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SHEAR BEHAVIOR OF STEEL BEAMS STRENGTHENING BY PRESTRESSING STRANDS

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Abstract: Seven simply supported steel beams were tested to explain the effect of existence of external prestressing strands on the shear behavior of steel beams. 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 groups according to existence of external prestressing strands, the first group consists of one steel beam as a reference, while, the second group deals with six steel beams strengthening by external prestressing strands divided according to the eccentricity location of prestressing strand (e) ranging from (0 to 165) mm at jacking stress (fpj=814.589 MPa). During the test, it was found that the shear load strain curves for tested beams were slightly stiffer than the reference beams and the percentage of stiffening increase with increase the eccentricity locations from the effective depth for shear zone, while, the maximum shear load increased about (0.173%, 26.086%, 33.043%, 48.521%, 13.739% and 69.565%) with increase the eccentricity location from (0 to 165) mm respectively as compare with the reference beam. On the other hand the maximum shear strain was decreased to 0.507%, 1.015%, 20.304%, 1.776% 25.634% and 28.172% with increase the eccentricity location from (0 to 165) mm respectively as compare with the reference beam.

Keywords: *shear behavior, strengthening of steel beams, prestressing strand, eccentricity location. Jacking stress*

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

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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 good 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 [6]

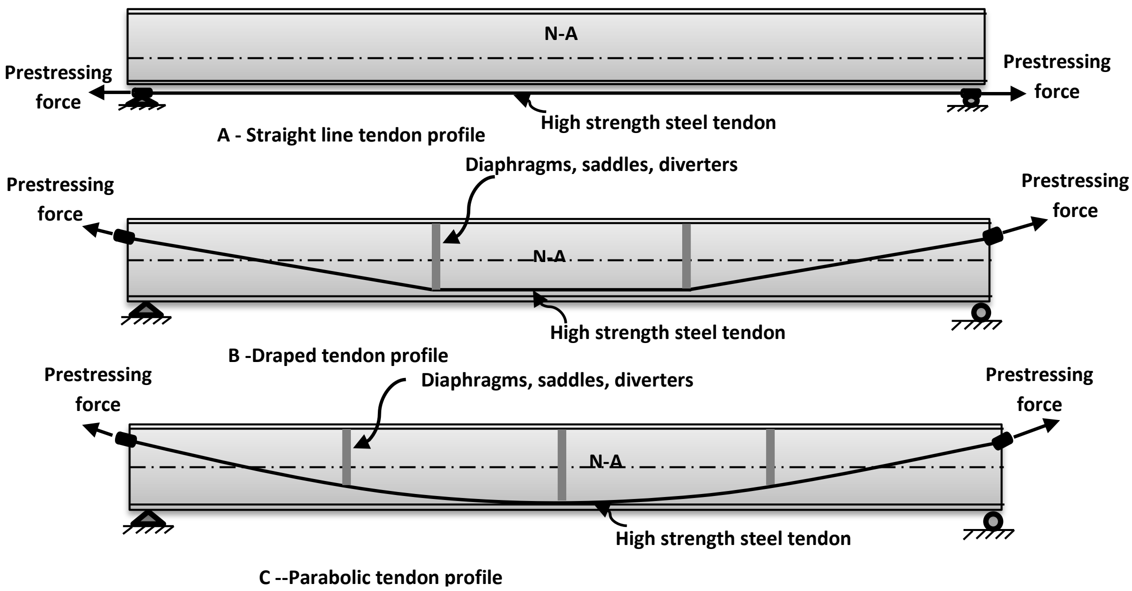


Figure (1) Strenthening by external high strength steel strands.

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 flexure behavior of I-steel beams strengthening by external prestressing strands at different eccentricity and jacking stress and compared with the reference steel beam.

4. Tested program.

4.1 Description of specimens.

During the design phase of the experimental stages, 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:

X_1 X_2 X_3, X_4, X_5

Where:

X_1: refer to type of tested beam type.

O : for original reference steel beam without any prestressing strand.

X_2: refer to initial jacking stress(fpj) .

L= initial prestressing jacking stress (814.589 MPa) applied.

