The Behavior of a Strengthened Steel Beam Section Under Eccentric Loadings

Mohammed M. Rasheed[1,a], Kamal Sh.Mahmoud[1,b], Saad Khalaf Mohaisen[1,c*], and Mohammed Z. Yousif[1,d]

[1] Civil Engineering Department, Mustansiriyah University, Baghdad, Iraq

[a]mmrk72@uomustansiriyah.edu.iq, [b]kamalshahada@uomustansiriyah.edu.iq,
[c]eng_saad@uomustansiriyah.edu.iq, [d]dr.mohammadalrawas@uomustansiriyah.edu.iq

Abstract. Thirteen simply supported steel samples have been tested to explain the effects of strengthening steel beams using an external prestressing strand. The samples have the same cross-sectional dimensions and overall length. One steel beam without strengthening was taken as a reference, while the other twelve of them had been strengthening by two external strands at various eccentricity locations and jacking stresses. The strengthening by external prestressing strands is sub-divided into two series according to jacking stress. Each series consists of six steel samples divided according to the eccentricity location of prestressing strand. During tests, it was found that the Load deflection response for the strengthened samples is stiffer as compared with the reference. The increasing percentage in ultimate load capacity was increased to 0.347, 2.758, 3.921, 8.898, 9.326, and 10.256% for beams under jacking stress of 1120 MPa, while increasing percentage in ultimate load capacity were increased to 0.17, 26, 33, 48.5, 13.7, and 69.56% for beams under jacking stress of 815 MPa. On the other hand, the maximum percentages of deflection were decreased to 4.88, 2.44, 20.62, 15, and 9.7% when the jacking stress increase from 815 to 1120 MPa and the ratio of the quarter to mid-span deflection (δ quarter / δ mid) is about 0.528 and 0.497 when jacking stress is 1120 and 815 MPa respectively. So, the increase in jacking stresses from 815 to 1120 MPa will not be preferable because it has a little increasing percentage in stiffening and behaviors compared with other tested beams at the same condition.

Keywords: Strengthening of steel beams; deflection behavior; pre-stressing; eccentricity of strand; jacking's stress.

Introduction

Post-tensioning form where the strands are located outside the cross-sectional area called an external prestressing and prestress force can be transported to the structural member through the deviators and anchorages. External prestressing is one of the best methods to strengthen and rehabilitate the old structural members. In general, it is utilized to develop bridges and buildings for the expected overloading design and fatigue state [1]. The external prestressing concept of the steel beams has been accomplished using the strand of high strength, which is anchored at both steel beam ends. A specific amount of the saddles may be fixed to the length of the internal span through strand profile that it stops the occurrence of the slipping in a strand, and it helps give the shape of the design profile of external prestressing strand (parabolic or draped) according to applied loads and bending moment diagrams [2].

The strand has been tensioned after that from one end simultaneously with the use of the same force of jacking utilized in prestressing strand tensioning. To prevent biaxial bending and specimen distortions, careful care has to be taken to balance the prestressing force in strands [3,4].

Tested Program

Sample Descriptions. This paper aims to focus on prestressing strand, the eccentricity locations, and jacking stresses (fpi). The steel samples are divided into two groups in accordance with the presence of prestressing strand. The first group included one steel sample and was considered as a reference. On the other hand, the second group included twelve steel samples strengthened with prestressing strand and sub-divided into two series following jacking stresses (fpj). Each series included six beams distributed as the eccentricity of prestressing strand (e) extending from 0 to 165 mm under jacking stressed fpj= 1120 and 815 MPa.

Sample Identification: The tested samples were depended on the eccentricity of pre-stressing strand (e) and the amount of jacking stresses. The following coding was adopted:

$OX_0X_1X_2X_3$
Where:-
O: refer to original steel sample.
O_{X0}: refer to strengthened beam under different jacking stresses as follows:
O_M: refer to strengthening beam under jacking stress =1120 MPa.
O_L: refer to strengthening beam under jacking stress =815 MPa
X_1: refer to the eccentricity of prestressing strand at mid-span, defined as (0, 1, and 2)
X_2: refer to the eccentricity of prestressing strand at end span, defined as (0, 1, 2, and 3)
X_3: refer to the eccentricity of prestressing strand at effective depth, defined as (0, 1, 2, 3, 4, and 5)

All definition of samples which used in this research are shown in Figure 1 and Table 1.

