A SYSTEMATIC LITERATURE REVIEW: BOLTED CONNECTION FAILURE IN COLD-FORMED STEEL BEAM-TO-COLUMN CONNECTION

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By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRACT

This study is based on a Systematic Literature Review (SLR), in which data from previous research studies on the bolted connection failure for Cold Formed Steel (CFS) beam-to-column connections is compiled. The goal of this research is to expand on the CFS study area where its use has begun to get recognition in the construction industry. In this study, the failure mechanism of the bolted connection, the variables that influence the failure inside the bolted connection, and the tests performed on the bolted connection in CFS are described. This study focuses on the failure mechanism, influencing variables, and method utilized to determine the failure of bolted connections in CFS for beam to column connections. The results of this investigation are local buckling, bearing failure, and distortional buckling failure on the bolted connection for the CFS beam to column connection. In addition, the diameter of the bolts, the number of bolts, the bolt grade, the edge distance, and the placement of the bolts influence the failure of bolted connections in CFS beam to column connections. According to previous research, tensile testing is a popular data collection approach, whereas the Finite Element Method (FEM) utilizing ABAQUS Software is the numerical method employed.

ABSTRAK

Kajian ini dijalankan berdasarkan Kajian Literatur Sistematik (SLR), di mana kajian ini dilakukan dengan mengumpul data daripada kertas kajian lepas mengenai aspek kegagalan sambungan bolt yang berlaku bagi sambungan Keluli Terbentuk Sejuk (CFS) bagi sambungan rasuk ke tiang. Tujuan kajian ini adalah untuk mempertingkatkan kawasan kajian CFS di mana penggunaannya telah mula mendapat pengiktirafan dalam kawasan bidang pembinaan. Dalam kajian ini, ia akan menerangkan tentang mod kegagalan yang dihadapi oleh sambungan bolt, faktor-faktor yang mempengaruhi kegagalan di dalam sambungan bolt, juga akan dibincangkan mengenai ujian yang dilakukan untuk sambungan bolt dalam CFS. Parameter utama yang diketengahkan dalam kajian ini terdiri daripada mod kegagalan, konfigurasi bolt, dan kaedah yang digunakan dalam menentukan kegagalan sambungan bolt dalam CFS untuk sambungan rasuk ke lajur. Daripada kajian ini, dapatan yang diperoleh daripada topik ini ialah, lekuk tempatan, kegagalan galas, dan lengkokan herotan bagi kegagalan pada sambungan bolt untuk sambungan rasuk CFS ke lajur. Selain itu, diameter bolt, bilangan bolt, gred bolt, jarak tepi, dan susunan bolt adalah faktor yang mempengaruhi kegagalan sambungan bolt dalam sambungan rasuk ke lajur CFS. Kaedah yang digunakan berdasarkan kajian terdahulu lazimnya adalah ujian tegangan, manakala kebanyakan kaedah numerikal yang digunakan adalah berdasarkan Kaedah Unsur Terhingga (FEM) menggunakan ABAQUS.

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LIST OF ABBREVIATIONS

CFS	Cold-Formed Steel
HRS	Hot Rolled Steel
FEA	Finite Element Analysis
EC	Eurocode
AISI	American Iron and Steel Institute
AS/NZS	Australia/New Zealand Standard
ASTM	American Society for Testing and Materials
IS	India Standard

CHAPTER 1

INTRODUCTION

1.1 Background

The use of steel has exploded in recent years, particularly in the construction industry. These days, low-to medium-rise structures as well as residential residences are frequently constructed utilizing steel components. The use of steel as a building material offers several benefits, which contribute to the overall satisfaction that can be achieved from this choice. This can be seen rather clearly, and it demonstrates that it satisfies the requirements of sustainable development by reducing the amount of waste produced by building. Additionally, it includes control over the high quality of the product; savings in both time and money; and a reduction in reliance on the use of timber resources (Lee et al., 2014). The material known as structural steel may be separated into two distinct categories, which are referred to as hot rolled sections and cold formed sections, respectively. The method in which the steel ingredients are processed in different ways is what differentiates these two types of steel. In a blast furnace or an electric arc furnace, the steel is heated to temperatures that can reach up to 1400 degrees Celsius during the manufacturing process of a hot rolled piece. Cold formed steel is created at room temperature, in contrast to hot rolled steel, which is made at a higher temperature. Because of the differences in the two processes, the resulting steels are distinct from one another in terms of their strength, structural performance, and mode of failure. As a result of the cold working method, the yield strength of the cold formed section is significantly greater than that of the hot rolled steel. This is because the cold formed section was treated at a low temperature (Lee et al., 2014).

