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Research Article:

Experimental Work on Using Fully Wrapped Post-Tensioned Metal Straps Around Normal Reinforced Concrete Beams to Increase Flexural Strength of R.C Beams

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Abstract

To increase the capacity load carrying of the beams, post tensioned metal straps are fully wrapped around the beams in their tensile zone in this study. In total four normal R.C beams with the depth of 160 mm, height of 240 mm and total length of 2100 mm are cast and tested under four-point load testing. The number of variables is kept to minimum of two which are the number and location of the straps. It is found that using post tensioned metal straps fully wrapped around the beams can increase the load-carrying capacity of the beams by 36% at least and 39% at a max. The main factor in influencing the rate is the location of the straps. A complete guide on using the material along with its application on the beams are explicitly described in the paper.

1. Introduction

The need for strengthening of the structural members in any building structure may arise from design or construction errors aging of the building, application of a sudden load such as earthquake loads. This need for strengthening might be an upgrade in their stiffness, strength, and/ or ductility capacity. For this purpose, a stronger material is usually used such as Fibre- Reinforced Polymer (FRP), and Post- Tensioned Metal Straps. Strengthening with Post Tensioned Metal Straps (PTMS) can be considered is relatively new and cost-effective method for strengthening reinforced members in the buildings. The method was first developed in 1995 in England by Frangou et. al [1] as a collaboration between University of Patras in Greece and University of Sheffield in England. Based on the developers' claims, the method is easier than the other methods such as using FRP, concrete caging, steel caging, and ferrocement concrete and it is the cheapest amongst them. After the developers' works, so many research studies can be found in the literature on using this material for different usages and for different members in various shapes both practically [1]-[21] and theoretically [16], [22]–[25]. However, a large part of those studies was performed testing small samples such as plain concrete cylinders of 150 mm in diameter and 300 mm in height or prisms with a height of 200 mm and a cross section of 100 mm* 100 mm. For instance, Lee H. et al [26] tested the effectiveness of the PTMS method in strengthening columns while they tested plain concrete cylinders that are 300 mm high with a diameter of 150 mm. Therefore, they have not studied steel reinforced members strengthened with this method. Thus, more research is needed to comprehend the behavior of the material in strengthening reinforced concrete members such as beams. The method of using PTMS consists of using metal straps that are ultra-high strength steel straps. These straps are flexible and their tensile yield strength is more than 900 MPa. The material is available in shape of long strips with different widths that vary from 15 mm to 32 mm. Their thicknesses are changing from 0.5 to 1 mm. This material can be wrapped around the structural elements and tensioned using a special pneumatic tensioner until the machine stops from tensioning. Then the two ends will be sealed with aluminum clips being pushed in shape of "push type" using a pneumatic sealer [18]. So, the idea is like the packaging cardboard boxes with plastic strap but instead it uses high tensile metal. The metal is ductile and its ultimate strength is close to its yielding stress [7]. The material itself increases confinement of the structural elements after its usage as it will be tensioned around the members using special pneumatic tensioner. This PTMS confines the elements further as it works as external stirrup or a tie. This is very useful when further confinement is needed such as in short columns in an earthquake zone designed based on a pre-seismic codes. However, when there is a need for an increase in the load carrying capacity o the beams failed in bending, this method has not been tested fully in the literature. This is because it is a challenge to wrap the metal straps around large scale beams longitudinally. The method is successfully used by Abdullah W. and Rafiq S. [27] on several beams which were strengthened with a help of steel channels. They achieved an increase of 63% in load carrying capacity when they used metal straps wrapped around steel channels that were anchored to the beams using bolts. However, Setkit and T. Imjai [4] tested a beam failed in flexure, but they used the metal straps as external stirrups of beams to improve bending capacity of the beams. Therefore, no much of improvement was observed from their results as only the ductility of the beams is improved rather than the strength. As it can be deduced from the literature review, no one used PTMS fully wrapped around reinforced concrete beams longitudinally. Also, using PTMS on large scale reinforced beams can rarely be found in the literature. Therefore, in this paper PTMS fully wrapped around the beams in their bending zone longitudinally is tested. This is the first time that the material is being used in this way as an attempt to increase the load carrying of the beams. This way, the material can be applied practically for external beams without any preparation. It can, also, be used on all beams in reality by drilling holes at desired places for the material and then applying tension longitudinally to confine the beams. To avoid having a hole right on top of the main reinforcement, stud detectors can be used to locate the main rebars. Abdullah W. and Rafiq S. [27] used stud detectors to locate the stirrups inside a beam after casting successfully.