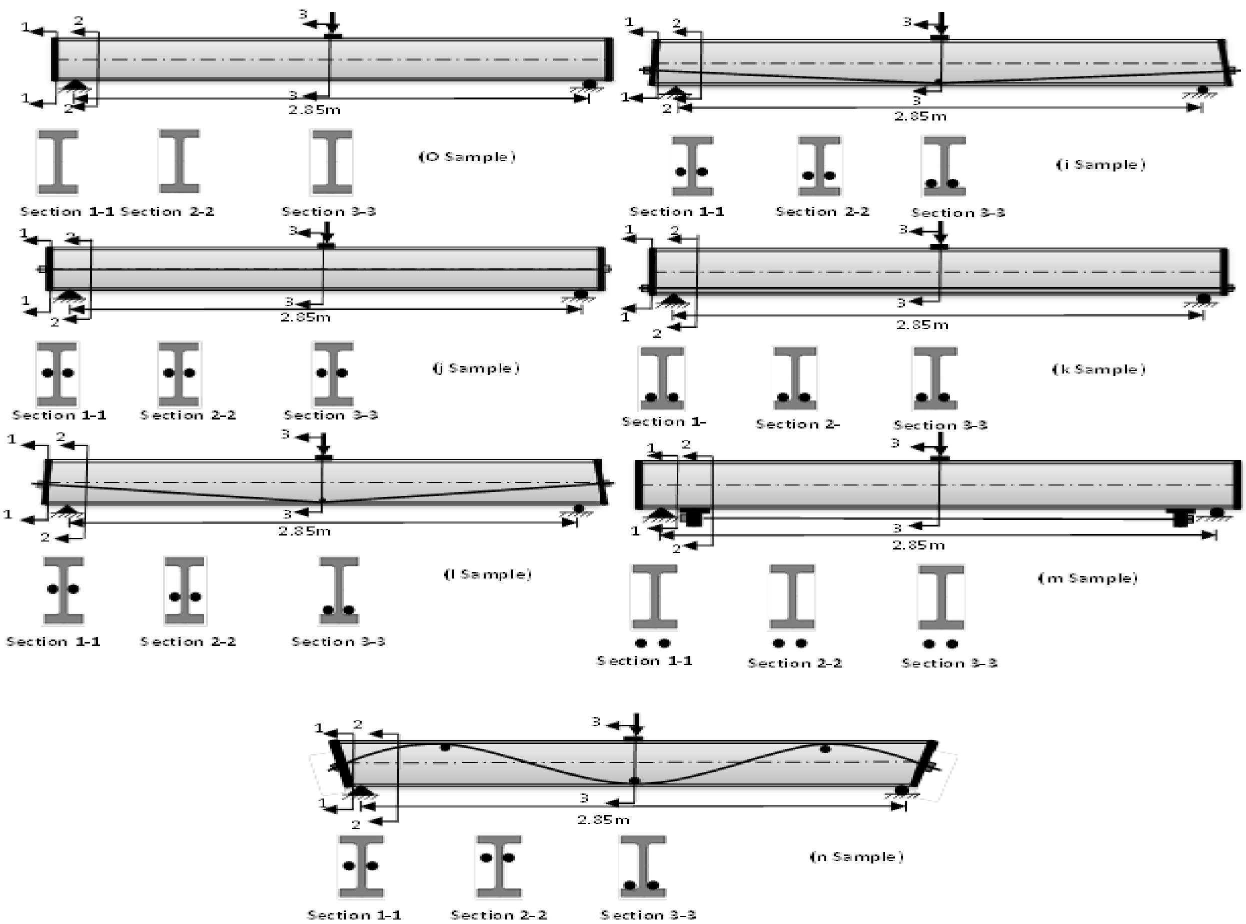
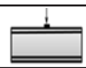
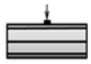
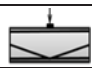
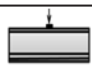
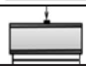
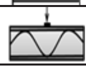
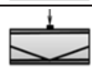
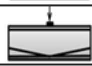
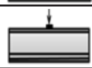
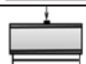
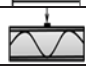


Figure 1. Samples descriptions.

Table 1. Samples identification.

Groups	serieses	Sample No.	Serial Symbol	Prestressing Strand Profile	Sample Shape	Jacking Stresses (fpj) (MPa)	Eccentricity (e) (mm)		
							e_1	e_2	e_3
1	1	Ref.	O	----		----	----	----	----
2	2	1	OM_i	Straight		1120	0	0	0
		2	OM_j	Draped		1120	96	0	19.51
		3	OM_k	Draped		1120	96	20	35.45
		4	OM_L	Straight		1120	96	96	96
		5	OM_m	Straight		1120	165	165	165
		6	OM_n	Sinewave		1120	96	0	-39
	3	7	OL_i	Straight		815	0	0	0
		8	OL_j	Draped		815	96	0	19.51
		9	OL_k	Draped		815	96	20	35.45
		10	OL_L	Straight		815	96	96	96
		11	OL_m	Straight		815	165	165	165
		12	OL_n	Sinewave		815	96	0	-39

Where: e_1 = middle eccentricity, e_2 = end eccentricity, e_3 = effective depth eccentricity, $OM_{sub.}$, $OL_{sub.}$: O= Reference steel beam, M=Initial Jacking's Stress (1120. MPa), L=Initial Jacking's Stress (814.6) MPa, i, j, k, L, m, and n.= Identification of eccentricity location. Note: negative sign mean e_3 is above the neutral axis of the section.

