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DESIGN OF BOLTED CONNECTIONS SUBJECT TO TORSION AND SHEAR IN THE ULTIMATE LIMIT STRESS STATE

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الملخص

تعددت الابحاث الخاصة بدراسة وصلات المسامير التي تنقل عزوم إنحناء أو إلتواء بالإضافة الى القوى المحورية وقوي القص. وتعتبر أغلب الوصلات المستخدمة فى جميع المنشآت الحديدية محملة لامركزيا أي معرضة لعزوم إنحناء وعزوم إلتواء بالإضافة لقوى القص والقوة المحورية وكأمثلة لها الوصلات الجاسئة الخاصة بربط الأعمدة والكمرات والوصلات التراكيبه للكمرات.
لذلك فقد أصبح دراسة تصميم هذه الوصلات من أهم النقاط البحثية في مجال المنشآت الحديدية حيث يجب الأخذ في الأعتبار الأجهادات الناتجه عن عزوم الانحناء أو الإلتواء بالإضافة إلى تلك الناتجة عن قوى القص والقوة المحورية. وبالرغم من ان هناك العديد من الأبحاث التى تم اعدادها في مجال تصميم وصلات المسامير المركزية واللامركزية المعرضة لعزوم إنحناء وإلتواء وقوي قص ، فإن سلوك وتصميم تلك الوصلات في مدى حدود الاجهادات القصوي يعتبر من الموضوعات التى تحتاج الى مزيد من الابحاث والدراسات.
وجدير بالذكر هنا ان معظم أكواد التصميم (كالكود المصري 205 والكود الأوربي 1993) تطبق نظريات الحدود المرنة عند تصميم هذه الوصلات في مجال الحدود القصوى للاجهادات مع وجود بعض الإستثناءات كالكود الكندي CSA/SA-16 والذي يستخدم معادلة تعتمد على نتائج معملية في تصميم تلك الوصلات في مدى حدود الاجهادات القصوى. وقد تم التحقق من هذه المعادلة بالتطبيق علي مسامير قطرها ¾ بوصه ورتبتها A325 وألواح معدنية رتبتها A36 ولم يتم التحقق من تعميمها فى حال إستخدام أقطار مختلفة للمسامير أو رتب مختلفة للألواح المعدنية .
وبناءا على ماتقدم تم في هذا البحث إجراء دراسة تحليلية عددية لدراسة سلوك وطرق وأشكال إنهيار وصلات المسامير اللامركزية المعرضة لقوى قص وعزوم التواء و ذلك عن طريق اجراء تجارب معمليه علي 12 عينه و معرفه القوة التي تنهار عليها و مقارنتها بالمعادلات المتاحه.
و يحتوي هذا البحث أيضا على إجراء دراسة تحليلية عددية لدراسة سلوك وطرق وأشكال إنهيار المسامير المعرضة لقوى قص و ذلك عن طريق اجراء تجارب علي المساميرو معرفه القوة التي تنهار عليها و عمل منحنيات تربط بين قوة القص و المسافه التي يتحركها المسمار حتي الانهيار.

ABSTRACT

Steel connections transferring axial and shear forces in addition to bending moment and/or torsional moment are widely used in steel structures. Thus, design of such eccentric connections has become the focal point of any researches. Nonetheless, behavior of eccentric connections subjected to shear forces and torsion in the ultimate limit state is still ambiguous. Most design codes of practice still conservatively use the common elastic analysis for design of the said connections even in the ultimate limit states.

Yet, there are some exceptions such as the design method proposed by CAN/CSA-S16-14 which gives tabulated design aid for the ultimate limit state design of these connections based on an empirical equation that is derived for ¾ inch diameter A325 bearing type bolts and A36 steel plates. It was argued that results can also be used with a margin of error for other grade bolts of different sizes and steel of other grades. As such, in this paper, the performance of bolted connection subject to shear and torsion is experimentally investigated. The behavior, failure modes and factors affecting both are scrutinized.

Twelve connections subject to shear and torsion with different bolts configurations and diameters are experimentally tested to failure. The accuracy of the currently available design equations proposed is compared to the outcomes of these tests.
Keywords: Bolts, Eccentric connection, Shear center, Instantaneous center, Shear failure, Steel structures.

INTRODUCTION

The majority of steel connections are eccentrically loaded. Thus, design of these eccentric connections has become the focal point of many research: for such connections, the moment-induced stresses must be taken into considerations besides the stresses induced due to normal and/or shear force.

