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A Review on Steel Connections and Structural Behavior

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A Review on Steel Connections and Structural Behavior

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Abstract

The demand for the use of steel in the construction industry has been on the increase over the years due to its several advantages over several other construction materials. Some of these advantages are light weight, ease of constructability and durability. In the constructability of a steel structure, the three major connection types that have been used in steel structure construction are the riveted connection, bolted connection and the welded connection and the type of connection employed in a steel structure has been seen to have a great influence on the steel structural behavior and the condition for operation. Hence, the condition of service and acceptable behavior of steel structure should guide the choice of connection to be employed in any steel structure. To this end, this paper reviews connections types and the structural behavior.

Keyword: Steel, Connections, Structural Behavior, Structures

1. Introduction

In steel structures, connections are very important to have the structural members connected together and have the structure function as a unit [1]. Connection types that have been explored over the years are bolted connection, riveted connection, welded connection, and welded and bolted connection [2]. Among the many types of connections in steel structures, welds and bolted connections have played vital roles in steel connections since a while after the time of World-War II [3]. Due to ongoing upgrade in structural developments, work is ongoing to device an advanced structural steel connection over the previous ones. The desire for the advanced or improved structural connection is due to the need to achieve better cost-effectiveness. Steel structures are known for the ease of construction and de-construction [4]. This is due to the fact that the structural members are sent from the manufacturer as a unit, hence it is easy to connect and to disconnect the steel members. Ease of de-constructability of steel structure for reuse is another reason behind the desire to improve on the usual connections [5]. In connecting a structural member to another structural member, there are forces in which such structure is subjected to. An example of such connection is the connection of a beam to a column as presented in the figure 1.

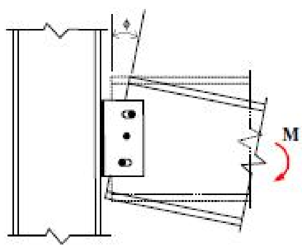

Figure 1. Beam to Column Connection [6].

The connection shown in figure 1 is subjected to bending moment, torsion (could be negligible), axial force, and shear force. The moment transmitted and the rotation generated ultimately describe the flexural behavior of the connection. Hence, much focus is driven to the moment-rotation characteristic as this can point to the possible response of the members [7]. Some of the many factors that are capable of influencing rigidities in a column to beam connection are column web, local beam flange buckling, depth and length of the connected beam, connection to a column web or its flange, and centre-centre distance between bolt holes [8].

Another connection is the shear connection in which vertical reaction of a structural element is primary transferred to the supporting member as shown in the figure 2.

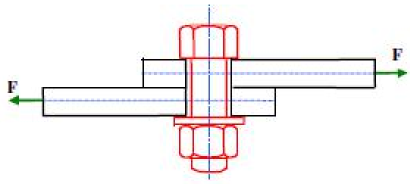

Figure 2. Typical Lap Joint with a Single Bolt [6].

In a typical lap joint with a single bolt, the structural behavior is such that the plates continue to pull apart as indicated with the directions of the forces till the bolt is set into single shear and the bolt shank surface bears into the hole circumference. As the load applied goes on the increase, there tends to be rotation of the bolt and the plates bend to align with the line of action.

Another common connection type is the fin plate connection. This is sometimes referred to as web side plate. A typical fin plate connection is presented in the figure 3. The fin plate connection is very economical and has ease of fabrication