Materials and Testing: The steel section material depends on the specification of the selected I hot rolled steel section. The mechanical results of the section are listed in Table 2.

Table 2. Mechanical Characteristics

Standards	Sample No.	Yielding Stress (f_y) (MPa)	Ultimate Tensile Stress (f_u) (MPa)	Total Elongation (%)
	PL 10	360	507	15.9
	PL 20	356	524	25.2
	PL 30	369	507	17.5
	Average value	362	513	19.6
American ASTM A36/A36-2014 [13]		250≥	400≥	20≥

On the other hand, I-section can be defined as an element with a cross-sectional area similar to the letter H and has been considered the most commonly utilized structural member. It has been designed so that the flanges can provide the strength of the horizontal plate, whereas the web provides the strengthening in the vertical plate [9]. Table 3 lists the steel section's geometrical details, whereas the end steel plate may be welded directly to the steel beam with the use of welding. Those are 5 mm fillet welds that the E-7018 electrodes have made. Those end plates include 2 holes to allow the strand of the prestressing to be passing through them [11-13].

Table 3. The steel section's geometrical details [15].

Size mm	Thickness mm		Radius of curvature mm	Cross-sectional Area $mm^2 \times 10^2$	Mass per meter kg/m	Moment of inertia mm^4x10^4		Gyration Radius mm		Modulus of the Elastic section $mm^3 \times 10^3$	
H × B	t_1	t_2	R	Ag		I_{x-x}	I_{y-y}	r_x	r_y	S_x	S_y
248 ×124	8	5	12	32.68	25.7	3540	255	104	27.9	285	41.1

Prestressing Steel Strands

Two low relaxation 7-wire strands grade 270 have been used to strengthen the section and have been confirmed according to ASTM A 416/A416M-12 [14]. The strand characteristics have been illustrating in Fig. 2.

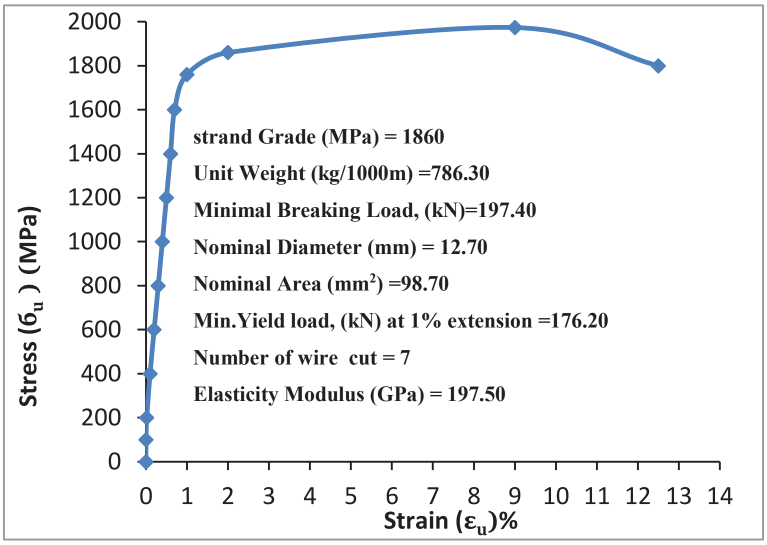


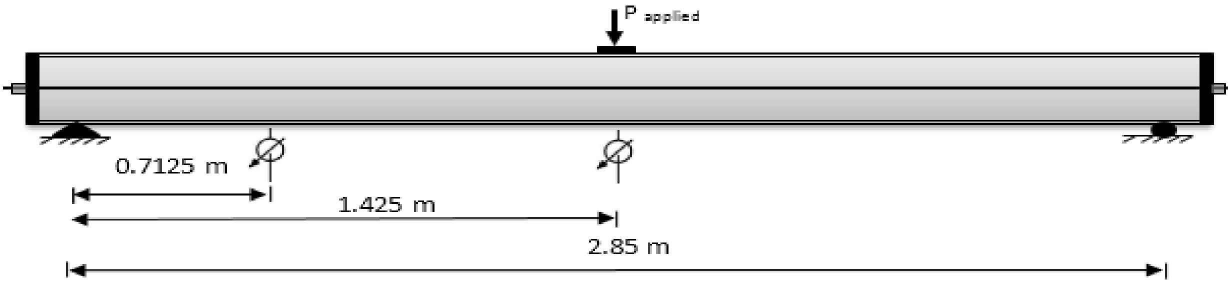
Figure 2. Stress -strain curve for strands.