By large, design of bolted concentric connection subject to bending moment has been extensively investigated. In contrast, behavior and design of eccentric connections subjected to shear forces and torsion in the ultimate limit state are still ambiguous. Most codes of practice (e.g. ECPSC 205-2008 and Euro Code EN 1993) still use elastic analysis for design of the said connections even in the ultimate limit states. Yet, there are some exceptions such as the design method proposed by CAN/CSA-S16-14 (2014) and AISC (2017) which give tabulated design aid for the ultimate limit state design of these connections based on an empirical equation that was derived for ¾ inch diameter Grade 4.8 bearing type bolts and A36 steel plates; it was argued that results can also be used with a margin of error for bolts of different sizes/grades and other type steel. As such, in this research, the performance of bolted connection subject to shear and torsion is experimentally investigated at the ultimate limit state. The behavior, failure modes and factors affecting connection capacity are scrutinized. The accuracy of the currently available method proposed for by CAN/CSA S-16-14 (2014) is investigated.

ELASTIC ANALYSIS

Figure 1 shows a schematic of a bolted connection subject to shear and torsion with bolts' shear areas and loads shown separately from the column and bracket plate. The eccentric load P can be replaced with the same load value acting at the bolts' centroid plus a couple M = PL, where L is the load eccentricity (Figure 1). As such, each bolt is assumed to resist an equal share of the load, which is given by $P_V = P/n$, where n is the number of bolts. Each bolt's force resulting from the couple M can also be assumed based on the distance between this bolt and the bolts' centroid. Based on this assumption, the forces acting on each bolt due to the couple M can be found from (Sayed-Ahmed and Elserwi 2017),

$$P_{mx} = \frac{M \cdot X_i}{\sum_1^n \left(X_i^2 + Y_i^2\right)} \qquad \text{and} \qquad P_{my} = \frac{M \cdot Y_i}{\sum_1^n \left(X_i^2 + Y_i^2\right)}$$

$$d_i = \sqrt{X_i^2 + Y_i^x} \tag{1}$$

where d is the distance from the centroid of the bolt to the bolts centroid. The total force acting on any bolt due to the shear force and the couple M is thus given by

$$P_i = \sqrt{\left(P_{mxi} + P_{vx}\right)^2 \left(P_{myi} + P_{vy}\right)^2} \tag{2}$$

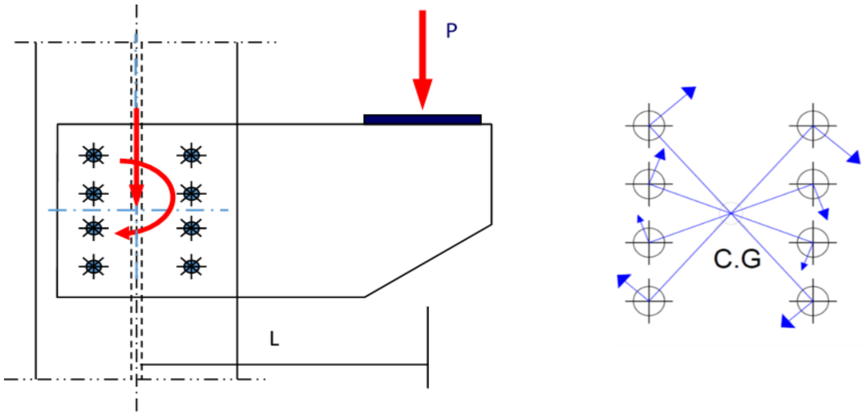

Figure 1. Parameters adopted in the elastic analysis of connections subject to shear and torsion.

THE EXPERIMENTAL PROGRAM

Twelve specimens were designed to investigate behavior and failure mode of bolted connections subject to shear and torsion. Two and three rows of bolts (Grade 4.8) with 10 mm, 12 mm, and 16 mm bolt diameters were adopted in the tested connections. Test set-up and instrumentation are shown in Figure 3 while Table 1 shows details of the tested specimen with L and S symbols in the specimen names indicating long (80 mm) and short (60 mm) bolts, respectively.

The moving plates (brackets) were bolted directly to a bracket (fixed part) which was rigidly connected to the testing frame column (as a cantilever) using 27 mm diameter G8.8 bolts. Instrumentations were set, as shown in Figure 3 via 14 LVDTs and six strain gauges. The load was applied on a top plate connected the two brackets by an automatically controlled hydraulic jack, which was adjusted to maintain constant loading rate. All instrumentations and load cell were connected to an automatic data acquisition system which was connected to a computer to record all data acquired by the system software.

