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Shear Behavior of R.C Beams Strengthened Using NSM Pre-stressed Bars

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ABSTRACT

This study attempts to understand the shear behaviour of externally pre-stressed R.C beams using NSM pre-stressed bars. Nine reinforced concrete beams of cross-section 150 mm width, 300 mm overall thickness and 1400 mm total length were fabricated and tested under three point loads. One of these was fabricated without strengthening while the others were strengthened to study different parameters; damage levels, pre-stressing levels, and spacing of NSM pre-stressed bars. The results showed that the effectiveness of the proposed technique is achieved in both ultimate and serviceability limit state. NSM pre-stressed bars could reduce the effect of the existing cracks and increase the beams capacities. Also, the mode of failure of the strengthened beam changed from brittle failure to ductile failure.

Keywords: Shear, Reinforced Concrete (R.C), Strengthening and repairing, NSM (Near-surface mounted reinforcement), Pre-stressing concrete.

INTRODUCTION

In the recent years, there has been an increased interest in strengthening and repairing of existing concrete structures, and this process requires a vast monetary investment. Therefore, today there is a need to find an appropriate and economical technique to strengthen or to repair existing concrete structures. External post-tensioning is one of the widely used strengthening techniques due to Economical construction, Easy monitoring and maintenance, Easy tendon placement, and concreting.
External post-tensioning refers to a pre-stressing technique where the tendons are placed outside the concrete section. The shear behavior of R.C beams strengthened with external post-tensioning are presented in many references [6] to [9]. Most of previous researches were focused on pre-stressing of members in the horizontal direction only. Limited papers were focused on pre-stressing of members in the transverse direction [10] to [12].
The present paper presents the results of an experimental study on the shear strengthening of R.C beams with existing shear cracks using NSM pre-stressed bars in the transverse direction. Nine reinforced concrete beams were tested to analyze the influence of the selected test parameters, i.e. pre-loading, pre-tensioning, and the spacing between NSM pre-stressed bars on the structural behavior and the failure mode of the tested beams.

EXPERIMENTAL PROGRAM

Test Beams

Nine reinforced concrete beams of cross-sections 150×300 mm, total length 1400 mm, and effective span 1200 mm were fabricated and tested under asymmetric three point shear load. The used flexure and shear reinforcement ensured shear failure of the beams. All beams were reinforced with 3Φ16 in tension, and 2Φ10 in compression. 6 mm web reinforcement were provided at critical shear zone each 150 mm, and extra web reinforcement 8 mm each 150 mm were provided at another side to ensure that the failure will occur at the critical shear zone. Fig 1 shows the dimensions and typical reinforcement layout of the beams before strengthening. One of the beams was served as control beam (BC), and was tested under static loading until failure. The others were strengthened with NSM pre-stressed bars at the critical shear zone. The details of the tested beams are shown in Table 1. The beam codes used for the strengthened beams are characterized by two initial letters (BS) refer to strengthened beams, followed by three digits refer to the pre-loading percentage (0, 30, and 90 %) Pu, followed by three digits indicating the pre-tensioning levels (0, 25, and 50 %) fy, and finally with three digits indicating the spacing between the NSM pre-stressed bars (100, 150, or 200 mm). For example beam BS 90–50–150 is pre-loaded up to 90% of ultimate capacity of (BC), and strengthened with NSM pre-stressed bars with pre-tension 50% of yield stress of pre-stressed bar at spacing 150 mm measured along the critical shear zone.

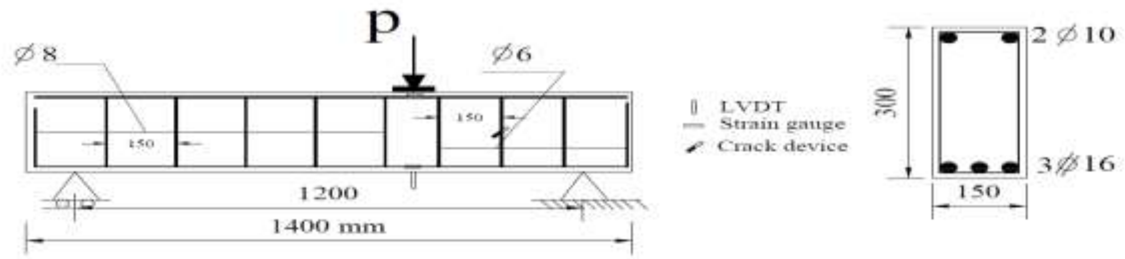


Fig1. Dimensions and reinforcement details of the tested beams

Table1. Details of test beams

Beam	As bottom	As top	No of pre-stressed bars	Pre-tension (%fy)	Pre-load(%Pu)	Spacing of NSM bars (mm)
BC	3Φ16	2Φ10	………	……..	………..	………
BS 0-0-150	3Φ16	2Φ10	3	0	0	150
BS 0-50-150	3Φ16	2Φ10	3	50	0	150
BS 30-50-150	3Φ16	2Φ10	3	50	30	150
BS 90-50-150	3Φ16	2Φ10	3	50	90	150
BS 90-0-150	3Φ16	2Φ10	3	0	90	150
BS 90-25-150	3Φ16	2Φ10	3	25	90	150
BS 90-50-100	3Φ16	2Φ10	4	50	90	100
BS 90-50-200	3Φ16	2Φ10	2	50	90	200

