PERFORMANCE ANALYSIS OF BOLTED FLANGE CONNECTIONS IN PREFABRICATED HIGH-RISE STRUCTURES

LITERATURE REVIEW

Aysha Sharvana P[1], Nivetha John[2], Anila Dani D.A[3]

[1]*II Year, M.E(Structural), RVS Technical Campus, Coimbatore, Tamil Nadu, India*
[2]*Assistant Professor, Dept. of Civil Engineering, RVS Technical Campus, Coimbatore, Tamil Nadu, India*

Abstract - *Prefabricated steel structures aid in reducing labour intensity and speeding up the construction process. They're popular in low-rise buildings, but they're rarely seen in multi-story structures. Bolted-flange connections have been studied all over the world, although they have mostly focused on pipeline and tower constructions, with only a few studies focusing on multi-high-rise structures. This document provides brief summaries of several studies on bolted flange connections and high-rise structures that can aid in the investigation of the efficacy of prefabricated steel structures in high-rise buildings. The bearing performance of a bolted-flange connection, a modular-prefabricated high-rise steel frame structure with diagonal braces, a beam–column joint used in a modularized prefabricated steel structure, seismic performance of a new light-frame cold-formed steel-frame system, glass-reinforced-plastics, the evolution of precasting technology in high-rise residential developments, damage to steel buildings observed during earthquakes, and more are among the studies presented. A test programme on bolted flange plate connections used in circular tubular structures, non-linear analysis of a telecommunication tower with circular flange-bolted connections, bending behaviour of flange-plate connections under pure-bending, connections for square hollow sections, a simplified nonlinear dynamic model with bi-linear springs, a test programme on bolted flange plate connections used in circular tubular structures, a finite element method based yield load determination procedure for hollow structural These literatures provide theoretical knowledge about the performance of bolted flange connections in high-rise structures.*

Key Words: prefabricated steel structures, bolted flange connection, high-rise buildings.

1.INTRODUCTION

1.1 General

Prefabricated steel structures can be built using a standardised design, industrial manufacture, and on-site assembly, reducing labour intensity and speeding up the construction process. In many nations, prefabricated steel constructions have become a popular building type. Prefabricated steel constructions, on the other hand, are common in low-rise buildings and are rarely employed in multi-story projects. The bolted-flange connection is a novel method of installing rectangular hollow section (RHS) columns in prefabricated multi-high-rise steel constructions that must withstand bending moment and shear under continuous, live wind loads or earthquakes (X.C. Liu et al. 2018). Because the applied force is different, the performance of a bolted-flange connection used in a structural column differs from that of a bolted-flange connection used in a pipe.

Only equal-strength columns can be welded together; otherwise, too many bolts are required, limiting the use of bolted connections between columns and lengthening the building period. The engineering practise, on the other hand, revealed that the flange connection may be utilised in multi-story constructions. Bolted-flange connections are commonly employed in pipelines, pressure containers, carrier rockets, and spacecraft, and they are primarily utilised to support tension. Researchers have researched the discontinuous and nonlinear changes in the stiffness of flanges under tension and have come up with a number of solid and dependable conclusions.

1.2 Scope of the study

The design formulas are mostly for bolted-flange under tension at the moment. They are not intended for structural columns in multi-story buildings, but they do provide a theoretical foundation for future flange connection research. Because it is subjected to a complex combination of forces, the structural column's performance is more complicated.

2. LITERATURE REVIEW

Various studies have been conducted by scholars about the performance of bolted flange connections for various applications. These studies can help to analyse the structural performance of bolted flange connections in high rise structures.

2.1 REVIEW OF LITERATURE

The bearing performance of a bolted-flange connection under bending moment and shear was examined by **X.C. Liu**

et al. (2018). Static tests and finite element analysis (FEA) were performed on 12 column-to-column bolted-flange connections with various flange thicknesses, bolt edge lengths, flange edge widths, and bolt hole diameters, as well as one column that was not connected. The test was in good agreement with the FEA, indicating that the FEA is correct. The effects of flange thickness, bolt edge distance, flange edge width, and bolt hole diameter on connection stiffness and strength, bolt tension, and contact force were investigated, and the connection's failure mode and mechanism were discovered. On the flange contact surface, a significant prying action occurred, increasing bolt tension in the tensile region and causing tension and bending moment in the bolt shanks. The thickness of the flange had a significant impact on the prying force, while other parameters had a minor impact. The bearing mechanism of the connection was discovered using the yield line theory. The yield bearing capacity formulas were proposed, and the test and FEA results confirmed them.

