The 2019 World Congress on
Advances in Structural Engineering and Mechanics (ASEM19)
Jeju Island, Korea, September 17 - 21, 2019

Flexural behavior of bolted beam-to-column connections of steel storage racks

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ABSTRACT

This paper presents an experimental investigation of bolted beam-to-column connections of steel storage racks. The conventional beam-to-column connections with and without additional bolts are experimentally tested using the standard cantilever test in order to evaluate the flexural behavior of the connection. Moment-rotation curves of rack's connections obtained from the experiment show a great benefit of additional bolts in terms of moment resistant and ductility. The experimental results show that the strength of bolted beam-to-column connections is higher than the conventional beam-to-column connections by up to 76%. The ductility of the bolted beam-to-column connection is also increased by up to 22%. The study shows that the additional bolts can be applied for the strengthening of beam-to-column connections of steel storage racks.

1. INTRODUCTION

Steel storage racks are wildly used in industry and large public warehouses for storing products. This type of structure has become a common feature in several countries. A structural system of steel storage racks is composed of a perforated thin wall cold-formed open section column, a box beam and beam end connectors. A beam end connector, welded into the ends of the beam, provides a means of connecting the beams and the column together. Steel tabs are often used as connectors. Steel tabs are the hooks in the beam end connector that are engaged into the perorated column at optional heights. Many experimental studies (Markazi et al. 1997: Bernuzzi and Castiglioni 2001; Bajoria and Talikoti 2006) have found that this type of connection has a low of strength which can be classified as a semi-rigid connection. The failure mode is usually the tearing of an outermost steel tab, which is a brittle failure mode.

For practical reasons, it has been found that some of the conventional beam-to-column connections use additional bolts to avoid the accidental unlocking of the

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connections. The bolts are tightened with washers on a slot of perforated columns as shown in Fig. 1. Generally, the strength and thickness of additional bolts is higher than the steel tab, therefore, it is possible that additional bolts may have some improvement on the flexural behaviors of the beam-to-column connections. The main objective of this study is to investigate the flexural behavior of the beam-to-column connections of steel storage racks with additional bolts, which will be referred to as "bolted beam-to-column connections" in this paper. The experimental testing results will be compared with the conventional beam-to-column connections without additional bolts (Asawasongkram et al. 2014) in terms of strength, ductility and failure mode to evaluate the possibility of using additional bolts for strengthening this type of connection.

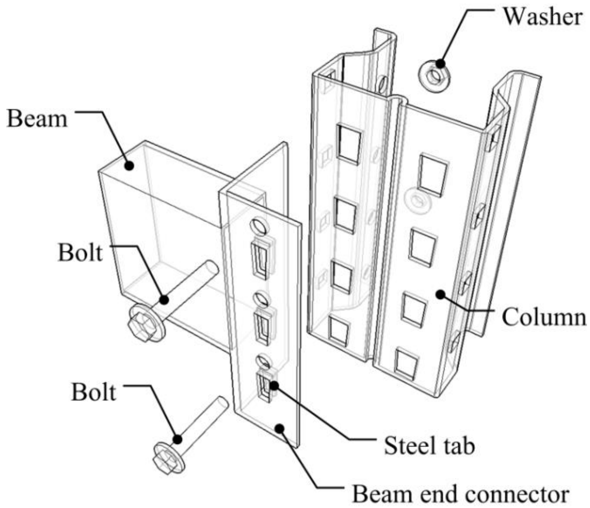


Fig. 1 Bolted beam-to-column connection of steel storage racks

2. EXPERIMENTAL INVESTIGATION

The test specimens are selected from a commercial manufacturer in which their configurations are commonly used in Thailand and other countries. In particular, it consists of a beam-end-connector made of a 3 mm thick angle welded to the end of a box beam. The column and beam are fabricated from cold formed steel. The thickness of column is 2.5 mm. The beam-end-connectors are made of hot rolled steel. The additional bolts are tightened with washers near the topmost tab and bottommost tab which are subjected to a substantial flexural tension and compression. The dimensions of specimens are shown in Fig. 2.

The cantilever test setups are performed according to the international design standard for steel storage racks (AS 4084, 1993; FEM, 1998; RMI, 2008). Fig. 3 shows an arrangement of transducers and a general layout of the experimental setups. Full details of the experimental test setup are available in an earlier paper by the authors (Asawasongkram et al. 2014).

The bolted beam-to-column connections are experimentally tested for ten connection samples which consist of five hogging moments and five sagging moments.

The moment-rotation curves for the connection subjected to hogging moments and sagging moments are presented in Fig. 4a-4b, respectively.

