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STRENGTHENING BEHAVIOR OF STEEL BEAMS UNDER VARIED ECCENTRICITY LOCATIONS AND JACKING STRESS

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Abstract: Thirteen simply supported steel beams were tested to explain the effect of strengthening by external prestressing strands. All of these beams have the same steel section, clear span length and strengthening by two external prestressing strands. The tested beams are divided into two categories according to existing of external prestressing strands, the first category consists of one steel beam as a reference, while, the second group deals with steel beams strengthening by external prestressing strands are divided into two groups according to jacking stress. Each group consists of six steel beams divided according to the eccentricity location of prestressing strand ranging from (0 to 165) mm at jacking stress1120.061 MPa and 814.589 MPa respectively. During the teste, it was found that the load deflection curves behavior for the beams strengthening by external prestressing strand are stiffer than the reference beams and the percentage of stiffening is slightly increase with increasing the jacking stress at constant eccentricity. Also, the maximum applied load with increase slightly rising as eccentricity increased at mid span. On the other hand the increasing percentage in maximum deflection decreases when the jacking stress increase from (814.589 to 1120.061) MPa at constant eccentricity locations.

Keyword: *Deflection behavior, strengthening of steel beams, prestressing strand, eccentricity location and jacking stress.*

سلوك التقوية للعتبات الفولاذية في حالة تغير موقع حديد السحب واجهاده.

الخلاصة: في هذه الدراسة تم أجراء التحري العملي على تجميع و فحص ثلاثة عشر نموذج من العتبات الفولاذية بسيطة الاسناد لدراسة تاثير التقوية باسستخدام تقنية الاجهاد المسبق الجهد على تصرف هذة العتبات. جميع العتبات الفولاذية لها نفس مساحة المقطع وطول الفضاء الصافي والمقواة منها صنعت بنفس نوع الحديد المسبق الجهد عدد اثنين وبقطر (12.7) ملم. قسمت النماذج الى مجموعتين رئيسيتين حسب وجود الحديد المسبق الجهد، حيث تحتوي المجموعة الاولى على نموذج فولاذي واحد غير حاوي على حديد مسبق الجهد واعتبر كمرجع (مصدر) للمقارنة مع النماذج الاخرى. بينما قسمت المجوعة الثانية الى مجموعتين حسب قيمة اجهاد السحب حيث يترواح قيمتهما بين (814.589 نت/ملم^2 و 1120.061 نت/ملم^2) على التوالي وتحوي كل مجموعة على ستة نماذج موزعة حسب موقع الحديد المسبق الجهد في العتبة الفولاذية .من خلال الفحص وجد انة نتائج تصرف منحني الحمل الى الانحدار للعتبات الفولاذية المقواة بحديد المسبق الجهد يكون اكثر انحدارا من العتبة الفولاذية المرجعية الغير مقواة بالحديد المسبق الجهد (المصدر) وان نسبة الانحدار والحمل الاعظم تزداد بنسبة ضئيلة تزداد بزيادة قيمة اجهاد السحب المسلط تحت نفس موقع الحديد المسبق الجهد. من ناحية اخرى فان نسبة الزيادة في الانحراف للعتبات الفولاذية المفحوصة تقل عند زيادة حسب قيمة اجهاد السحب من (814.589 نت/ملم^2 و 1120.061 نت/ملم^2) تحت نفس موقع الحديد المسبق الجهد.

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1. Introduction.

Steel is the most important construction material at the present time due to a high strength to weight ratio, uniform and homogeneous properties, high ductility, can be easily recycled, high elastic modules, high amount of energy absorption in seismic action, easier, quicker to fabricate and erect. Dimension of beams and column in steel frame can be reduced because of the low ultimate load to self-weight ratio. As a result self-weight ratio between reinforced concrete and steel building can be reduced down to 1/10[1].

Producing permanent stress in the structural member to improve resistance against service loads is called as prestress or prestressing. Prestressing is a purposeful phenomenon aims to generate internal stress in structural member to counter balance stressed caused by external loads so as to enhance performance and durability of the structural members [2, 3].

2. External Prestressing.

External prestressing refers to a posttensioning method in which tendons are placed on the outside of a structural member and prestressing forces are transferred to the structural member through anchorages and deviators. It is a wonderful method in strengthening and rehabilitation of old structural members, generally it is used for developing buildings and bridges for fatigue state and over loading design expected[4].
The concept of external prestressing of steel beams is achieved by means of high strength strand anchored at the two ends of steel beams. The strand profile can be fixed on the internal span length by a specific number of saddles which it prevent slipping occurs in the strand and help to give the design profile shape of the external prestressing strand (draped, or parabolic) depending on the applied load and bending moment diagrams introduced [5] as shown in Fig. (1), then the strand was tensioned simultaneously from one ends using the same jacking force used in tensioning the prestressing strand. Special care must be taken to balance the prestressing force in the strands to avoid biaxial bending and distortion of the specimens [8]

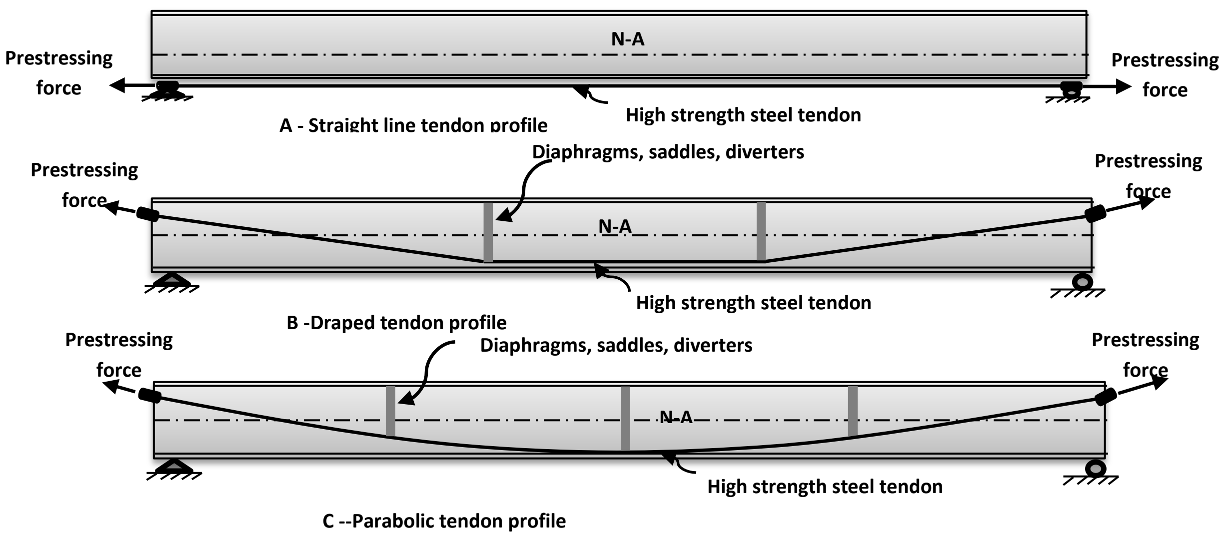


Figure (1) Strenthening by external high strength steel strands.