Material

1. Concrete mix design was made to produce concrete have cubic compressive strength of 25 MPa after 28 days.
2. Ordinary Portland cement and local natural sand were used. The coarse aggregate with a maximum nominal size of 10 mm and 20mm.
3. Deformed H.T.S bars of proof stress 500 MPa, ultimate strength 700 MPa were used as main reinforcement. Mild steel bars having yield strength 380 MPa, ultimate strength 520 MPa were also used as web reinforcement. For the NSM pre-stressing bars, mild steel bars 8 mm diameter having an average yield stress, Fy = 380 MPa, and average ultimate tensile strength, Fu = 520 MPa were used.
4. Epoxy 165 was used as a binder paste, used for embedment of the NSM reinforcement in the grooves.
5. All the used materials have properties are agree with the limits of ECP 203 [13].
6. The mix proportions for 1 m3 of concrete consisted of 375 kg ordinary Portland cement, 1200 kg coarse aggregate, 563 kg sand, 202 kg water.

Strengthening and repairing technique procedures

The NSM strengthening technique was performed as follows:

1. 15×20 mm grooves with vertical length 300 were cut off based on the size of the pre-stressing bar with inter-spacing between two consecutive grooves equals to 150 mm.
2. Cleaning the grooves by vacuum cleaner in order to have a good bond between the epoxy and the concrete surface.
3. The external NSM bars were inserted in each grooves and then pre- stressed.
4. Grooves were filled with epoxy.

The NSM technique was applied by vertically pre-tensioning the critical shear zone using steel bars, steel plates, and bolts as shown in Figs 2 and 3. The required level of pre-tensioning stress on the beam was achieved by tightening the bolts using torque wrench key. The stress in the NSM pre-stressed steel bars was monitored through strain gauges attached to the NSM pre-stressed steel bars.

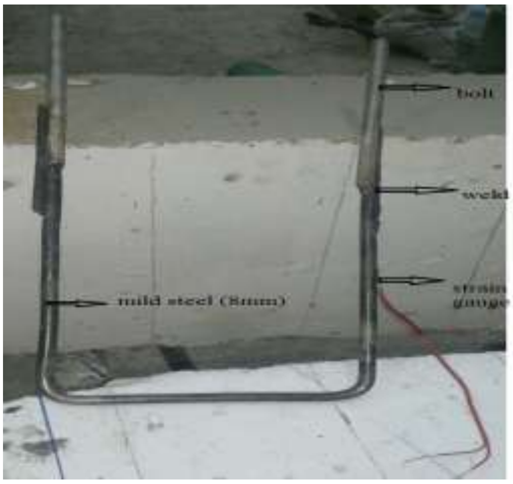
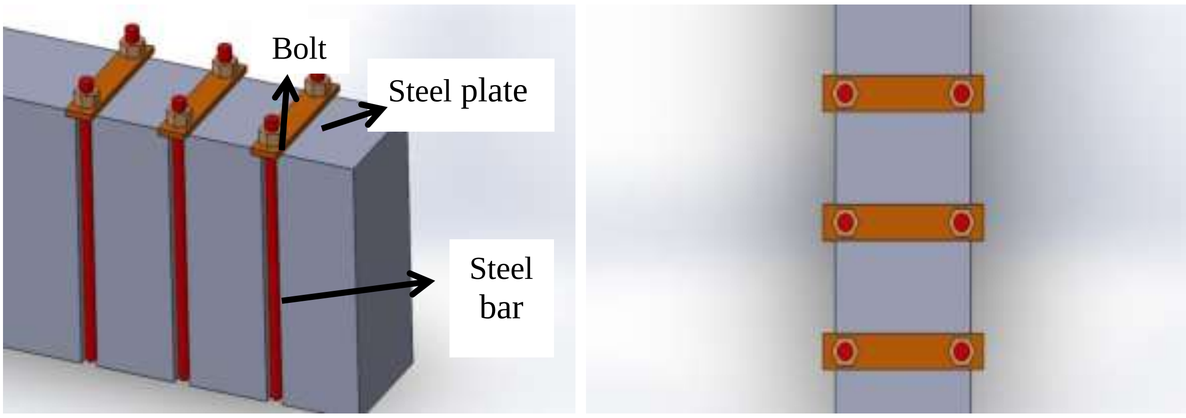
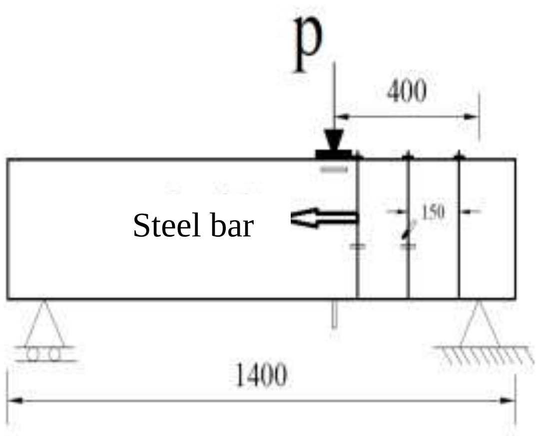


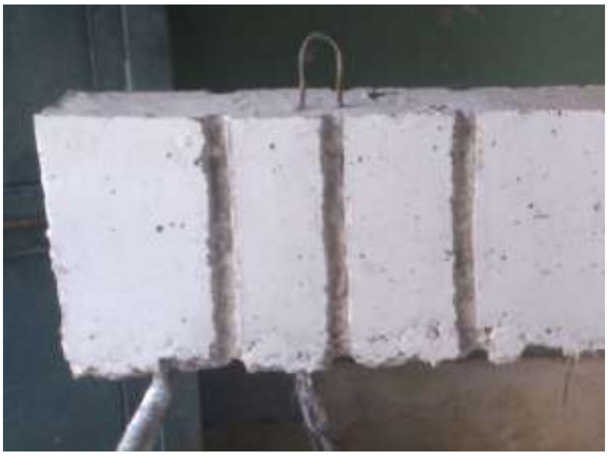
Fig 2. External steel bar.