Table 1. Details and results of all the tested connections.

Specimen ID	Bolt Dia.(mm)	No of rows	Exp. failure load P_{Exp} (kN)	Elastic Load Eq. 2 $P_{Eq.2}$ (kN)	$P_{Exp}/P_{Eq.2}$
M(10)-2R-e1-S	10	2	60	43	1.39
M(10)-2R-e1-L	10	2	62		1.43
M(10)-2R-e2-S	10	2	52	35	1.47
M(10)-2R-e2-L	10	2	53		1.50
M(12)-2R-S	12	2	60	43	1.40
M(12)-2R-L	12	2	60		1.40
M(12)-3R-S	12	3	90	61	1.47
M(12)-3R-L	12	3	83		1.36
M(16)-2R-S	16	2	95	65	1.46
M(16)-2R-L	16	2	100		1.53
M(16)-3R-S	16	3	132	95	1.39
M(16)-3R-L	16	3	130		1.37
Average ± St. Dev.					1.4±0.05

TEST RESULTS

Table 1 provides a summary of the failure loads of all tested connections and compares these loads to elastic design approach are shown in Figure 4.
Table 1 reveals that the experimental failure load of the tested connections is about 140%±5% of that predicted vial the elastic design approach (Equation 2). As such the elastic design tends to be very conservative and significantly underestimate the failure load of connections subjected to shear and torsion.

CONCLUSIONS

An experimental program was conducted on twelve steel bolted connections which are subjected to shear and torsion. The results of the experimental investigation were compared to the currently adopted elastic techniques.

