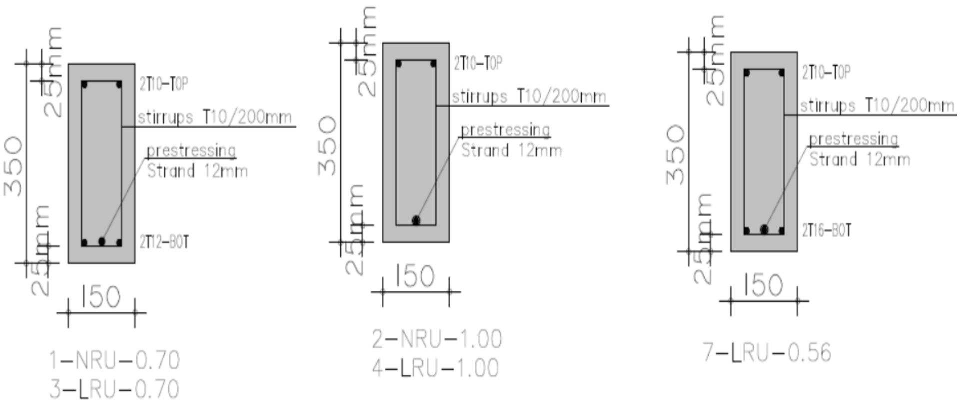

Fig 4: Shows the Rectangular Cross Section for Various Beams.

Fig. 5: Application of Prestressing Force and Elongation After Tensioning the Tendon

Fig. 6: Experimental Setup

Table 1: The Experimental Specimens' Variable

Specimens Code	***Type of concrete***	***Prestressing index (ip) %***	***Number of Tendon***	***Bottom RFT. A_s***	***Top FRT. A_s'***
B1-NRU-0.70	N	0.70	1T12.7	2T12	2T10
B2-NRU-1.00	N	1.00	1T12.7	------	2T10
B3-LRU-0.70	L	0.70	1T12.7	2T12	2T10
B4-LRU-1.00	L	1.00	1T12.7	------	2T10
B7-LRU-0.56	R	0.56	1T12.7	2T16	2T10

3- Discussion of the Experimental Results

The parameters used in this study are the type of concrete and the prestressing index. Effect of the type of concrete is presented by the specimens B1 and B3 as well as B2 and B4 for partially and fully prestressed beams, respectively.

Table 2 summarized the cracking, failure and service loads for all tested beams as well as their relative vertical deflection, energy absorption capacity, initial stiffness and post-cracking stiffness for all specimens.

Table 2: Summarized the Test Result of All Specimens

Specimens no.	***P_{cr}*** *(kN)*	***p_{max}*** *(kN)*	***Δ_{max}*** *(mm)*	***$P@\Delta all$*** *(kN)*	***E.A*** *(kN.mm)*	***D.M*** *(mm)*	***I.S*** *(kN/mm)*	***P.S*** *(kN/mm)*
B1-NRU-0.70	42.0	97.0	45.3	75.5	3412	15.9	17.0	2.8
B2-NRU-1.00	31.1	51.2	25.6	47.3	1035	19.1	12.4	0.8
B3-LRU-0.70	30.3	89.0	51.7	70.0	3393	15.0	8.9	2.6
B4-LRU-1.00	29.0	49.3	60.8	39.0	2251	12.0	7.9	0.5
B7-LRU-0.56	37.4	93.0	55.0	84.5	4368	16.1	9.3	4.0

Where:

P_{cr} : Cracking load, **P_{max}** : Failure load, Δ_{max} : The vertical deflection at mid span corresponding to maximum load, ***$P_{@\Delta all}$*** : The service load corresponding to deflection at mid span = L/250,
E.A : The Energy Absorption Capacity, **D.M** : The ductility measured was defined as the deflection at 70% of failure load, **I.S** : Initial stiffness, **P**.S : Post-cracking stiffness.

3-1 Crack Patterns and Modes of Failure

The failure pattern of the foamed concrete tested specimens is different from that of NWC where the number of cracks in the foamed concrete decrease and the width of crack increased due to the weak bond of the foamed concrete compared to NWC.

The crack pattern of the partially pre- stressed beams in the region between the two concentrated loads was distributed along this length with small width and large number, as shown in Fig. 7, Fig. 9 and Fig. 11 compared to the fully prestressed concrete beams in the same region, where the cracks were few and with large width as shown in Fig. 8 and Fig.10. This is again due to the presence of non-prestressed steel in the partially prestressed beams, which it controls the cracks in the tension zone. According to the pervious observations the non-prestressed steel improves serviceability of the beams, because it decreases the crack width and distributes it along the beam length. In addition, the small crack width produces lower stress concentration at the location of cracks. These results are complying with those given in the literature for the prestressed beams with different prestressing indices.

