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Fikry Salem
Department of Structural Engineering., Faculty of Engineering., Mansoura University., Mansoura., P.O. Box 35516., Egypt., drfikry_salem@yahoo.com

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Experimental Study of Extended End-Plate Connections in Steel Moment Resisting Frames

دراسة عملية لوصلات اللوح الطرفى الممتد فى الإطارات المعدنية المقاومة للعزوم

FIKRY A. SALEM

Department of Structural Engineering, Faculty of Engineering

Mansoura University, Mansoura, P.O. Box 35516, Egypt

E-mail: drfikry_salem@yahoo.com

ملخص

الإطارات المعدنية هي واحدة من أكثر العناصر الإنشائية المستخدمة في المنشآت الحديثة ونظرا للتطور فى طرق التصميم وأساليب التصنيع لوصلات اللوح الطرفي (Extended-end-plate-connections) أصبحت هذه الوصلات شائعة الإستخدام فى الإطارات المعدنية المقاومة للعزوم والمنشآت المتعددة الطوابق ومن ميزات هذه الوصلات أن عملية اللحام لهذه الوصلات تتم في الورشه وبالتالى تقلل مشكلات اللحام المصاحبه للحام فى الموقع وبالتالى فإن عملية التنفيذ تكون أسرع الأمر الذى ينتج عنه إنخفاض فى التكاليف.

يتضمن هذا البحث دراسة عملية لإختبار وصلات اللوح الطرفي (Extended End-Plate-Connections) أكثر الوصلات إستخداما في المنشآت المعدنية. وتم دراسة تأثير تغير سمك اللوح الطرفي. وقطر المسامير.وأنواع التقويات بعصب العمود المقابل للوصلة.و تغير رتبة المسامير علي سلوك هذه الوصلات.

Abstract

In this paper, experimental tests have been carried out to investigate the behavior of extended end-plate moment connections.

The experimental program has been executed in the heavy structures laboratory, Faculty of Engineering, Mansoura University, Egypt. In this program, ten end-plate moment connections have been tested to failure. The studied parameters in the experimental work are: (i) thickness of end plate, (ii) diameter of bolt, (iii) column stiffeners opposite the tested connections and (iv) grade of bolt.

Keywords

Steel frames, end-plate moment connections, experimental program. thickness of end plate, diameter of bolt, column stiffeners and grade of bolt

1- Introduction

The use of end-plates in multi-story moment resistant frame construction is becoming more common because of more accurate fabrication and better design techniques, the use of these connection also reduce the time of construction and more economically feasible for use in multi -story buildings. Several researches are conducted for investigated end plate connections [1-12].

In the current study an experiment program was carried out for ten extended end plate moment connections divided into four groups under static load to studying the structural behavior of connection. In parallel with experimental work, a non-linear analysis for the end-plate moment connections as a space structure using the finite element method is presented. Cosmos/M program has been used for three dimensional analyses of end-plate moment connections to determine the stress distribution.

Finally, a comparison is carried out between the experimental results and theoretical analysis to discuss and investigate the structural behavior of end-plate moment connections.

2- The Experimental Program

A total of ten extended end plate moment connections have been tested under concentrated static load. These

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connections are divided into four groups according to four parameters studied in the experimental work. These parameters studied are ; (i) thickness of end-plate, (ii) diameter of blot, (iii) horizontal and diagonal stiffeners in the column and (iv) grade of bolt. As shown in Table (1).

According to Egyptian Specifications for Steel Construction [19], all beams and columns of the connections are rolled steel sections S.I.B. (180) as shown in Fig.(1). Each beam has a total length 820 mm and an affective length of 720 mm and the column length is 1500 mm. The dimensions of the end-plate are equal to (260x82 mm). The spacing between the centers of two bolts "S" is equal to 41 mm. and the distance from the center of the bolt to the edge of the end plate is 20.5 mm. The distances between the bolts and end plate in horizontal and vertical directions are given in Fig. (1). The steel material of the tested beam is nominally STEEL 37. However, the tension tests performed on it have given an actual experimental value at 2.90 t/cm^2 and 4.00 t/cm^2 for the yield and ultimate stresses respectively.