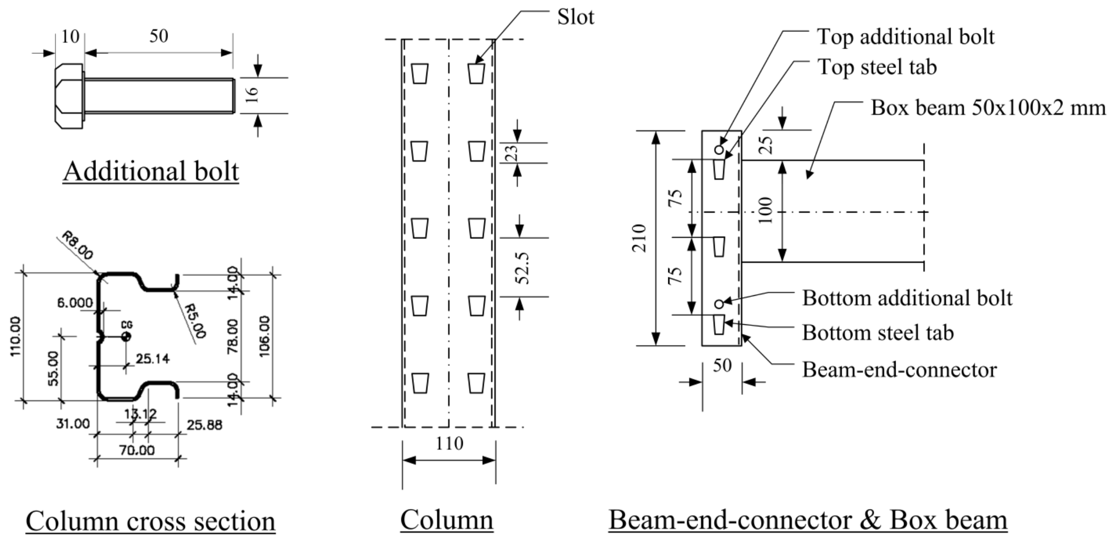
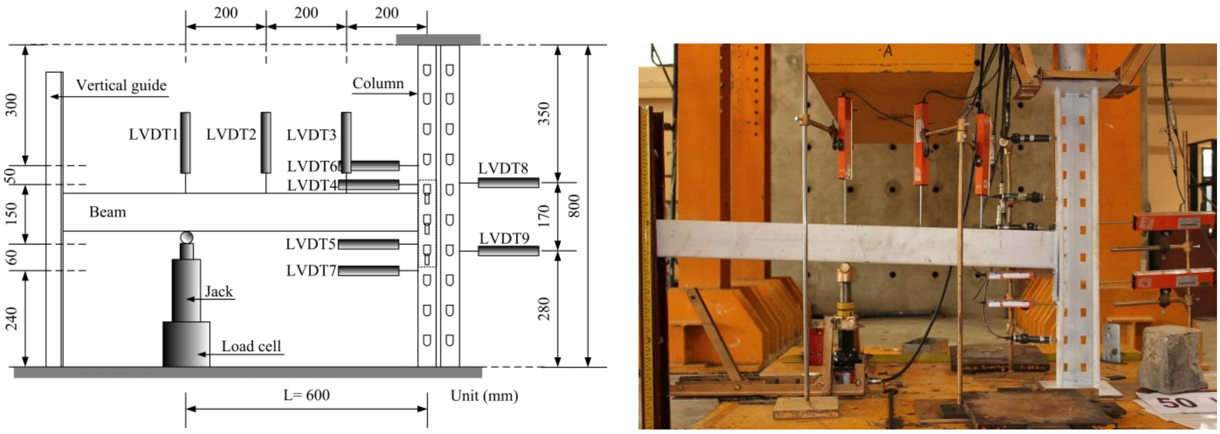


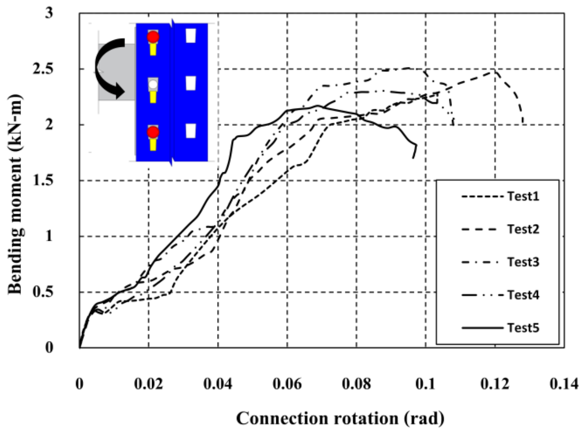
Fig. 2 Dimensions of connection samples (Unit: mm)



