



Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895



Structural Damage Model of Steel Structure Connections with Initial Defects: A Review

Huang Yancai^{1,2}, Andri Kusbiantoro^{1,*}, Amalina Hanani Ismail¹, Lin Lin², Nindyawati³

¹ Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, Malaysia

² Department of Civil and Architectural Engineering, Liming Vocational University, 362000 Quanzhou City, Fujian Province, China

³ Department of Civil Engineering, Universitas Negeri Malang, 65145, Malang, Jawa Timur, Indonesia

ARTICLE INFO

Article history:

Received 19 April 2024

Received in revised form 14 June 2024

Accepted 27 June 2024

Available online 30 July 2024

Keywords:

Steel connections; initial defects; damage model; seismic performance

ABSTRACT

As the application of steel structures in construction continues to grow, research into their seismic performance is becoming increasingly important. This paper focuses on steel structure connections, specifically those between components with varying profiles such as H-profiles, box-profiles, and L-profiles. Additionally, it encompasses three core areas: seismic performance (bearing capacity, ductility, stiffness), initial defects (initial cracks, residual stresses, manufacturing imperfections), and damage models (weld fractures, bolt failures, plate buckling). In addition, this paper employs experimental testing and finite element, with a focus on conducting parametric analyses for the connections. Based on the primary findings, the presence of initial defects such as cracks, residual stresses, and manufacturing imperfections can lead to premature failure, concentrating damage near welds and exacerbating stress concentrations. This adversely affects factors like fatigue strength, fracture toughness, and buckling strength, ultimately reducing the seismic performance of the connections. Moreover, factors like bolt over-tensioning, geometric deviations in plate components, and corrosion can further impact bearing capacity, fatigue performance, and ductility. Crucially, these initial defects not only compromise the seismic resistance of structures but also increase the risk of structural failure. However, majority of existing research has focused on monotonic and cyclic loading studies, with limited exploration of connections under seismic conditions. Acknowledging this gap, this paper outlines a future research agenda aimed at refining the design of steel structure connections. This initiative seeks to mitigate potential adverse consequences stemming from formidable seismic events, thereby enhancing the overall resilience of these crucial connections.

1. Introduction

Recently, the rapid socio-economic development has correlated with the increasing usage of steel frame structures. These structures exhibit a wide range of complex and diverse construction designs. In China, the government has committed to promoting steel frame structures, aiming for them to

* Corresponding author.

E-mail address: andri@uthm.edu.my

<https://doi.org/10.37934/aram.121.1.163186>

constitute more than 15% of newly constructed building areas by 2025 and projecting a further increase to 40% by 2035 [1].

However, there is a risk of significant structural damage in numerous steel frame buildings that was observed during seismic events, including the Northridge earthquake in the United States (1994), Kobe earthquake in Japan (1995), Wenchuan earthquake in China (2008), Haiti earthquake (2010), Nepal earthquake (2015), Sulawesi Earthquake (2018), and recent Turkish earthquake (2023) [2-8]. These unfortunate events lead to significant losses of both life and property. Consequently, greater attention should be directed towards the safety of steel frame structures under seismic effects, particularly during intense earthquakes.

Researchers have been analysing structural seismic vulnerability since the early 20th century to determine the likelihood of structural response and failure under seismic effects [9,10]. The primary focus among researchers often revolves around monotonic loading, hysteretic loading, and fatigue loading when subjecting connections to various loads. Nevertheless, it should also be noted that earthquake loads inherently affect the entirety of steel structure buildings [11].

Fewer researchers have directly investigated how the connections respond to earthquake loads, thus assessing their seismic performance [12,13]. Addressing this research gap, this review aims to explore the seismic behaviour of steel structure connections with initial defects under the direct influence of earthquake loads.

This review focuses on steel structure connections, specifically examining the common steel profiles used in the structure (H-profile, box-profile, L-profile). It includes seismic performance (bearing capacity, ductility, stiffness), initial defects (cracks, residual stresses, imperfections), and damage models (weld fractures, bolt failures, plate buckling). The main aim is to investigate the impact of initial defects in various steel profile connections on their seismic performance and failure modes under different loading conditions. The review is expected to aid subsequent research focused on enhancing steel connection designs for better seismic resilience.