3. Research Significance.

Steel structures have been used in the construction industry for centuries. Many modification and developments have been made to improve the performance of steel properties by adding a new material to the row material of steel manufactures. Engineers have found new mothed to improve of the original steel section strengths by external prestressing strand. The main objective of the work described in this study is to investigate and to get more information and more understanding about the deflection behavior of I-steel beams strengthening by external prestressing strands and compared with the reference steel beam.

4. Tested Program.

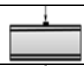
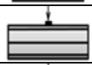
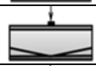
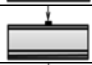
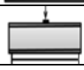
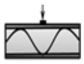
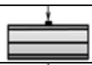
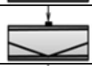
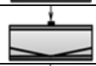
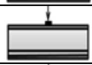
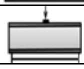
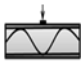
4.1 Description of Specimens.

The variable parameters included in this study are focused mainly on the existence of prestressing strands and layout of prestressing level (i.e. the eccentricity of the prestressing strand (e)). Six simply supported steel beams strengthening by external prestressing under one point load and one reference beam without prestressing strands were tested. All specimens have same I-section, two external prestressing strands of (12.7mm) diameter, the ends steel plate (25x125x250) mm and clear span length (2850) mm.

4.2 Specimens Identification and Retrofitting Schemes.

To identify the tested specimens with different retrofitting schemes, which it depending on different parameters such as amount of prestressing jacking stress and the layout of prestressing strands, the following system is used:
O: refers to the reference steel beam without any prestressing strand.
OX1X2X3X4: refers to the strengthened steel beam by prestressing strand.
Where
X1: refers to initial jacking stress (fPj). Defined by M or L.
M= initial prestressing jacking stress of 1120 MPa.
L= initial prestressing jacking stress of 815 MPa.
X2= eccentricity of prestressing strand at mid span
X3= eccentricity of prestressing strand at end span
X4= eccentricity of prestressing strand at critical effective depth for shear span
All definition of samples can be listed in flow-chart shown in Fig.(2) and table (1) illustrates the used specimen identification system used based on specimen identification pattern described, while, the details of test specimens are shown in Fig. (3).

Table (1) Description details of tested specimens

Categories	Groups	Beams N0.	Serial Symbols	Prestressing Strand Profile	Beams Shape	Jacking Stress(fpj), MPa	Eccentricity (e), (mm)		
							e_1*	e_2**	e_3***
1	1	Ref.	O	----		----	----	----	----
2	2	1	OM000	Straight with $e_1e_2e_3$ (000)		1120.061	0	0	0
		2	OM101	Draped with $e_1e_2e_3$(101)		1120.061	96	0	19.514
		3	OM112	Draped with $e_1e_2e_3$ (112)		1120.061	96	20	35.45
		4	OM123	Straight with $e_1e_2e_3$ (123)		1120.061	96	96	96
		5	OM234	Straight with $e_1e_2e_3$ (234)		1120.061	165	165	165
		6	OM105	Sinewave profile with $e_1e_2e_3$ (105)		1120.061	96	0	-39
	3	7	OL000	Straight with $e_1e_2e_3$ (000)		814.589	0	0	0
		8	OL101	Draped with $e_1e_2e_3$ (101)		814.589	96	0	19.514
		9	OL112	Draped with $e_1e_2e_3$ (112)		814.589	96	20	35.45
		10	OL123	Straight with $e_1e_2e_3$ (123)		814.589	96	96	96
		11	OL234	Straight with $e_1e_2e_3$ (234)		814.589	165	165	165
		12	OL105	Sinewave profile with $e_1e_2e_3$ (105)		814.589	96	0	-39

Where: - e_1* = Eccentricity at mid span, e_2** = Eccentricity at end span, e_3*** = Eccentricity at effective depth for shear zone.