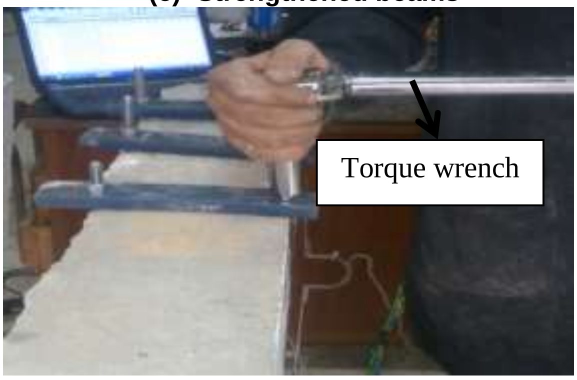
(a) Layout of beam **(b) Plan layout of beam**



(c) Strengthened beams



(d) Preparation of beam for strengthening



(d) Tightening the bolts

(e) Beam before testing

Fig 3.Set-up of strengthened beams.

Test set up and instrumentations

All beams were tested under static loading using a hydraulic machine with bearing capacity of 600 KN. All beams were loaded as simple beam with clear span 1200 mm using asymmetric three point shear loads. The beams with pre-loading percentage were loaded first, after that were strengthened. For all tested beams; third span deflection was measured by displacement transducer (LVDT), and strain measurements were made at the main longitudinal reinforcing steels, external steel bars, and top surface of concrete beam. All data at every step of loading were simultaneously recorded using data-logger. Crack pattern and their propagation are recorded by digital camera while crack width is measured by crack device as shown in Fig 4.

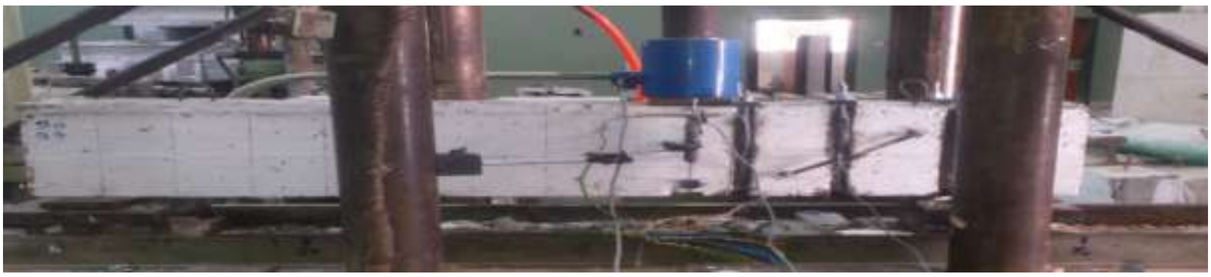


Fig 4. Test set-up of tested beams

TEST RESULTS

The cracking loads, the ultimate loads, maximum deflections and strains as well as the failure mechanism of tested beams are presented in Table 3.

3-1- Pattern of cracks and mode of failure.

For control beam, BC, The first shear crack was developed at about 100 KN load, near the support point and moved up at an angle about 45 ° to the point of applied load of the test side. It was fully developed as the load increased. No flexural cracks was observed. The beam finally failed in shear in the test side at 177 KN.

Table 3. Test results

Beam	**F_{cu} MPa**	**Pcr_f KN**	**Pcr_{sb} KN**	**Pcr_{sa} KN**	**Pu KN**	**δ_{max} mm**	**εs_{max} micro strain**	**$\varepsilon s_{max}b$ micro strain**	**Mode of failure**
BC	24	—	100	—	177	3.37	1482	—	shear
BS 0-0-150	26	175	—	110	278.5	9.35	13720	2090	shear
BS 0-50-150	25.5	175	—	110	291	9.00	4108	1595	shear
BS 30-50-150	27	175	—	110	275.5	7.71	3430	1600	shear
BS 90-50-150	23	180	100	140	274	13.3	4574	2905	shear
BS 90-0-150	23	190	100	120	294	6.48	2550	12260	shear
BS 90-25-150	24	200	100	130	285.5	9.63	2820	1290	shear
BS 90-50-100	26	170	100	200	297	13.76	13500	2613	shear
BS 90-50-200	25	200	100	140	277	7.35	3870	2150	shear

Fcu: average cube compressive strength of the used concrete (150 × 150 × 150 mm)
Pcrf: Flexure crack load
Pcrsb: Shear crack load before pre-stressing.
Pcrsa: Shear crack load after pre-stressing.
Pu: Ultimate capacity of the beams.
δmax: Maximum deflection.
εsmax: Max.strain in main bars.
εsmaxb: Max.strain in NSM bars.