X.C. Liu et al. (2017) suggested the modular-prefabricated high-rise steel frame structure with diagonal bracing as a novel form of prefabricated steel structure. The mechanical properties, failure mode, failure mechanism, and elastic–plastic development laws of the T30 building, which is a hotel building with 30 storeys above ground, were researched using elastic and elastic–plastic design and analyses under various load scenarios and combinations. The response spectrum and elastic time-history methods were used to analyse the internal force and displacement response in frequent earthquakes, while static elastic–plastic pushover analysis was used in rare earthquakes. The methods and processes of elastic and elastic–plastic structural design are summarised in this work. The design method for this type of modular-prefabricated high-rise steel structure has been compiled into a design specification called Technical Specifications for Prefabricated Steel Frame Structure with Diagonal Bracing Joints, and the study provides important references for the design of this type of modular-prefabricated high-rise steel structure.

X.C. Liu et al. (2015) proposed a factory-welded beam–column junction for usage in a modularized prefabricated steel construction. Using model testing and finite element analysis, the seismic and static performance of four full-size joints was investigated under monotonic static and cyclic loads. We discovered the rules of hysteretic behaviour, static behaviour, ductility performance, skeleton curve, stiffness dissipation, energy dissipation capacity, and rotational capacity. The influence of the web and chord thickness of the truss beam on the joint's static performance and seismic capability was investigated. The influence of weld quality on various joint performances was also investigated. The welded beam–column joint's simplified equations agree well with the experiment data. The study found that weld quality has a major impact on the failure mechanism and various mechanical properties of welded joints; equal strength welds meet the static strength requirement, but elastoplastic seismic criteria are difficult to meet. The joint has a high rotation stiffness and a high ultimate bearing capacity. The presence of an axillary plate at the chord's end increases the joint's ductility, energy dissipation, and plastic rotation capability greatly. The ultimate bearing capacity of the joint is greatly reduced when the chord and web thickness of the truss beam are reduced, however this is not linearly related to the section area and has no effect on ductility or energy dissipation capacity.

T.N. Dao and J.W. van de Lindt (2013) described the methodology and findings of a study that looked at the seismic performance of a new light-frame cold-formed steel-frame system. Floor trusses, open panels, V-braced panels, columns, and connections are all part of the system. Subassemblies were subjected to a series of reversed-cyclic tests in order to accomplish this. The results of this experimental programme offered insight into the behaviour of the subassemblies under cyclic loading, which in turn provided critical information for numerical modelling of the subassemblies and the entire system, as well as the frame's failure mechanisms. To demonstrate the behaviour of a typical V-braced system in a moderate earthquake, nonlinear time history calculations were done utilising a new formulation for a 4-story frame and a suite of earthquake ground motions. Because of the screwed plate connections between the light-gauge parts and square columns, both test results and numerical analysis reveal that the system has good ductility. At four storeys, the frame system performed admirably, giving it a viable midrise construction choice in seismically active areas of the United States and around the world.

H. Kurz and E. Roos (2012) presented a paper with the purpose of allowing chemical plant operators to design and operate glass-reinforced-plastics (GRP) pipework with grp flanges at temperatures up to 80 °C utilising polytetraflourethylene (PTFE) gaskets to replace the obligatory rubber gaskets. In order to investigate the boundary conditions in bolted flange connections with glass-fiber reinforced plastic flanges in accordance with DIN EN 13555, various gaskets made of rubber (EPDM) and PTFE were investigated. Under the conditions of bolted flange connections with grp flanges, the rubber gasket and the PTFE-based gasket with a PTFE-diffusion barrier meet the TA Luft leakage rate criteria. The mechanical behaviour of DN50 bolted flange connections with grp flanges was studied and is taken into account in a new calculation procedure that accounts for the specific material properties of grp and thus allows higher bolt forces, resulting in increased plant tightness and operational reliability. To design bolted flange connections with grp flanges, this draught technique including experimental pre-tests (already required by DIN 16966) is now available.