Fig.7: Crack Pattern and Failure for Specimen B1 (NRU-0.70).

Fig. 8: Crack Pattern and Failure for Specimen B2 (NRU-1.00).

Fig. 9: Crack Pattern and Failure for Specimen B3 (LRU-0.70).

Fig. 10: Crack Pattern and Failure for Specimen B4 (LRU-1.00).

Fig. 11: Crack Pattern and Failure for Specimen B7 (LRU-0.56).

3-2 Comparison Between the Behavior of NWC and LWC

The effect of concrete types NWC and LWC on the behavior of tested beams was examined for two groups beams specimens considering the effect of prestressed index (Pi=0.70 and 1.00). Fig.12 and Fig. 13 shows that by using foamed concrete with un-bonded tendon, the cracking load decreased by 27.85% and 3.71 in case of prestressing index 70% and 100% respectively, the maximum load decreased by 8.24% and 3.71b% in case of prestressing index 70% and 100% respectively, Also noticed that by using foamed concrete with prestressing index 70% the deflection at load equal 89 kN increased by 55.30% and in case of prestressing index 100% the deflection at load equal 49 kN increased by 170.4%. Fig.14 show that the initial stiffness decreased by 47.64% and 36.20 in case of prestressing index 70% and 100% respectively, while the post-cracking stiffness decreased by 7.14% and 37.50% in case of prestressing index 70% and 100% respectively. Fig.15 shows that, the energy absorption capacity increased by 6.40% and 117.48% in case of prestressing index 70% and 100% respectively.

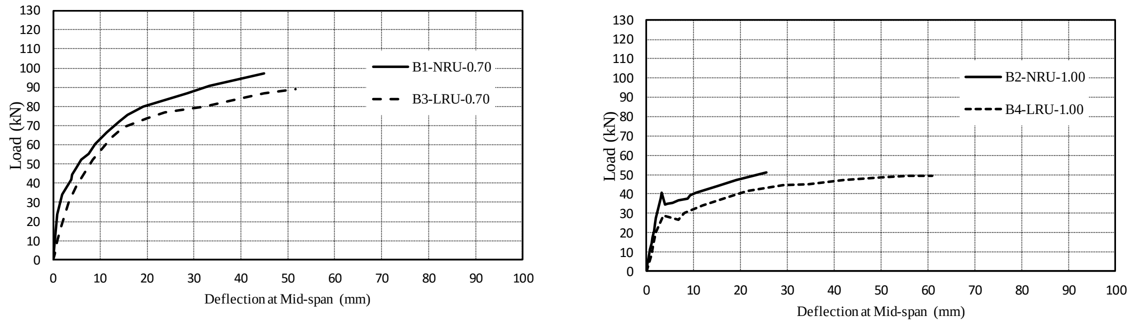

Fig.12: Comparison Between Load-Deflection Relationship for Specimens B1- NRU 0.70 , B3-LRU-0.70 and B2- NRU-1.00, B4-LRU-1.00.

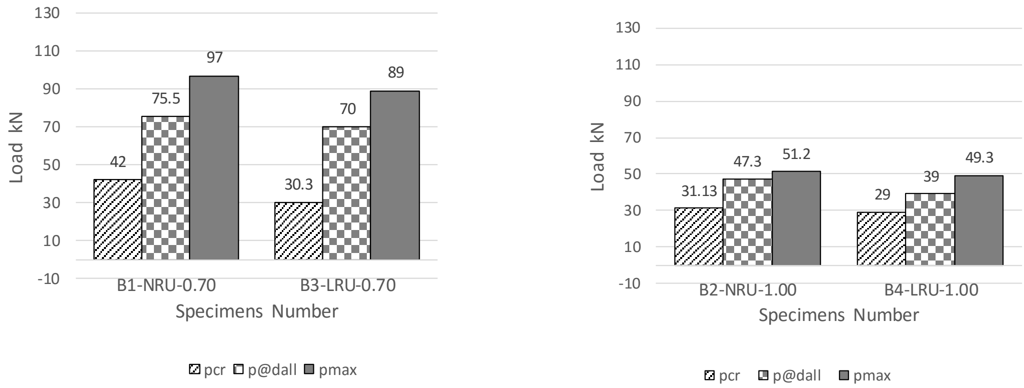

Fig.13: Comparison Between Cracking, Service and Failure Load for Specimens B1-NRU-0.70, B3-LRU-0.70 and B2- NRU-1.00, B4-LRU-1.00.