X_3= eccentricity of prestressing strand at mid span

0= when the eccentricity of prestressing strand at neutral axis of steel beam

1= when the eccentricity of prestressing strand at (96 mm) below neutral axis of steel beam

2= when the eccentricity of prestressing strand at (165 mm) below neutral axis of steel beam

X_4= eccentricity of prestressing strand at end span

0= when the eccentricity of prestressing strand at neutral axis of steel beam

1= when the eccentricity of prestressing strand at (20 mm) below neutral axis of steel beam

2= when the eccentricity of prestressing strand at (96 mm) below neutral axis of steel beam

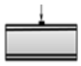
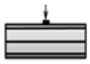
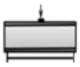
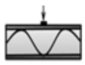
3= when the eccentricity of prestressing strand at (165 mm) below neutral axis of steel beam

X_5= eccentricity of prestressing strand at critical effective depth for shear span

0= when the eccentricity of prestressing strand at neutral axis of steel beam

1= when the eccentricity of prestressing strand at (19.15 mm) below neutral axis of steel beam
2= when the eccentricity of prestressing strand at (35.45 mm) below neutral axis of steel beam
3= when the eccentricity of prestressing strand at (96 mm) below neutral axis of steel beam
4= when the eccentricity of prestressing strand at (165 mm) below neutral axis of steel beam
5= when the eccentricity of prestressing strand at (39 mm) above neutral axis of steel beam
Table (1) illustrates the used specimen identification system used based on specimen identification pattern described and all definition of samples can be listed in flow-chart shown in Fig. (2),while,th the details of tested specimens are shown in Fig. (3).

Table (1) Description details of tested specimens

Groups	*Beams No.*	*Serial Symbols*	*Prestressing Strand Profile*	*Beams Shape*	*Jacking Stress(fpj), MPa*	*Eccentricity (e), (mm)*		
						e_1^{*}	e_2^{**}	e_3^{***}
1	Ref.	O	----		----	----	----	----
2	1	OL000	Straight with $e_1e_2e_3$ (000)		814.589	0	0	0
	2	OL101	Draped with $e_1e_2e_3$ (101)		814.589	96	0	19.514
	3	OL112	Draped with $e_1e_2e_3$ (112)		814.589	96	20	35.45
	4	OL123	Straight with $e_1e_2e_3$ (123)		814.589	96	96	96
	5	OL234	Straight with $e_1e_2e_3$ (234)		814.589	165	165	165
	6	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.