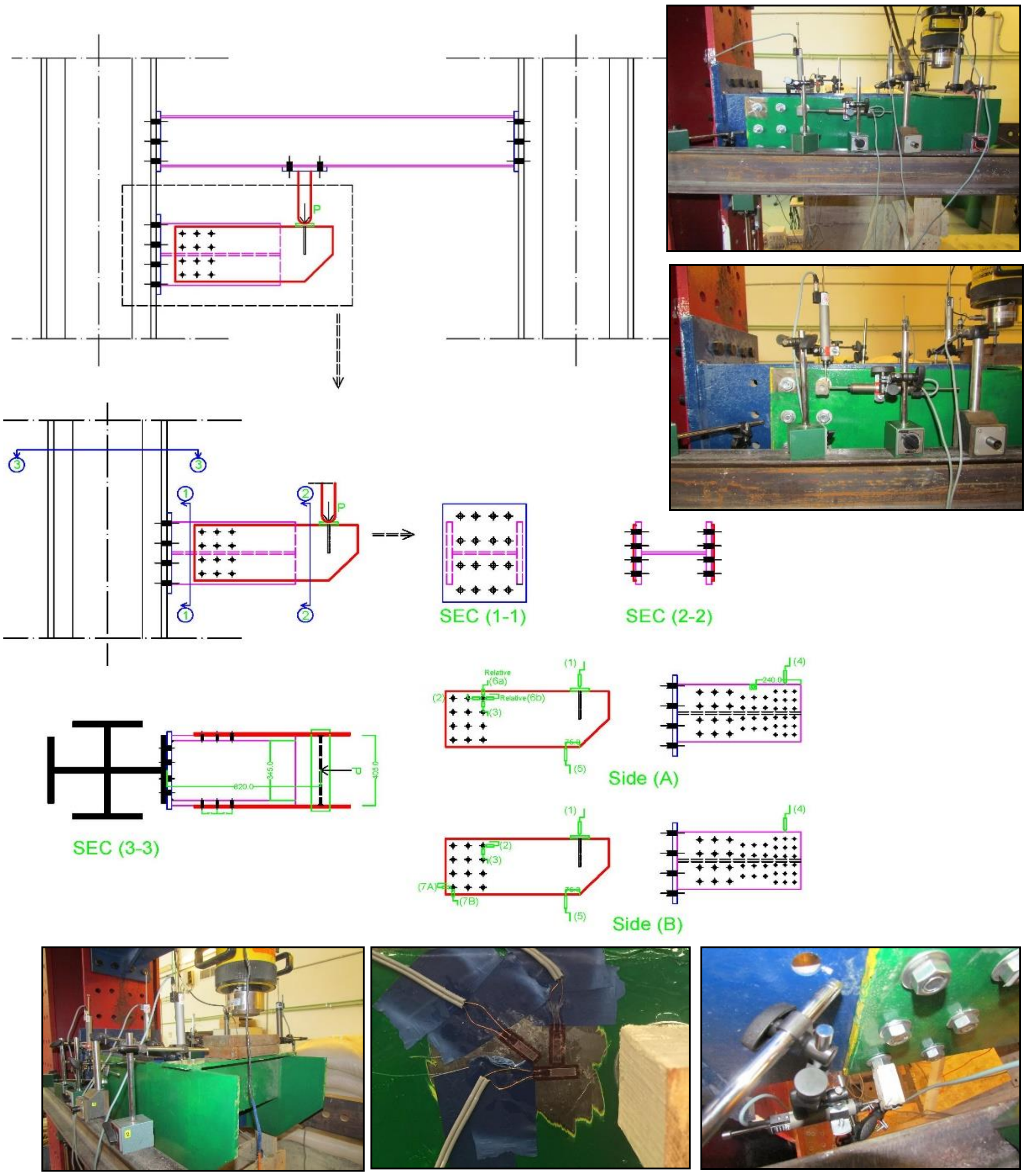

Figure 3.Test set-up and details of the tested connections.

The comparative investigation revealed that the elastic approach significantly underestimates the connection capacity and tends to be very conservative and uneconomic.

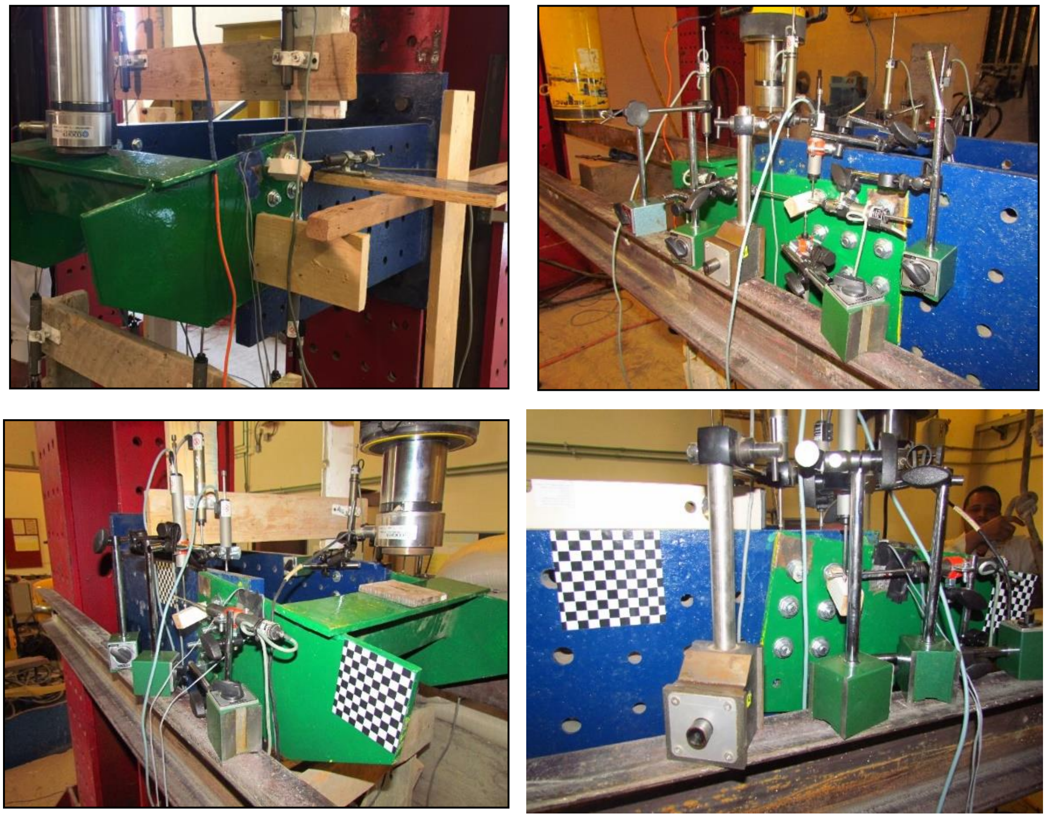

Figure 4. Test Failure

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