

STATE-OF-THE-ART REVIEW ON BOLTED STEEL BEAM-TO-COLUMN CONNECTIONS

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Abstract: *This paper presents an overview of current state of knowledge regarding bolted beam-to-column connections employed for moment-resisting framed steel structures. The connections of steel structures are one of the determining factors of economy in structural steel work. Moreover the manual evaluation of bolted connection is a difficult task. The selection of connections is often based upon simplicity, duplication and ease of erection, which can be done with relatively unskilled workers and with basic tools. From this point of view the designer have to avoid complicated joint configurations with costly fabrication and laborious design. The state-of-the art report presented in this paper highlights the new tendencies in the field of steel beam-to-column bolted connections, and the importance of knowledge of their behaviour.*

Key words: *steel frames, beam-to-column steel joint, semi-rigid, bolted connections.*

1. Introduction

Beam-to-column connections play a crucial role in the performance of moment resisting framed structures [1].

The behaviour of beam-to-column connections is under extensive studies even nowadays: the researchers conduct experimental, numerical and analytical assessments.

Since the 1994 Northridge and 1995 Kobe earthquakes, bolted moment connections have garnered considerable interest for their application in seismic

lateral resisting systems [2].

However, the considerable amount of research conducted over the last two decades has not produced many design procedures that would allow the applications of bolted connections either as fully-restrained or partially-restrained.

There are several advantages provided by bolted joints like reduced cost and reduced complexity of execution. Compared to welded joints, bolted connections are more ductile, have relatively high capacity to dissipate energy and can be fitted relatively easy.

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Framed steel structures with moment resisting joints are recognized as highly dissipative structures in seismic design.

According to Eurocode 8 rules the dissipative zones could be located either in elements or in beam-to-column connections. From this point of view de configuration of joint is an important task, in order that the resulted joint provide sufficient resistance, rotation and flexibility [3]. After evaluation of joint performances, these can be classified in terms of strength, stiffness and ductility.

In the structural analysis practice of multi-storey steel framed structure, the beam-to-column connections are considered to be simplified, either rigid or pinned: rigid implies complete rotational continuity and pinned implies no moment transfer. Besides these classical connections there is another category called semi-rigid.

Analysis of frame structure with semi-rigid joints requires knowing the behavior of joint moment-rotation behavior. Taking into account the behavior of semi-rigid connections results closer to the reality are obtained.

The main advantage of a frame design using semi-rigid joint behaviour is that beam moments are reduced leading to lighter beam. Assuming appropriate semi-rigid connections, the moments value can became more balanced.

Figure 1 shows the cost effectiveness of semi-rigid joints. Although the literature provides a high volume of studies on semi-rigid behavior of joints, they are not used as such in the usual designing practice.

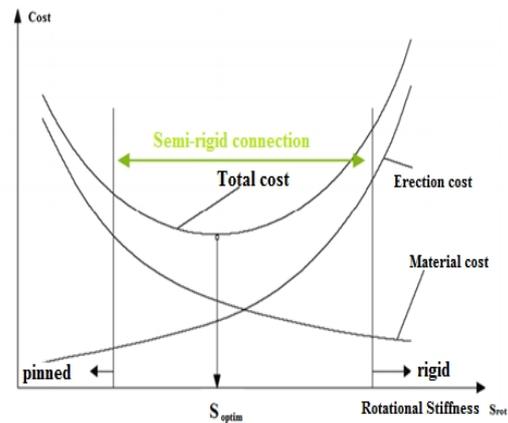


Fig. 1. Cost effectiveness of semi-rigid connections [4]

Most of the structural calculation programs allow defining a flexible connection at the end of the bars in terms of rotational springs, but these moment-rotation curves are available for a relatively small number of joints types and their parameters.