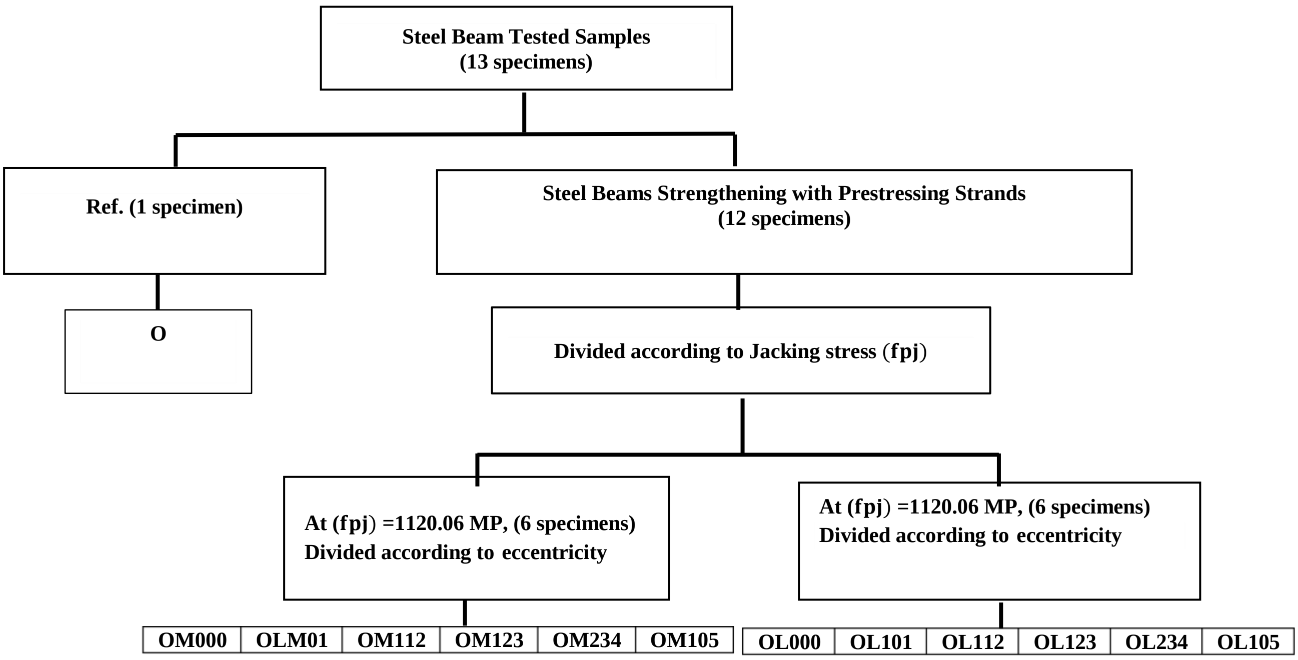


Figure (2) Flow chart of the experimental details of tested beams

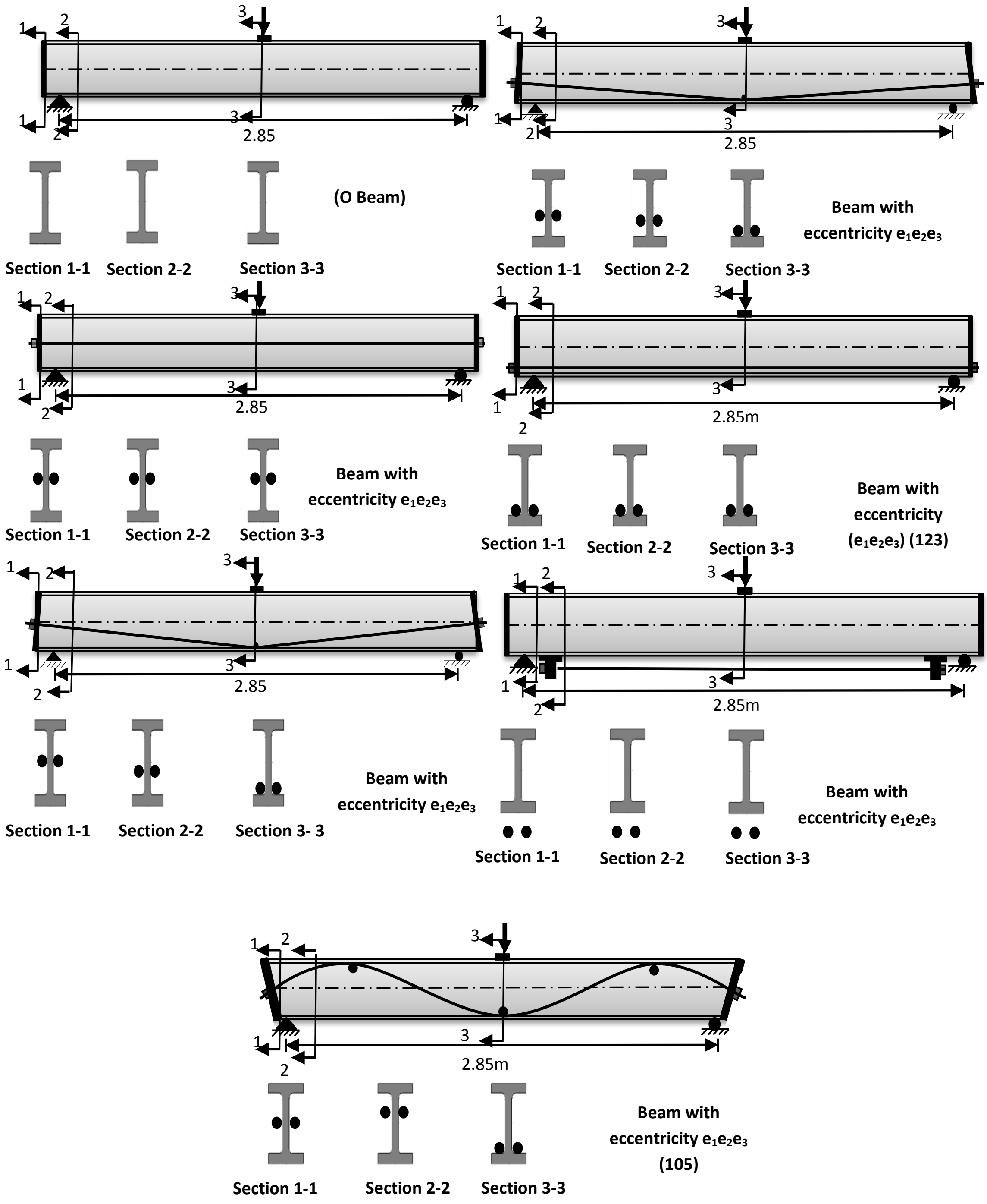


Figure (3) Details of tested beams

4.3 Material properties of the test specimens and fabrication.

4.3.1 Structural steel type.

JIS G 3101 is a Japanese material standard for hot Rolled steel plates, sheets, strips for general structural usage, according to this specification, the thickness for this SS400 material starts from 6 mm to 120 mm, the chemical composition of SS400 steels is listed in table (2), while the mechanical properties of SS400 Steels is listed in table (3) [7,8].

Table (2) Chemical Composition for SS400 Specification [7, 8]

Grad	Chemical composition,% by weight				
	Carbon Max.	Silicon Max.	Manganese Max.	Phosphorus Max.	Sulfur Max.
SS400	*	*	*	0.05	0.05

* = Content is not controlled

Table (3) Mechanical Properties for SS400 Specification [7, 8]

Grade	Min .Yielding Strength according to Thickness (MPa)		Tensile strength,	Elongation according to Thickness, (mm)			Min Impact resistance,
	not over 16 mm	over 16 mm	(MPa)	not over 5 mm	5 to 16 mm	over 16 mm	(J)
SS400	245	235	400-510	21	17	19	*

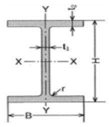
* = Content is not controlled

4.3.2 Structural Steel Section, Fabrication and Plate Tests.

I-shape is a structural element which has a cross section forms the letter H and is the most widely used structural member. It is designed so that its flanges provide strength in a horizontal plane, while the web gives strength in a vertical plane [9, 10]. Hot rolled I-steel section 248 x 124 with 25.7 kg/m mass per meter was used in this study.

All welds are 5 mm fillet made with E7018 electrodes. The end plates have two holes to allow to the prestressing strand to pass through them. End plate fabricated normally to the strand profile area as possible as to reduce the stress concentration around the hole in the end plate and its can be problematic if the structural member is already under strength also local stiffeners may be required at end plate to prevent local buckling occur in the end plate [11].

Table (4) Dimension and properties of steel section [11]



Size mm	Thickness mm		Radius of curvature mm	Cross sectional area mm^2x10^2	Mass per meter Kg/m	Moment of inertia mm^4x10^4		Radius of gyration mm		Elastic section modulus $mm^3x\ 10^3$	
H x B	$t1$	$t2$	r	Ag		$Ix.x$	$Iy.y$	rx	ry	Sx	Sy
248 x124	5	8	12	32.68	25.7	3540	255	104	27.9	285	41.1

The direct tension test was performed in the National Center for Constriction Laboratories and Research (NCCLR), the used machine for tests is (Zwick/Roell) universal hydraulic machine of (1200kN) capacity which used in testing direct tension steel symbols. The results of three specimens testing are listed in table (5) and the stress strain curve of the three specimens testing is shown in Fig. (4).

Table (5) Material properties of steel test symbols based on direct tension test

Standards Specifications	Symbols No.	Min .Yielding Strength(F_y), MPa	Min. Ultimate Tensile strength (f_u), MPa	Total Elongation, %
NCCLR according to ASTM A36/ A36-2005[12]	PL 10	356	524	25.2
	PL 20	369	507	17.5
	PL 30	360	507	15.9
	Average value	362	513	19.6
American ASTM A36/ A36-2014[13]		≥250	≥400	≥20 *
Japan of JIS G 3101[7]		≥245	≥400	≥17
Teste of results		Conforming	Conforming	Conforming

* For wide flange shapes with flange thickness over (75 mm),the (550 MPa) maximum tensile strength does not applied and the minimum elongation of 19 % is applied [12,13]

So, one can be observed that all results value obtained from NCCLR were conforming to the technical standards specifications.