This study focuses on the cold formed section and its connection failure for the CFS section beam to column connection. Cold-rolled forming, press braking, and bending brake operations are the three procedures that may be used to produce cold-formed section steel. Cold roll forming is widely employed in the production of individual members, wall sections, roof panels, and other components, whereas press braking is typically used to create basic shapes such as roof sheets and decking sections. However, in steel design, cold-formed steel produced by cold roll forming is significantly more cost-effective (Billah et al., 2019). The deformation mechanism in cold roll-forming is known to be highly complicated, with the procedure usually necessitating a trial-and-error approach to overcome several practical challenges (Bhattacharyya et al., 1984). Cold-formed steel is widely employed in structural engineering and steel industries, particularly to produce building components, structural members, roof trusses, wall panels, window and door frames, and more. Historically, it was utilized as a supplementary source for structural elements such as roof purlins and side rails for wall cladding (Lee et al. 2014).

Cold-formed steel was invented in 1960 in the United States during World War II. This is due to the fact that prior to that time, it was affordable, required no specialized skills, and simply required hand tools. Due to their reliance on standard engineering design for a restricted number of off-the-shelf configurations, they employ the technical term "cold-formed steel". In the late 1990s, it was launched and made available in India (Satpute and Varghese, 2012). Several advantages of cold-formed steel include material reduction since cold-formed steel may be produced in extremely thin sections compared to hot-rolled steel. Consequently, the required stiffness requirement is significantly lower than for hot-rolled sections. In addition, cold-formed sections have a consistent and

accurate profile. The characteristics of cold-formed materials enable the production process to preserve the desired profile.

Steel is comprised of many types, including beam, column, purlin, and connector. A connection is a steel component that aids in joining the steel structure to other forms. It is a physical component that mechanically fastens the structural parts, and it is concentrated where the attaching action takes place (Lee et al. 2014). Commonly utilized connections for cold-formed steel sections include bolts, self-tapping screws, blind rivets, powder-actuated pins, spot welding, puddle welding, clinching, and self-piercing rivets. Typically, self-tapping screws, blind rivets, and powder-actuated pins are utilized to secure thin sheets to the section. Bolts are utilized to link the heavier cold-formed steel, whereas spot welding is typically employed to join thin steel in the factory (Batista et al., 2021). Due to the diversity of connection types, each connection has a unique purpose. However, steel connections are popular because they are simple to install, inexpensive to install, require minimal maintenance, and are readily available on the market (Bondok and Salim, 2017).

In comparison to other fasteners, the bolt is the most often employed. This is because it is easier to assemble and remove than other fasteners. Self-drilling screws, for instance, are utilized more frequently in panel manufacturing and less frequently in structural connections. This is due to the fact that the screw is most prone to failing on the pull-out. Therefore, the use of bolts is likely safeguarded by the presence of nuts. Welded connections for CFS members, on the other hand, are difficult to achieve due to the thinness of the members. (Natesan et al., 2020).

1.2 Problem Statement

Cold-Formed Steel (CFS) is one of the common materials used in proposing designs for structural purposes. As the production results in higher yield strength and stiffness, steel has become an excellent substance in structural design. Moreover, CFS has a better surface characteristic compared with hot-rolled. So, technically, it needs to be used in a specific way or when the way it looks is very important (Reliance Foundry, 2022).

Steel has been widely acknowledged by developed countries such as China, Japan, and India (John Steel, 2019). In Malaysia, the use of cold steel formed is minimal compared to reinforced concrete as the steel pricing is relatively higher. Most of the construction combines concrete and steel structures on certain parts, for instance, braces, trusses, metal decking, and more.

Even though steel has been around for a while, the studies on the steel part are not widely done compared with the reinforced concrete structure, especially in Asia, where the primary construction material is concrete. Consequently, this project intends to add more information about the steel component.

1.3 Systematic Literature Review (SLR): Review Objectives

The failure mode of cold-formed steel connections has not been thoroughly studied or included in structural design. Research on numerical and experimental analysis is still dispersed and has not been well generalized. This thorough assessment of the literature was conducted in order to generate a well-documented examination of the connection's failure for its cold-formed steel segment.

Multiple types of connections exist, including beam to beam, column to column, beam to column, and column to base plate. This literature study focuses on the

relationship between the beam and the column where the section collapse occurred. The aims of this systematic evaluation of the literature are therefore centred on the behaviour of the connection on the beam-to-column segment, where failure may occur depending on its behaviour.