2. Experimental Program

In total, four normal reinforced concrete (R.C) beams were cast and tested under four-point loading. The total length of the specimens was 2100 mm. from that length, 200 mm was left to count for the supports from each side of the beam. So, the clear span of beams was 1900 mm. As for the cross section of the beams, their width was 160 mm and their height were 240 mm. These dimensions are selected based on a scaling down of a real beam with a cross-section of 400 mm x 600 mm by dividing the dimensions by 2.5. In fact, the length of the beam is selected by using the same method. The beam had two main steel rebars at the bottom. The diameter of the main rebars was 10 mm. There was a hook of 70 mm at the end of each main bar to hold the bars in place during testing. Each beam had two reinforcement bars of a diameter of 8 mm on top. In total, 18 stirrups of diameter of 10 mm was provided for each beam which was governed by the maximum spacing of d/2 were d is the effective depth of the beam. So, the spacing of the stirrups was 105 mm. The compressive strength of concrete for the beams at the age of 28 days is 27.4 MPa on average and the split tensile strength of the concrete is measured to be 3.4 MPa. The slump of the concrete is found to be 110 mm. From all the specimens, two beams are considered as control specimens. This is to achieve more accurate results. The other beams are strengthened using PTMS wrapped fully around the beams longitudinally to increase the load-carrying capacity of the beams. The main materials used for strengthening in this study are metal strap, air compressor, tensioner and sealer. The metal straps will be wrapped around the beams like a belt then a tension will be applied on it using pneumatic tensioner until it is fully locked. After that the tensioned metal strap will be locked using a pneumatic sealer. The common strength that is used for beams locally is approximately 25 MPa. To reach that strength, Ordinary Portland Cement (IQS

5-CEM I 42.5 R) is used. This cement is bought from Sulaimania, Kurdistan Region, Iraq. The coarse aggregate is from in a quarry which is in Sulaimania governorate. The source of this coarse aggregate is a mixture between crushed stones natural stones. As for the maximum size of aggregate, it is chosen to be 10 mm. To verify the ranges of the coarse and fine aggregate sieve analysis, ASTM C33 ranges are used. They both are complies with ranges provided by the standard. The rest of its properties of the coarse aggregate is shown in Table 1. The fine aggregate was natural. It is brought from the same quarry. The other properties of are listed in Table 2. A pure, potable, clean water from a well that was existed aside the laboratory is used in all casting and curing process. The steel rebars were from bought from Sulaimania city, Iraq. The steel rebars had a yield strength of 504 MPa on average. The properties of them are shown in Table 3. ACI 211.1-91is used in designing the concrete mix. The mixing ratio was 1: 2.02: 2.38 which are cement, coarse aggregate, and fine aggregate respectively. The water to cement ratio was 0.61 based on the desired strength. Table 4 shows the mix proportions of concrete. To measure the strain in the tensile zone inside the concrete beam, two strain gauges were glued to the two main steel rebars. The location of the strain gauges was right in the middle of the beams. Plastic concrete covers of diameters of 25 mm are put around the steel rebars before concrete casting to ensure the concrete cover of the beams. From the specimens, two of the of the beams were selected as control beams and the rest were strengthened with PTMS wrapped fully around the concrete beam. The curing process of all the beams continued for 28 days in a row. The main material for used for strengthening is heavy duty metal straps. The metal straps bought from China. To test for their properties, ASTM D3953 standard is used. The material is just like a belt but made from a special metal instead of rubber. These metal straps had a thickness of 0.8 mm and a width of 31.75 mm. Figure 1 shows the metal straps used with an aluminum clip. To buckling up the two ends of the metal straps after tensioning, aluminum clips like the one shown in Figure 1 are used with a pneumatic sealer. The jaws from a pneumatic sealer creates 4 notches on the clips to ensure the lock. To ensure that there is no relaxation in the clips, Moghadam et al. [15] tested a setup for two months and proved that, there is no relaxation within time in the lock. The metal strap samples are tested in China and in Sulaimania. There was a difference of 15 MPa between the yield strength of the material when tested in China and Iraq. The yield strength of the metal strap was 928 MPa when tested in China while it was only 913 MPa in when tested in Iraq. The modulus of elasticity of the straps was 237 GPa. The behavior of the material can be categorized under elastic perfect plastic here it reaches its yielding strength and remains there for an elongation of 9% until failure. The machine used in this experiment to apply tension on the straps consists of two parts connected which are the tensioning part and the sealer. They run on an air compressor using a special pneumatic hose. It can deliver more than 9.8 kN per 0.6 MPa of pressure with the strength of the locking part of 18.4 kN. To operate the pneumatic tensioner and sealer, an air compressor is used. The capacity of the air compressor is 160 litres with four oil-free pistons and its air pressure is 7 bars. To fully wrap the metal straps around the beams effectively, first the edges of the beams must be rounded using an angle grinder by approximately 10 mm. Then the material is applied in the desired locations and a tension force is applied on it. Finally, the clips are locked using the sealers. The testing machine had two adjustable supports (see Figure 2). The exact location of the beams can be easily adjusted based on the length of the beam and the type of loading. The capacity of the jack is 80 tons the rate of its loading is approximately 0.3 mm/ min. The cracking loads written on the crack patterns of the beams in the figures shown in the later paragraphs should be multiplied by two as two load cells are used in recording the loads with a reading capacity of 30 tons each. Four-point loading is used in testing the beams to ensure a ductile flexural failure in all the specimens. As an indicator for bending failure the aspect ratio of the distance between load and support to the depth of the beam is found to be 2.95 using Equation 1.