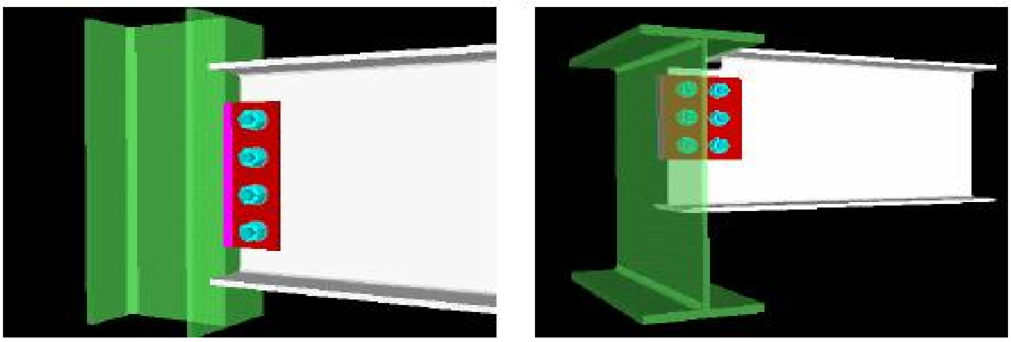

Figure 3. Typical Fin Plate Connection (a) Beam to Column (b) Beam to Beam [8].

The fin plate connection demonstrates failure in 5 possible modes as shown in figure 4.

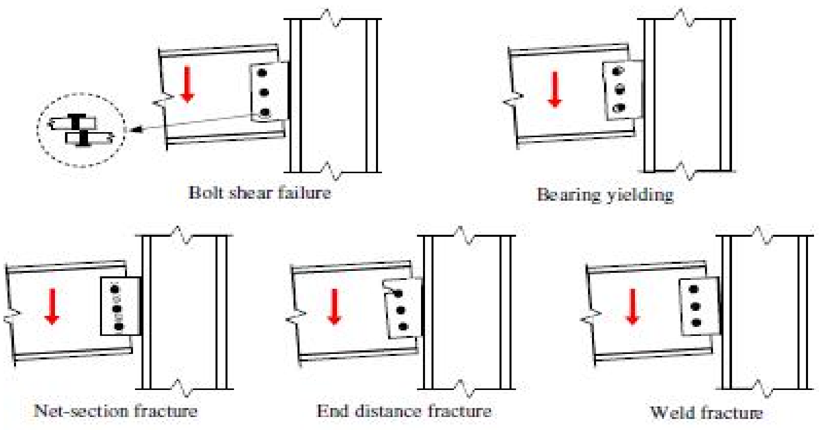

Figure 4. Five Possible Mode Failures in Fin Plate Connection [3]

2. Major Connection types

2.1. *Riveted Connection*

The riveted connection is manufactured in grade 1, grade 2 and grade 3 as stated in table 1. Several years ago, especially in the 20th century, when steel and iron began to gain attention in the construction industry, riveted connection became widely accepted as means to connect steel structural members due to its attribute of clamping force. Nevertheless, the use of riveted connection began to decline in the 1990s due to the introduction of other connection types such high strength bolts.

Table 1. Rivet structural steels [9].

ASTM A502	Composition	Use
Grade 1	Carbon Rivet Steel	General purpose
Grade 2	Carbon-Manganese Rivet Steel	Can be used with-strength carbon and high-strength low alloy structural steels
Grade 3	Carbon-Manganese Rivet Steel	Grade 2 with enhanced corrosion resistance

The Construction industry started to witness a proper engagement of the high strength bolt in the early 1930s [6] . Most of the structures that used riveted connection as the means of connection in the 20th century is very okay till date. Some of these structures are railways and steel bridges. Hence riveted connection is very durable. Typical riveted connection used in construction is related in plate 1.

Plate 1. Riveted Connection used in Construction [11].

2.1.1. *Installation of Riveted Connection*

In the installation of a rivet, it is slotted into a hole called shank. This hole is usually 1/16in wider than the diameter of the rivet itself. The rivet has a head called rivet head. This head laps with the end of the shank when the rivet is inserted into the shank. The other rivet head of the rivet is driven into the rivet from the other end through a pressure riveter or it is pounded through a pneumatic hammer. The figure 1 relates an installed rivet [12].