The systematic literature review is conducted based on the objectives shown in Table 1.1 below:

Table 1. 1 Review Objective

No	Review Objectives
RO1	To study the failure mode of bolted connection for cold-formed steel section beam to column connection.
RO2	To study the factor that influenced the bolt failure on the cold-formed steel section for the beam to column connection.
RO3	To study the method used in investigating the failure of the bolt on the cold-formed steel section beam to column connection.

1.4 Systematic Literature Review (SLR): Review Questions

RQ1, RQ2, and RQ3 are the three sorts of review questions included in this thesis' review questions. RQ1 is based on the failure mode of the bolted connection for cold formed steel for beam-to-column connections, whereas RQ2 focuses on the variables that impact the failure mode of the connection. The RQ3 concludes by detailing the procedures used to determine the connection failure. The examination questions are collated as given in Table 1.2.

Table 1. 2 Review Question

No	Review Questions
RQ1	What is the failure mode of bolted connection for cold-formed steel section beam to column connection?
RQ2	What are the factors that influenced the bolt failure on the cold-formed steel beam to column connection?
RQ3	What are the methods used in investigating the failure of the bolt on the cold-formed steel section beam to column connection?

1.5 Contribution and Importance

Due to its superior surface polish compared to hot-rolled steel, cold-formed steel is the ideal option where aesthetic value is required. In addition, it possesses greater dimensional precision, tensile strength, and hardness (Matmatch, 2019). However, failure at the beam-to-column connection for cold-formed steel is also possible due to its increased thermal conductivity, which causes the temperature of the cold-formed steel to rise rapidly. Changes in temperature alter the behaviour of the steel, causing it to become weaker and more susceptible to failure.

Consequently, the study on the behaviour of failed connections was conducted in order to:

1. Enhance the quality of the CFS characteristic to lower the risk of failure.
2. Assist the engineer in distinguishing the appropriate material for a given circumstance, such as where the final result is the key criterion.
3. Increase public knowledge of CFS through the dissemination of relevant information.

1.6 Overall Thesis Structure

To satisfy the objectives of this study, each section of the dissertation has been divided into five chapters. Chapter 1 focuses on the study's introduction, while Chapter 2 focuses on the systematic literature review approach for collecting data from relevant research sources. The third chapter contains a comprehensive literature review based on the findings of around 30 previous researchers.

The purpose is to acquire a deeper understanding of the topic and collect pertinent facts. The focus of Chapter 4 is on the review questions listed in Table 1.2, with an appropriate discussion and report on data collection. Chapter 5 is the concluding chapter, and it contains both the conclusion and the suggestions that were made regarding this matter.

This systematic review of the literature focuses on research pertaining to the failure of the bolt connection between the beam and column in a cold steel section.

CHAPTER 2

METHODOLOGY: SYSTEMATIC LITERATURE REVIEW(SLR)

2.1 Introduction of Systematic Literature Review (SLR)

Systematic Literature Review, sometimes referred to by its abbreviation SLR, is one of the methodologies that may be utilized to perform a thesis, along with numerical and experimental analyses. SLR is a research strategy and procedure for locating and critically evaluating relevant research as well as collecting and analysing data from earlier researchers (Liberati et al., 2009). In addition, by combining the findings and acquiring the perspective of several findings, it solves research concerns with a strength that no single study possesses (Snyder 2019).

This method differs from the literature review. A literature review is an inclusive term used to provide a synopsis of the topic's data collection. Moreover, it is simple and compatible with any approach for data access, location, and presentation. A systematic review is a type of review that combines the information that already exists using strict and clear methods. It follows the international standard Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Venebio, 2017).

2.2 Methodology Planning

2.2.1 Protocol of SLR

Conducting SLR requires protocol-based preparation to obtain a pre-established and well-defined review. This is to assure the study's repeatability and that the review is

conducted appropriately and in a balanced manner, since it is led by various stages to be followed (Mariano et al., 2017). The SLR is not the same as a standard review because it includes a set of criteria to be followed.

The SLR procedure consists of several distinct steps. These processes are essential for ensuring the advancement of the study and the accuracy of data collection and reporting. Figure 2.1 demonstrates the steps of the SLR method.