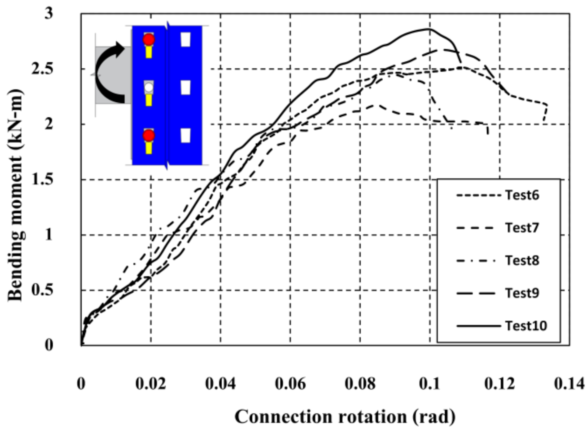
a) Transducer arrangement b) Actual test setup

Fig. 3 Cantilever test setup

To simplify the connection behaviors, the experimental moment-rotation curves in Fig. 4 are idealized as a multilinear line shown in Fig. 5. The flexural behavior of the connection up to failures is presented by photos taken from the experimental testing as illustrated in Fig. 6a-6d. According to Fig. 5-6, the flexural behaviors of the connections can be described as follows.



a) Hogging moment



b) Sagging moment

Fig. 4 Moment-rotation curves of bolted beam-to-column connections

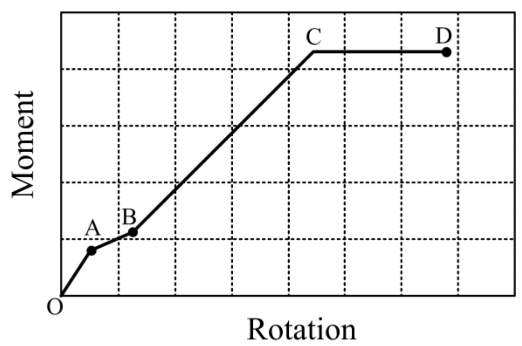


Fig. 5 Idealization of moment-rotation curves of bolted beam-to-column connections

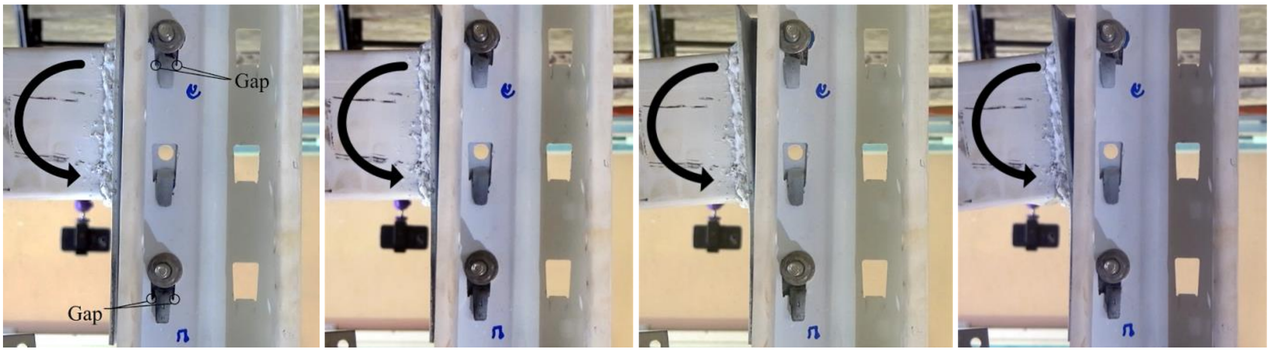
Point O: At the beginning of the test, the steel tab is not perfectly fit with the column slot as shown in Fig. 6a. A small gap between the edge of the steel tab and the column slot is about 1.8 mm.

Stage OA: The connection is initially subjected to an applied moment and starts to gradually deform as shown in Fig. 6b. At this stage, the deformation is very small due to high frictional force from the tightening of additional bolts.

Stage AB: After the applied moment overcomes the frictional force, the connection deforms largely as shown in Fig. 6c due to an imperfect fit of the steel tab and the column slots. The flexural characteristic in this stage is similar to the initial looseness of beam-to-column connections without additional bolts which are found in many experimental studies (Bernuzzi and Castiglioni, 2001; Bajoria and Talikoti, 2006; Prabha et al., 2010; Asawasongkram et al. 2014). At the end of this stage the additional bolts begin to attach with the column wall.

Stage BCD: In this stage, the moment-rotation characteristic of the connection exhibits non-linear behavior. The non-linear behavior comes from many factors such as the yielding of the perforate column or the bending of the beam-end connector. The connection develops a flexural capacity with a large amount of deformation as shown in

Fig. 6d. The non-linear characteristic of moment-rotation curves is similar to the characteristic of beam-to-column connections without additional bolts as shown in the previous study by the authors (Asawasongkram 2014). At the end of this stage, the connection fails at beam ends by local buckling at the compression region without shearing of the steel tab as shown in Fig. 7. This mode of failure is more ductile than the conventional beam-to-column connection which is mostly failure by shearing of the steel tab.