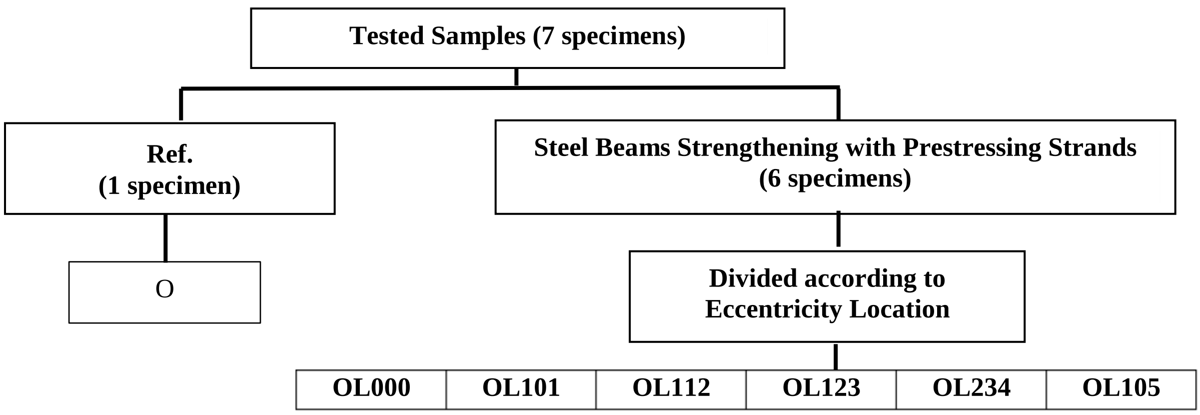


Figure (2) Flow chart of the experimental details of tested beams

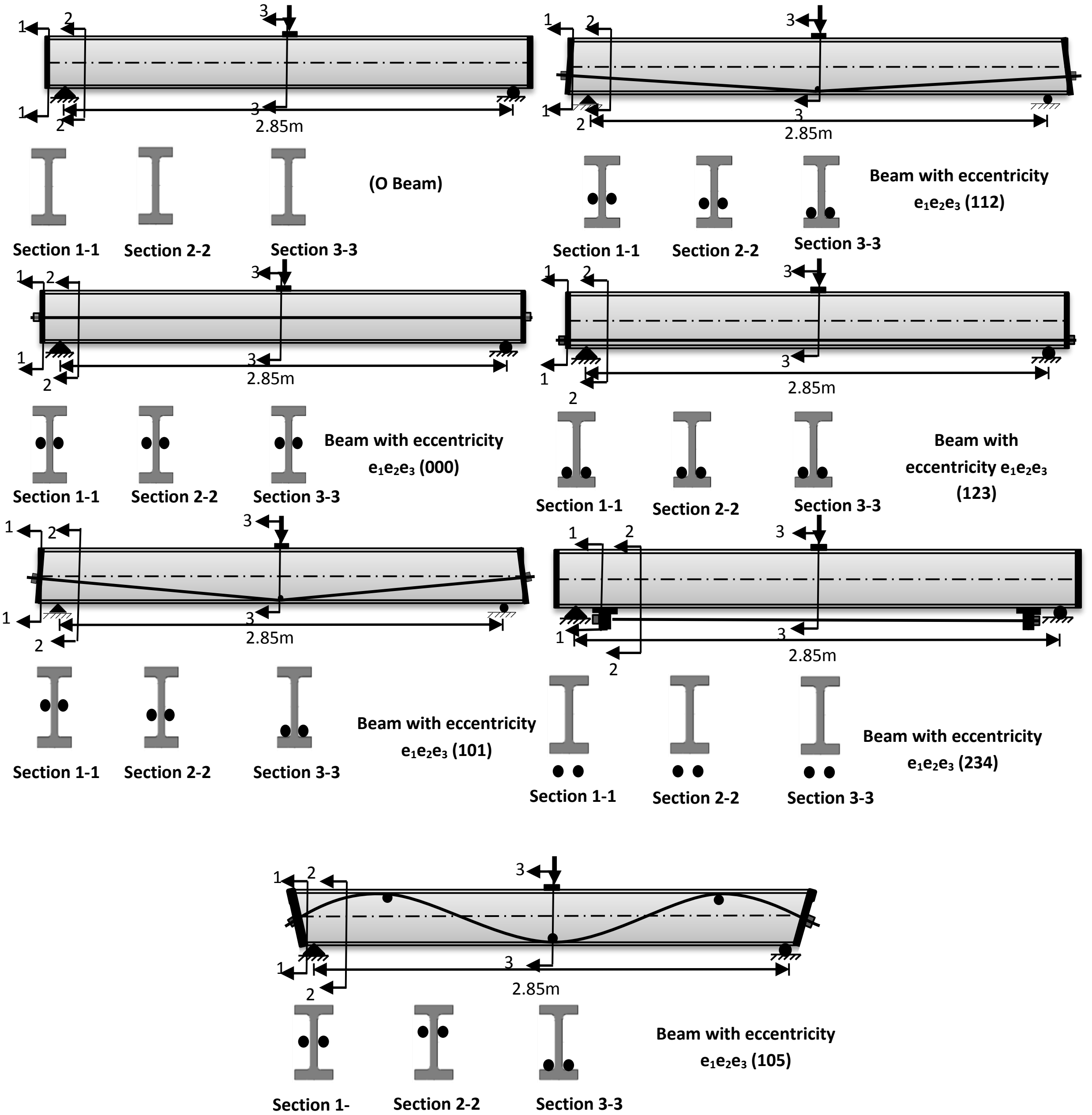


Figure (3) Details of tested beams.

4.3 Material properties of the test specimens and fabrication.

4.3.1 Structural steel type.

SS400 steel is one commonly hot rolled steel and used in the general structural element applications. SS400 is a material grade and designation defined in JIS G 3101 standard. 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]

	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]

Grad	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	*

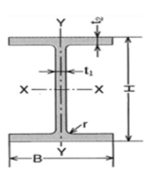
Content is not controlled*

4.3.2 Structural steel section, fabrication and plate tests.

Hot rolled steel I-section with 25.7 kg/m mass per meter which it is manufactory in China and it used in this study. Table (4) shows geometrical details of steel section, while the end Steel plate can be welded directly to the steel beam by using welding process. The welds are 5 mm fillet welds made with E7018 electrodes. The end plates have two holes to allow to the prestressing strand to pass through them. End plate must be normally to the strand profile area as possible 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 [10]. The cutting process was conducted by using automaticity technique by using Computer Numerical Control (CNC) (ajan cnc) plasma machine to obtain exact design dimension and smooth cutting shapes.