2. New Beam-to-Column Connections Behind Classical Ones

Several typical connections are provided in SR EN 1993 1-8: Design of steel structures: Part. 1-8 Design of joints, or AISI standards, which, after all are similar. To give an example, one of the most popular beam-to-column connection in design practice is the bolted end-plate connection. Bolted end-plate connections are made by welding the beam to an end-plate and bolting the end-plate to a column flange. The end-plate connection configuration is shown in figure 2.

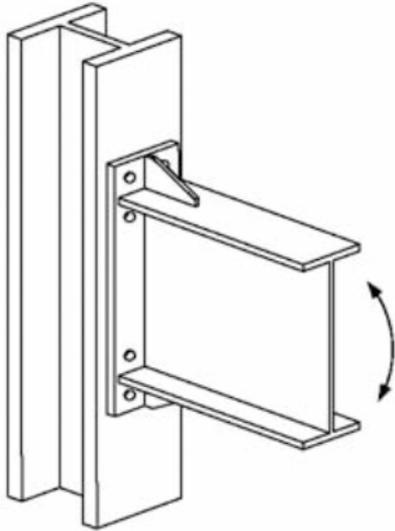


Fig. 2. *Extended end-plate configuration* [5]

The behavior of this type of connection can be controlled by a number of different limit states including flexural yielding of the beam section, flexural yielding of the end-plates, yielding of the column panel zone, tension rupture of the end-plate bolts, shear rupture of the end-plate bolts, or rupture of various welded joints. The design criteria provide sufficient strength in the elements of the connections to ensure that the inelastic deformation of the connection is achieved by beam yielding [5].

Excessive extending of the end-plate with properly stiffener will lead to the hammer-headed connections. Hammer-heads have the effect of increasing the lever arm between the compression and tension forces within the joint and of reinforcing the end-plate submitted to bending.

A newer bolted moment-resisting connection is the T-stub configuration. A typical T-stub connection is shown in figure 3.

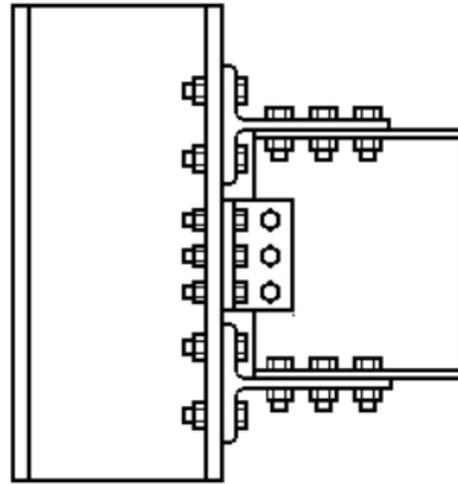


Fig. 3. *Typical T-Stub Connection* (Leon, et al., 2000, Roeder, 2000) [5]

The failure mechanism of an equivalent T-stub is described by yield line models. The model of the equivalent T-stub can be used to calculate the load-bearing capacity of the basic components of bolted connections. Experimental data provided by Leon (2000) served as the basis for estimating the stiffness and the strength of the T-stub connection [5].

In the following, some newly developed connection configuration are presented. One of them is named Kaiser bolted bracket connection.

In a Kaiser bolted bracket (KBB) moment connection, a cast high-strength steel bracket is fastened to each beam flange and bolted to the column flange as shown in figure 4. The Kaiser bolted bracket (KBB) moment connection is designed to eliminate field welding and facilitate frame erection.

The obtained connections is full-strength one, while the bracket configuration is proportioned to develop the probable maximum moment strength of the connected beam.

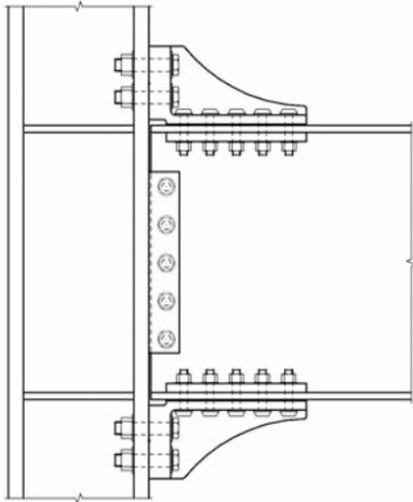


Fig. 4. Kaiser bolted bracket connection [5]

Yielding and plastic hinge formation are intended to occur primarily in the beam at the end of the bracket away from the column face (Figure 5).