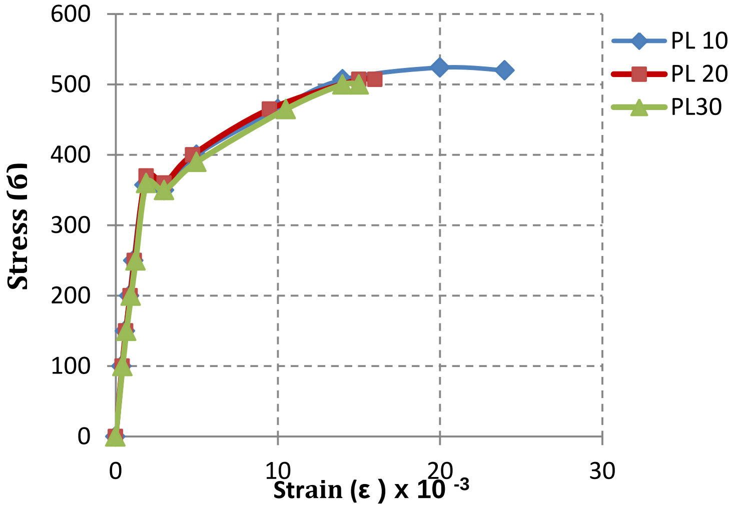
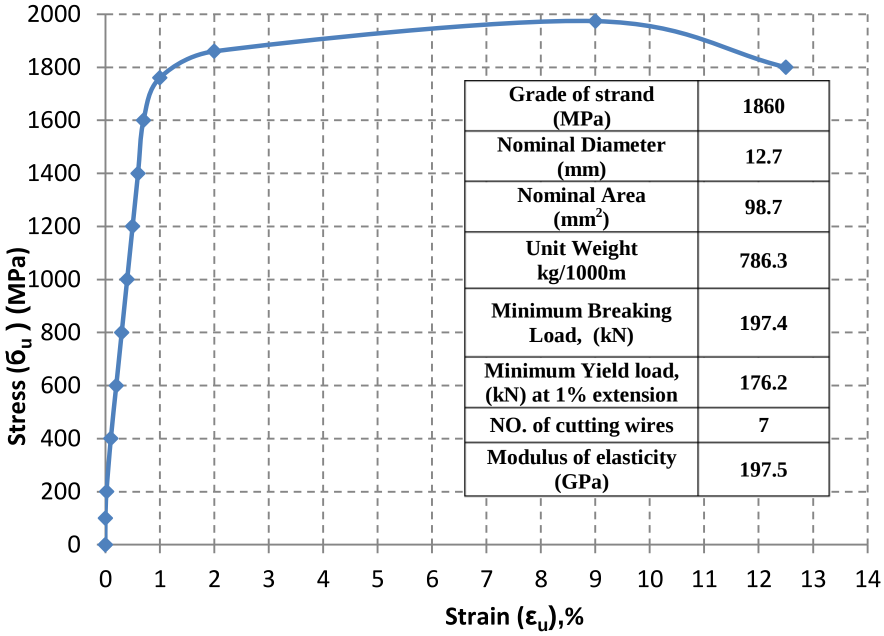


Figure (4) stress strain curve of steel plate specimens

4.3.3 Prestressing Steel Strands.

4.3.3.1 Prestressing Steel Strands test.

Prestressing strand grade 270 low relaxation Seven-wire strands of (12.7mm) nominal diameter which manufactured by national meatal manufacturing and casting company (MAADANIYAH, Kingdom of Saudi Arabia) which used in this study. They strand was tested in the National Center for Constriction Laboratories and Research (NCCLR) and confirming to ASTM A416/ A416M-12a [14]·The properties of the strand is shown in Fig. (5).



Grade of strand (MPa)	**1860**
Nominal Diameter (mm)	**12.7**
Nominal Area (mm^2)	**98.7**
Unit Weight kg/1000m	**786.3**
Minimum Breaking Load, (kN)	**197.4**
Minimum Yield load, (kN) at 1% extension	**176.2**
NO. of cutting wires	**7**
Modulus of elasticity (GPa)	**197.5**

Figure (5) stress -strain curve of grade 270 low relaxation seven wire strands at (12.7 mm) diameter

4.3.3.2 Jacking stress applied.

Two low relaxation seven wire strands at (12.7 mm) diameter were selected and arranged at different location of eccentricity ranging from (0 to 165) through the longitudinal axis of the tested beams. The two strands were tension simultaneously from one end with gradually increasing in jacking stress until reaching to denoted jacking stress to balance the prestressing stresses and avoid the biaxial bending stress which introduce in the steel section during applied jacking stress(fp_j).

Prestressing levels were applied at (275 and 200 bar), then it's converted to (814.589 MPa and 1120.061 MPa) respectively.

The hydraulic machine which it used in this study, consists of motor-driven hydraulic pump, hydraulic pipes attached to the four hydraulic jacks and to the single strand jack and measuring gauge to notice the applied pressure with (bar unit) which graduated from 0 to 600 bar, as shown in Fig. (6).

Plate (6) Hydraulic machine and single strand jack prestressing strand. (a) Hydraulic machine and measuring gauge at (200 bar), (b) Hydraulic machine and measuring gauge at (275 bar), (c) the single strand jack and Hydraulic machine with hydraulic pipes attached to the four hydraulic jacks, (d) single jacking prestressing strand.

4.4 Deflection Measurements.

Deflection measurements are taken at two points by using two dial gauges of (0.01mm) accuracy with (30 mm) capacity. For each tested beam, one dial gauge is placed under concentrated point load at mid span, while, the other one is placed at quarter span. The locations of the dial gauges are shown in Fig. (7).