For strengthened beams which were initially strengthened, the NSM technique delayed appearance of the first shear crack and increased the shear capacity of the beam compared with control beam. As the load increased, more shear cracks with small width were appeared in both sides of the beam. The width of the cracks has been increased until the beam failed. For repaired beams, the NSM technique; not fully closed the initial cracks, and increased the shear capacity of the beam compared with control beam. Similar behavior was observed for these beams as strengthened beams. All strengthened and repaired beams failed in shear in the critical shear zone except beams (BS 0-50-150, BS 90-0-150, and BS 90-50-100) failed in shear in other side. Fig 5 shows the cracking pattern and mode of failure for the tested beams.

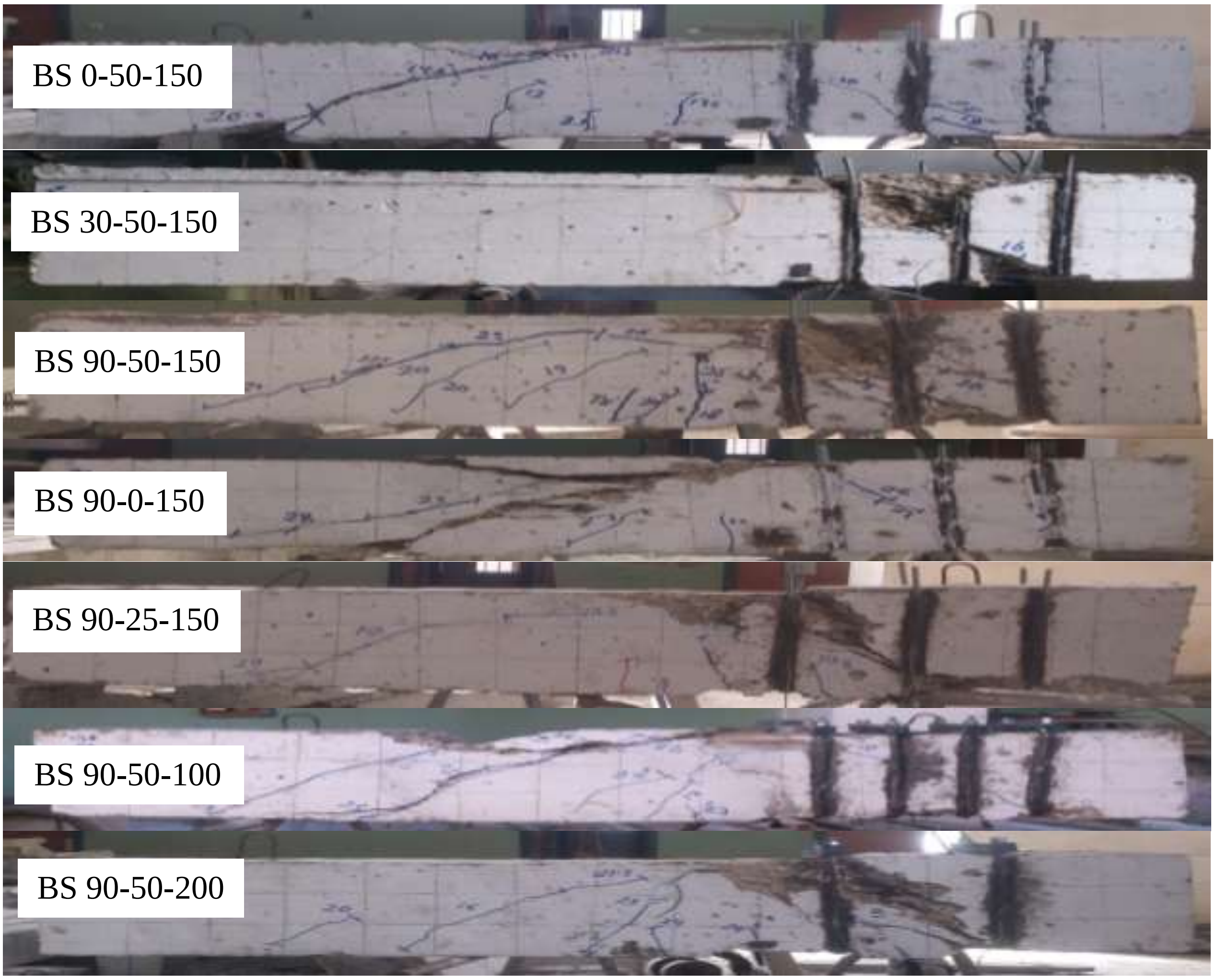


Fig 5 Cracking pattern and mode of failure for tested beams.

Deformation response
Deflection

The load-deflection relationships for all tested beams are shown in (Fig 6.a to Fig 6.c). From these Figs the following observations can be conclude:

- For strengthened and repaired beams, using NSM technique increased the ductility of the beams.

Effect of pre-loading parameter

As expected, the ultimate capacity of strengthened beams increased about (55%) of ultimate capacity of the control beam. This because the use of pre-stressed steel bars reducing the effect of existing shear cracks, and increasing the beam capacity. Increasing the pre-loading value; decreasing the stiffness of the beams comparing to beams with low pre-loading value, and increasing the max-deflection. Beams (BS 0-50-150 and BS 30-50-150) have the same behavior. This because the pre-load value of beam (BS 30-50-150) was low and no cracks were developed.