Jacking Stresses: The strands have been fixed at different locations from the neutral axis of the steel section, varying from 0-165 mm. 275 and 200 bar. Jacking stress levels were used, and then the jacking stress was converted to 1120 and 815 MPa. A hydraulic jacking machine was used to pull the strands, as shown in Figure 3.

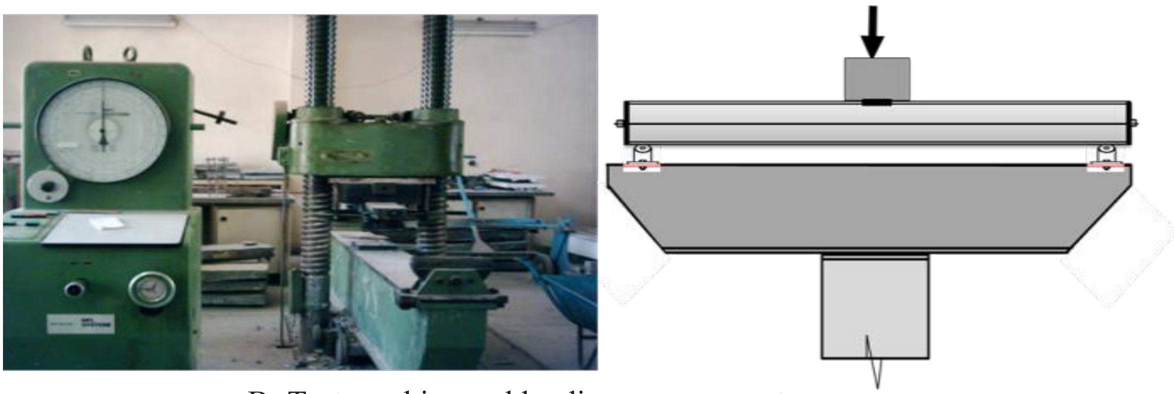
Measurements of the Load- Deflection and Test Process: The test of the steel beams have been conducted in the structural Lab. of Civil Eng. Dept., at the Engineering College, Al-Mustansiriyah University. The machine that has been utilized for the testing was the (MFL) universal hydraulic machine which has a capacity of (3000 kN). The steel beam has a 2850 mm clear span. A steel bearing plate (12×100 mm) has been utilized to convert the concentrated load to line load. Dial gauges with an accuracy of (0.01 mm) and a (30 mm) capacity have been fixed at the mid and quarter span. At first, a load of (5 kN) has been applied and removed to re-check zero reading cases. Measurements have been taken at every (10 kN) increment with a load step (2 kN). The measurements have been recorded up to the failure occurs where the applied load drops with an increase in the deformation, the instrumentation details, and the testing machine shown in Figure 4.

 https://doi.org/10.1051/e3sconf/202131803007

Figure 3. Prestressing hydraulic machine.



A-Locations of dial gauges for tested beams



B- Test machine and loading arrangements

Figure 4. A- Locations of dial gauges for tested sample, B- testing machine, and the loading arrangements.

Discussion of Results

Load Deflection Response: During the test, it can be observed that the load-deflection curves for strengthened samples are stiffer as compare with the reference sample. The percentage of stiffening increases with increasing in eccentricity locations. Due to an external prestressing strand, which improved the web resistance and bottom flange, it also contributes to resisting the applied load, as shown in **Error! Reference source not found.** and 6 [7].