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(Fy), MPa	Min. Ultimate Tensile strength (Fu), MPa	Total Elongation, %
Test results according to NCCLR	PL 10	356	524	23.2
	PL 20	369	507	20.5
	PL 30	360	507	18.9
	Average value	362	513	20.87
American ASTM A36/ A36-2014[12]		≥250	≥400	≥20
Japan of JIS G 3101[7]		≥245	≥400	≥17

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

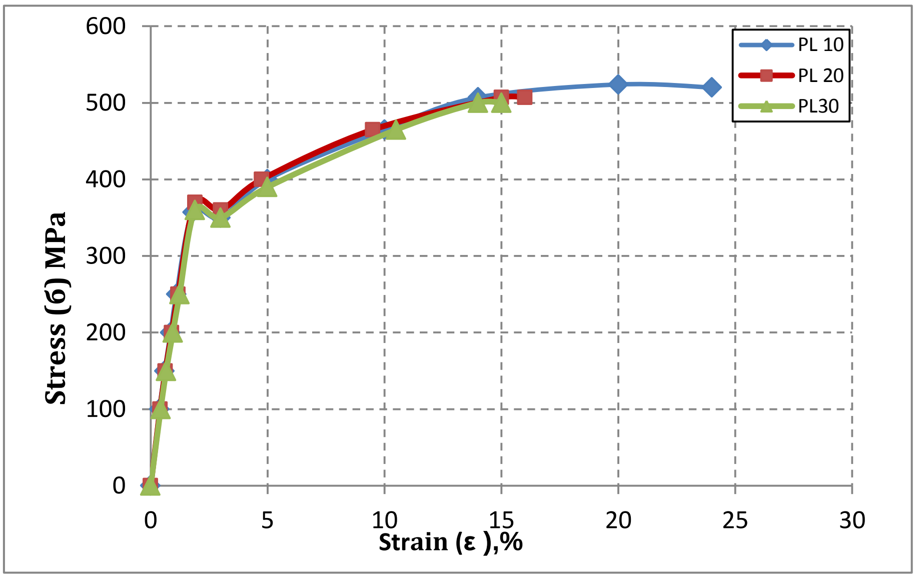


Figure (4) stress strain curve of steel plate specimens

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 metal 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 [13].The properties of the strand is shown in Fig. (5).

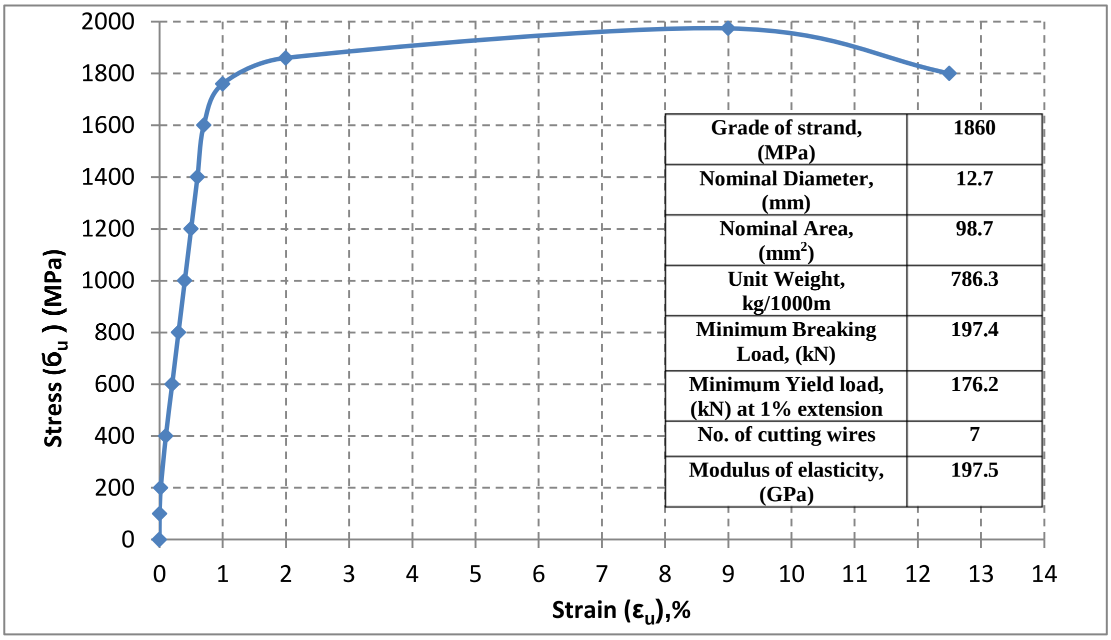


Figure (5) stress -strain curve of grade 270 low relaxation seven wire strands at (12.7 mm) diameter.

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. Prestressing strands are passed through out a thick steel bearing plates (25 x250x125) mm fixed at both ends of tested beams by welding process. The welds are 5 mm fillet welds made with E7018 electrodes, which have two holes, were formed to allow to the prestressing strand to pass through them. Prestressing strands are fixed firstly at the dead end using special wedge anchored (grips) and finally anchored at the jacking end, then the steel strands are individually tensioned with the jacking end by using single strand jack operated by a motor-driven hydraulic pump. 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 level was applied at (200) bar, the prestressing stress converter from (bar) to (MPa) is listed as the following:

<u>Bar converter to Mpa</u>:

- 200 bar

1bar = 1.01975[14] kgf/cm ^{2}

The grond acceleration value (g) = 9.80665[15] m/s^2

Then the converter factor will be =1.01975x9.80665=10

Jacking prestressing stress= 200x10= 2000 N/cm^2

The ram area of single-pull jack = 40.2 cm^2.

