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Comparative Study on Bolted Riveted and Welded Connections-A Review

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Abstract

Structural connections are crucial to the integrity, safety, and performance of steel frameworks. This review compares the three main connection types bolted, riveted, and welded in terms of strength, behavior, failure modes, fabrication, inspection, and cost. It traces the evolution from traditional riveted joints to the widespread use of bolted and welded connections today. Drawing from experimental studies, numerical models, and code provisions, the paper analyzes their performance under static and dynamic loads. It also highlights factors influencing connection choices and outlines current challenges and future research directions, offering practical insights for engineers and designers.

Keywords: Bolted connection, Riveted connection and Welded connection.

1. Introduction

Connections are the backbone of any structural system, enabling individual elements to work together as a unified whole. In steel structures, the performance of the entire system significantly depends on the behavior and reliability of its connections. Over the years, three primary types of connections riveted, bolted, and welded have played dominant roles in the evolution of steel construction.

Riveted connections, once the standard during the early 20th century, have largely been replaced by bolted and welded alternatives due to advancements in technology and construction practices. However, riveted joints remain in service in many heritage structures, and their study is still relevant for structural assessment and retrofitting. Bolted connections are widely favored today for their simplicity, ease of installation, and ability to be dismantled, making them suitable for both temporary and permanent structures. On the other hand, welded connections offer high rigidity and seamless load transfer, making them ideal in situations requiring minimal deformation or high precision.

Each connection type has distinct characteristics that influence strength, ductility, fatigue resistance, fabrication time, cost, and maintenance. Moreover, their behavior under static, dynamic, and seismic loading varies significantly, influencing the choice of connection in different engineering applications.

This review paper aims to provide a comparative study of bolted, riveted, and welded connections with respect to their structural performance, failure modes, and suitability in modern engineering practice. By synthesizing findings from experimental research, numerical modeling, and international design codes, this paper highlights the advantages, limitations, and application domains of each connection type. The ultimate goal is to support informed decision-making in the selection and design of steel connections for both new construction and retrofitting projects.

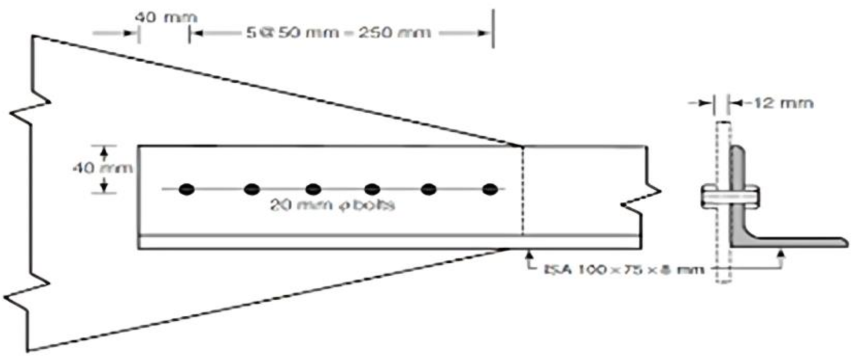

Figure.1 Angle section connected to gusset plate by bolting

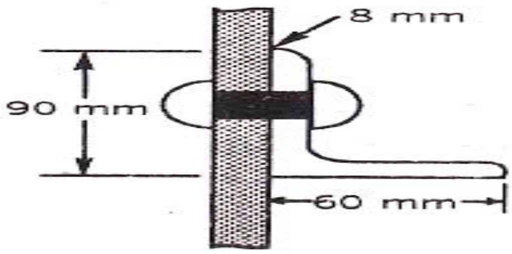

Figure.2. Angle section connected to gusset plate by riveting

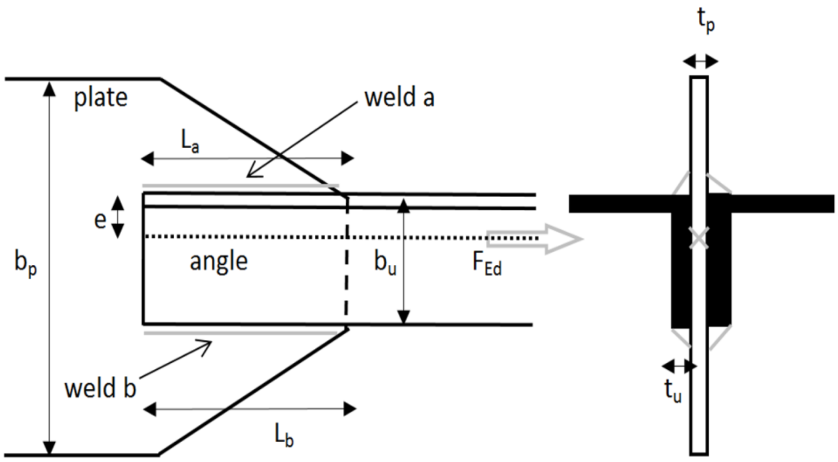

Figure.3. Angle section connected to gusset plate by welding

It is evident that damping in bolted and similar joints is significant. However, predicting damping levels in actual structures remains challenging, regardless of the sophistication of the mathematical methods employed[1].