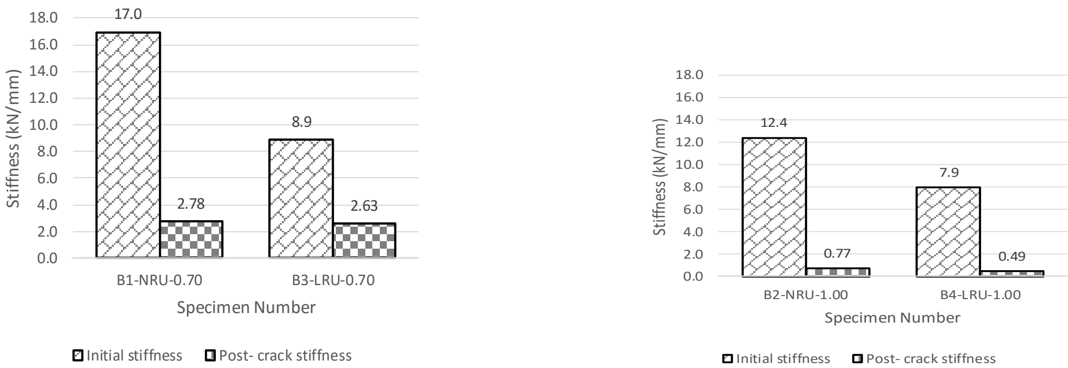

Fig.14: Comparison Between Initial Stiffness and Post-Cracking Stiffness for Specimens B1- NRU-0.70, B3-LRU-0.70 and B2- NRU-1.00, B4-LRU-1.00.

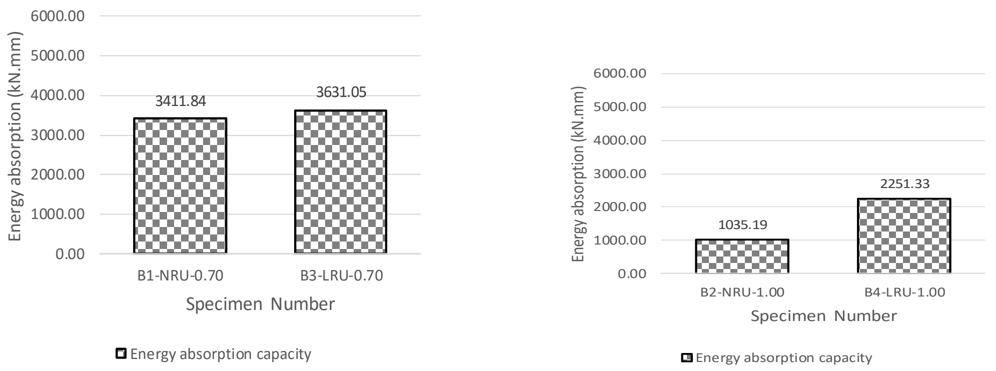

Fig.15: Comparison Between Energy Absorption Capacity for Specimens B1- NRU-0.70, B3-LRU-0.70 and B2- NRU-1.00, B4-LRU-1.00.

3-3 Effect of Prestressing Index (Presence of Non-Prestressing Steel)

The prestressing index was examined by using three levels of the prestressing indices 1.00%,0.70% and 0.56% in three different LWC beams specimens B4, B3 and B7 respectively, having rectangular cross section with un-bonded tendon. The test results show that, presence of non-prestressed steel in partially prestressed LWC beams with un-bonded tendon in the tested specimens led to increase the cracking load by 4.50% and 28.70% for Pi equal 0.70 and 0.56 respectively and the maximum load by 80.52% and 88.60% for Pi equal 0.70 and 0.56 respectively as shown in Fig.16 and Fig.17. Also noticed that, also presence of non-prestressed steel in partially prestressed beams enhanced the ductility up to 25% and 34% for Pi equal 0.70 and 0.56 respectively in comparison to concrete beams with Pi equal 1.00, Fig. 18 show that the energy absorption capacity increased by 50.73% and 94.04% for Pi equal 0.70 and 0.56 respectively and also controlled the crack formation and crack width, while improves serviceability of the beams because it decreases the crack width and distributes it along the beam length. In addition, the small crack width produces lower stress concentration at the location of the cracks.