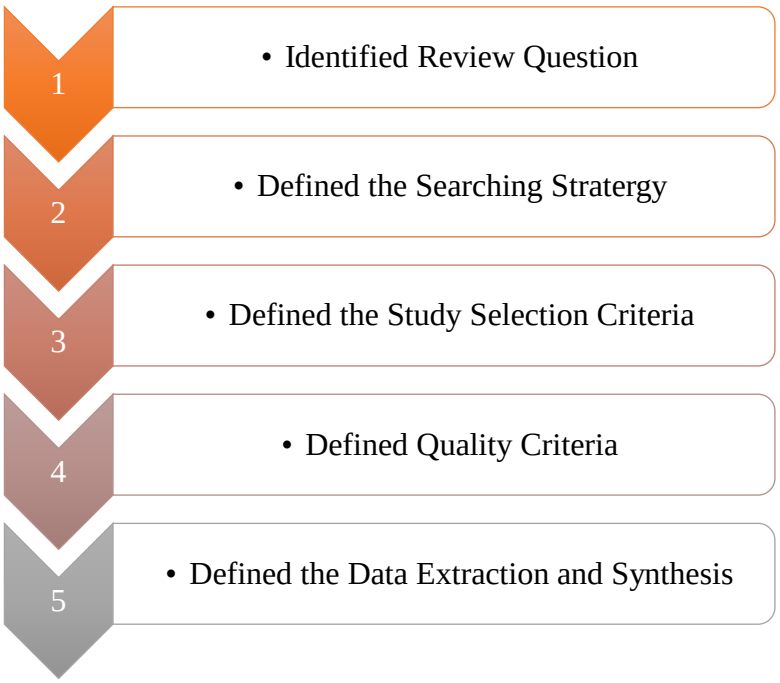

Figure 2. 1 Steps in Conducting SLR

The review questions were identified to ensure the flow track and important for discussion of this study. Then, searching strategies were defined to help in collecting the data. After that, study selection criteria were managed as the data are separated into the exclusion and inclusion criteria. The net process was focused by defining the quality criteria. Finally, data extraction and synthesis were obtained based on the descriptive and analytical data for discussion.

2.2.2 Definition of Review Question

A systematic review was conducted by interpreting the data collected by the researcher, called primary data. The collected data was sorted and categorised to come into a discussion and conclusion of the thesis study. The review question should be clear and well-defined so the studies can be explained in a way that everyone can understand.

This study was focused on the steel member's connection, where the failure occurred on the cold-formed steel, based on the review questions in Table 1.2. According to the review questions, three separate questions were highlighted, consisting of RQ1, RQ2, and RQ3, for some further discussion of the review question. The connection has various types and classifications, consisting of rigid and semi-rigid types. However, this thesis focused on bolt failure and its behaviour in the cold-formed steel section. Cold-formed steel has a criterion where its tensile strength is higher than that of hot rolled. The strength was gained during the manufacturing process due to the strain hardening process of the steel member.

In Malaysia, cold-formed steel was not extensively researched. The purpose of this comprehensive literature study was, therefore, to provide information on cold-formed steel. Consequently, the review was associated with the analysis and discussion of the primary data acquired for the failure of the bolt connection on the cold-formed steel section.

2.3 Conducting SLR

2.3.1 Systematic Searching Strategy

Systematic searching strategies were done to help in categorising the data collection from previous work in this study area. Therefore, in achieving the goal, a good search string

was used to achieve the goal of collecting the data. The information was gathered from digital sources such as ScienceDirect, Scopus, and the International Journal of Steel Section. Findings in this study were managed by using keywords and Boolean to emphasize the searching materials. In the research, 80 papers were collected based on the CFS scope, and only 31 papers were related to the study area. Therefore, the search terms for this study were:

Keywords: Failure, behaviour, bolt, cold-formed steel.

((“failure” OR “deformation” OR “defect” OR “deteriorate”) AND (“behaviour” OR “action”) AND (“bolt”) AND (“cold-formed steel”))

2.3.1 (a) Identification

The identification process was carried out so that the keywords of the research study could be brought to the forefront during the categorization of the research effort into its respective classification. This would make it easier to sort the data. The identification of the keywords is as in Table 2.1.