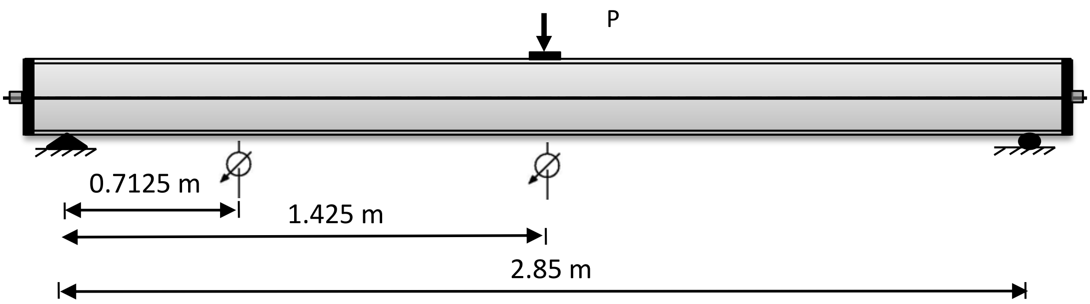


Figure (7) Locations of dial gauges for tested beams

4.5 Load Measurements and Testing Procedure.

Steel beams test were conducted in the Structural Laboratory of the Civil Engineering Department, at the College of Engineering, University of Al-Mustansiriyah. The used machine for tests is (MFL) universal hydraulic machine of (3000kN) capacity. Simply supported steel beams are tested under one concentrated point load at mid span, steel beam are placed with clear span of (2850mm). Steel bearing plate (12x100) mm is used to convert the applied load to line load over the steel beam surface,

At time of test, steel beam is placed over supports; deflection dial gauges of (0.01 mm) accuracy with (30 mm) capacity are fixed in the designated locations at mid and quarter span. All dial gauges were rested to zero. Load of (5kN) is applied and removed in order to recheck the zero readings. All the tests are carried out under load step of (2kN) and measurements are taken at each (10kN) increment, dial gauges are taken at each increment. Measurements are recorded until the failure of steel beams at which the applied load is drop with increasing deformation, the test machine and instrumentation details show in Fig.(8)

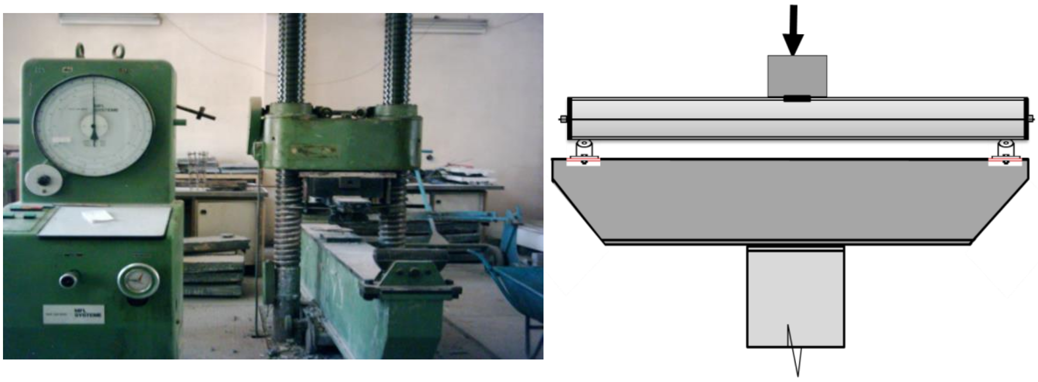


Figure (8) Test machine and loading arrangements

5. Experimental Parametric Studies.

The experimental study has been carried out to investigate the effect of jacking stress on the deflection behaviors of steel beams strengthening by external prestressing strand under one point load. The experimental deflection information's for tested beams were monitored through two dial gauges fixed at quarter and mid span length during applied load until failure occurs. Full experimental results of tested beams are illustrated in table (6).

Table (6) Experimental load deflection results of tested beams

Categories	Groups	Beams No*.	Series Symbols	Max. Exp. applied load (Pu),(kN)	Max. Exp. deflection at quarter span (mm))	Max. Exp. deflection at mid span (mm)
1	1	Ref.	O	287.50	13.200	28.890
2	2	1	OM000	289.00	9.700	19.500
		2	OM101	372.50	13.450	26.000
		3	OM112	397.50	8.350	18.400
		4	OM123	357.50	11.400	21.120
		5	OM234	537.50	16.600	31.750
		6	OM105	465.00	13.650	27.500
	3	7	OL000	288.00	11.700	20.500
		8	OL101	362.50	15.000	26.650
		9	OL112	382.50	12.100	23.180
		10	OL123	327.00	14.850	26.300
		11	OL234	487.50	12.400	22.020
		12	OL105	427.00	14.750	32.350

5.1 Load Deflection Response.

In order to inspect the effect of the jacking stress on the load deflection behavior of tested beams, the beams are divided in two groups according to jacking stress (fp_j=1120.061MPa and 814.589 MPa). Each group is subdivided to six symbols according to the location of eccentricity which change from (0 to 165) mm. It was can be observed that the load deflection curves behavior for the beams strengthening by external prestressing strand are stiffer than the reference beams and the percentage of stiffening is slightly increase with increasing the jacking stress (fp_j) at constant eccentricity (e). Since the increasing in jacking stress from (814.589 to 1120.061 MPa) will be not preferable to be use because it has a little increasing percentage in stiffening and behaviors as compare with other tested beams at same condition but at different jacking stress, as shown in Fig.(9) .