L. Jailon and C.S. Poon (2009) investigated the growth of precasting technology in Hong Kong's high-rise residential constructions, as well as the technical influences in both sectors. A database of 179 prefabricated residential buildings was created, and five residential projects were studied in depth. The data revealed that prefabrication has been more prevalent over time, both in terms of precasting percentage by volume and the types of precast parts used. The technological improvement in prefabrication in Hong Kong was inspired by major prefabrication innovations in both areas.

M. Nakashima et al. (1998) published a summary of the damage to steel structures caused by the 1995 Hyogoken-Nanbu earthquakes. It outlines the Japanese seismic design philosophy as well as the magnitude of earthquake stresses exerted on steel structures constructed in seismically active areas. Statistical information on the damage is supplied in relation to the building height and type, as well as the location of the damage and normal damage. Materials, welding, connection details, and plastic rotation requirement all have a role in the damage to welded beam-to-column connections. Finally, the harm was graded based on existing knowledge and the complexity of finding solutions.

L.Z. Zhang et al. (2015) investigated the MMC bolted flange joint's assembly pattern. The stress on sealing surfaces in a Metal-to-Metal Contact (MMC) bolted flange joint is continuous. It is capable of withstanding higher bolt loads. As a result, the sealing effect of MMC bolted flange joints is better than that of floating (FLT) bolted flange joints under working conditions of high temperature, high pressure, or their variations. In this study, a new tightening method (SH-Method) was recommended based on the structure characteristics of MMC bolted flange joints. With the finite element analysis software ANSYS, the bolt forces during the tightening process of an MMC bolted flange joint with SH-Method were estimated and studied. The calculating model and results were tested in the lab. In comparison to the star pattern and the alternative pattern #3 of ASME PCC-1, in which only the pattern methods for FLT flange joints are recommended, the novel tightening method 'SH-Method' has the advantages of fewer stages, simpler operation, more uniform bolt force, and greater sealing effect.

Y.Q. Wang et al. (2013) investigated the bending behaviour of flange-plate connectors in pure bending with the goal of developing a useful design model. Four different forms of bolted flange-plate connections are investigated, as well as related finite element analysis. Experiment results validate the finite element model, proving it to be precise and dependable. The distribution of von-Mises strain and contact pressure at the end plates of the connections is shown using finite element analysis. The useful data can be directly incorporated into the theoretical model to present a relatively clear yield line mechanism and a distinct pressure centre. The virtual work principle is used to calculate the bending capacity of flange-plates. The theoretical model is shown to be capable of accurately predicting the yield bending capacity of the connections. Meanwhile, to obtain the bending capacity dictated by bolts, a classic T-stub analogy is used. A feasible design approach is proposed by combining the two separate design models and assuming that end plates should fail before high strength bolts. This approach will result in connections that meet the demands of safety and economy. In addition, the design model presented here can be used as a guide for the practical design of different types of bolted flange-plate connections.

The findings of a study on connections for square hollow sections with bolts symmetrically positioned on all four sides of the tube and the hollow section loaded in axial tension were presented by **S. Willibald et al. (2002)**. The prying forces were of great interest, as they had been in previous research. During the tests, strain gauged bolts and an ultrasonic bolt gauge monitored the bolt forces to reveal any prying movement. A total of 16 specimens were evaluated, each with a different number of bolts, bolt pattern, and flange-plate thickness. Different existing design approaches and analytical models are provided, and their associated connection strength forecasts are compared to the outcomes of the tests, as well as 10 more tests performed before. The best predictions were derived using a slightly modified version of the design approach provided by the AISC HSS Connections Manual (1997).