3-Experimental Procedure

Ten end plate moment connections were tested under static load. The digital load pressure device having an accuracy of 350 kg. per one digit is used to measure the applied load with the hydraulic jack and hydraulic pump. The maximum capacity of the hydraulic jack is 60 tons. For the tested end-plate moments connections, dial gauges were mounted to record the vertical deflections in the beam and different positions along the column for each tested connections as shown in Fig. (2).

Strain gauges have been glued and fixed to the compression and tension beam flanges as well as to the column flange and one strain has been fixed to the end plate of the connection. The strain gauges have a gauge length of 10 mm to register the strains in any required direction. The strain gauges are connected with the digital strain indicator device which has 48 channels as shown in Fig. (2). The arrangement of test strain and dial gauges are shown also in Fig. (2). The strains in the bolts were measured by clip gage apparatus and given in the same figure.

The applied load is gradually increased till the failure occurs and this is controlled by using the stopwatch every 10.0 minutes. At each step of loading, the vertical deflections and strains at different positions are recorded. The strain in the bolts was measured by Clip Gage as shown in Fig. (3), the clip gage is connected to the test specimen in a way that it is supported to the aluminum slices. One slice is fixed between the head of the bolt and the end plate and the other slice is fixed between the nut and the flange of the column.

The main mechanism of the clip gage, when the clip gage is connected to the specimen the digital strain-meter reads an initial value, when the specimen is loaded and the bolt begins in deformation, in the same way the arms of the clip gage diverge or converge, and so the digital strain-meter reads another value, and so on.

4- Experimental Results

The structural behavior of the tested end-plate moment connections is studied and the main parameters that have been investigated are the thickness of the end-plate, the diameter of bolts, the type of stiffeners in the column web (horizontal and diagonal stiffeners) and the grade of bolts.

Discussion and investigation of the experimental results include the failure loads, strains in end-plates as well as in bolts, strains in upper and lower flanges, and the load-deflection curves till failure for all tested end-plate moment connections. The relation between the recorded strains in end-plates and the applied loads for all tested connections Co.1, Co.2, Co.3, Co.4, Co.5, Co.6, Co.7, Co.8, Co.9 & Co.10 are given in Figures (5) to (9). Also, the relation between the measured strains in bolts and the applied loads for all tested connections are shown in Figures (10) to (14). Figures (15) to (19) show the relation between the recoded strains in upper and lower flanges and the applied loads for all tested connections. While the relation between the applied loads and the recorded deflections till failure for tested connections are shown in Figures (20) to (24). Finally, the modes of failure for all tested connections are given in Figure (25) to (28).

Experimental failure loads, strains in end-plates as well as in bolts, strains in upper and lower flange plates and deflections in the beam under the applied load for all tested end-plate moment connections are summarized in Table (2).

4.1- Failure Loads

The failure loads for the tested end-plate moment connections are given in Table (2). Form this table it is noticed that, for **group (I)**, the failure load for tested connection Co.2 increased by 65.4 % than that of tested connection Co.1 due to increase in the end-plate thickness from 6 mm to 8 mm. Also, The failure load for connection Co.3 with end-plate thickness 12 mm increased by 16.5 % than that of connection Co.2 with end-plate thickness 8 mm. The failure loads for tested connection Co.3 increased by 92.6 % over that of tested connection Co.1. From above, it can be concluded that the failure loads for group (I) are highly affected by the increase in the end-plate thickness. In **group (II),** the failure loads for tested connections Co.4, Co.5 & Co.6 increased due to increase in the diameter of ordinary bolts. The failure loads for connections Co.5 & Co.6 are greater than that of tested connection Co.4 by 128.5 % and 153 % due to change in the bolt diameter form 12 to 14 mm and form 14 to 16 mm respectively.

In **group (III),** the failure loads for tested end-plate moment connection Co.5 with horizontal stiffener and connection Co.8 with horizontal and diagonal stiffeners increased by 12 % and 18 % respectively than the failure load of tested connection Co.7 without stiffeners in column web. In **group (IV),** the failure load for tested connection Co.9 with high strength bolts is greater that of tested connection Co.4 with ordinary bolts by 116.2 %. Also, the failure load of connection Co.10 with high strength bolts increased by 20.3 % than the failure load of connection Co.8 with ordinary bolts.