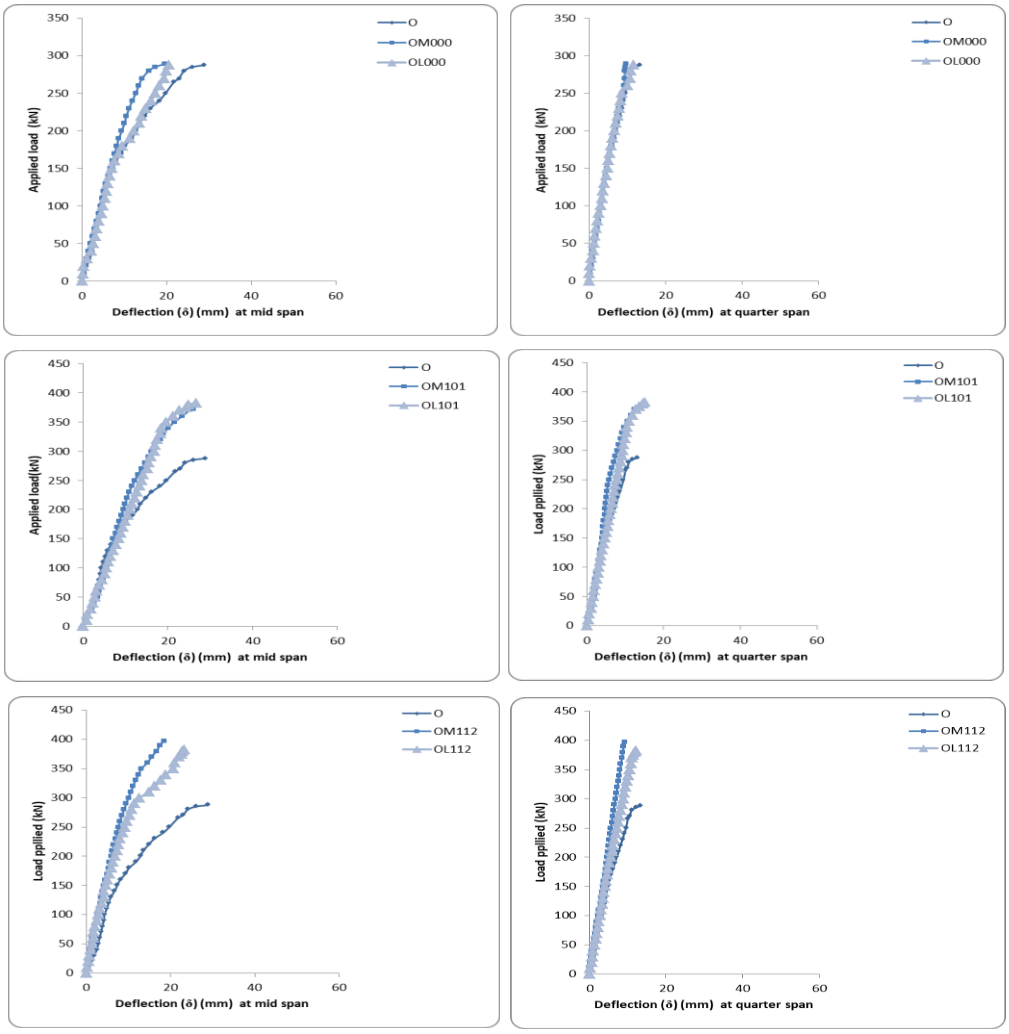


Figure (9) Effect of jacking stress (fp_j) on load deflection curves of tested beam at different eccentricity as compare with reference

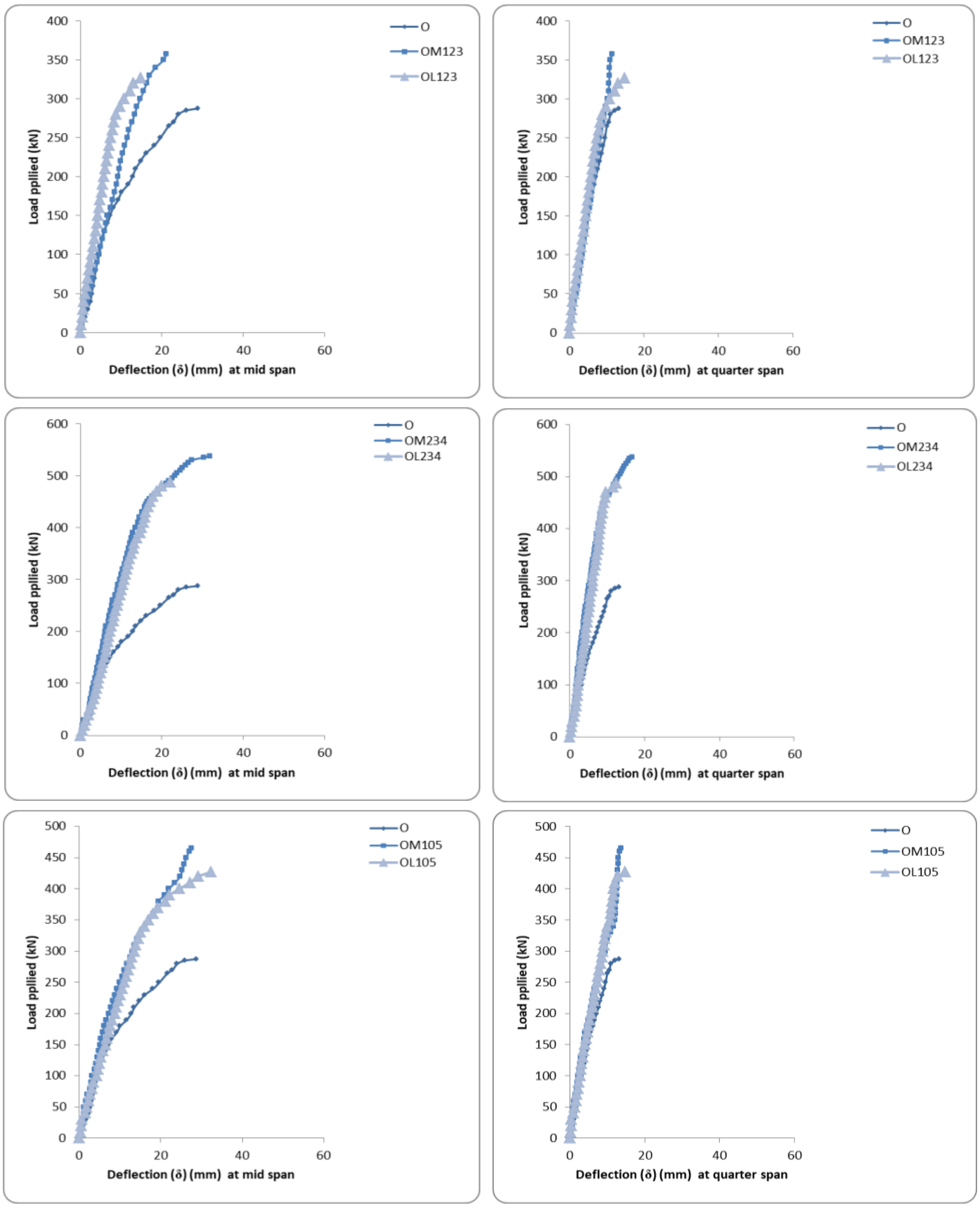


Figure (9) continue

5.2 Maximum Applied Load of the Tested Beams.

To study the influence of jacking stress (fp_j) on the maximum applied load of the steel beams, the beams are tested at different jacking stress(fp_j) with constant location of eccentricity ranging from (0 to 165) mm. During the tests it was found that the increasing percentage in maximum load capacity increase to 0.347 %, 2.758%, 3.921%, 8.898 %, 9.326% and 10.256% when the jacking stress increasing from (814.589 to 1120.061) MPa at constant eccentricity locations change from (0 to 165) mm respectively, as listed in table (6). So, one can be observed that the percentage increasing in maximum load applied increase nearly with increase the jacking stress for same eccentricity locations ranging from (0 to 165) and the increasing were slightly rising as eccentricity increased at mid span. Since the increasing in jacking stress from (814.589 to 1120.061 MPa) will be not preferable to be use because it has a little percentage increasing in maximum load applied as compare with other tested beams at same condition but at jacking stress (fp_j =814.589 MPa), on the other hand, it was more expensive, reduction in time, cost and more safety to use as compared with jacking stress (fp_j =814.589 MPa). The maximum load applied and percentage increasing of a maximum load applied at different location of eccentricity and jacking are shown in Fig.(10) and Fig. (11).