Jack force = jacking prestressing stress x ram area

= 2000x40.2

Jack force =80400 N

Jacking prestressing stress= Jack force/strand area=80400/98.7

=814.589 MPa

Then the percentage of jacking prestressing stress to ultimate stress ratio will be

Jacking prestressing stress/ultimate stress = 814.589/1860

=0.438fpu < 0.7 fpu ok

For post tensioning tendons at anchorage devices and coupler immediately after force transfer < 0.7 fpu [16]

The hydraulic machine 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).

Figure (6) Hydraulic machine and single strand jack prestressing strand.

4.4 Strain measurements in steel section.

The experimental shear strains for tested beams were monitored through one channel TML data logger and switching box during the applied load until the failure. The strain gauge was fixed at distance of 248 mm (which represent the effective depth with inclined line of 45° on the neutral axis from the support. The location of strain gauge is shown in Fig. (7).

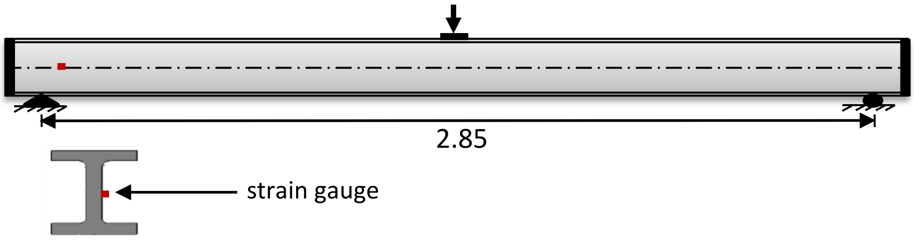
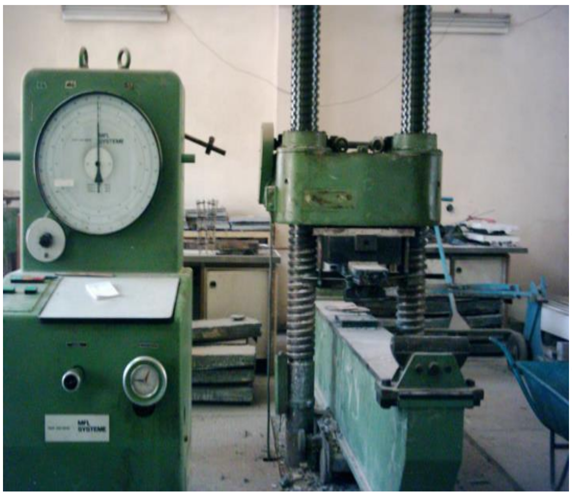


Figure (7) Location of strain gauge at typical steel beams

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. During testing time, 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, strain gauges reading and 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)



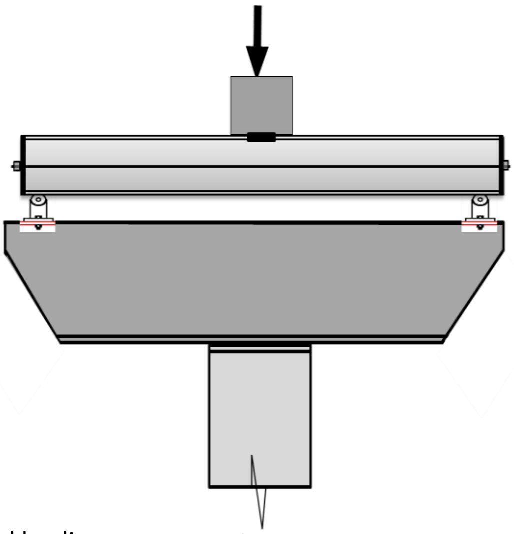


Figure (8) Test machine and loading arrangements

5. Experimental parametric studies.

The experimental study has been carried out to investigate the effect of eccentricity location on the shear behavior of steel beams strengthening by external prestressing strand under one point load. Full experimental results of tested beams are illustrated in Table (6).