$$\frac{a}{d} = \frac{1900/3}{240-25} = 2.95 \quad \ldots\ldots\ldots\ldots(1)$$

30 mm strain gauges were used to measure strain inside the steel bars and metal straps while 80 mm strain gauges were used to measure the strain in the concrete. The length capacity of the LVDT used was 150 mm which was bought in China. A data logger is used to collect all the data from the strain gauges, load cells, and LVDTs. A Windmill software is a link between the data logger and the computer. The data logger has 9 channels for strain gauges, 4 channels for LVDTs and 2 channels for load cells. This paper is part of a bigger project where more than 50 beams are cast and labelled. The beams are labelled in a way that the first number represents the number of the batches and the second letter represents the number of the beam in that same batch. For instance, beam 74 is the fourth beam being cast on the seventh batch. The purpose is to know the exact compressive strength of each batch that matches with the compressive strength of the

beam. The beam labels are summarized in Table 5. The beams' layout is shown in Figure 3. The beam had no strengthening Each of the beams had three strain gauges to measure strain in the concrete. They are glued to the surface of the beams before testing. For strengthened beams, a set of other strain gauges attached to the metal straps to measure the strain inside them along with having the same strain gauge set up for the control samples. First step is to cut the required length of the strap based on the location of its application. In cutting the straps, a length of 1000 mm should be added to the length of the circumference of the beam to count for the tensioning it. The location of the straps should be marked using a marker pen. Then using the prescribed procedure, the metal strap should be applied. The beam 05 is strengthened with one metal strap wrapped fully around the beam to confine it longitudinally. The center of the strap is 45 mm away from the bottom of the beam. The layout of the beam is shown in Figure 4. During post tensioning 500 macrostrain is developed in the strap. The configuration of this beam is the same as the previous one with having another layer of metal strap fully wrapped around the beam right above the bottom layer. The top of the bottom layer strap is 45 mm away from the bottom of the beam while the top of the second layer is 100 mm away from the bottom of the beam. The layout of the beam is shown in Figure 5.