Yuchen Song conducted experimental testing and numerical simulations to assess the block shear behavior of bolted connections made from duplex stainless steel. The results were compared with those of bolted connections fabricated from austenitic stainless steel and carbon steel. Drawing on the experimental data and numerical findings, several design approaches were evaluated and contrasted for different materials. A unified design method was ultimately proposed to estimate the ultimate block shear strength of both austenitic and duplex stainless steel connections. Reliability analyses were performed to determine suitable partial safety factors or resistance factors for the proposed design approach[2].

This paper presents a model aimed at predicting the constant amplitude fatigue life of a riveted double shear connection with many rivets[3].

The research conducted by Ashraf ElSabbagh is divided into two primary phases. The initial phase involved validating finite element analysis (FEA) models using existing experimental data under both monotonic and cyclic loading conditions. In the subsequent phase, a comprehensive parametric study was carried out using 108 three-dimensional FEA models. This analysis explored the influence of key geometric parameters, such as steel section profiles, beam lengths, head plate thicknesses, stiffeners, and bolt sizes. Each model was analyzed under monotonic and cyclic loads to evaluate the effects of these variables, gain insights into connection behavior, and generate relevant data for the nonlinear analysis of frames with semi-rigid connections in seismic regions[4].

Carlos Jiménez-Peña emphasizes that the primary goal of this study is to advance the current understanding of failure mechanisms in High Strength Steel (HSS) bolted connections subjected to fretting fatigue. The research also aims to assess the impact of preload force on fretting fatigue behavior, with particular focus on parameters such as slip amplitude, contact interface damage, and other contributing factors[5].

G. Jeevi's article presents a comprehensive review of recent advancements in the application of adhesively bonded components and bonding techniques across various industries, such as automotive, aerospace, and construction. The paper offers clear and accessible explanations of adhesive joints, hybrid bonded-bolted joints, and mortared joints, aiming to support researchers working in this field[6].

2. Methodology

This review paper employs a structured and qualitative research approach to systematically collect, analyze, and synthesize existing literature on bolted, riveted, and welded connections in steel structures. The objective of the methodology is to ensure a comprehensive and balanced comparison of the three connection types based on their performance characteristics, historical evolution, design considerations, and practical applications.

2.1. Gross Section Yielding

A tension member without bolt holes is capable of withstanding loads up to its ultimate capacity without experiencing failure. However, it will undergo significant longitudinal deformation before fracturing, rendering the structure unserviceable. Therefore, for design purposes, the yielding of the gross section is considered the appropriate criterion for determining its design strength.

$$T_{dg} = (A_g * f_y) / \gamma_{m0} \quad (1)$$

A_g - gross area of cross-section,

f_y - yield stress of the material, and

γ_{m0} - partial safety factor for failure in tension by yielding = 1.1 (refer to Table 1 of IS 800).

Table.1. Partial Safety Factor for Materials, γ_m (IS 800)

S. NO	Definition	Partial Safety Factor	
1	Resistance, governed by yielding, γ_m	1.10	
2	Resistance of member to bucklin, γ_{m0}	1.10	
3	Resistance, governed by ultimate stress, γ_{m1}	1.25	
4	Resistance of connection:	Shop Fabrications	Field Fabrications
	a) Bolts-Friction Type, γ_{mf}	1.25	1.25
	b) Bolts-Bearing Type, γ_{mb}	1.25	1.25
	c) Rivets, γ_{mf}	1.25	1.25
	d) Welds, γ_{mw}	1.25	1.50

2.2. Net Section Rupture

When a tension part is attached with bolts, the net area (useful cross-sectional area) is smaller because of the bolt holes. When service loads are put on these holes, they cause stress clusters. Elasticity theory says that the tension stress close to a hole can be two to three times higher than the average stress over the whole net area. The stress concentration factor is the ratio of the main stress to the average stress, which is written as fmax/favg. It's important to pay attention to stress concentration when the member is dynamically loaded, which can cause brittle fracture, or when it's loaded over and over again, which can cause fatigue failure.

$$T_{dn} = (0.9 * A_{nc} * f_u / \gamma_{m1}) + (\beta * A_{go} * f_y / \gamma_{m0}), \quad (2)$$

where,

$$\beta = 1.4 - 0.076 * (w/t) * (f_y/f_u) * (b_s/L_c) \leq ((f_u*\gamma_{m0}) / (f_y*\gamma_{m1})) \text{ and } \geq 0.7, \quad (3)$$

where,

w - outstand leg width,

b_s - shear lag width,

L_c - length of the end connection that is the distance between the outermost bolts in the end joint measured along the load direction or length of the weld along the load direction.

A_n - net area of the total cross-section,

A_{nc} - the net area of the connected leg,

A_{go} - the gross area of the outstanding leg,

t - thickness of the leg

γ_{m1} - partial safety factor for failure at ultimate stress = 1.25 (Table 1 of IS 800: 2007),

γ_{m0} - partial safety factor for failure governed by yielding = 1.1 (Table 1 of IS 800: 2007),

f_u - ultimate stress of the material, and

f_y - yield strength of the material.