4.2- Strains

Figures (5) to (24) show the measured longitudinal strains in the end-plate, in the bolt, and in the upper and lower flange plates of the beam in all the tested connections. Table (2) also gives the recorded longitudinal strains of all tested connections. From table and figures (5&15), it is noticed that, for **group (I),** the recorded longitudinal strains in end-plate of tested connection Co.2 which have end-plate thickness 8 mm decreased by 58 % than the corresponding strains of tested connection Co.1 with end-plate thickness 6 mm. Also, the longitudinal strains in end-plate of connection Co.3 which have end-plate thickness 12 mm decreased by 57.7 % that the corresponding strains of connection Co.1 which have end-plate thickness 6 mm. while the longitudinal strains in the upper and lower flanges of the beam in connections Co.1, Co.2 & Co.3 gradually increased due to increase in the end-plate thickness form 6 mm to 12 mm.

Referring to Table (2) and Figs. (6&11), for **group (II),** it is noticed that, the measured longitudinal strains in the bolts of connections Co.6 & Co.5 reduced about 2 to 7 times the longitudinal strains in the bolts of tested connection Co.4 due to the change in the bolt diameter from 12 to 14 mm and form 14 to 16 mm respectively.

Form above, it can be concluded that the measured longitudinal strains in the bolts of the connections are highly affected by the thickness of the end-plate and the diameter of the ordinary bolts.

For **group (III),** the recorded longitudinal strains in the end-plates, in the bolts and in the upper and lower flanges of the beam for the tested connections Co.7, Co.5 & Co.8 are given in Table (2) and Figs. (7& 12), it is noticed that the longitudinal strains in the bolts and end-plate and the upper and lower flanges of the beam are highly affected by the horizontal and diagonal stiffeners in the connections Co.5 and Co.8. The longitudinal strains in the bolts and end-plate of connection Co.8 which have horizontal and diagonal stiffeners decreased by 22.6 % and 49.7 % than the corresponding longitudinal strains in the bolts and end-plate of connection Co.5 with horizontal stiffener only respectively. Also, the measured longitudinal strains in the upper and lower flanges of the beam of connection Co.8 reduced by 83.5 % and 35.4 % than the corresponding longitudinal strains in the connection Co.5 respectively. While values of the strains in the different elements of tested connection Co.7 smaller values than the corresponding strains in the connections Co.5 & Co.8 due to the different modes of failure happened (crippling in column web and yielding in column flange) as shown in Fig.(4)

By referring to **group (IV),** the measured longitudinal strains in the end-plate, in the bolt, and in the upper and lower flange plates of the beam for the tested connections Co.4 & Co.9 and Co.8 & Co.10 at load 4.67 ton are given in Table (2). Also, the load-strain curves till failure for these connections are shown in Figs. (8&9&13&14).

4.3- Deflections

For **group (I)** with different thickness of the end-plate of the connections Co.1, Co.2 & Co.3, it is noticed that, the maximum deflections at the end of the beam under the applied load for the tested connections decreased due to increase in the end-plate thickness from 6 to 8 mm and from 8 to 12 mm.

For **group (II)** with different types of the bolt diameter in the tested connections Co.4, Co.5 & Co.3, it is also noticed that, , the maximum deflections at the end of the beam under the applied load decreased due to the increase in the bolt diameter from 12 to 14 mm and from 14 to 16 mm. While for **group (III)** where the horizontal and diagonal stiffeners are studied, it is noticed that, the recorded deflections under the applied load for tested connections Co.5 & Co.8 were not effect by using the different types of stiffeners.

Also, for **group (IV)** where the grade of bolts is investigated, it is noticed that, the measured deflections under the applied load for tested connections Co.4 & Co.9 and Co.8 & Co.10 were nearly constant.

Form above it can be concluded that the recorded deflections the beam under the applied load for tested connections are highly affected by the end-plate thickness and the bolt diameter, while these defections are not effected by the different types of stiffeners and the grade of the bolt.

5- Conclusions

The main conclusions based on the experimental results can be summarized in the following.

1- The failure loads of the end-plate moment connections were highly affected by the increase in the end- plate thickness as well as in the bolt diameter.

2- The failure loads for the end-plate moment connections with stiffeners in the column web has larger values than those of end-plate moment connection without stiffeners the web column.

3- The failure loads for the connections with high strength bolts have greater values than those of the connections with ordinary bolts.

4- The recoded longitudinal strains in the end-plate and the bolts of the connections are highly affected by the thickness of the end-plate and the diameter of the ordinary bolts respectively.