Table 2. 1 Identification of Keywords

Section	Main keywords	Enrich keywords
Title: A systematic literature review on bolted connection failure in the cold-formed steel section beam to column connection.	Behaviour Failure Bolt Cold-formed steel	Behaviour= action Failure = deformation, defect, deteriorate Bolt Cold-formed steel = CFS
RQ1:	Failure	

What is the failure mode for the connection on the cold-formed steel section?	Bolt Cold-formed steel	Failure = deformation, defect, deteriorate, bearing, buckling Bolt Cold-formed steel = CFS
RQ2: Which of the factors influenced the connection failure on the cold-formed steel?	Factor Failure Bolt Cold-formed steel	Factor = influence, effect, impact, reason Failure = deformation, defect, deteriorate Bolt Cold-formed steel = CFS
RQ3: What methods are used in investigating the connection's failure on the cold-formed steel section?	Method Failure Bolt Cold-formed steel	Method = test, experiment Failure = deformation, defect, deteriorate Bolt Cold-formed steel = CFS

2.3.1 (b) Screening

In the process of constructing the systematic literature review, the screening step was the second sub-process. The data obtained from the research studies was sorted through to carry out this operation. This procedure's goal was to define the parameters of the search in order to verify that the information gathered was pertinent to the subject matter of the investigation. Table 2.2 outlines the steps involved in the filtering process, which takes into account the period of time, topic area, form of publishing, and language of the research publications.

Table 2. 2 Screening Criteria

Criteria	Inclusion	Exclusion
Timeline	2017-2022	Before 2017

Subject area	Engineering, Structures,	Physic & Astronomy, Computer Science.
Publication type	Review Papers, Research Articles, Journal	Conference Proceeding, Newspaper, Book Chapter
Language	English	Non-English

2.3.1 (c) Developed the Searching Strings

Searching strings were developed to focus on the keywords of the search area. The purpose was to ensure that the research studies meet the requirements of this study's objective. For example, the tables below show the search strings of the review question, which consists of searching strings for the title, RQ1, RQ2, and RQ3.

Table 2. 3 Searching Strings

Section	Searching Strings
Title	(“behaviour” OR “action”) AND (“failure” OR “deformation” OR “defect” OR “deteriorate” OR “buckling”) AND (“Bolt”) AND (“Cold-formed steel” OR “CFS”)
RQ1	(“Failure” OR “deformation” OR “defect” OR “deteriorate” OR “bearing” OR “buckling”) AND (“Bolt”) AND (“Cold-formed steel” OR “CFS”)
RQ2	(“Factor” OR “influence” OR “effect” OR “impact” OR “reason”) AND (“failure” OR “deformation” OR “defect” OR “deteriorate” OR “buckling”) AND (“Bolt”) AND (“Cold-formed steel” OR “CFS”)
RQ3	(“method” OR “test” OR “experiment”) AND (“failure” “deformation” OR “defect” OR “deteriorate” OR “buckling”) AND (“Bolt”) AND (“Cold-formed steel” OR “CFS”)

2.3.1 (d) Eligibility

This subprocess was performed following the compilation of all study materials. This procedure ensured that the acquired data was pertinently connected to the study area's requirements. In addition, this ensured that the substance of the data was easily analysed and accessible for debate. The flow of this investigation was represented using a PRISMA flowchart.

The Quality Assessment Criteria was a net procedure based on the eligibility of the research. This step occurs once all acquired data were filtered. The goal of research work filtering was to get rid of unimportant or unclear research papers.

2.3.2 Data Extraction and Synthesis

The acquired data was extracted in accordance with the review question posed by the research presented in Chapter 1. Then, the data was retrieved in Chapter 3, followed by the discussion process in Chapter 4.

2.4 Reporting the SLR

A comprehensive evaluation of the existing literature was provided, together with an appropriate documentation flow and categorization. It conforms to the norm, which ensures that the review can be simply comprehended and makes it simpler for readers to locate any pertinent facts relating to the investigation. As was indicated earlier, the PRISMA requirement was adhered to throughout the systematic review. This requirement consists of a checklist from the beginning of the process until the data is correctly documented. The following items make up the elements of the checklist:

1. Executive summary.
2. A summary was written for the lay public.

3. Analytical framework and description of the logic of study.
4. The rationale for results across studies done.
5. Results of qualitative synthesis.
6. The table and figures summarize the results.
7. Gaps in evidence.
8. Future research needs.

2.5 Summary

In this chapter, the SLR that would be used for this thesis study was presented, and its execution was detailed. After that, it takes into account all of the data that is associated with the research area up to the discussion. The subsequent chapters were devoted to the process of data collection as well as the analysis of the findings.

CHAPTER 3

DATA EXTRACTION AND SYNTHESIS

3.1 Introduction

The extraction and synthesis of data was another step in the development of the systematic review. After the work was gathered, the extracted data from the screening procedure was subjected to synthesis and analysis. The objective of the process was to assist in producing a conclusion and summary of the study.

It was necessary to read and summarize data in order to have a deeper and more precise understanding of the relevant research topic. In addition, analysing the data facilitates the categorization of the data into much more specific inputs. Therefore, it is beneficial for the research discussion to be appropriately elaborated and presented.