2. Methodology

This study adopted a systematic review approach to integrate existing research on the seismic performance of steel structure connections, with a particular focus on those exhibiting initial defects. The methodology was designed to ensure a comprehensive and unbiased aggregation of relevant literature, thereby laying a solid foundation for the analysis.

2.1 Selection Criteria

The inclusion criteria for this study were prepared to ensure the relevance and quality of the data. Research articles, conference papers, and technical reports were considered if they met the following conditions:

- i. Published in peer-reviewed journals or reputable conferences.
- ii. Focused on the seismic performance of steel structure connections, including but not limited to H-profile, box-profile, and L-profile connections.
- iii. Addressed initial defects in connections such as cracks, residual stresses, and manufacturing imperfections.
- iv. Provided empirical data, theoretical analyses, or both on the impact of these defects on seismic performance.

2.2 Data Analysis

Following the identification of relevant studies, key information such as study design, connection type, identified initial defects, testing methods, and main findings were collated into a structured format. This facilitated a comparative analysis across different studies, allowing for the identification of patterns, discrepancies, and knowledge gaps in the current literature. It also involved categorizing studies based on connection types and defects and summarizing their findings with respect to seismic performance indicators such as bearing capacity and failure modes.

This methodology ensures a systematic and transparent review of the existing body of knowledge on the seismic performance of steel structure connections with initial defects. It will not only help to highlight the current understanding and advancements but also identify areas that need further investigation.

3. Steel Structure Connections

3.1 Connections of H-profile

The H-profile beam and column connection is a crucial component in steel structure fabrication that attracts significant research interest, especially concerning its seismic performance. The identification of critical beam-to-column connection has been achieved by comparing the maximum rotational angles of various connections [14]. Li *et al.*, [15] investigated different connection types (Conventional Joints (CJ), Reduced Beam Section Joints (RJ), and Cover Plate Joints (CPJ)) and their impact on seismic performance, as illustrated in Figure 1. The study examines various aspects including damage models, dynamic responses, displacement responses, strain, and acceleration responses. The results revealed that Reduced Beam Section (RJ) and Cover Plate Joints (CPJ) contributed to the outward displacement of plastic hinges, showcasing enhanced seismic performance and ductility [11,15–17].

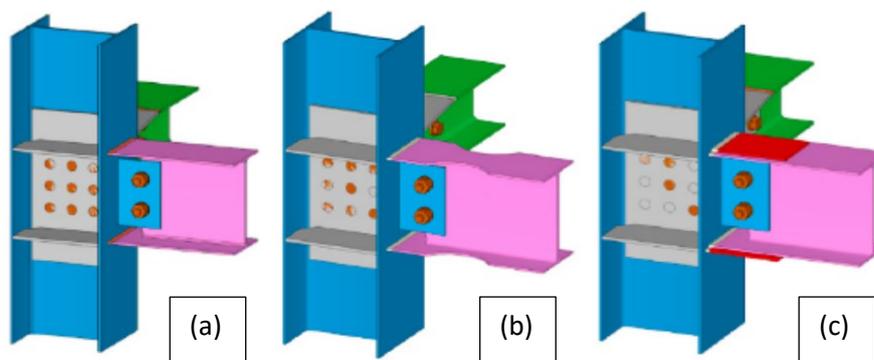


Fig. 1. Connection Types (a) Common Joint (CJ) (b) Reduced Beam Section Joint (RJ) (c) Cover Plate Joint (CPJ)[15]

Further research by Sepasdar *et al.*, [18] on the beam-to-column joint regions suggested the importance of incorporating joint regions when estimating the lateral bearing capacity of steel frames [18]. The study also revealed that Reducing Web Section (RWS) enhanced the seismic collapse resistance of structures, while Welding Flange Plates (WFP) comprehensively elevated the seismic capacity of structures. However, in the multi-story structures, the collapse resistance of WFP is relatively weaker compared to RWS connections [13,19]. The depth and width of the cut in RWS connections greatly influence ductility, with up to 30 % difference compared to the full beam section

[20]. In addition to that, another type of connection, namely the Double Reduced Beam Section (DRBS) connection, introduced an extra reduction section, which further shifting the plastic hinge and enhancing ductility [21].