Table (6) Shear results of the tested beams

Groups	Beams No.	Series Symbols	Maximum applied load (Pu),(kN)	Maximum Exp. shear strain $x10^{-6}$	Maximum applied. shear load, (Vu),(kN)
1	Ref.	O	287.5	394	143.75
2	1	OL000	288	392	144
	2	OL101	362.5	390	181.25
	3	OL112	382.5	314	191.25
	4	OL123	327	293	163.5
	5	OL234	487.5	283	243.75
	6	OL105	427	387	213.5

5.1 Shear load strain response.

During the test, it can be observed that the shear load strain curves for tested beams were slightly stiffer than the reference beams and the percentage of stiffening was increased with increasing the eccentricity locations from the shear points, as shown in Fig.(9) .

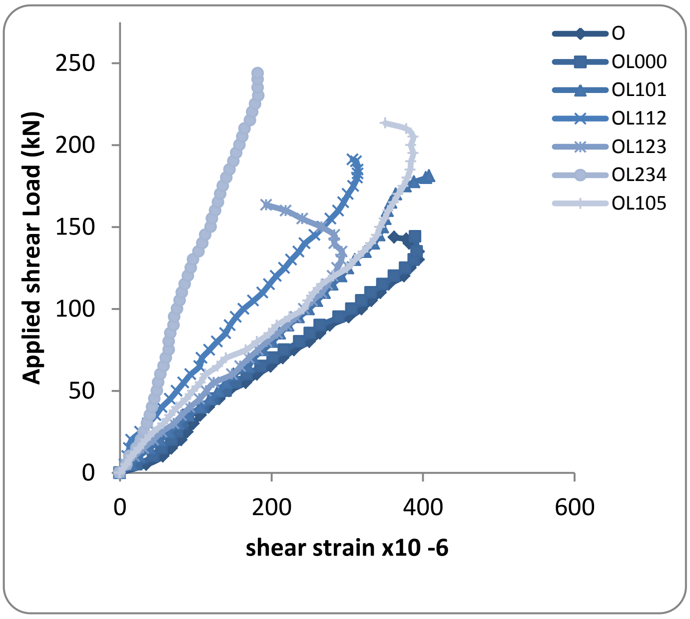


Figure (9) Effect of eccentricity location of prestressing strand on the shear stress strain curves of tested beams at (fp_j =814.589 MPa)

5.2. Applied shear load of the tested beams.

During the tests it was found that the maximum shear load was increased about (0.173%, 26.086%, 33.043%, 48.521%, 13.739% and 69.565%) with increase the eccentricity location from (0 to 165) mm respectively as compare with the reference beam, as listed in Table (7), while, the increasing percentage in maximum shear load of tested beams are shown in Fig.(10) and Fig .(11). So, one can be observed that the maximum shear load increase with increasing the eccentricity locations from the shear points at jacking stress (fp_j=814.589 MPa).

Table (7) Maximum shear load of tested beams

Beams No.	Series Symbols	*Jacking Stress, (fp_j) (MPa)*	*Maximum shear load, (Vu),(kN)*	*Percentage increasing in maximum shear load (Vu), (kN)*
Ref.	O	-------	143.75	0
1	OL00N	814.589	144	0.173
2	OL101	814.589	181.25	26.086
3	OL112	814.589	191.25	33.043
4	OL123	814.589	163.5	13.739
5	OL234	814.589	243.75	69.565
6	OL105	814.589	213.5	48.521

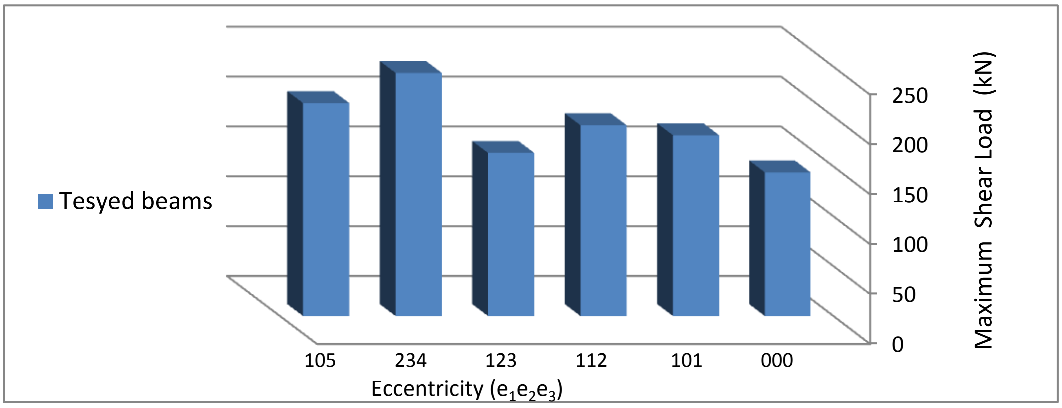


Figure (10) Maximum shear load of tested beams at different values of eccentricity