4. Results and Discussion

Figure 6 shows the load-deflection diagram of a control specimen, beam 74. Because the beam is designed to fail in bending, therefore, it is obvious from the figure that the beam has the required ductility. The maximum load-carrying capacity of the beam is 49.5 kN. The deflection of the beam shown represents the moment of the appearance of the first crack on the strain gauge attached to the steel bars. Otherwise, the beam continued to deflect more than that is shown as it behaved in a ductile manner. The rupture moment of the main steel bar is happened at a load of 49.68 kN. After that load the main rebar cracked. This can be deduced as the strains developed in the steel strain gauges is more than 100000. As in Figure 7, all the cracks point upwards indicating the bending failure of the beam. The first crack is a flexure crack which appeared right in the middle of the beam at a load of 18 kN. As in Figure 8, the maximum load carrying capacity of the control specimen beam 102 is 52.83 KN which is 3.15 kN more than that of the control specimen of beam 74. This difference might be due to the difference between the maximum compressive strength between the two batches as they are cast in two different days. The batch of beam 74 has the of the beam of 25 MPa while the average compressive strength was 27.8 MPa for the batch of beam 102. From, Figure 9, almost all the cracks started at the bottom of the beam towards up which indicates the flexural failure of the beam. The first crack initiated at a load of 18 kN which is the same load that initiated crack in beam 76. The strain of the steel surpassed its yield limit and then a crack passed through the strain gauge at a load of 49.3 kN. This is obvious from the reading of the strain gauges attached to the steel bars. For comparison, the average of the both load carrying capacity is used which is 51.25 kN. From Figure 10 the maximum load carrying capacity of the beam 05 has increased from only 51.25 kN to 71.47 kN which represents 39% of increase. The stiffness of the beam is linear until the load of 20 kN then the beam loses its strength rapidly until the yielding load of 65 kN. Then it regains strength to withhold the load thanks to the metal straps until the rupture of clips. After that the stiffness of the beam decreases suddenly and the test was stopped. This sudden decrease in load carrying capacity is due to the rupture of the clips. The strain data from the strain gauges attached to the straps indicate that there was a premature failure in the straps as the maximum strain developed in each of the straps is 2681 microstrain. This is due to a failure in the clip as it is loosened up after application of the ultimate load. A load of 64.75 kN caused a crack passing over the strain gauge attached to the main steel rebar. In Figure 11, the first crack is initiated at load of 17.8 kN. From the crack pattern, it is obvious that the cracks are a mixture of shear cracks and the flexure crack indicating that most of the section is involved in carrying the load now thanks to the straps. It worth mentioning that the crack widths are minimized if compared with the size of the cracks of the control specimens as the straps successfully confined the beam longitudinally. The failure was due to loosening up the clips as they could not bear the amount of tension applied on the straps as it is shown in Figure 12. In Figure 13, the maximum load carrying capacity of the beam 06 is 69.46 kN. If compared with the control specimens, it has increased by 36 %. The stiffness of the beam decreases with an increase of the load on it, until it reaches its maximum capacity. Then the lower strap is ruptured causing a decline in the load carrying capacity. After that, the beam is held by only one strap which resisted the load of 64 kN and then the clip loosened up causing further decrease in load carrying capacity. The reason for that is the lower straps takes more load as it is farther from the neutral axis. Therefore, it is cut first and then the upper strap has failed in its clips. The cracked beam is shown in Figure 14 which is right after the rupture of the bottom strap of the beam. The first crack is initiated at a load of 25 kN which is a sign of an active confinement as it arrested the cracks. Generally, the size of the cracks is minimized across the whole section as most of the cracks appeared on top of the top layer of the straps.A closer picture of the location of the failure in the bottom strap is shown in Figure 15. The lower strap is being cut right in front of the clip as there might be a weak point created due to the existence of the notches in that area. A contribution of the bottom strap is evident right from the beginning of the test until it developed a strain of 1447 microstrain in it. Then the second strap which is the upper one is triggered to work until it developed a strain of 2111 microstrain and then suddenly the clip is loosened up as shown in Figure 16. The clip has shifted towards left of the figure as it is indicated on the figure due to high tension force on the straps. There was a crack passing through the strain gauges attached to the main steel bars at a load of 67.54 kN, which is delayed if compared with the control specimens. This is an indication that the straps actively strengthened the beam and helped the main rebars to carry more loads. As a rule, it is accepted that the lower strap should carry more loads, therefore, having two layers at two different locations such as in case of beam 06 will not help in increasing the load carrying capacity. Rather the two layers should be applied at the same location on top of each other which might increase the load carrying capacity of the beams as the two layers will help each other in resisting the tensile force upon them. Research carried out by Abdullah W. and Rafiq S. [27] used the same beam configurations but strengthened their beams with metal straps wrapped around steel channels. Seven beams strengthened with PTMS wrapped fully around steel channels in the flexural zone of the beams have been tested. The dimensions of the beams are the same as used in this paper. They also, had two control specimens. The labels of the tested beams are (control, 01, 55, 56, 73, 75, 76, and 101) which are strengthened with different configurations of metal straps wrapped around steel channels. The steel channels are anchored to the beam faces using bolts, therefore, there was a room for the straps to move along the deflection of the beams. Figure 17 shows a comparison between the beams strengthened with fully wrapped PTMS (beam 05 and 06) and their beams. The deflection capacity of the beams 05, and 06 is less than that of the other beams as they are post tensioned around the beams confining the beams longitudinally. There is no flexibility for the straps to translate with the deflection of the beam. This is not the case with the beams strengthened with PTMS wrapped around the steel channels as there was a room for movement of the straps along the deflection of the beams. However, the load carrying capacity can increase with the same rate. This indicated that applying PTMS on steel channels is more effective than applying it straight away to the beam in a shape of full wrap as both ductility and strength of the beam can be increased.

5. Conclusions

This paper investigated the structural behavior of normal concrete beams strengthened using PTMS wrapped fully around the beams. From the results obtained throughout this work, the following conclusions can be drawn: 1. Using PTMS fully wrapped around the beam can successfully increase the load carrying capacity of the beam by at least 36 % and the maximum of 39%. 2. If the straps fully wrapped around beams at the lowest point of the beam, they are susceptible a rupture before loosening up of the clips. 3. Straps applied at a height of 45 mm from the bottom of the beam might fail in the clips as the clips might loosen up. 4. To achieve increase in both strength and ductility capacity, there should be an allowance for the straps to move along the deflection of the beam as the elongation of the straps is only 9% which is nearly 65% lower than that of the steel bars used in reinforcing the beams. Therefore, only the load carrying capacity of the beams will increase largely by wrapping the straps fully around the beams. 5. Using the straps with steel channels will cause increase in both load carrying capacity and ductility capacity of the beam as there is allowance for movement with the deflection of the beams.