Fig. 5. Kaiser Bolted Bracket connection failure [6]

Another innovative connection is the ConXtech ConXL™ moment connection, which is designed to provide robust cost effective moment framing, while eliminating field welding and facilitating fast frame erection. The ConXtech

ConXL™ moment connection permits full-strength, fully restrained connection of wide flange beams to concrete-filled square hollow section, built-up box columns using a high-strength, field-bolted collar assembly.

Figure 6 shows the connection geometry and major connection components. Each collar assembly is made up of forged collar corners and collar flanges.

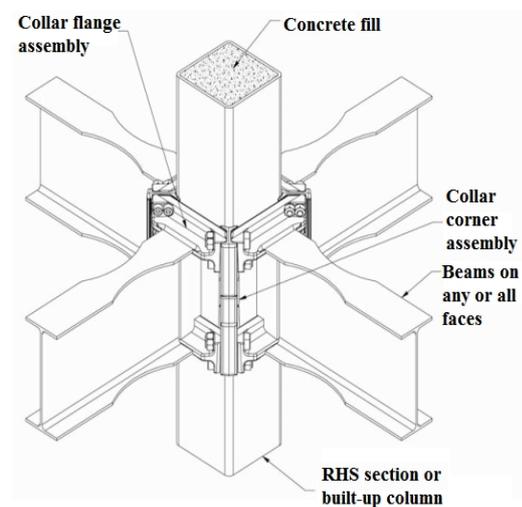


Fig. 6. Configuration of Conxtech Conx spatial connection (<http://www.conxtech.com/>)

Beams are shop-welded to forged flange and web fittings (collar flange assembly) and are field-bolted together through forged column fittings (collar corner assembly) that are shop welded to the columns [5]. Beams may be provided with reduced beam section (RBS) cut-outs if necessary to meet strong-column/weak-beam criteria. ConXL connections may be used to provide moment connections to columns in orthogonal frames. All moment beams connecting to a ConXL node (intersection of moment beams and column) must be of the same nominal depth.

Figure 7 shows an application of such connectors.



Fig. 7. *Conxtech Conx connection*
(<http://www.conxtech.com/>)

Another typology of connections appears due to the extensive application of rectangular hollow sections. As field weld is not a desired solution in this case, particular connections were developed using blind bolts.

Figure 8 presents a RHS beam-to-column connection using hollow-bolts and angle cleats.



Fig. 8. *Rhs beam-to-column connections using angles and blind bolts*
(<http://keesafety.de/>)

Rectangular hollow sections (RHS) are more suitable for structural applications like H shaped, owing to their efficient structural performance and attractive appearance.

Blind bolts have a lot of advantages, such as one-side fastening, quick, construction, reliable behaviour and good seismic performance, and are expected to be widely used in engineering projects [11].

Figure 9 shows a blind-bolt typology named hollo-bolt



Fig. 9. *Hollo-bolt*
(<http://www.lindabter.com/>)

A newly proposed innovative bolted beam-to-column connections are those, where the column is made of high strength steel while the beam are made of mild carbon steel [8] (Figure 10). These joints are full-strength non-dissipative and the plastic hinge will form at the beam extremity in the beam, while the joint remain elastic.

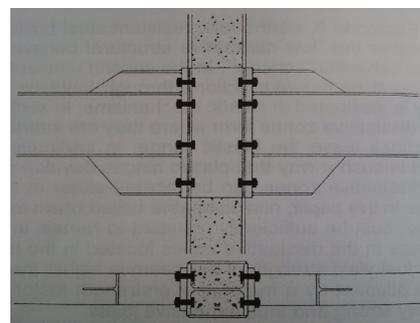


Fig. 10. *High-strength steel column and mild carbon steel beam full-strength connection* [8]

Beam-to-column connections with shape memory alloys are using special metallic alloys to obtain high ductility capacity.