Effect of pre-tensioning parameter

All beams; have nearly the same the load-deflection behavior, and the ultimate capacity increased comparing to the control beam. For beam BS 90-0-150, ultimate capacity increased about (66%) of ultimate capacity of control beam comparing to other strengthened beams. This because the beam was strengthened without pre-tensioning.

Effect of spacing of NSM bars parameter

As expected, decreasing the spacing of NSM pre-stressed bars increasing the ultimate capacity of the beam and the maximum deflection.

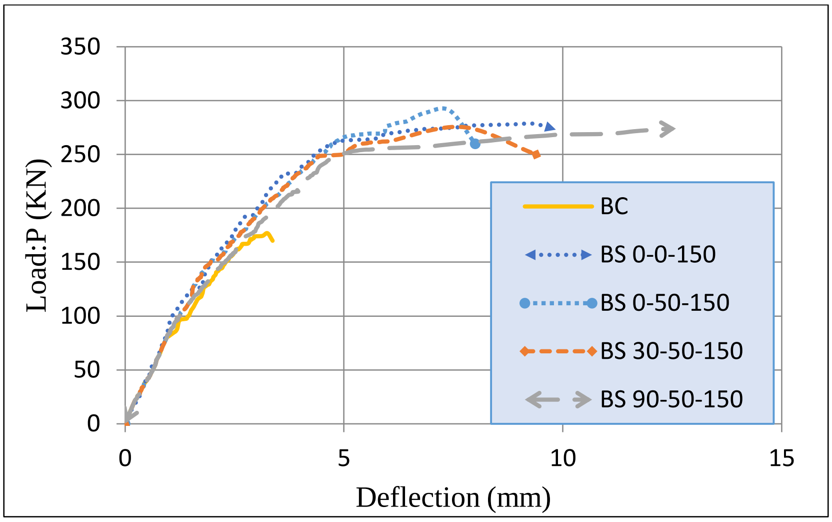


Fig 6.a. Effect of pre-load on load-deflection curve

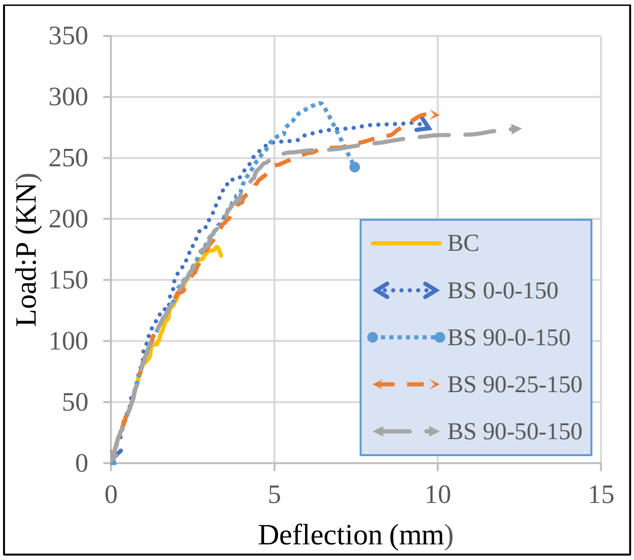


Fig 6.b. Effect of pre-tension on load-deflection curve

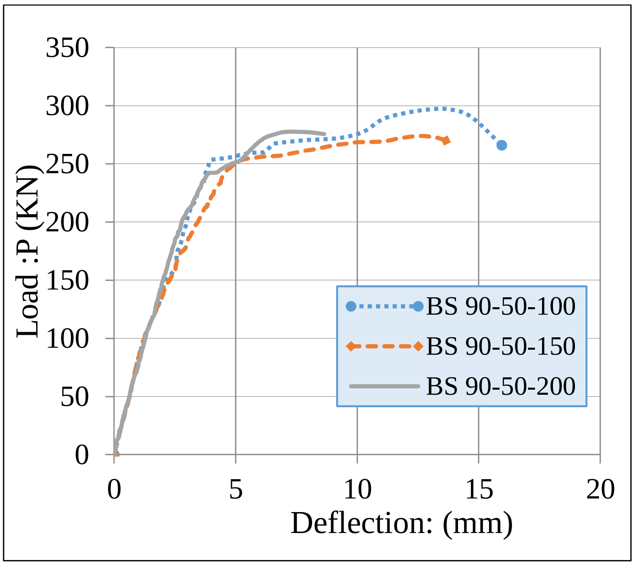


Fig 6.c. Effect of spacing on load-deflection curve

Strains

The variation of strain measured in tension reinforcement with increase in load is shown in (Fig 7.a to Fig 7.c) for some chosen beams. (Fig 8.a to Fig 8.c) illustrates the load–strain curves of the externally NSM pre-stressed bars. NSM bars strains become significant at load levels larger than the load at first shear cracking. Unlike strains in the tension reinforcement, strains in NSM bars did not increase as the applied load increased. In some beams, there were intervals of applied load at which the NSM bars strains remained constant or decreased while the applied load was increasing. This can be caused by the loss of bond between the NSM bars and the concrete beam. For beams which pre-loaded up to

90% of its capacity, the strain gages attached to NSM bars started to develop strains from the beginning of the load due to the presence of cracks.