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تجارب عملية لتقوية مقاومة الانحناء لكونكريت المسلح عن طريق لف رباط حديد مسبقة الشد

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المستخلص

لزيادة القدرة حمل العارضة في البناء، يتم لف الأشرطة المعدنية بعد الشد بالكامل حول العوارض في منطقة الشد الخاصة بها في هذه الدراسة. يتم صب أربعة عوارض خرسانية بعمق ١٦٠ ملم وارتفاع ٢٤٠ ملم وطول إجمالي يبلغ ٢١٠٠ ملم واختبارها تحت اختبار الحمل من أربع نقاط. يتم الاحتفاظ بعدد المتغيرات إلى اثنين على الأقل وهما عدد وموقع الأشرطة. لقد وجد أن استخدام الأشرطة المعدنية بعد الشد الملفوفة بالكامل حول العوارض يمكن أن تزيد من قدرة تحمل الأحمال بنسبة ٣٦٪ على الأقل و ٣٩٪ كحد أقصى. العامل الرئيسي في التأثير على المعدل هو موقع الأشرطة. تم وصف دليل كامل حول استخدام المواد مع تطبيقها على الحزم بشكل واضح في الورقة.

الكلمات المفتاحية:

فشل الانحناء ، حزام ما بعد الشد المعدني (PTMS)، حزام الفولاذي (SS) ، اختبار الانحناء ، سعة حمل الحمولة.

Table 1: Properties of course aggregate.

Properties of course aggregate	Value
Bulk dry specific gravity	2.632
Bulk saturated surface dry specific gravity	2.667
Apparent specific gravity	2.729
Water absorption	1.364 %
Dry density	1481 kg/m^3
Compacted dry density	1613 kg/m^3
Properties of course aggregate	Value
Bulk dry specific gravity	2.632
Bulk saturated surface dry specific gravity	2.667

Table 2: Properties of fine aggregate

Properties of fine aggregate	Value
Bulk dry specific gravity	2.571
Bulk saturated surface dry specific gravity	2.618
Apparent specific gravity	2.698
Water absorption	1.833 %
Dry density	1509 kg/m^3
Compacted dry density	1659 kg$^{/m3}$
Bulk dry specific gravity	2.571
Bulk saturated surface dry specific gravity	2.618
Apparent specific gravity	2.698

Table 3: Properties of steel bars

Sample number	Yield Strength (MPa)	Ultimate strength (MPa)	Elongation %
1	504.8	640.7	22.5
2	504.9	635.9	27
3	502.3	638.1	27
Average	504	638.2	25.5

Table 4: Mass of the main components of the concrete mix

Water (kg)	Cement (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Total(kg)
255	380	769	907	2311

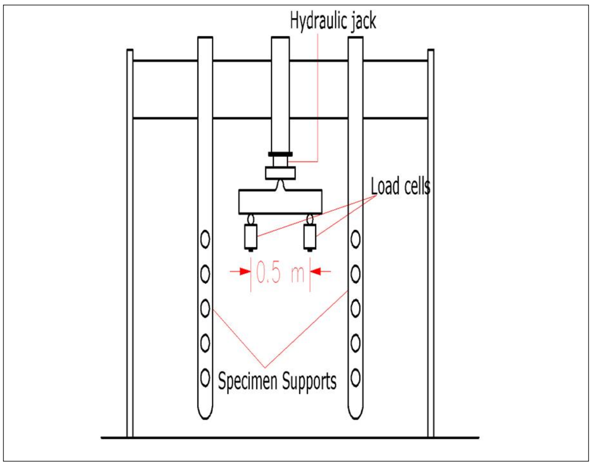

Figure 1: Metal strap and an aluminium clip.

Figure 2: Testing machine with two movable supports [27]

Table 5: Sample labels in this paper.