5- The recoded longitudinal strains in the bolts and in the end-plate as well as in the upper and lower flanges of the beam are highly affected by the horizontal and diagonal stiffeners.

6- The deflections at the end of the beam under the applied load are highly affected by the end-plate thickness and the bolt diameter, while these deflections are not affected by the different types of stiffeners and the grade of the bolt.

7- During the test, the modes of failure were yielding in the end-plate, failure in the bolt and crippling in the column web and yielding in the column flange

8- The yield and ultimate loads for the end-plate connections are highly affected by the studied parameters viz: end plate thickness, diameter of the bolt and the grade of the bolt .

9- The yield and ultimate loads for end-plate moment connection with stiffeners have greater values than those of connections without stiffeners in the column web.

10- The yield and ultimate loads of end-plate moment connections with high strength bolts have greater values than those of connections with ordinary bolts.

6- Recommendations for Future Work

1- More experimental study and nonlinear analysis on the other different types of end-plate moment connections using stiffeners in the end-plate.

2- analytical verification for the expressions used in the different method of analyzed this type of connections such as yield line theory.

3- Further applications of the end-plate moment connections with different sections of beam and column under static and dynamic loads.

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Table (1): Geometric Properties of Tested End-Plate Moment Connections

Group	Connection	Thickness of End-Plate, (mm)	Diameter of Bolts, mm (grade)	Type of Stiffener in column web	
				Horizontal Stiffener, (mm) (160 * 37.5 * 6)	Diagonal Stiffener, (mm) (240 * 37.5 * 6)
Group (I)	Co.1	6	14 (4.6)	yes	No
	Co.2	8			
	Co.3	12			
Group (II)	Co.4	14	12 (4.6)	yes	No
	Co.5		14 (4.6)		
	Co.6		16 (4.6)		
Group (III)	Co.7	14	14 (4.6)	No	No
	Co.5			yes	No
	Co.8			yes	Yes
Group (IV)	Co.4	14	12 (4.6)	yes	No
	Co.9		12 (10.9)		
	Co.8	14	14 (4.6)	yes	Yes
	Co.10		14 (10.9)		

Table (2): Summary of the Experimental Results for Tested End-Plate Moment Connections

Connection		Test Failure Load P_u (ton)	Strain*10^{-6}				Maximum Deflection (Δ) mm	Mode of Failure
			End-plate	Bolt	Upper Flange	Lower Flange		
Group (I)	Co.1	5.243	6856	620	490	-560	37.21	Plate failure.
	Co.2	8.671	2886	85	564	-570	43.49	Plate failure.
	Co.3	10.1	2895	213	1513	-580	44.82	Plate failure.
Group (II)	Co.4	4.671	8122	369	272	-209	36.71	Bolt failure
	Co.5	10.671	1351	124	115	-93	48.12	Bolt failure.
	Co.6	11.814	3155	50	49	-55	57.21	Plate failure.
Group (III)	Co.7	9.528	746	82	58	-38	73.36	Yielding in column flange and crippling in Column web
	Co.5	10.671	1351	124	115	-93	48.12	Bolt failure.
	Co.8	11.243	586	96	19	-49	50.31	Bolt failure.
Group (IV)	Co.4	4.671	8122	369	272	-209	36.71	Bolt failure.
	Co.9	10.1	12290	30	1276	-1500	53.86	Yielding in Column flange
	Co.8	11.243	586	96	19	-49	50.31	Bolt failure.
	Co.10	13.523	14522	399	1158	-549	54.27	Yielding in Column flange

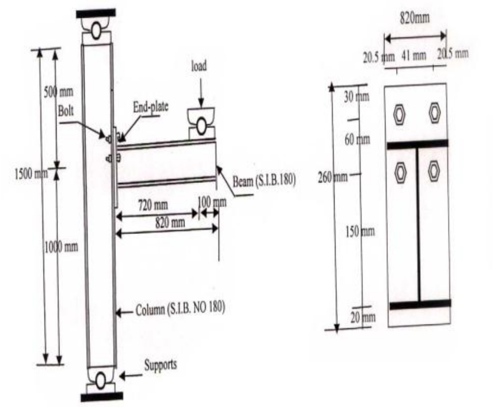
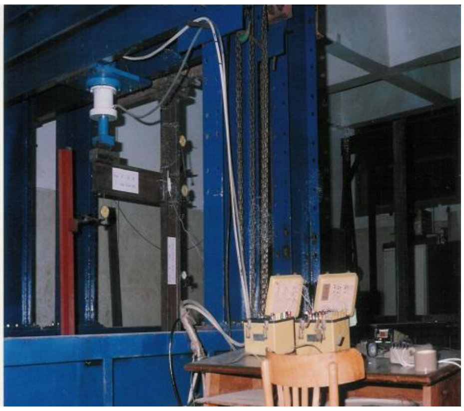


Fig. (1): Arrangement of the Experimental Program.