Table (6) Increasing percentage in maximum applied load of tested beams

Beams No.	Series Symbols	Jacking Stress(fp_j) , (MPa)	Maximum applied load, (kN)	Percentage Increases in maximum applied load, (%)
1	OL000	814.589	288.000	0
2	OM000	1120.061	289.000	0.347
3	OL101	814.589	362.500	0
4	OM101	1120.061	372.500	2.758
5	OL112	814.589	382.500	0
6	OM112	1120.061	397.500	3.921
7	OL123	814.589	327.000	0
8	OM123	1120.061	357.500	9.327
9	OL234	814.589	487.500	0
10	OM234	1120.061	537.500	10.256
11	OL105	814.589	427000	0
12	OM105	1120.061	465.000	8.899

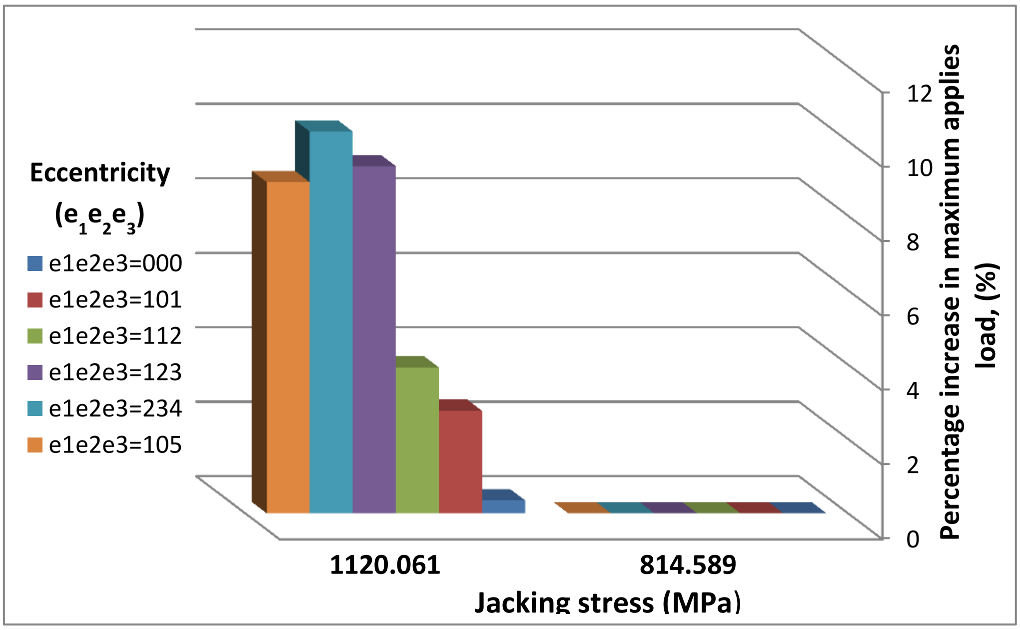


Figure (11) Percentage increasing in maximum applied load of tested beams at different values of eccentricity and jacking stress as compare with fpj=814.589 MPa

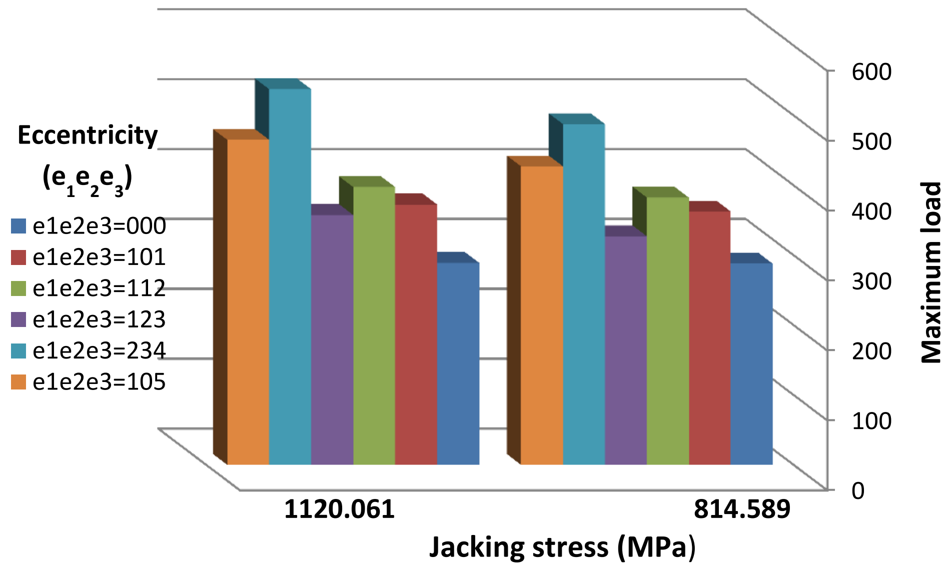


Figure (10) Maximum load applied of tested beams at different values of eccentricity and jacking stress

5.3 Deflection Values of the Tested Beams

During the tests, it was found that the increasing percentage in maximum deflection decrease to-4.878 %, -2.439%, -20.621%, -14.992 % , -19.695% and 44.187% when the jacking stress increase from (814.589 to 1120.061) MPa at constant eccentricity locations increased from (0 to 165) mm respectively.
So one can be observed that the increasing percentage in maximum deflection decrease with increase the jacking stress for same eccentricity locations ranging from (0 to 165) except beam with eccentricity (234) because bottom flanges in these beams lie at constant eccentricity for all bottom flange due to improve the bottom flange area and the bottom flange strain and the percentage increasing increased with increased the jacking stress.

The maximum deflection and increasing percentage in maximum deflection for tested beams are listed in table (7), while, the figures of theirs relations are shown in Fig. (12) to Fig.(14) respectively.

Table (7) Maximum experimental deflection results of tested beams

Beams No.	Series Symbols	Maximum Exp. deflection (δ)(mm) at		Quarter span deflection to mid span deflection ratio ($\delta_{quarter}/\delta_{mid}$)	Percentage increase in mid span deflection of tested beams,%
		Quarter span	Mid span		
1	OL000	11.700	20.500	0.57	0
2	OM000	9.700	19.500	0.497	-4.878
3	OL101	15.000	26.650	0.562	0

4	OM101	13.450	26.000	0.517	-2.439
5	OL112	12.100	23.180	0.522	0
6	OM112	8.350	18.400	0.453	-20.621
7	OL123	14.850	26.300	0.564	0
8	OM123	11.400	21.120	0.539	-19.695
9	OL234	12.400	22.020	0.563	0
10	OM234	16.600	31.750	0.522	44.187
11	OL105	14.750	32.350	0.455	0
12	OM105	13.650	27.500	0.496	-14.992