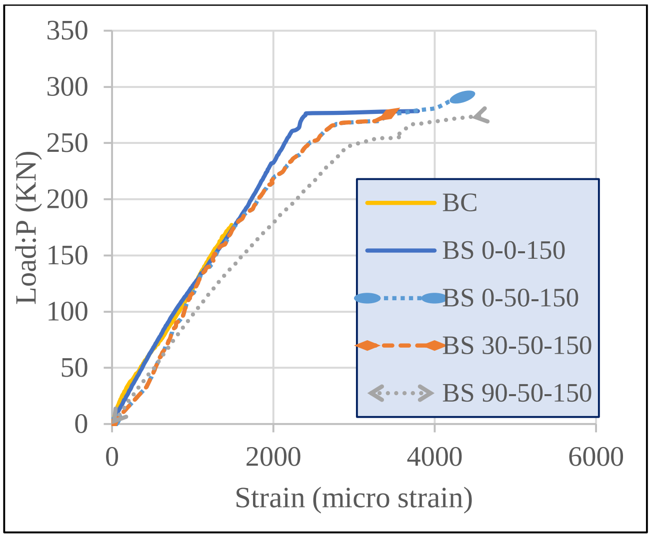


Fig 7.a. Effect of pre-load on tension steel strain

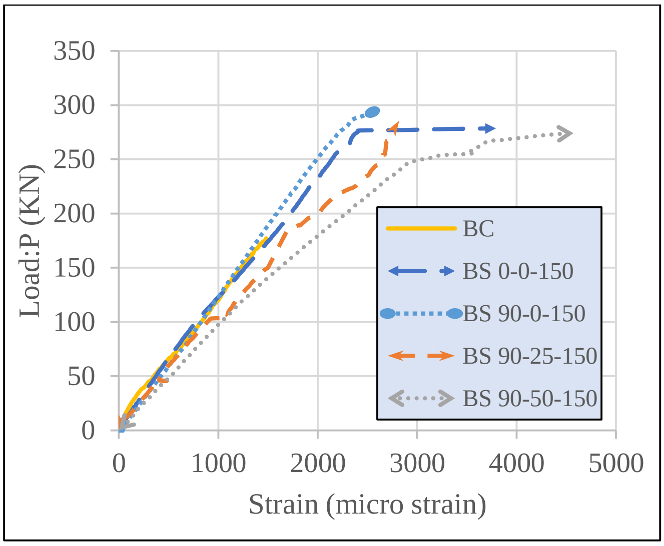


Fig 7.b. Effect of pre-tension on tension steel strain

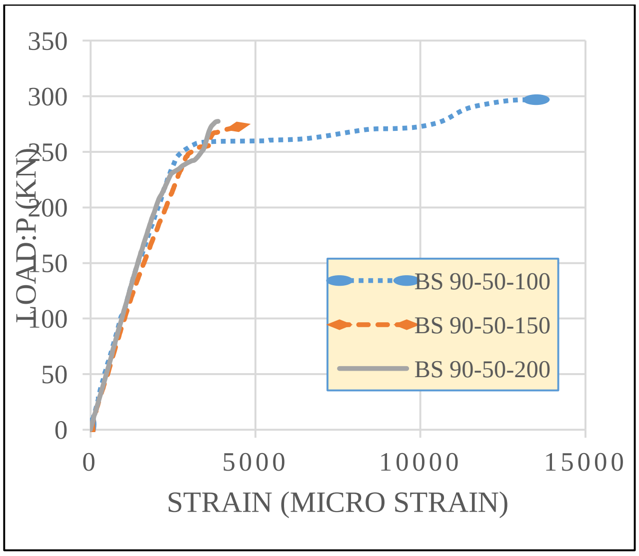


Fig 7.c. Effect of spacing on tension steel strain

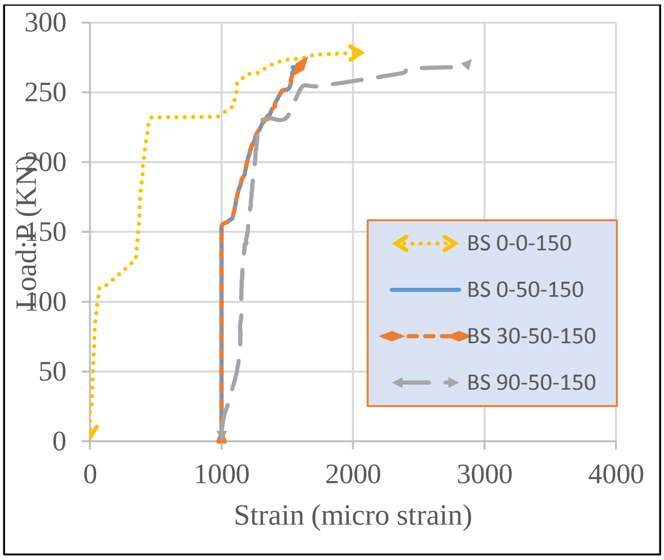


Fig 8.a. Effect of pre-load on pre-stressed steel bar strain

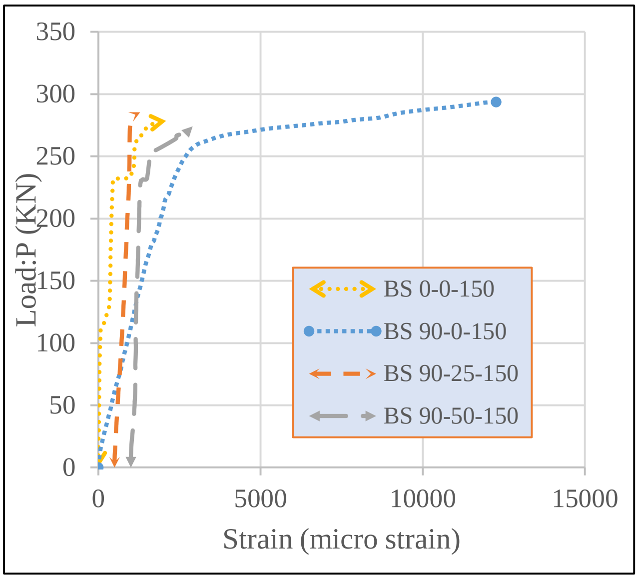


Fig 8.b. Effect of pre-tension on pre-stressed steel bar strain

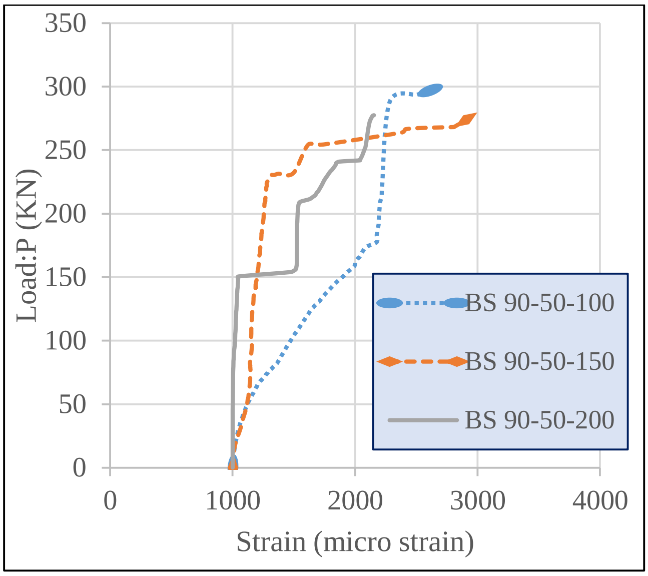


Fig 8.c. Effect of spacing on pre-stressed steel bar strain

DISCUSSION OF TEST RESULTS

The obtained test results were analyzed to declare the effect of the various parameters included in this work on strength and deformation up to failure. These properties were measured by means of ultimate load and maximum deflection, as follows:

Effect of pre-loading:

Fig 9. shows that increase in pre-loading percentage from 0% to 30 and 90% results in decrease in ultimate capacity by 5.8% in failure load of the beam. However, this increase leads to increase from 4% to 70% respectively in deflection at max-ultimate load. This behavior confirms the effect of NSM bars in improving ductility of the beams.

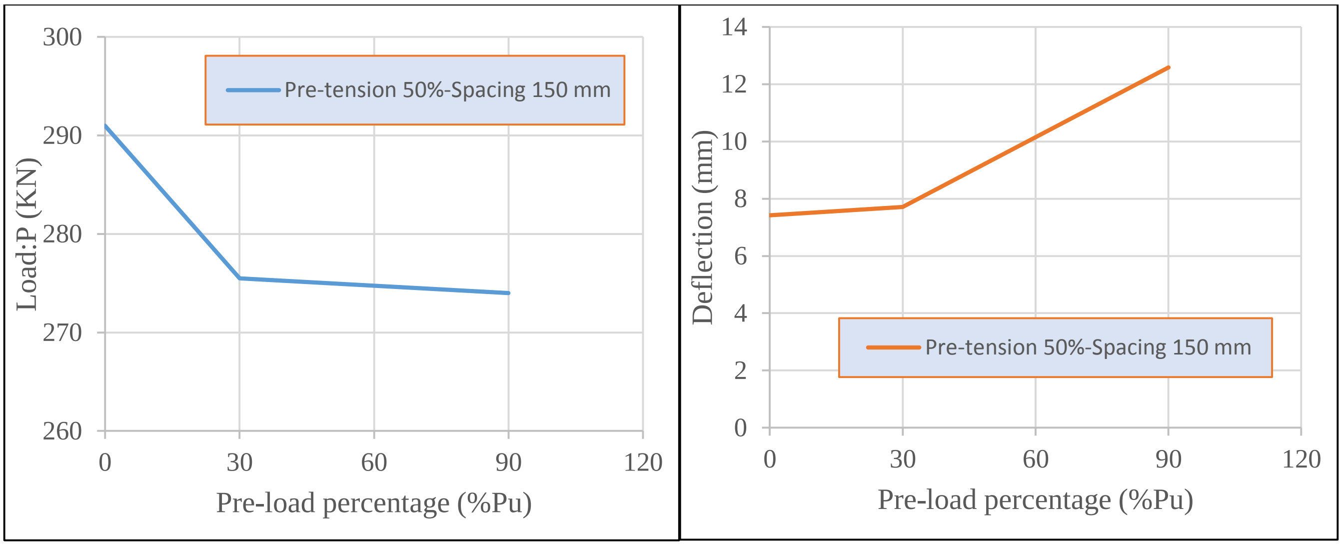


Fig 9. Effect of pre-load on failure load and max-deflection

Effect of pre-tensioning:

Fig 10. shows that increase in pre-tensioning percentage from 0% to 25 and 50% results in decrease in ultimate capacity by 6.8% in failure load of the beam. However, this increase leads to increase from 48.6% to 94.3% respectively in deflection at max-ultimate load. This behavior confirms the effect of NSM bars in improving ductility of the beams.