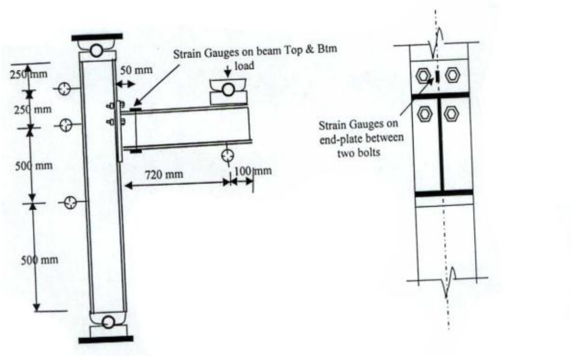


Fig.(2): Arrangement of The Strain Gages and Dial Gages on The Tested End-Plate Moment Connections.

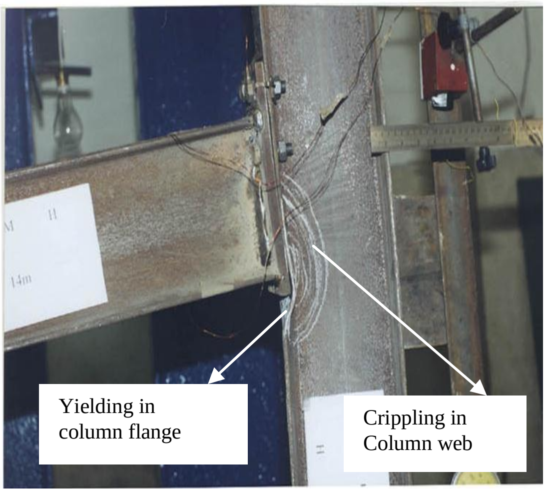


Fig. (3): Clip Gage Apparatus and the Connected Connection

Fig.(4): Modes of Failure for Tested Connection 7 (Crippling in Column Web and Yielding in Column Flange)

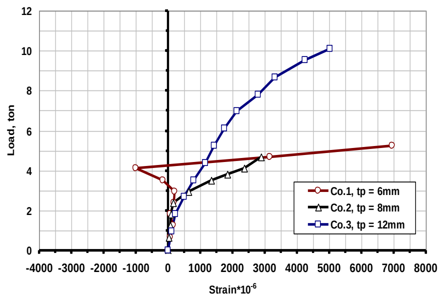


Fig. (5): Relation between the Load and Recoded Strains in End-plate till Failure for Tested End-Plate Moment Connections (Co.1, Co.2 & Co.3).

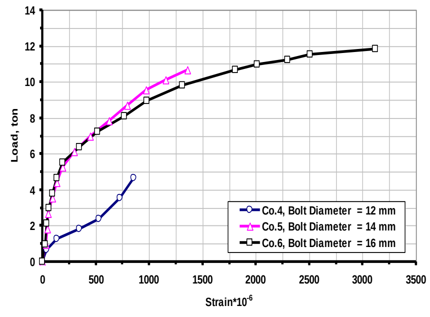


Fig. (6) :Relation between the Load and Recoded Strains in End-plate till Failure for Tested End-Plate Moment Connections (Co.4, Co.5 & Co.6)

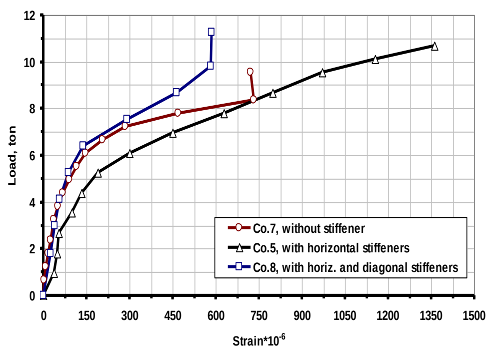


Fig. (7): Relation between the Load and Recoded Strains in End-plate till Failure for Tested End-Plate Moment Connections (Co.7, Co.5 & Co.8).