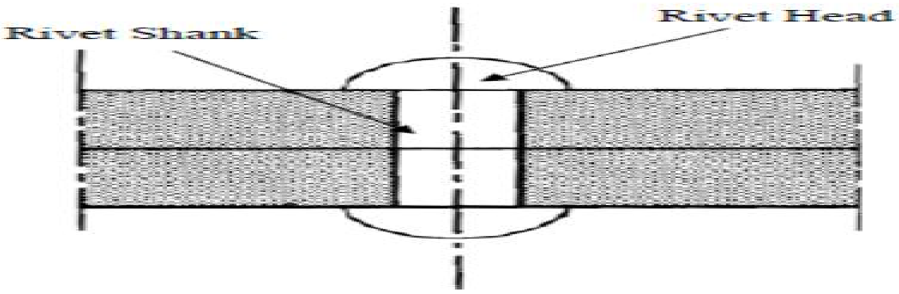

Figure 5. Installed Rivet [13].

Riveted connections can be installed either in a cold state or by heating to a temperature of 1800F in the shop. The clamping force attribute of rivet connection is created during the cooling process as the pliers get squeezed together. While the clamping force of rivet connection has no impact on the strength of the rivet connection itself, it is very important to slip resistance [13].

2.1.2. Recurrent behavior of Riveted Connection across Literature

The recurrent behavior of riveted connection reiterating through several literatures are as follows:

1. The ultimate shear strength in riveted joints is mainly determined by the strength of the riveted materials

2. In riveted connections, stiffness of the joints, geometry of the joint, treatment and preparation of the surface, type of steel, clamping force of the fastener and the grip length have a way of affecting slip resistance.
3. Deformation of the riveted joints occurs due to the slipping of surfaces in contact after yield point is exceeded.
4. Deformation of the rivet body occurs when the end of the hole or shank and the rivet bears against each other
5. When plastic flow occurs in the connection, excessive deformation of end rivets takes place.
6. Deformation in riveted connection develops to shear failure when there is sufficient ductility.
7. Failure mode in riveted connections could be summarized into rivet shear, tension on net section and bearing at rivet holes of thinner plates [9].

2.2. *Bolted Connection*

Among the types of bolt connections that exist, the bearing bolted connection is the common and most popularly used connection [14]. The classification of bolted connections can be based on their behavior or reaction to geometry or loading conditions. A typical picture of bolted connection used in construction is related in plate 2.

Plate 2. Bolted Connection used in Construction [11].

2.2.1. *Behavior of Bearing Bolted Connection*

In a bearing bolted connection as related in the figure 6, the tension in the connected members is equilibrated through the bearing stress between the bolt and the hole drilled in the plate. In a bearing bolted connection, there is no mobilization of the bearing stress until the plates slip relative to each other and bearing is kick started on the bolt [15]. The point of critical stress in bearing bolted connection is labelled section x-x. In a bearing bolted connection, for failure to occur, the failure either takes place in the plates connected or in the bolt itself [16].

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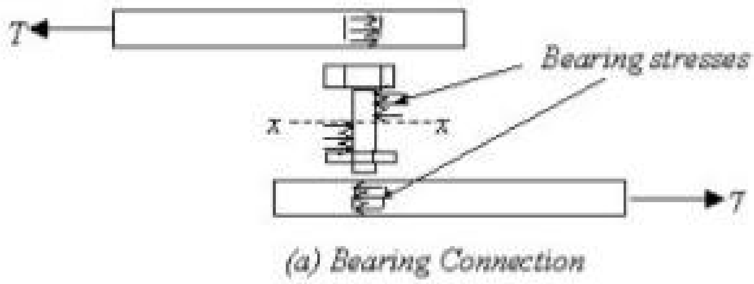

Figure 6. shear stress in bearing bolt type [17].

When bearing connections are used, the structural behavior stays linear till the following happens:

1. Failure of plate occurs

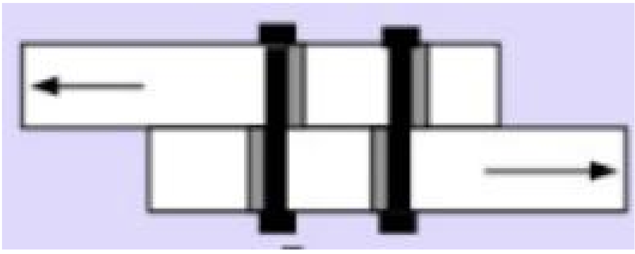

Figure 7. Failure of plate [18].