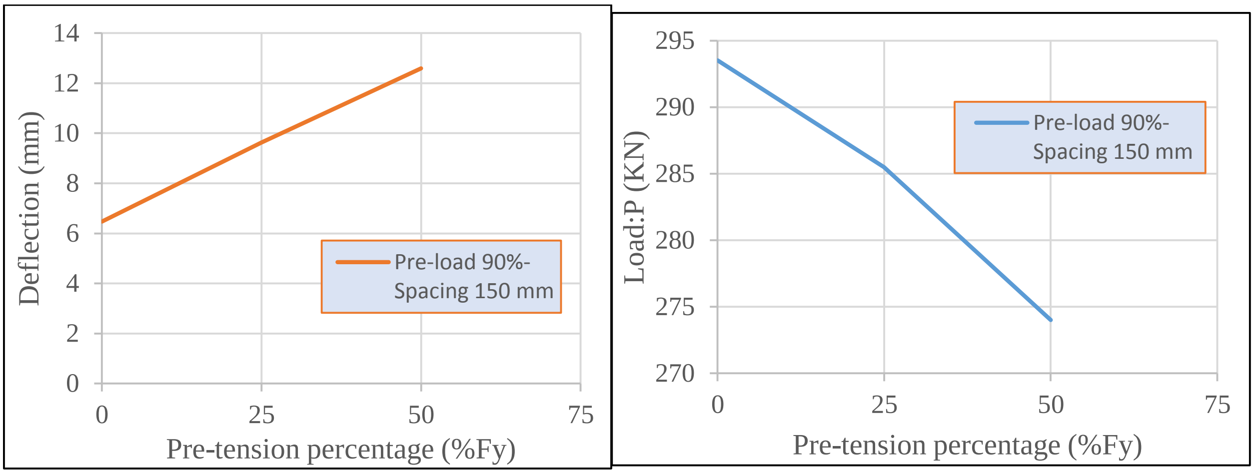


Fig 10. Effect of pre-tension on failure load and max-deflection

Effect of spacing of NSM bars:

Fig 11. shows that increase in spacing of NSM bars from 100 mm to 150 and 200 mm results in decrease in ultimate capacity by 7.75% to 6.6% respectively in failure load of the beam and this increase leads to decrease from 8.6% to 46.7% respectively in deflection at max-ultimate load.

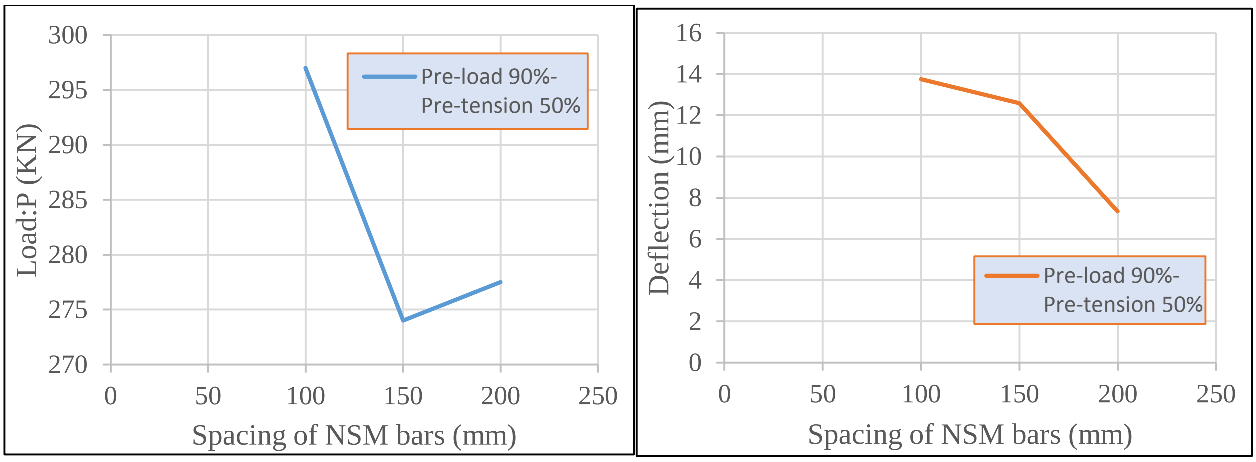


Fig 11. Effect of spacing on failure load and max-deflection

CONCLUSIONS

Based on results of the present investigation, the following main conclusions can be drawn:

1. NSM pre-stressed bars can significantly enhance the shear capacity of R.C beams in presence of a limited amount of steel shear reinforcement. The amount of increase in shear capacity was about 55%.

2. The use of the external pre-tensioning technique to strengthen the R.C beams reduces the width of shear cracks and increases the member shear capacity.
3. Decreasing the spacing of NSM bars results in an increase in the ultimate shear capacity.
4. Using NSM pre-stressed bars in strengthening of R.C beams without pre-tension increase the ultimate capacity of the beam larger than the beams strengthen with pre-tension.
5. Non pre-stressed NSM bars are suitable for increasing ultimate capacity however, pre-stressed NSM bars are suitable for increasing serviceability of beams.
6. The mode of failure of the strengthened beam changed the shear failure from brittle failure to ductile failure.

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