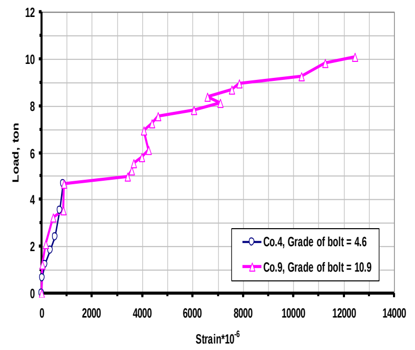


Fig. (8): Relation Between the Load and Recoded Strains in End-plate till Failure for Tested End-Plate Moment Connections (Co.4 & Co.9).

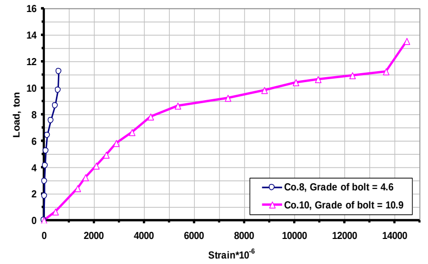


Fig. (9): Relation Between the Load and Recoded Strains in End-plate till Failure for Tested End-Plate Moment Connections (Co.8 & Co.10).

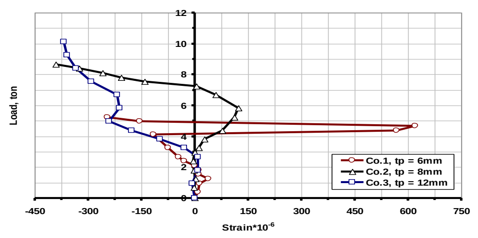


Fig. (10): Relation Between the Load and Recoded Strains in Bolt till Failure for Tested End- Plate Moment Connections (Co.1, Co.2 & Co.3).

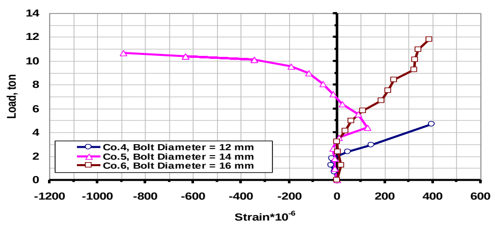


Fig. (11): Relation Between the Load and Recoded Strains in Bolt till Failure for Tested End- Plate Moment Connections (Co.4, Co.5 & Co.6).

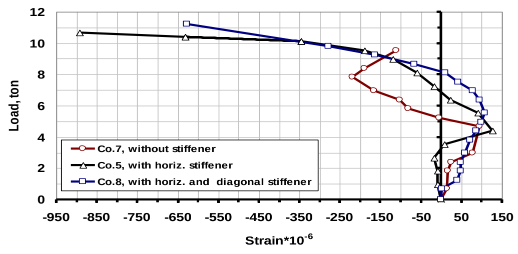


Fig. (12): Relation Between the Load and Recoded Strains in Bolt till Failure for Tested End- Plate Moment Connections (Co.7, Co.5 & Co.8).

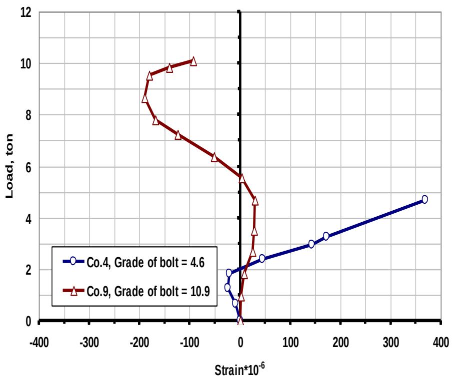


Fig. (13): Relation Between the Load and Recoded Strains in Bolt till Failure for Tested End- Plate Moment Connections (Co.4 & Co.9).