2. Occurrence of block shear failure
3. Occurrence of failure in the bolt

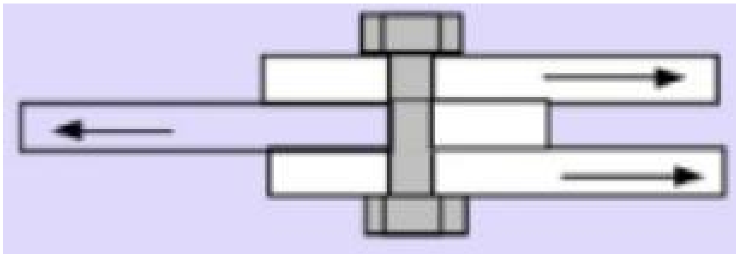

Figure 8. Failure of Bolt [18].

4. Yielding of the net section of the plate due to subjection to both flexure and combined tension

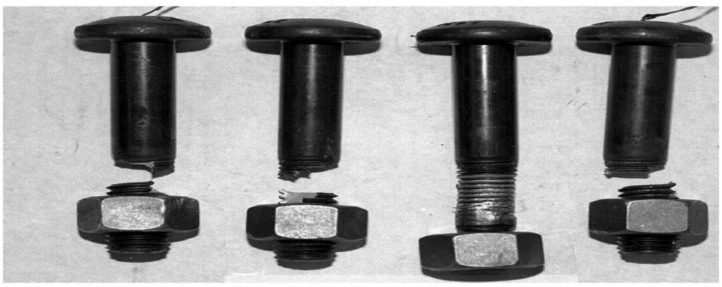

Plate 4. Yielding of bolts due to tension [18].

5. Occurrence of shear at the bolt shear plane

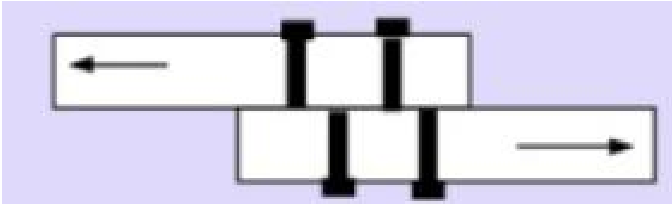

Figure 9. Shear of Bolt [18].

2.3. *Welded Connection*

Welded connection among other types of connections is very efficient in the transfer of forces from a member to another member. A typical representation of welded connection is as represented in the plate 5.

Plate 5. Welding of Plates [19].

In a welded connection, the connection is formed when a melted base metal joined with the weld metal cools. The connection is classified into either fillet or butt welds as related in the figure 10. The fillet in the figure 10a are welded at two surfaces while the butt is achieved by welding two surfaces together

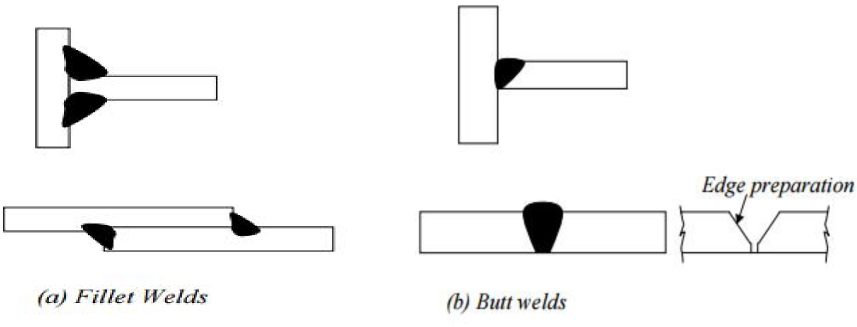

Figure 10. (a) Fillet Welds (b) Butt Welds [20].