Beam Sample	Label
Control Sample	74 and 102
R. C beams strengthened with fully wrapped PTMS 60 mm from bottom of the beam	05
R.C beams strengthened with two layers of fully wrapped PTMS applied at 60 mm from bottom and 100 mm from bottom	06

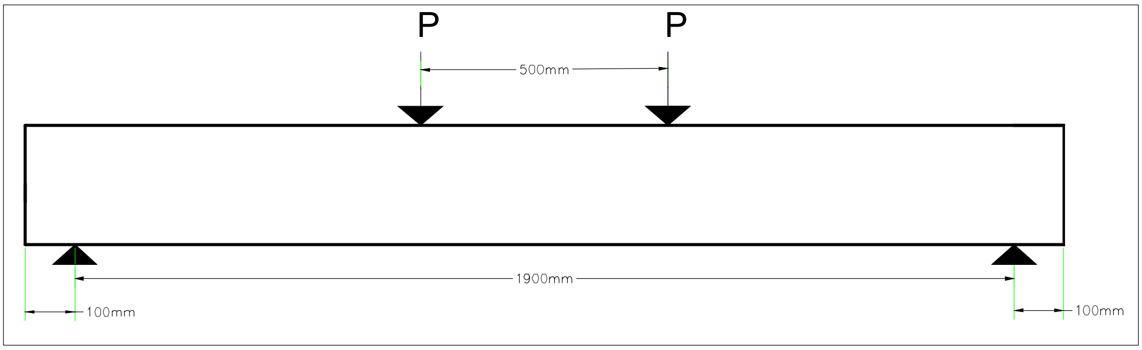

Figure 3: layout of the control samples 74 and 102.

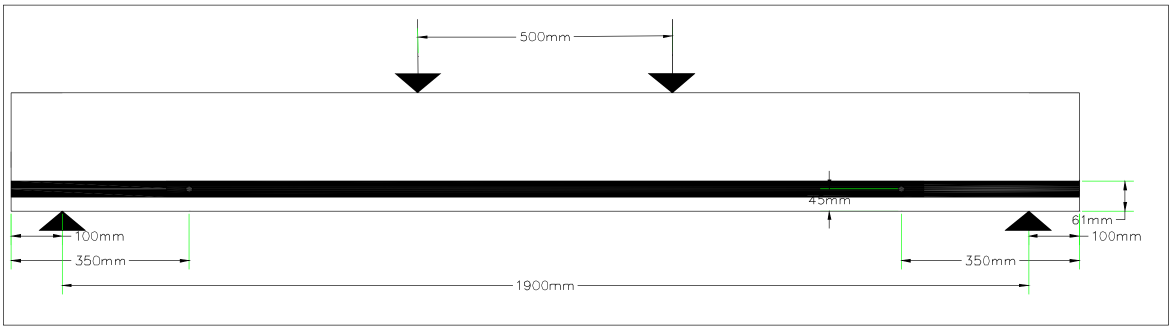

Figure 4: Layout of the beam 05.

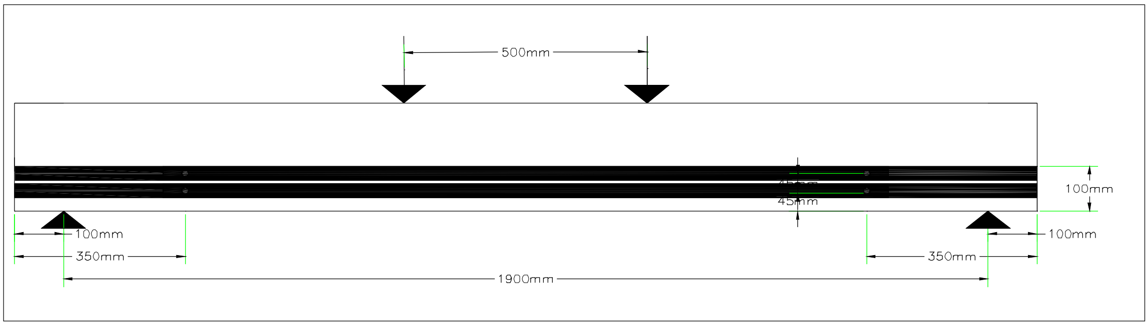

Figure 5: Layout of the beam06.

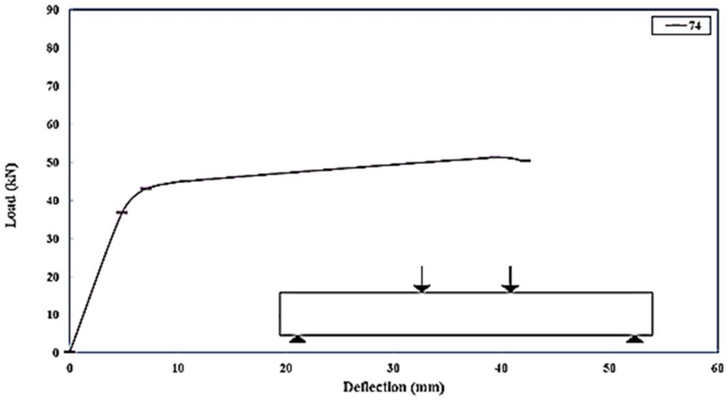

Figure 6: Load - deflection diagram of the control sample 74.