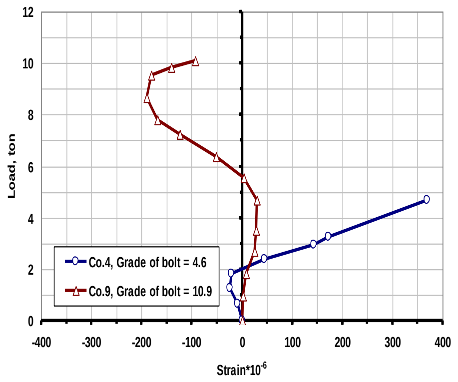


Fig. (14): Relation Between the Load and Recoded Strains in Bolt till Failure for Tested End- Plate Moment Connections (Co.8, Co.10).

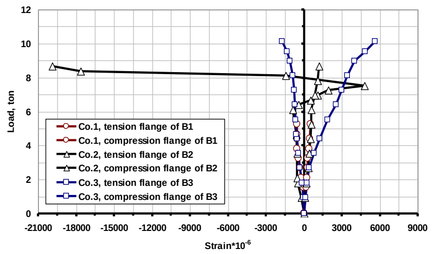


Fig. (15): Relation between the Load and Recoded Strains in the Upper and Lower Beam Flanges till Failure for Tested End-Plate Moment Connections (Co.1, Co.2 & Co.3).

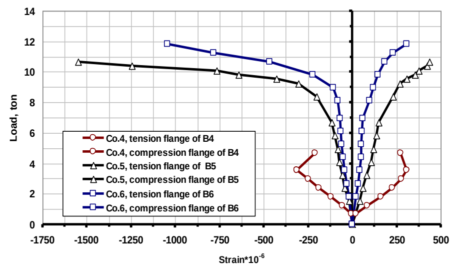


Fig. (16): Relation between the Load and Recoded Strains in the Upper and Lower Beam Flanges till Failure for Tested End-Plate Moment Connections (Co.4, Co.5 & Co.6).

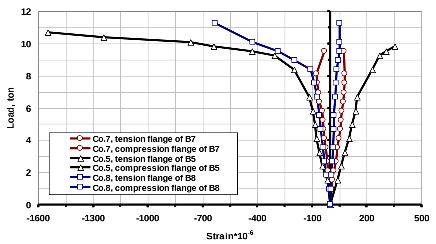


Fig. (17): Relation between the Load and Recoded Strains in the Upper and Lower Beam Flanges till Failure for Tested End-Plate Moment Connections (Co.7, Co.5 & Co.8).

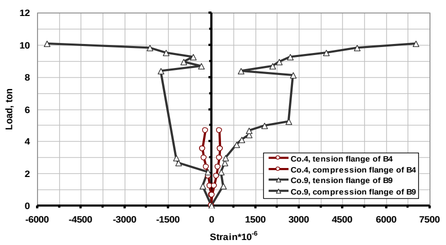


Fig. (18): Relation between the Load and Recoded Strains in the Upper and Lower Beam Flanges till Failure for Tested End-Plate Moment Connections (Co.4 & Co.9)

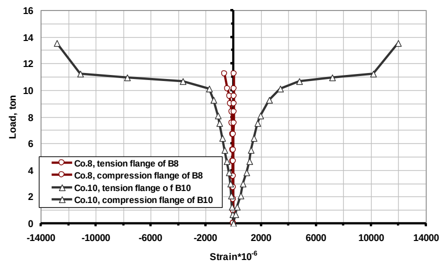


Fig. (19): Relation between the Load and Recoded Strains in the Upper and Lower Beam Flanges till Failure for Tested End-Plate Moment Connections (Co.8 & Co.10)

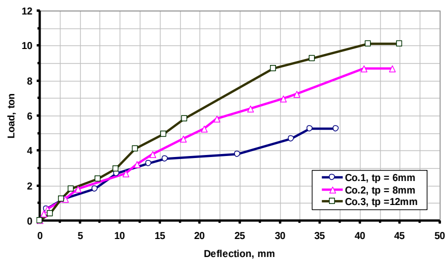


Fig. (20): Relation Between the Load and Recoded Deflections at the End of the Beam till Failure for Tested End-Plate Moment Connections (Co.1, Co.2 & Co.3).