2.3. Block Shear Failure

This failure type involves the member's failure along a route characterized by tension on one plane and shear on a perpendicular plane, including the fasteners. The likelihood of block shear failure escalates as the materials bearing strength and bolt shear strength are elevated, yet the connection length diminishes as the quantity of bolts used for the connection drops.

$$T_{db\,1} = [\,(\,(A_{vg} * f_y) / (\sqrt{3} * \gamma_{m0})\,) + (\,(0.9 * A_{tn} * f_u) / \gamma_{m1}\,)\,] \text{ or}$$

(4)

$$T_{db\,2} = [\,(0.9 * A_{vn} * f_u) / (\sqrt{3} * \gamma_{m1}) + (\,(A_{tg} * f_y) / \gamma_{m0}\,)\,]$$

where,

A_{vg}, A_{vn} - minimum gross and net area in shear along bolt line parallel to external force,

A_{tg}, A_{tn} - minimum gross and net area in tension from the bolt hole to the toe of the angle, end bolt line, perpendicular to the line of the force,

f_u, f_y - ultimate and yield stress of the material respectively,

γ_{m1} - partial safety factor for failure at ultimate stress = 1.25 (refer to Table 1 of IS 800: 2007), and

γ_{m0} - partial safety factor for failure governed by yielding = 1.1 (refer to Table 1 of IS 800: 2007).

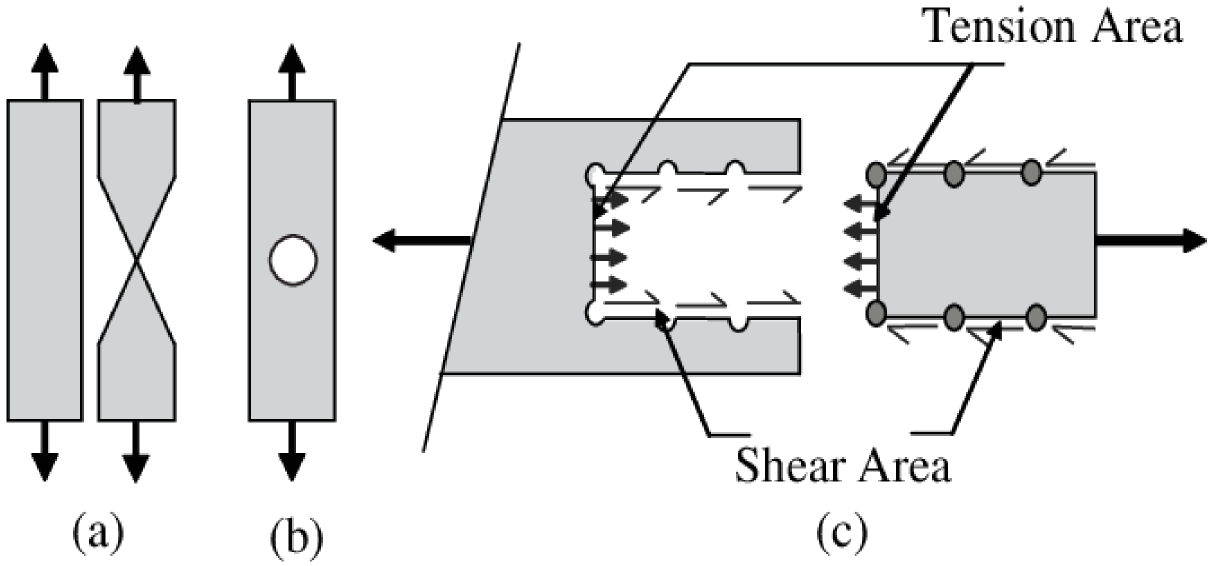

Figure.4. Modes of failure in tension members (a) Gross Section Yielding (b) Net section Rupture (c) Block Shear

3. Conclusion

This review paper has presented a comprehensive comparison of bolted, riveted, andwelded connections, examining their historical evolution, structural behavior, failure mechanisms, and practical applications. Riveted joints, though largely obsolete in modern construction, remain important in the assessment and preservation of older structures. Bolted connections offer flexibility, ease of installation, and are widely used in both temporary and permanent steel structures. Welded joints, known for their high rigidity and clean aesthetics, are preferred where seamless force transfer and precision are critical.

The comparative analysis reveals that each connection type has unique advantages and limitations, and the choice often depends on factors such as load conditions, fabrication constraints, cost, inspection requirements, and design standards. Experimental and numerical studies have further highlighted that performance under fatigue, seismic loading, and long-term durability varies significantly between connection types.

While bolting and welding dominate modern construction, understanding the behavior and evolution of all three connection methods is essential for informed decision-making in design, retrofitting, and maintenance. Future research should focus on hybrid connections, long-term performance under dynamic loads, and the development of standardized guidelines for advanced modeling and testing.

This review aims to serve as a valuable reference for structural engineers, researchers, and students engaged in the design, analysis, and maintenance of steel structures.

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