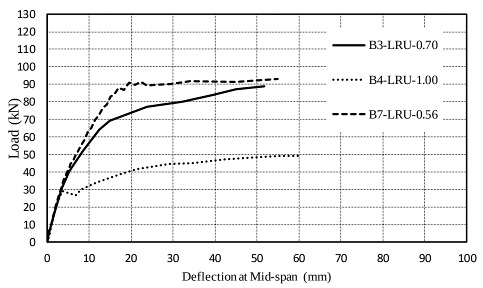

Fig. 16: Load-Deflection Relationship for Specimens B3 LRU-0.70, B4-LRU-1.00 and B7-LRU-0.56

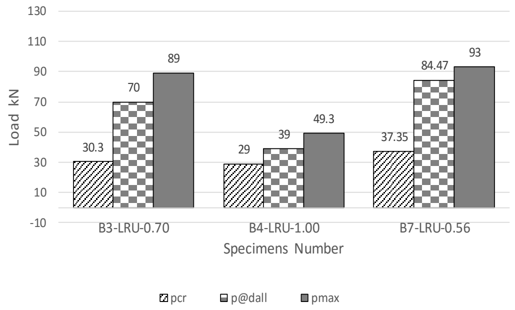

Fig. 17: Cracking, Service and Failure Load for Specimens B3 LRU-0.70, B4-LRU-1.00 and B7-LRU-0.56

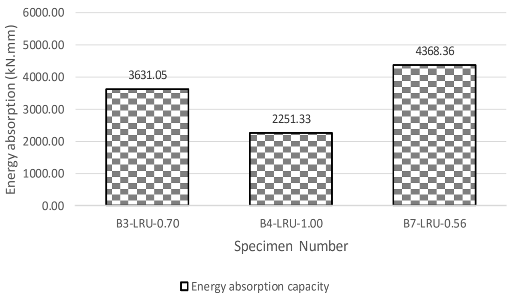

Fig. 18: Energy Absorption Capacity for Specimens B3 LRU-0.70, B4-LRU-1.00 and B7-LRU-0.56

4- CONCLUSIONS

The test result as well as the analysis comply generally with experimental investigation carried by other researchers (using other lightweight aggregate) as follow:

1. The failure pattern of the foamed concrete (LWC) tested specimens is different from that of NWC where the number of cracks in the foamed concrete decrease and the width of crack increased due to the weak bond of the foam compared to that of NW aggregate.
2. By using (LWC) the cracking load decreased by 27.85% and 3.71 in case of prestressing index 70% and 100% respectively. while, the maximum load decreased by 8.24% and 3.71b% 71 in case of prestressing index 70% and 100% respectively
3. By using (LWC) with prestressing index 70% the deflection at load equal 89 kN increased by 55.30% and in case of prestressing index 100% the deflection at load equal 49 kN increased by 170.4%.
4. Presence of non-prestressed steel in partially prestressed beams with un bonded improved serviceability of the beams because it decreases the crack width and distributes it along the beam length. In addition, the small crack width produces lower stress concentration at the location of the cracks.

5-REFERENCES

[1] N.M. Hawkins, and D. Mitchel, "Progressive collapse of flat plate structures", ACI Struct. J., vol. 76, no. 7, pp. 775-808, 1979.

[2] S.F. El-Fitiany, and M.A. Youssef, 2009 "Assessing the flexural and axial behavior of reinforced concrete members at elevated temperatures using sectional analysis", Fire Safe. J., vol. 44, pp. 691-703.

[3] Y.J. Kum, T.H. Wee, and M.A. Mansur, Shear Strength of lightweight concrete one-way slabs., National University of Singapore: Singapore,2007.

[4] I. David, "Punching shear behavior of lightweight concrete slabs and shells", ACI Struct. J., vol. 87, no. 4, pp. 386-392, 1990.

[6] Magdy Youssef Riad1 and Ata El-kareim Shoeib. (2018) “Behavior of Structural Lightweight Polystyrene Foam Concrete Flat Slabs When Exposed to Fire” The Open Construction and Building Technology Journal, Volume 12, pp. 362-374.
[5] J.H. Tan, S.K. Lim, J.H. Lim, (2017), “Flexural Behavior of Reinforced Lightweight Foamed Concrete Beam”, Kuala Lumpur, Malaysia.
[6] Hussein, O. F., T. H.K. Elafandy, A. A. Abdelrahman, and S. A. Abdel Baky.(2012) "Behavior of bonded and unbonded prestressed normal and high strength concrete beams." HBRC Journal, 1-13.