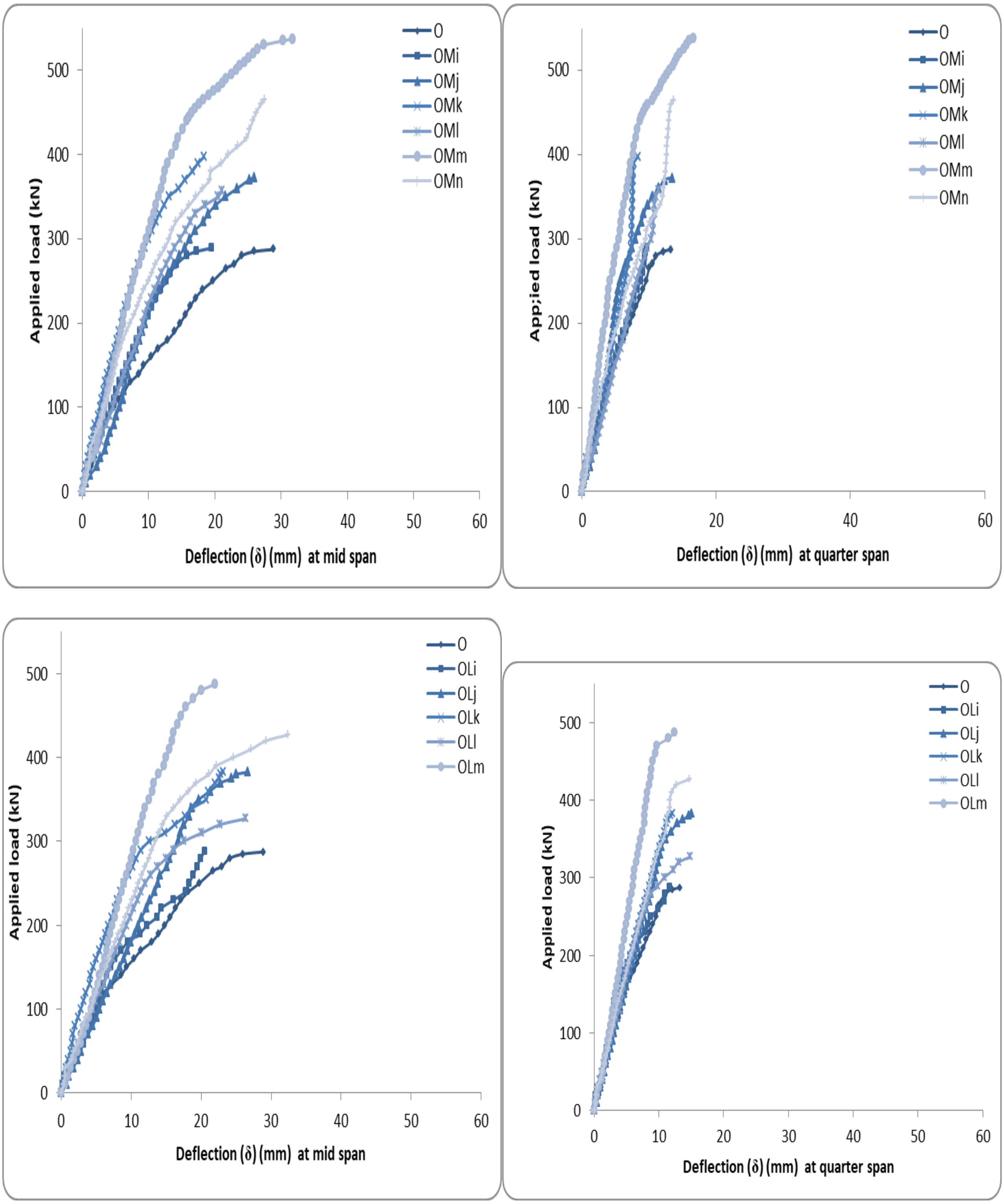


Figure 5. Load deflection curves for tested samples.

Ultimate Load Capacity: During the tests, it was found that ultimate load capacity increased to 0.52, 29.56, 38.26, 61.74, 24.35, and 86.96% with an increase in the locations of eccentricity from (0 mm to 165 mm) respectively at fpj =1120 MPa in comparison to reference sample, whereas, at fpj = 815 MPa, the increasing percentage in the maximal applied load is increased to 0.17, 26, 33,48.5, 13.74, and 69.6%). So, it was found that ultimate load capacity for tested samples was increased when the eccentricity was increased at the same fpj, that as a result of the existence of an external prestressing strand which enhanced bottom flange and web resistance and it played a role as well in enabling steel beams in resisting applied loads. [4,6,7]. The ultimate load capacity of the tested samples is listed in Table 4 and shown in Figure 6.

Table 4. Ultimate Load Capacity of tested beams.

Beams Number	Series Symbol	Jacking's Stresses, (fpj) (MPa)	Ultimate Exp. applied load (P_u) (kN)	Percentage of ultimate load (%), as compared with the reference
1	O	-------	287.5	0
2	OM_i	1120	289.0	0.52
3	OM_j	1120	372.5	29.57
4	OM_k	1120	397.5	38.26
5	OM_L	1120	357.5	24.35
6	OM_m	1120	537.5	86.96
7	OM_n	1120	465.0	61.74
8	OL_i	815	288.0	0.17
9	OL_j	815	362.5	26.09
10	OL_k	815	382.5	33.04
11	OL_L	815	327.0	13.74
12	OL_m	815	487.5	69.57
13	OL_n	815	427.0	48.52