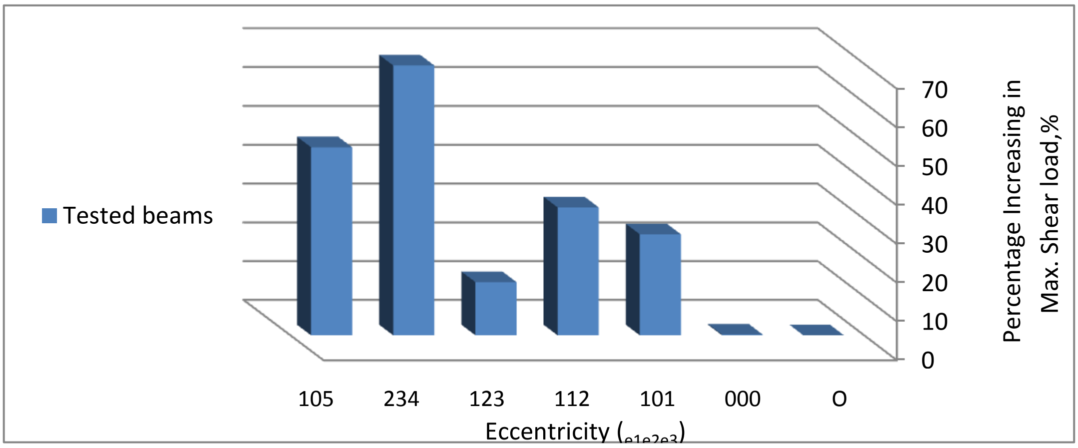


Figure (11) Percentage increasing in maximum shear load of tested beams at different values of eccentricity as compare with a reference

5.3. Shear strain of the tested beams.

During the tests, it was found that the maximum shear strain was decreased to 0.507%, 1.015%, 20.304%, 1.776% 25.634% and 28.172% with increase the eccentricity location from (0 to 165) mm respectively at jacking stress (fp_j=814.589 MPa) as compare with the reference beam, as listed in Table (8). While, the percentage of increasing in maximum shear strain of tested beams is shown in Fig.(12) .

Table (8) Percentage increasing in maximum experimental shear strain of tested beams

Beams No.	Series Symbols	Jacking Stress,(fp_j) (MPa)	Maximum exp. Shear Strain x 10^{-6}	Percentage increasing in maximum exp. Shear strain,%
Ref.	O	-------	394	0
1	OL000	814.589	392	-0.507
2	OL101	814.589	390	-1.015
3	OL112	814.589	314	-20.304
4	OL123	814.589	293	-25.634
5	OL234	814.589	283	-28.172
6	OL105	814.589	387	-1.776