3.2 Data extraction

A well-written study was possible with well-organized data extraction. Extraction of the main data may appear challenging in the absence of a comprehensive tabulation since a systematic literature analysis necessitates reading from the work of earlier researchers. Because the data needed to be interpreted back as secondary data, there was a requirement for a systematic flow to aid in the assistance of the data.

About 31 research articles were analysed and extracted after sorting in order for this study's evaluation to be completed. The data was finalized in Microsoft Excel in table form, as in Table 3.1, to provide a better understanding of the study project.

Table 3. 1 Description of Data Collected from Previous Researchers

No	Title of publication, Author		Publishing Country	Type of Publication	Publication Outlet	Research objective	Research Scope	Brief Description	Method	Variable
1	Experimental and numerical study of connection effects in long-span cold-formed steel double channel portal frames	(Blum and Rasmussen, 2019)	Australia	Journal	Constructional Steel	Determine the impact of frame components, including column base connection stiffness and knee brace-to-column design, on frame capacity and behaviour.	Frame to column connection	This paper provides numerical and experimental testing of the modelling methods using the finite element method. An experiment assessed column base connection stiffness using L-brackets fastened via column flanges. Wind-induced frame loads affect column base stiffness. Increasing the thickness of the knee-to-column connection increases the frame's vertical stress.	Numerical and Experimental	Rafter channel thicknesses and depths.
2	Comparative experimental studies on the web cleat bolted CFS beam-to-column connection	(Natesan et al., 2020)	India	Journal	Constructional Steel	To compare a three-bolted web cleat to a two-bolted web cleat connection between a beam and column under shear load	Beam to column connection	This study explains the relationship between the web cleat leg's maximum load and ratio. It also monitors buckling and bearing failure of the CFS beam under loading points. This study considered lateral column deflection, connection rotation, and vertical loading point deflection.	Experimental	The thickness of the web cleat, the ratio of the web cleat leg attached to the column
3	Cold-formed steel beam-to-column bolted connections for seismic applications	(Papargyriou et al., 2022)	United Kingdom	Journal	Thin-Walled Structures	Include flanges in the connection behaviour to generate two	Beam to column bolted connection	This analysis balances the load-carrying capability of connections with their seismic performance. Material nonlinearity and early geometric imperfections assist in validating experimental findings.	Numerical	Beam thickness, the gusset plate Shape and thickness,

						new connection configurations.				on the moment–rotation behaviour of the connections
4	Effect of staggered bolted connections on CFS channel sections	(Natesan et al., 2020)	India	Journal	Constructional Steel	Determine the effect of staggered bolted connections on cold-formed steel channel sections attached to gusset plates.	Bolted connection	This study describes factors influencing bolts. Two-bolt staggered connections provide adjustable tensile resistance, but three-bolt connections burst.	Experimental	Channel dimensions, staggered and gauge distances, bolt hole diameter.
5	Effectiveness of CFS web cleat bolted connections between beam–to–column	(Natesan et al., 2021b)	India	Journal	Structure	To evaluate the impact of 230 mm depth (B) of web cleat subjected to a shear load on strength, relative rotation, and failure mechanism of web cleat leg attached to column web.	Beam to column bolted connection	This test involves four-point bending. Reduced web cleat leg-to-column ratio increases ultimate strength. Three-bolt designs provide better ultimate strength. Most specimens failed due to local buckling, and just a few due to bolt shearing and beam bearing under loading points.	Experimental	The ratio of web cleat leg Attached to the column, thicknesses of web cleat, bolt Configuration
6	Push-out tests on bolted shear connectors in composite cold-formed steel	(Hosseinpour et al., 2021)	Iran	Journal	Thin-walled Structures	To test bolted shear connections as an alternative to welded shear studs in	Bolted connection in beam	This study measured the ultimate load, ductility, stiffness, and failure mode of all specimens. From the test, a higher CFS section thickness results in a higher ultimate load per shear connector.	Experimental	The thickness of CFS sections, size of bolt,