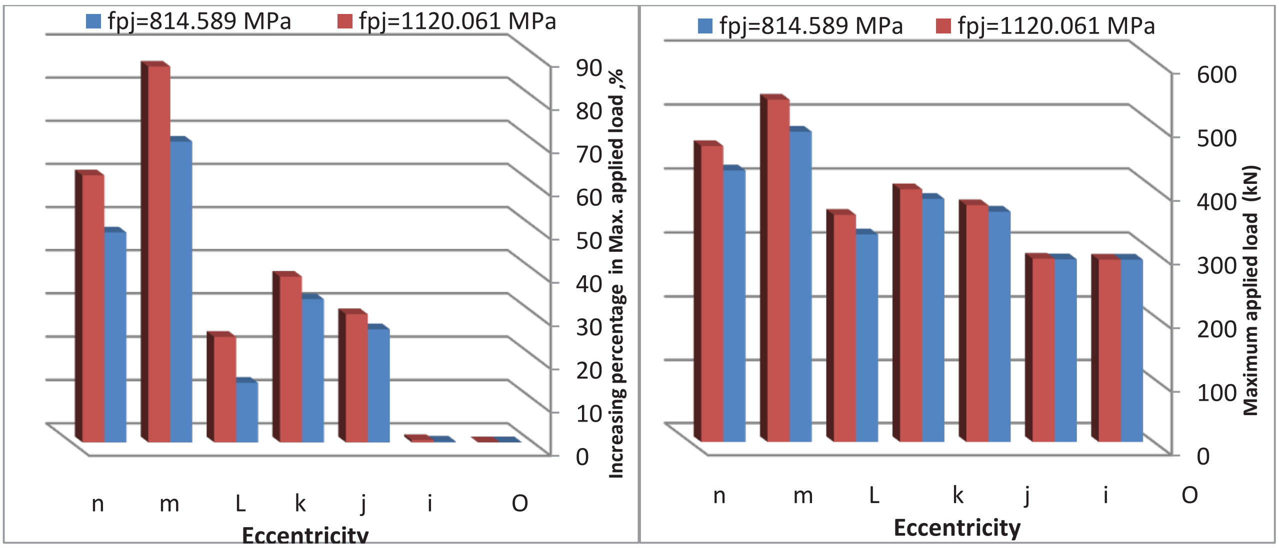


Figure 6. Ultimate load capacity and Percentages increase the ultimate load of tested beams.

Mid and Quarter Deflection Values: During the test, it was noted that at fpj =1120 MPa, the percentage increasing in mid-span deflection was decreased to 32.5, 10.3, 36.3,4.8, and 26.9% when the eccentricity increased from 0 to 165 mm, respectively, as compared with a reference sample, while, at fpj=815 MPa, the increasing percentage in mid-span deflection was decreased to 29.1, 7.75, 19.76, 11.98, 8.97, and 23.78% when the eccentricity increased from 0 to 165 mm, respectively as compared with reference sample too, and the ratio of the quarter span to mid-span deflection (δ quarter / δ mid) is about 0.528 and 0.497 when fpj is 1120 and 815 MPa respectively. So, the maximum deflection at mid-span is decreased when the eccentricity increased at the same fpj as a result of existing of prestressing strand, which improves the web resistance near the bottom flange, and it contributes with the steel section to withstand the applied loading as listed in Table 5 and shown Figures 7 to 11 [4,6,7].

Table 5. Increasing percentage in maximum deflection for tested beams.

Beams No.	Series Symbols	δmax. (mm) at		% increase in maximum deflection for tested beams %	(δquarter/δ mid)
		Quarter span	Midspan		
Ref.1	O	13.20	28.89	0	0.456
1	OM_i	9.70	19.50	-32.50	0.497
2	OM_j	13.45	26.00	-10.00	0.517
3	OM_k	8.35	18.40	-36.31	0.453
4	OM_L	11.40	21.12	-26.89	0.539
5	OM_m	16.60	31.75	9.90	0.522
6	OM_n	13.65	27.50	-4.81	0.496
7	OL_i	11.70	20.50	-29.04	0.570
8	OL_j	15.00	26.65	-7.75	0.562
9	OL_k	12.10	23.18	-19.76	0.522
10	OL_L	14.85	26.30	-8.97	0.564
11	OL_m	12.40	22.02	-23.78	0.563
12	OL_n	14.75	32.35	11.98	0.455

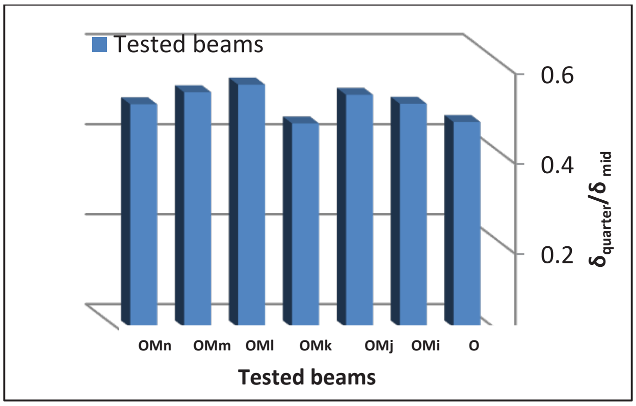


Figure 7. The ($\delta_{quarter}/\delta_{mid}$) for tested samples.