Y. Luan et al. (2012) suggested a simpler nonlinear dynamic model with bi-linear springs for pipe constructions with bolted flange joints, which they tested. The bolted flange joint's static mechanical properties are evaluated first. The axial rigidity of the bolted flange joint is different in tension and compression, according to the analytical solution. The bolted flange joint is then represented by nonlinear springs with varied stiffness in tension and compression. Analytical derivation reveals a unique sort of dynamic behaviour: vibration coupling in the transverse and longitudinal directions. Finally, physical experiments and numerical simulations are carried out if needed. The existence of the coupling vibration behaviour is confirmed by physical studies. There is a discussion of the link between longitudinal and transverse vibration frequencies. The numerical results show that the simplified nonlinear dynamic model more closely matches the practical response than the reduced linear beam model.

A test programme on bolted flange plate connections utilised in circular tubular structures was given by **H. Van-Long et al. (2013).** The connected tube elements in the tested joints are made of high strength steel (TS590), whereas the flanges are made of conventional steel grade (S355). The tests were carried out under monotonic loadings to determine the mechanical properties of the connections, as well as cyclic loadings to characterise the connections' behaviour for low and high cycle fatigue. The test findings are first presented, along with a critical analysis of the latter; after that, design methodologies from the literature are applied to the tested configurations with the goal of determining their accuracy through comparisons with the experimental results.

Non-linear analysis of a telecommunication tower with circular flange-bolted connections was studied by **B. Blachowski and W. Gutkowski (2016)**. (CFBCs). They're made up of two flanges that are welded to the structural tubes before being linked with pre-tensioned bolts. In two examples, a thorough FEM analysis is used to determine the connection stiffness. The first is for all bolts that are unbroken, while the second is for one or more bolts that are broken. When joints are under strain, the bolts are not only subjected to axial forces, but also to bending moments due to the prying effect, according to the analysis, which includes contact and friction forces. The value of bending strains is highly influenced by bolt pre-tension and flange thickness. When one of the six connection bolts is removed, the other bolts are put under a lot of stress. It is feasible to study the behaviour of the entire structure by studying the behaviour of the connection. The multilevel substructuring method is used to accomplish this. The first level is concerned with flanges and bolts, and the connection model is simplified in comparison to the rigorous one. The second level is concerned with the entire tower's construction. Several examples of connections of various thicknesses and bolt pre-tensions are included in the paper. The tower in question is based on a real design.

N. Kosteskin et al. (2003) provided a yield load estimation strategy for hollow structural section connections using the finite element method. The yield load must be rationally determined from experimental results in order to confirm analytical calculations based on yield line theory. The inability to establish the yield load using load-deformation curves further complicates such a comparison. Existing methods for calculating the yield load from load-deformation curves are subjective. For connections that do not otherwise exhibit a clearly defined yield or peak load, a FEM-based stiff, perfectly-plastic yield load determination, as provided in this study, represents a logical yield or ultimate limit state load. A complete parametric FEM numerical research on stiffened branch plate-to-rectangular Hollow Structural Section (HSS) connections demonstrates the feasibility of this newly proposed rigid, perfectly-plastic yield load prediction.

Using the yield line theory, **B. Kato and R. Hirose (1985)** calculated the maximum strength of high-strength bolted tension flanged joints of circular hollow section members. Theoretical results are compared to experiments conducted at University College, Cardiff, and the British Steel Corporation, indicating that they are in close agreement. A basic design formula is proposed as a result of this research.

3. CONCLUSIONS

A thorough review of the literature provides theoretical insight into the performance of bolted flange connections in high-rise structures. When the flange thickness is less than a specific value and the bolts have not yielded, the stiffness and strength of a flange connection is mostly affected by the flange thickness, according to these literatures. With an increase in flange thickness, the yield mode of the flange connection may change from flange to bolt yield. When the flange edge width and bolt edge distance reduce, the prying force decreases, and the bending stiffness and bearing capacity of the flange rise, according to the bearing performance of the flange. The prying force is heavily influenced by the thickness of the flange. The prying motion could be significantly reduced if the flange thickness is increased. The flange thickness had the most influence on the placement of the boundary between the tension and compression regions.

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