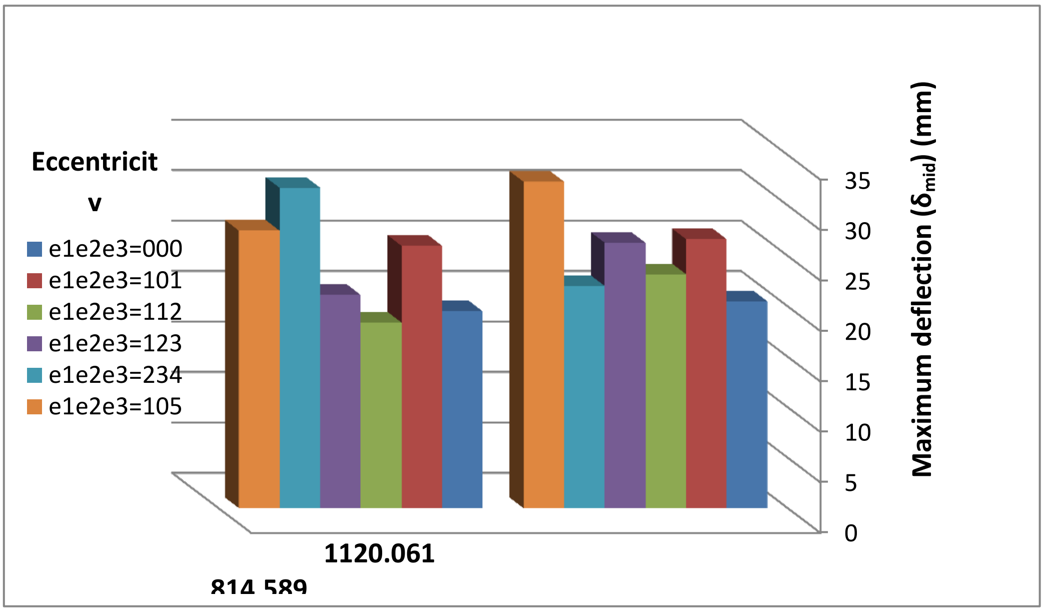


Figure (12) Maximum deflection of tested beams at different location of eccentricity location and jacking stress

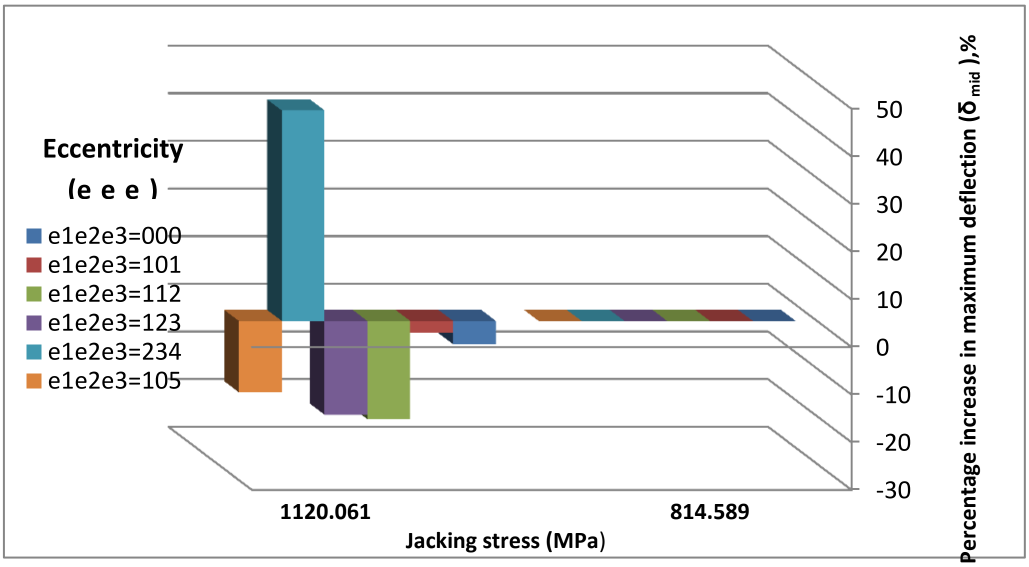


Figure (13) Percentage increase in maximum deflection of tested beams at different location of eccentricity location as compared with fpj =814.589 MPa

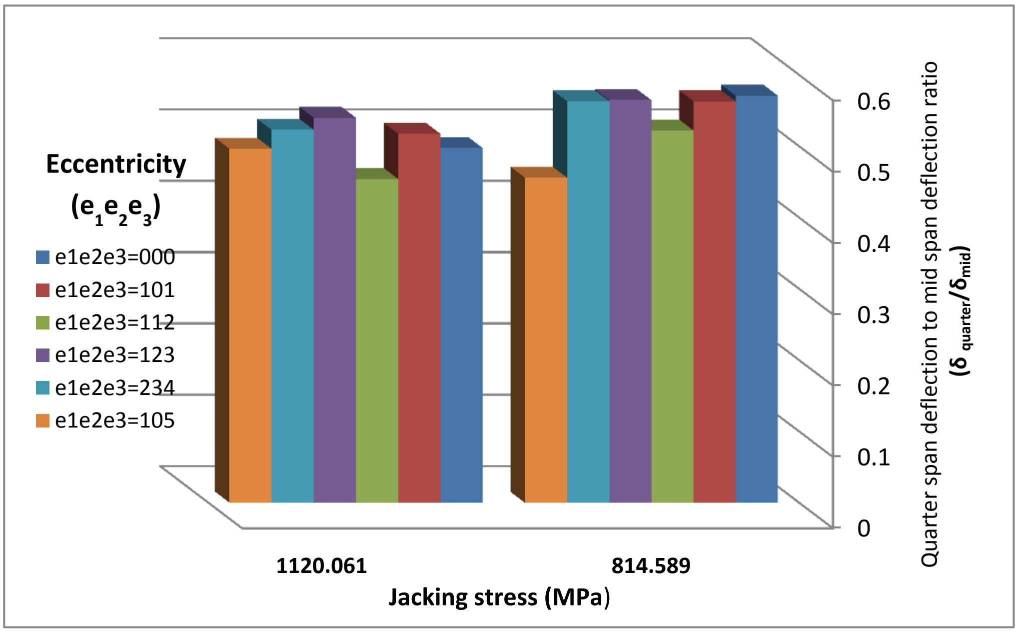


Figure (14) Quarter span deflection to mid span deflection ratio ($\delta_{quarter}/\delta_{mid}$) for tested beams at different location of eccentricity location and jacking stress

6. Conclusions.

Based on the tested beams results of this experimental investigation on the deflection behavior of steel beams strengthening by prestressing strands, the following conclusions are drawn.

1. The load deflection curves behavior for the beams strengthening by external prestressing strand are stiffer than the reference beams and the percentage of stiffening is slightly increase with increasing the jacking stress (fp_j) at constant eccentricity (e).
2. The increasing percentage in maximum load capacity increase to 0.347 %, 2.758%, 3.921%, 8.898 %, 9.326% and 10.256% when the jacking stress increasing from (814.589 to 1120.061) MPa at constant eccentricity locations change from (0 to 165) mm respectively. So the percentage increasing in maximum load applied increase nearly with increase the jacking stress for same eccentricity locations ranging from (0 to 165) and the increasing were slightly rising as eccentricity increased at mid span.
3. The increasing percentage in maximum deflection decrease to -4.878 %, -2.439%, -20.621%, -14.992 % , -19.695% and 44.187% when the jacking stress increase from (814.589 to 1120.061) MPa at constant eccentricity locations increased from (0 to 165) mm respectively
4. The quarter span deflection to mid span deflection ratio ($\delta_{quarter}/\delta_{mid}$) with bout (0.528) at jacking stress (fp_j=1120.061 MPa), while the quarter span deflection to mid span deflection ratio ($\delta_{quarter}/\delta_{mid}$) with average value bout (0.497) (fp_j=814.589 MPa).

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