	beams					composite cold-formed steel beams.				the strength of bolts
7	Numerical study on behaviour of bolted shear connector used in composite cold-formed steel beams	(Hosseinpour et al., 2022)	Iran	Journal	Thin-walled Structures	To investigate the behaviour of 8.8 grade bolted connectors in CFS composite beams	Bolted connection in beam	This study validates the results obtained from numerical models against the experimental results, where geometric details, material nonlinearities, material damage models, and loading protocols were considered. In addition, it also examines the effects of the parameters on the ultimate strength, ductility, and failure modes of the bolted shear connectors.	Numerical	CFS thickness, CFS ultimate strength, concrete compressive Strength, embedded bolt's height, and bolt diameter.
8	Behaviour of different bolted connection configurations in frames composed of cold-formed sections	(El-Hadary et al., 2022)	Egypt	Journal	Ain Shams Engineering Journal	To investigate the effect of different parameters on the ultimate capacity and the failure mode of the eave connection	Beam to column bolted connection	This study's results show five failure modes considering lateral out-of-plane buckling of the gusset plate, local buckling of the corresponding section, bolt bearing of C-section web and the gusset plate, and tearing of C-section web. The typical failure occurs on the bearing failure. However, in some cases, lateral-out-of-plane buckling of the gusset plate occurs, resulting in premature failure of the connections at low values of applied loads. Local failure of the connected sections happens at the ultimate loading phase	Numerical	Bolt configuration, bolt diameters, gusset plate thickness, The bolt pre-tensioning force, edge distance

9	Development of new types of bolted joints for cold-formed steel moment frame buildings	(Yin et al., 2022)	United Kingdom	Journal	Building Engineering	To presents an experimental programme and the corresponding results on two types of beam-to-columns CFS joints, which assembles to the two adjacent surfaces of the built-up CFS column	Beam to column bolted connection	This study proposes two types of joints that satisfy seismic design for 'strong connection weak beam,' Joint 1(JT1) and Joint 2 (JT2), potentially suitable to connect CFS members in T-, L- and cruciform joints for multi-story framed-structure buildings. The test shows that beams buckled before the occurrence of apparent damage to the tested joints. JT2 exhibits higher performance in strength, ductility, and energy dissipation capacity than JT1. JT1 satisfies the rotational requirement for Ordinary Moment Frames (OMFs), while JT2 satisfies the rotational requirement for Special Moment Frames (SMFs), as defined in AISC Seismic Provisions. The connection zones within both joints classify as semi-rigid according to the approach recommended by Eurocode 3: Part 1–8, with JT1 exhibiting higher stiffness than JT2. The proposed two joints connected with very slender beams and fewer bolts have a moderate performance to provide resistance and ductility in CFS framed buildings in seismic regions.	Experimental	Type of joints
10	Optimization Of Cold-Formed Steel	(Gondhale, 2018)	Pune	Journal	JETIR June 2018,	To study on the various local modes of failure	Cold-formed steel	This study focuses on the failure mode in the cold-formed steel structure, which is on the web	Experimental	Length of span, Section

	Section				Volume 5, Issue 6	and effective section properties in cold-formed steel.		crippling. Experiments performed for pure web crippling show that AISI S100-16 considers combined failure modes in which web crippling is a critical mode of failure. The conclusion also find that when the span for the beam increase, failure on the bearing also may increase		(two Flange loading (ETF), Interior two Flange loading (ETF), Interior One Flange Loading (IOF), End One Flange loading (EOF)
11	Structural Performance of Cold-Formed Steel Angle	(Makesh and Rivalagan, 2018)	India	Journal	International Journal of Research and Review	To investigate the load capacity tension members of single angle sections of 2, 3 mm 4, and double angles sections of 2mm under plain (Without Lipped) and with Lipped conditions subjected to tension.	Cold-formed steel	This study consists of the type, which is numerical and experimental. For numerical, finite element analysis helps to validate the experimental results, where materials are assumed to behave as isotropic hardening material. For experimental, all specimens have been designed to undergo net section rupture or block failure. As a result, load carrying capacity increases the connection to the other side of the gusset more than those connected to the same side.	Numerical and Experimental	Angle sizes, number of Bolts and the bold pitch distance.
12	Numerical Study of Unstiffened	(Ghamry et al., 2021)	Egypt	Journal	The Egyptian International Journal	To study numerically the behaviour of the apex bolted	Cold-formed steel connection	The deflection and the stress distribution at critical sections for unstiffened 2C (double back-to-back) CFS were investigated for two	Numerical	Gusset plate thickness, bolts