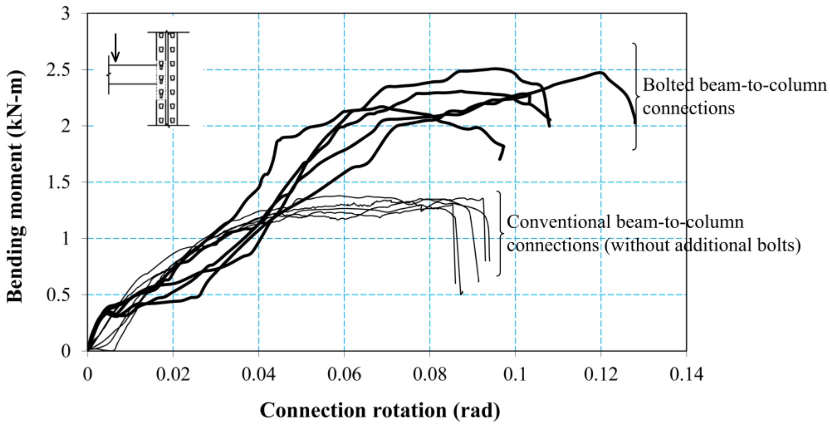
a) Initial stage b) Stage OA c) Stage AB d) Stage BCD

Fig. 6 Flexural behavior of bolted beam-to-column connections during experimental testing

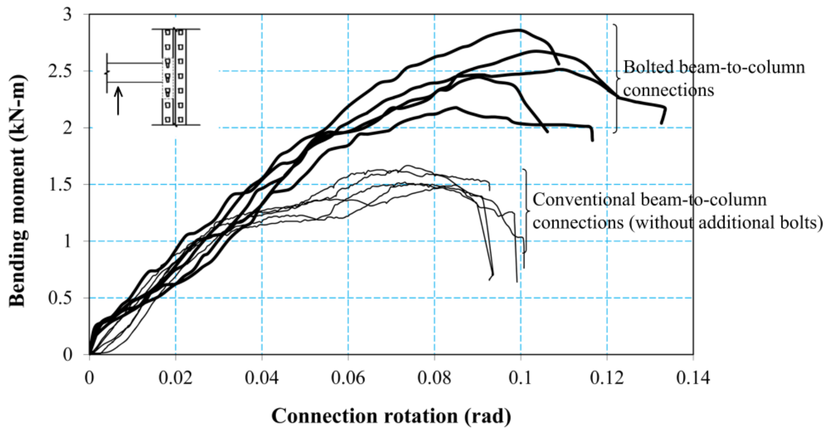
Fig. 7 Failure of bolted beam-to-column connections at beam ends

3. COMPARISION OF MOMENT-ROTATION CURVES BETWEEN CONVENTIONAL BEAM-TO-COLUMN CONNECTIONS AND BOLTED BEAM-TO-COLUMN CONNECTIONS

This section provides a comparison of moment-rotation curves between conventional beam-to-column connections (without additional bolts) and bolted beam-to-column connections to investigate the effect of additional bolts. Ten connection samples for the conventional beam-to-column connections with the same dimension as the bolted beam-to-column connections are experimentally tested by the authors (Asawasongkram et al. 2014). The experimental testing is composed of five for hogging moment testing and five for sagging moment testing. The experimental results are compared with the bolted beam-to-column connections in the form of moment-rotation curves as shown in Fig. 8. The results show a great benefit of additional bolts in terms of strength and ductility. The strength and ductility of bolted beam-to-column connections are higher than the conventional beam-to-column connections by approximately up to 76% and 22% for strength and ductility, respectively. The effects of additional bolts are not clearly seen in terms of stiffness of the connection.



a) Hogging moment



b) Sagging moment

Fig. 8 Comparison of moment-rotation curves between conventional beam-to-column connections and bolted beam-to-column connections

4. CONCLUSIONS

This research presents the experimental study of a bolted beam-to-column connection of steel storage racks. The flexural behavior of the connection is investigated using the experimental test setup according to the international design standard. The results show that the strength and ductility of the bolted beam-to-column connection are higher than the connection without additional bolts by approximately up to 76% and 22% for strength and ductility respectively. The bolted beam-to-column connection fail at the beam ends by local buckling at compression region which are a more ductile mode than the conventional beam-to-column connection.

Generally, the beam-to-column connections for this type of structure are classified as a semi-rigid connection with a low to moderate strength and stiffness. By adding the additional bolts to the existing beam-to-column connections, the strength and ductility of the connections will be enhanced and the overall structural response should be improved especially under a lateral excitation. A seismic assessment of case study steel storage racks with conventional beam-to-column connections and bolted beam-to-column connections will be studied in the next stage of research.

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