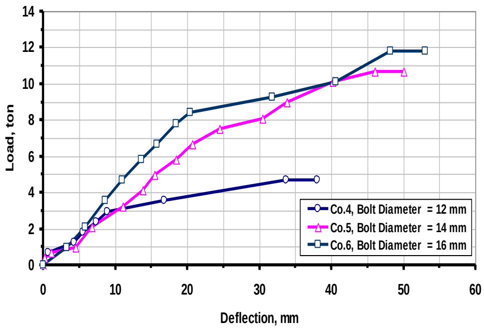


Fig. (21): Relation Between the Load and Recoded Deflections at the End of the Beam till Failure for Tested End-Plate Moment Connections (Co.4, Co.5 & Co.6).

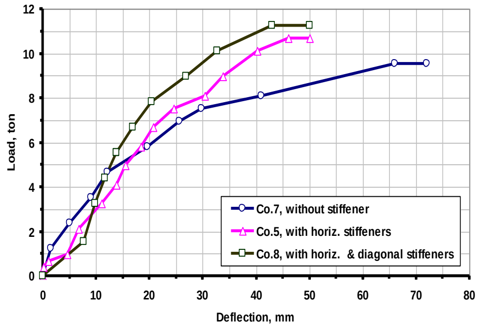


Fig. (22): Relation Between the Load and Recoded Deflections at the End of the Beam till Failure for Tested End-Plate Moment Connections (Co.7, Co.5 & Co.8).

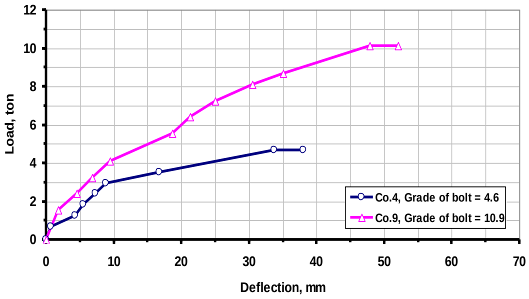


Fig. (23): Relation Between the Load and Recoded Deflections at the End of the Beam till Failure for Tested End-Plate Moment Connections (Co.4 & Co.9)

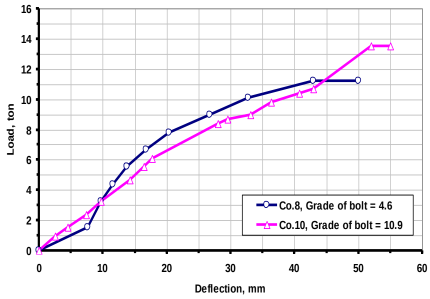


Fig. (24): Relation Between the Load and Recoded Deflections at the End of the Beam till Failure for Tested End-Plate Moment Connections (Co.8 & Co.10)

Fig. (25): Modes of Failure for the tested connections (Co.1, Co.2 &Co.3) in the group I

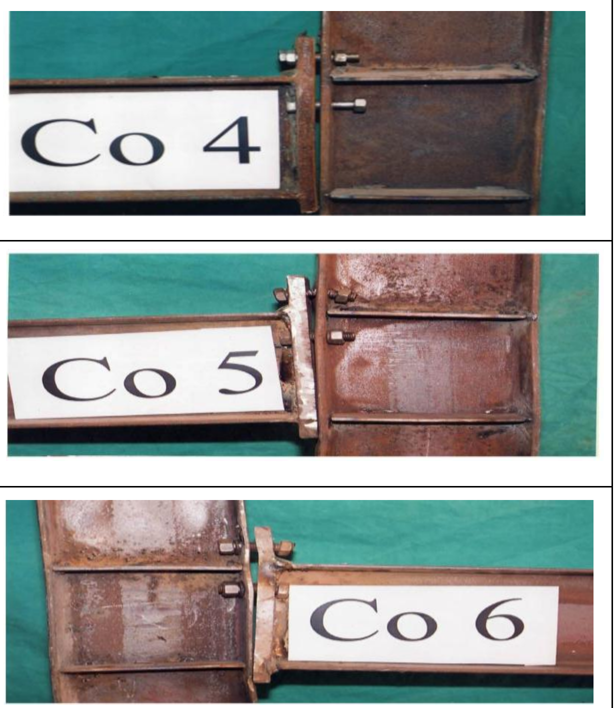


Fig. (26): Modes of Failure for the tested connections (Co.4, Co.5 &Co.6) in the group II

Fig. (27): Modes of Failure for the tested connections (Co.7, Co.5 &Co.8) in the group III

Fig. (28): Modes of Failure for the Tested Connections (Co.4, Co.9, Co.8 & Co.10) in the group IV