	Cold-Formed Steel Apex Moment Connection				of Engineering Sciences and Technology	moment connection for cold-formed sections.		cases. Connecting a single gusset plate was used in the first case, while two connecting double gusset plates in the second case. Moreover, specimens' deflections, ultimate failure load, and failure mode in this analysis include local yielding in cold-formed section, flexural distortional buckling in the connecting gusset plate, and bearing failure near bolts.		patterns, and bolts pretension force on The resistance of the cold-formed steel sections
13	Tension Behaviour on the Connection of the Cold-Formed Cut-Curved Steel Channel Section	(Mohd Sani et al., 2017)	Malaysia	Article	IOP Conference Series: Materials Science and Engineering	To study the tension behaviour of the connection in the cold-formed steel	Cold-formed steel connection	CFS bents use a cut-curved method for easy production without using skilled labour and high-cost machine. Therefore, the tension behaviour of the cutting-curved strengthening method or could be recognised as a connection of the cut-curved section was tested and analysed. Specimen with full weld along the cut section and added with flange element plate with two self-drilling screws (F7A) have a higher value of the ultimate load.	Experimental	Types of connection
14	Non-Linear Analysis of Bolted Extended End-Plate Steel Beam-To Column Connection	(Amir and Abdullah, 2019)	Malaysia	Journal	N/A	To analyse the behaviour of extended end-plate connection.	Bolted connection on the beam to column	This study compares the finite element analysis with experimental results for the shape of the moment-rotation (M-) curve, moment resistance, and mode of failure. Also, data compares and validates the maximum capacity of the computer model and Eurocode 3. It shows that the thickness of the end-	Numerical	Plate Thickness and number of bolts

								plate slightly increased the connection behaviour while the number of bolts indeed increased the connection rigidity. However, from the moment-rotation curve, the plate thickness does not affect the rigidity and moment capacity of the connection. In contrast, the number of bolts affects the rigidity and moment capacity, where the number of bolts increases the rigidity and moment capacity.		
15	Design procedure to bearing concrete failure in composite cold-formed steel columns with riveted bolt shear connectors	(Mariano et al., 2017)	Brazil	Journal	Engineering Structure	To study the behaviour of riveted bolt shear connectors applied in composite columns of cold-formed steel sections (CFS) filled with concrete.	Riveted bolted connection in CFS filled with concrete	This study performs experiments of two series of push tests to evaluate the behaviour of these connectors applied in composite columns. The numerical model was calibrated with the tested specimens to correlate the numerical and experimental outputs. The strength capacity of the connectors governs by the concrete bearing failure and other failure types, such as bolt shear.	Numerical and Experimental	Riveted bolt shear connectors
16	Experimental and numerical investigation into the fire performance of glulam bolted beam-to-column	(Luo et al., 2022)	China	Journal	Journal of Building Engineering	To study the beam-to-column connections loaded with a combination of stress caused by bending moment and shear force.	Beam to column connection	This study tests real-scale bolted beam-to-column connections loaded with coupled bending moment and shear force under average temperature and ISO fire exposure. Three-dimensional numerical model of the bolted beam-to-column connections is developed and validated by	Numerical and Experimental	Bending moment, shear force

	connections under coupled moment and shear force							experimental results. The model simulates the evolution of temperature in the connections as well as their mechanical behaviour. Comparing the rotation time curve between experimental data and the thermo-mechanical model results in a comparable tendency.		
17	Experimental investigation on monotonic bending behaviour of TSOBs bolted beam to hollow square section column connection with inner stiffener	(Sun, Liang, Cai, Liu, & Wang, 2022)	United Kingdom	Journal	Journal of Building Engineering	To study the experimental behaviour of web cleat bolted between beam–to–column in terms of strength, relative rotation, and failure mechanism of web cleat leg attached to the column web.	Beam to column bolted connection in CFS	This paper studies the effect of the length and plate thickness for the stiffener on the connection performance. Inner stiffeners are used as connection splices to connect the upper column and the lower. A total of six TSOBECs with stiffeners tests under monotonic bending moments. The test results show that the stiffeners can avoid the bolt pulling-out failure and improve the deformation capacity of TSOBEC	Experimental	H-section and double channel section
18	Exterior beam-to-column bolted connections between GFRP I-shaped pultruded profiles using stainless steel cleats. Part 1:	(Martins et al., 2021)	Portugal	Journal	Thin-Walled Structures	To study the mechanical behaviour of exterior beam-to-column connections between I-shaped pultruded GFRP profiles using		This study performs the full-scale to investigate the monotonic response of nine different connection series and the cyclic response of four of those series. Tensile rupture happens on the series without reinforcement at the columns' web-flange junction during the initial stage of the monotonic and cyclic tests. The rupture limits the connections' strength, ductility, and	Experimental	Number of bolts/rods (one or two bolt rows), cleat thickness (3, 6, and 8 mm), position Of the cleats