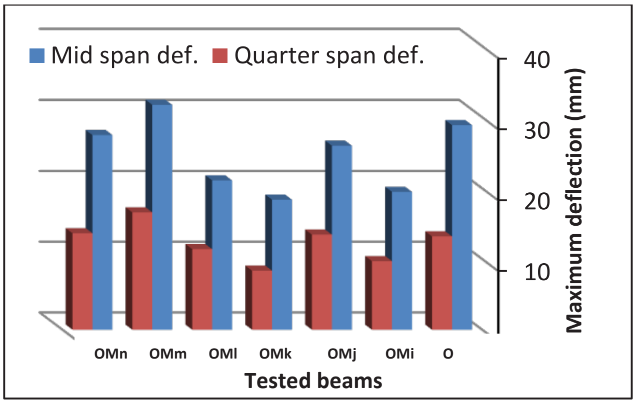


Figure 8. Deflection values of tested samples.

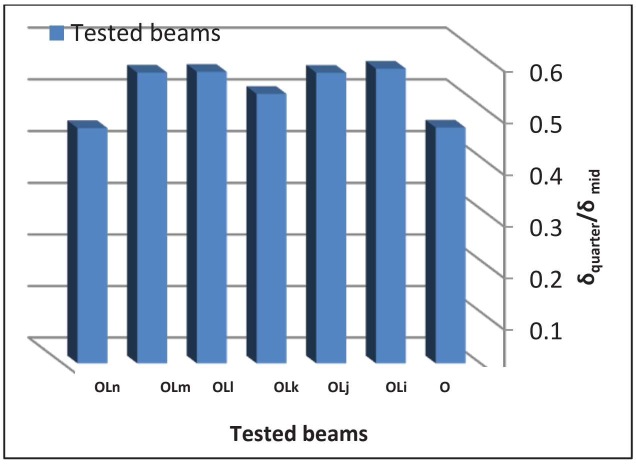


Figure 9. The (δ ($\delta_{quarter}/\delta_{mid}$) for tested samples.

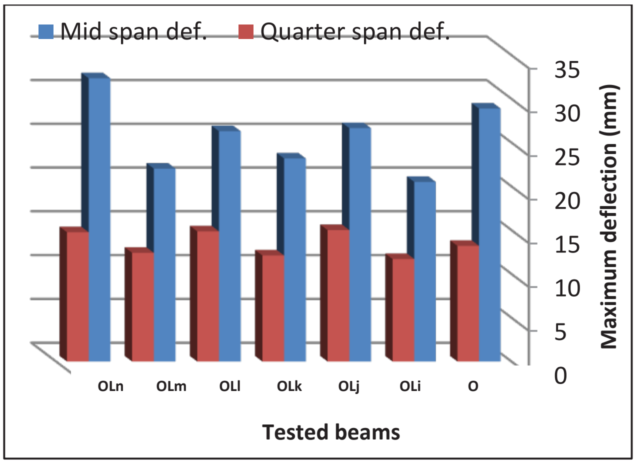


Figure 10. Deflection values of tested samples.

https://doi.org/10.1051/e3sconf/202131803007

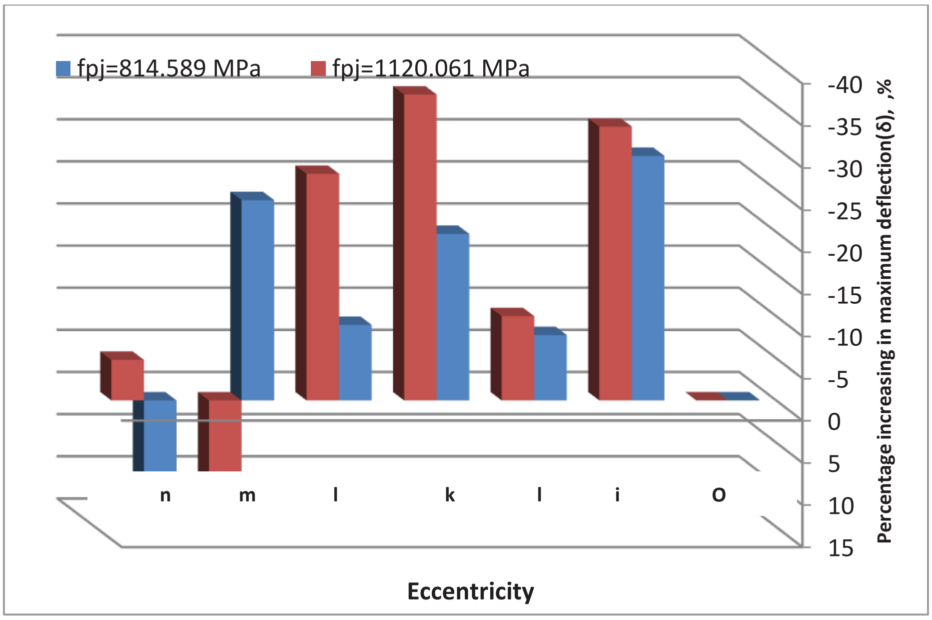


Figure 11. Increasing percentages in maximum deflection for tested samples.