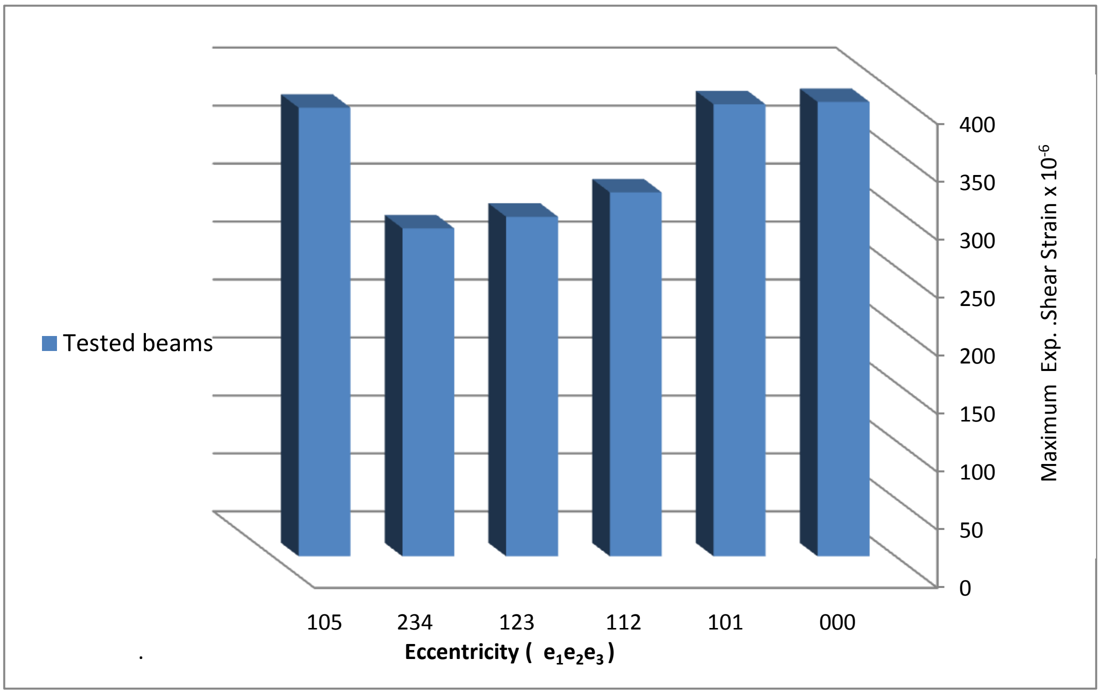


Figure (12) Maximum experimental shear strain of tested beams at different values of eccentricity

5.4 Failure mode of the tested beams.

In generally that the mode of failure of all tested beams were occurred under load either flexural or local buckling for web, and the shear region zone will be not distress due to the applied load since the web has sufficient thickness, holes and coped are not found in the webs and the length of beams are long, therefore, the webs of steel beams are capable of resisting rather large shearing force applied, as shown in Fig.(13).

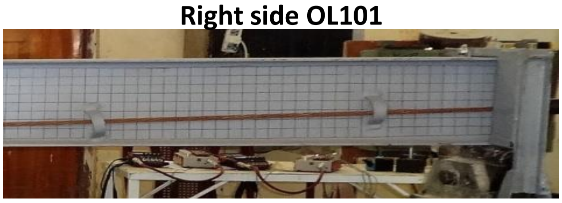
Left side of O beam

Right side of O beam

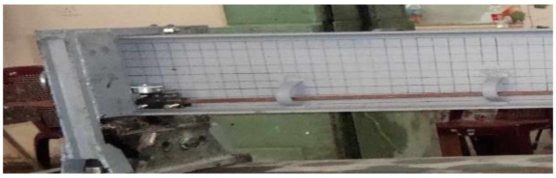
Left side of OL101

Right side OL101

Left side of OL112



Right side of OL112

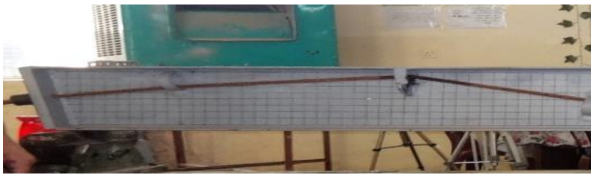


Left side of OL123

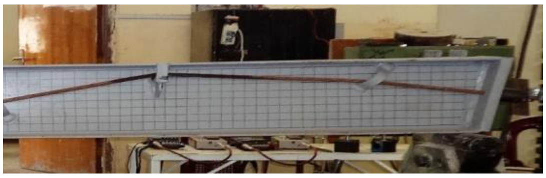
Right side of OL123

Left side of OL000

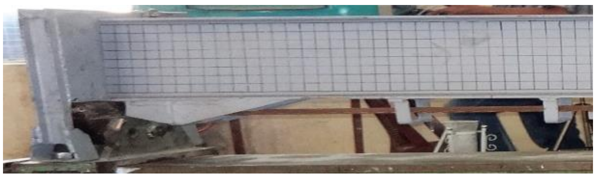
Right side of OL000



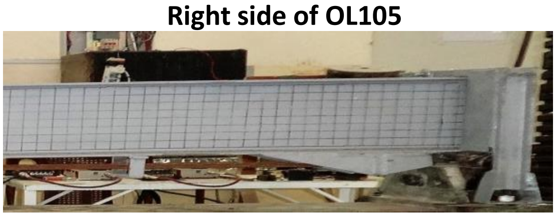
Left side of OL105



Right side of OL105



Left side of OL234



Right side of OL234

Figure (13) Right and left side at zone shear region for tested beams

5. Conclusions.

Based on the experimental investigation on the share behavior of steel beams strengthening by prestressing strands, the following conclusions are drawn.

1. The shear load strain curves for tested beams were slightly stiffer than the reference beams and the percentage of stiffenging was increased with increase the eccentricity locations from the shear points.
2. The maximum shear load increased about (0.173%, 26.086%, 33.043%, 48.521%, 13.739% and 69.565%) with increasing the eccentricity location from (0 to 165) mm respectively as compare with the reference beam.
3. The maximum shear strain decrease to 0.507%, 1.015%, 20.304%, 1.776% 25.634% and 28.172% with increase the eccentricity location from (0 to 165) mm respectively at jacking stress (fp_j=814.589 MPa) as compare with the reference beam.

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