In the formation of the metallurgical bond between two metals, the metals are brought together and the metal is melted through an electric arc or oxy-acetylene flame along with weld rod which makes metal to the joint [20].

`2.3.1. Behavior welded Connection

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The behaviors of welded connection are usually expressed in lap joints splices, shear is the main design consideration, side fillets and end fillets, end fillet loaded in tension - high strength and low ductility, side fillet loaded - Limited to weld shear strength (50% tensile strength) Improved ductility and average stress in weld throat.

3. Other Connection Types

3.1 *Intermeshed Connection*

According to [21], Intermeshed connection in steel structure is one that does not depend on the usage of either welded connection or bolted connection. In order to have an intermeshed connection in steel structures, there must be an engagement of high definition plasma, water jet cutting and laser, ict controlled and an advanced manufacturing approach. In a bid to develop connections with cost-effectiveness, recent studies have diverted attentions to simple intermeshed connections where the web connection of the beam is by a web stepped pattern and the top and bottom flange connection of the beam is by dovetails connection. The structural behavioral function of the dovetail connection is resistance to compression while the web stepped pattern of the web is primarily resistance to shear forces in one direction.

3.2 *ATLSS Connection*

In the 1990s, the desire to have a better, safer and quicker erection of structural steel members made some researchers to focus their research on a connection type referred to as the ATLSS connection. The concept that guides the use of the ATLSS connection for structural steel members is such that a column that has been erected has attached to it a grooved guide with a fixture wherein the tapered plate designed into the end of a beam fit. Several studies of this approach of the 1990s showed that the ATLSS connection caters adequately for developed shear, moment and full moment. The results from study of the ATLSS connection showed that the capacity of the ATLSS connection to transfer shear force is what predominantly governs its capacity to carry load [22].

3.3. *The Quicon Connection*

As a research upgrade on the ATLSS connection of the early 1990s, the development of the quicon connection began in the early 2000. The motivation behind the development of the quicon connection was to achieve a safer and quicker operations on site in place of the ATLSS connection of the 1990s. The approach the quicon connection uses is a T-brackect shoulder bolts when a steel beam connection is used. On site, the shoulder bolt is fixed safely into the notches of the T-bracket. In a case where a faster assemblage in needed on site, the structural members have attached to them the shoulder bolts and the T-brackets. Despite the unique attributes of the quicon connections, its usage didn’t get a widespread attention being that it was mostly used in warehouses and garages.

3.4. *The CONX Moment Connection*

The ConX moment connection is another connection type that guarantee speedy assemblage on the site. In ConX moment connection, on-site welding is by-passed by off-site welding where a column has welded to it a collar corner at the proper floor framing locations. This helps to save time in assemblage on site. The beams are fitted into the corner collar on site with ease and in a very short time. A challenge identified with this connection type is the tolerance in the foundation level where the columns are erected. Another challenge identified with the ConX moment connection is the restriction in the dimensions. These are the thickness of the wall of column being used in the construction, width and thickness of the flange, and the clear span to depth ratio of the beam [23]. Unlike the quicon connection that has only gained most of its usage in garages and warehouses application, the ConX moment connection was successfully commercialized for usage in many other sectors.

3.5. *Sideplate Connection*

The sideplate connection is another type of connection that was developed to foster speedy assemblage of structural members on site. In site assemblage using the sideplate connection, the point of connection between the beam and the column member makes use of an extra plate to further reinforce the beam-column connection. The installation process is a heavy duty one due to the several connecting parts required. The sideplate connection is basically developed to carry frame moments and its four variants gets bolted on site or welded on site. Unlike the quicon connection that has only gained most of its usage in garages and warehouses application, the sideplate connection was successfully commercialized for usage in many other sectors [24-27].

4. Conclusion

The behavior of a steel structure largely depends on the type of connection employed. Hence, the acceptable structural behaviour and the condition of service for a steel structure should guide designers in the choice of connection that is employed in the steel construction.

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