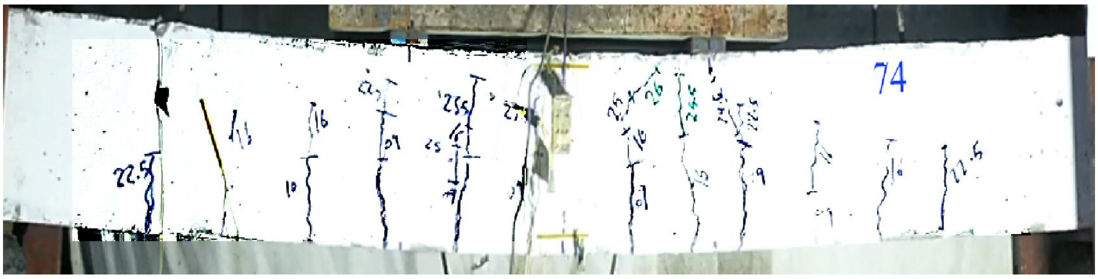

Figure 7: Crack pattern of the control sample 74.

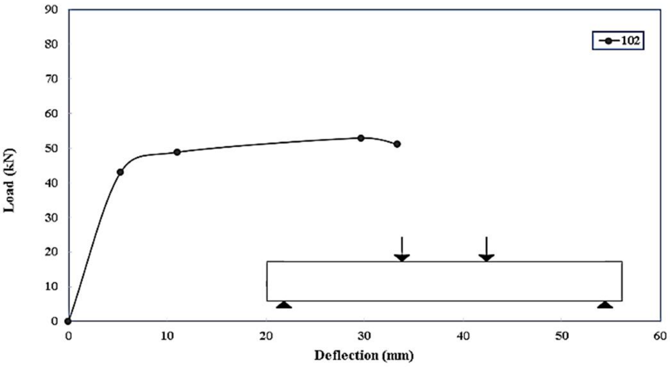

Figure 8: Load - deflection diagram of the control sample 102.

Figure 9: Crack pattern of the beam 102.

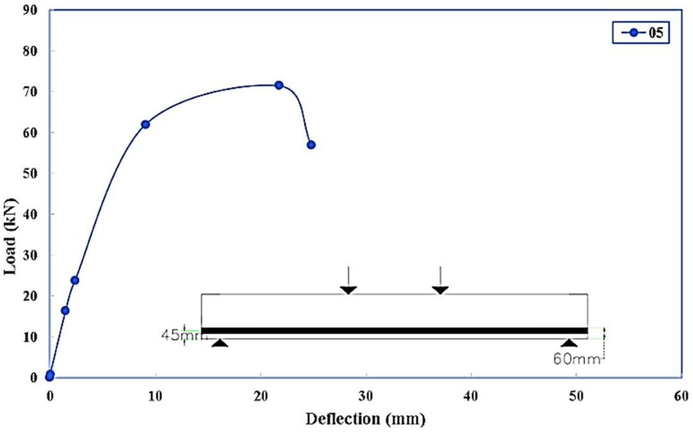

Figure 10: Load – deflection diagram of beam 05.

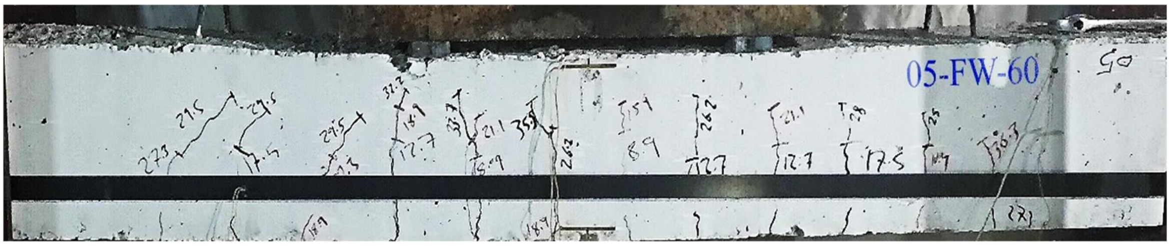

Figure 11: Crack pattern of beam 05.

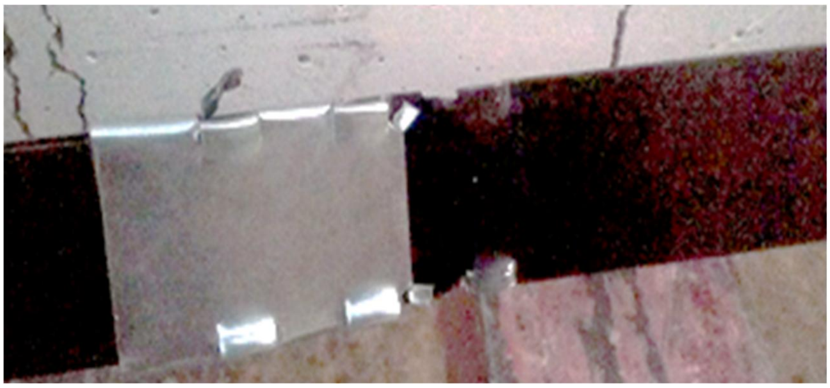

Figure 12: Location of failure in the clip of beam 05.