Conclusions

Depending on the experimental results of tested samples, the summaries of findings are as follows.

- Load deflection response for the strengthened samples is stiffer as compared with the reference.
- Increasing the percentage in the ultimate load capacity was 0.347, 2.758, 3.921, 8.898, 9.326, and 10.256%, respectively, when the eccentricity rises from 0 to 165 mm under jacking stress of 1120 MPa.
- The increasing percentage in the ultimate load capacity was 0.17, 26, 33, 48.5, 13.7, and 69.56%, respectively, when the eccentricity increased from 0 to 165 mm under the jacking stress of 815 MPa.
- Maximum percentages of deflection were decreased to 4.88, 2.44, 20.62, 15.0, and 19.7% when the jacking stress increase from 815 to 1120 MPa
- The quarter's ratio to mid-span deflection ($\delta_{quarter}/\delta_{mid}$) is about 0.528 and 0.497 when jacking stress was 1120 MPa and 815 MPa, respectively.
- The increase in jacking stresses from 815 to 1120 MPa will not be preferable because it has a little increasing percentage in stiffening and behaviors compared with other tested beams at the same condition at jacking stress (fpj = 815 MPa).

Acknowledgment

The authors would like to thank the staff of Mustansiriyah University (www.uomustansiriyah.edu.iq), Baghdad-Iraq, for support in the present work.

References

[1] Ghallab, A. and Beeby, A.W., 2005. Factors affecting the external prestressing stress in externally strengthened prestressed concrete beams. Cement and Concrete Composites, 27(9-10), pp.945-957.
[2] Harajli, M.H., 1993. Strengthening of concrete beams by external prestressing. PCI Journal, 38(6), pp.76-88.
[3] Salamone, S., Bartoli, I., Phillips, R., Nucera, C. and Di Scalea, F.L., 2011. Health monitoring of prestressing tendons in posttensioned concrete bridges. Transportation research record, 2220(1), pp.21-27

. [4] Mahmoud, K.S., Rasheed, M.M. and Mohaisen, S.K., 2020. Strengthening of I-section steel beams by prestressing strands. In Key Engineering Materials (Vol. 857, pp. 169-176). Trans Tech Publications Ltd.
6] Yousif, M.A., Mahmoud, K.S. and Atshan, A.F., 2020. The Effect of prestressing strands on the shear behaviours of steel beams. In IOP Conference Series: Materials Science and Engineering (Vol. 671, No. 1, p. 012152). IOP Publishing.
[7] Mahmoud, K.S., Rasheed, M.M. and Khalaf, S., 2020. Strengthening behavior of steel beams under varied eccentricity locations and jacking stress. Journal of Engineering and Sustainable Development, 24(01).
[9] Sulamet-Ariobimo, R.D., Soedarsono, J.W., Sukarnoto, T., Rustandi, A., Mujalis, Y. and Prayitno, D., 2016. Tensile properties analysis of AA1100 aluminium and SS400 steel using different JIS tensile standard specimen. Journal of applied research and technology, 14(2), pp.148-153.
[10] Daly, A.F. and Woodward, R.J., 2000. Strengthening of concrete structures using external post-tensioning. Annex L, Rehabcon, Strategy for Maintenance and Rehabilitation. IPS-2000-0063. Available online at http://www. civil. ist. utl. pt/~ cristina/RREst/Annex_L. pdf.
[11] Roger Brockenbrough, P.E. and Merritt, F.S., 2011. Structural steel designer's handbook. McGraw-Hill Education.
[12] American Institute of Steel Construction, 2005. Steel construction manual. Amer Inst of Steel Construction.
[13] ASTM, A370., 2014. Standard testing method and definitions for mechanical testing of steel products. ASTM International, Pennsylvania, United States.
[14] Standard, A.S.T.M., 2012. C618-12a, Standard Specification for coal fly ash and raw or calcined natural Pozzolan for use in concrete. 2012 Annual Book of ASTM Standards; American Society for Testing and Materials (ASTM): West Conshocken, PA.
[15] Mahmoud, K.S., Yousif, M.A. and Rasheed, M.M., 2020, February. Effect of external prestressing strands on the Yielding Stage behaviours of steel beams. In IOP Conference Series: Materials Science and Engineering (Vol. 737, No. 1, p. 012032). IOP Publishing.