Figure 11 shows a detail how the alloy elements are disposed within the joint.

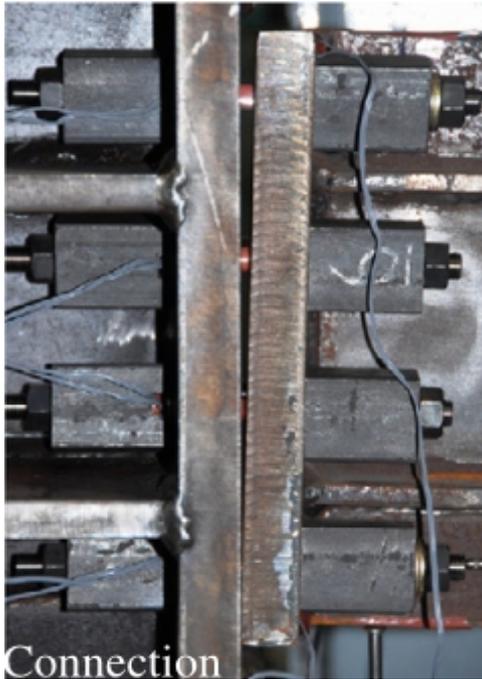


Fig. 11. *Beam-to-column connections with shape memory alloys [8]*

Shape memory alloys (SMAs) are a group of metallic alloys that can return to their original form (shape or size) when subjected to a memorisation process between two transformation phases, which is temperature or magnetic field dependent [8]. Because of their super-elastic property, these alloys are able to withstand non-elastic stresses and undergo large deformations, as well as to restore to their original configuration after being unloaded. These connections exhibit a high level of energy dissipation, large ductility capacity, and no strength degradation after being subjected to cycles [9].

3. Design Method

The history of research into the behaviour of steel beam-to-column connections is traced starting from early developments in 1917. Attention is focussed on moment-rotation characteristics as this is the most important influence on the response of either individual members or complete frames. The nonlinear nature of this characteristic were identified and methods of representing moment-rotation curves for subsequent use in analytical procedures were discussed even nowadays [10].

Many papers have been published to report on behalf of design models to determine the structural properties of joints in steel structures. Also design tools, simple softwares and design tables were reported by researchers.

Traditional design methods for connections were based on a series of capacity checks and did not include methods for calculating a connection's stiffness and rotational capacity [12].

In order to predict connections behaviour, several mathematical expressions comprising curve-fitting models, simplified analytical models, and mechanical models are available. Furthermore, advanced 3D finite element models are usually used to capture the complex behavior of the connections.

According to EN 1993-1-8, the load-bearing capacity and stiffness of connections in steel engineering are determined by calculating the basic components of a connection.

The component method is suitable to determine the deformation behaviour of the connection in addition to the moment resistance. Therefore, it allows the consideration of yielding connections. The

connecting stiffness of the joints is considered in the calculation by means of springs and leads to an optimisation of the entire structure through iterative computation.

4. Conclusions

The review highlights the main problems regarding beam-to-column moment-connections and the importance of research in this field.

Several type of bolted beam-to-column moment connections are presented, and their behaviour are described.

The review presented newly developed innovative connection arrangements for beam-to-column joining, available in recently reported literature.

Connection design problems were discussed with the main focus on the component method.

The performance of a bolted connection is complicated and both the stress distribution in the connection and the forces in the bolts are dependent on the stiffness of the bolts, and the connecting steel elements (end plates, cleats, etc.).

The design of a bolted connection is semi-empirical, namely based on past experience of good performance, custom and practice, but always validated with a statistical evaluation of test results.

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