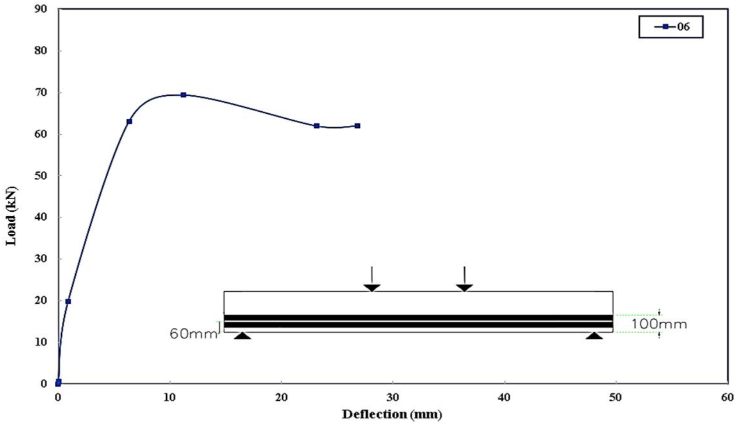

Figure 13: Load- deflection diagram of beam 06.

Figure 14: Crack pattern of beam 06.

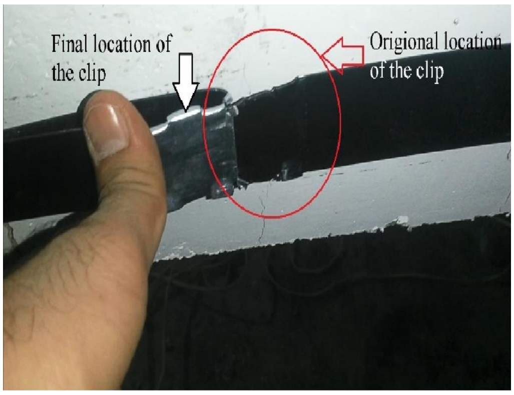

Figure 15: Location of the strap failure in the place of the notches in beam 06.

Figure 16: loosening up the clip of beam 06.

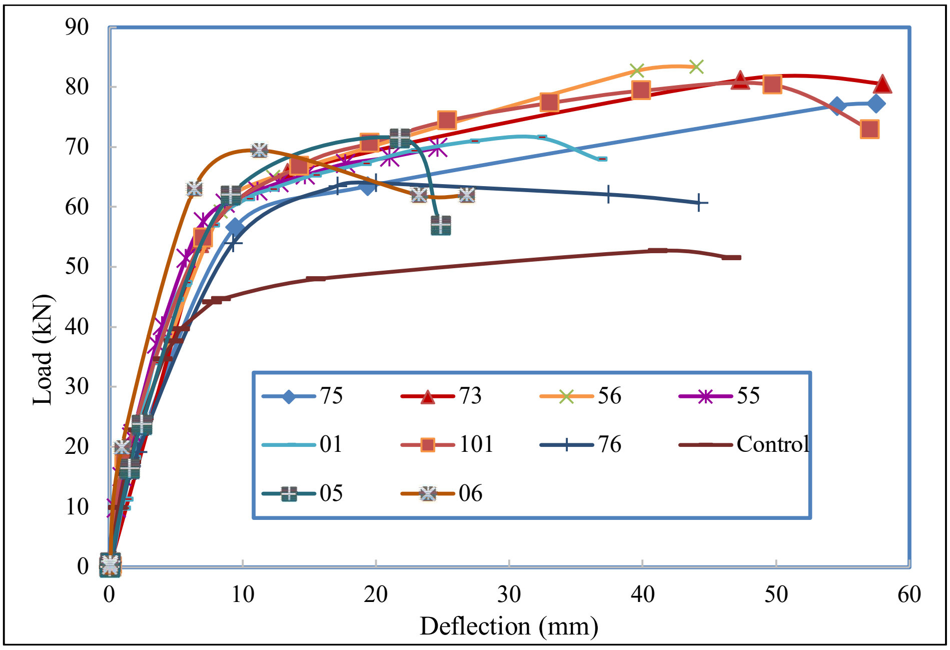

Figure 17: Comparison between all the beams.