3.1.1 Seismic performance of diverse connection types

Chen and Shi [22] conducted a study on the damage modes, bearing capacity, stiffness, and ductility of column connections in cover plate-reinforced beam-to-column connections. The study explored various parameters such as thickness and length of cover plate, additional angle welds in the web connection, and the arrangement of angle welds around the cover plate. In cases involving beam connections of unequal heights, the relative displacement between the cover plate and beam flange resulted in the simultaneous buckling of the beam's bottom flange and web. This mechanism lead to an unfortunate damage model where the deeper section of the beam's bottom flange experiences fracture [23].

The seismic performance of beam-to-column connections that utilize weak-axis bolts is notably affected by the quantity of high-strength bolts used, as indicated by Lim *et al.*, [24]. Testing through experimental cyclic loading of various beam-to-column connections (both strong- and weak-axis) has demonstrated that the ductility of web plate connections closely resembles that of flange plate connections, provided that brittle rib failure is avoided. Somarriba *et al.*, [25] suggested that the yielding pattern of the ribs is crucial to understanding the failure mechanisms of column web plate connections. These results emphasise the importance of careful bolt selection and design to enhance the seismic resilience of these connections.

The seismic resilience of steel frames is influenced by the proportion of rigid versus semi-rigid connections, affecting fundamental periods, drift ratios, and column forces [26]. Research shows that semi-rigid frame connections may outperform rigid frame connections under seismic stress, prompting detailed studies in this area [27]. In the previous literature, welded weak-axis connections with end plates offered good rotational and bearing capacity, ductility, and energy absorption [28]. In another study, Kang and Zhang experimented on bolted angle connections, and highlighted the role of rib placement, steel grade, and additional ribs in enhancing stiffness and load-bearing capacity [29]. Comparatively, welded flange plates provide better flexural strength, and welded stiffeners help avert weld fractures [30]. Adjustments to angle steel thickness and bolt spacing in bolted angle connections have been shown to impact strength and stiffness [31]. Li *et al.*, proposed L-profile stiffeners for beam-to-column connections, finding that larger and thicker stiffeners improve performance [32]. These studies illuminate the nuanced factors that affect the seismic performance of steel connections, offering insights for improved structural design.

3.1.2 Bolted end-plate connections in seismic performance

Bolted end-plate connections are primarily employed for beam-to-column connections and beam-to-beam splicing in steel frames and steel gabled frames. Under seismic effects, the thickness of these end plates plays a significant role in influencing contact stress, while its impact on contact area remains marginal. Notably, the simultaneous yielding of both the column web and beam maximizes the energy dissipation coefficient, thereby augmenting the overall seismic performance [12]. Radmehr and Homami [33] conducted seismic vulnerability analysis on bolted end-plate connections in steel frames, considering random variables such as the horizontal and vertical distances of bolts from the plate's edge, bolt pre-tension force and ultimate strength, yield strengths

of beams and columns, and elastic modulus of the plate. This study provides valuable insights into the intricate behaviour of such connections under seismic loads.

The integration of side plates into end-plate connections has been shown to enhance energy dissipation capacity and yield an equivalent hysteresis damping ratio, thereby improving overall seismic performance [34]. For inclined end-plate beam-to-column connections, increasing the beam inclination angle reduces both ductility and flexural capacity of the connection [35]. Based on this, Masoudi and Broumand [36] proposed an innovative strengthened bolted connection with extended end plates, outperforming traditional end-plate connections. Additionally, Zhandong [37] introduced a semi-rigid connection node with T-stubs, demonstrating favourable seismic performance. Bezerra *et al.*, [38] studied the influence of different flange thicknesses on the bearing performance of T-stub connections [38]. Bolt thickness and location are crucial factors affecting bolt forces [39]. Moreover, when calculating the initial stiffness of T-stub connections, the bending stiffness of bolts should be considered [40]. These insights collectively contribute to a more comprehensive understanding of the intricate behaviour of various bolted connection configurations.

High-strength bolted connections in cantilevered beam splicing and column connections can serve as energy dissipation devices, mitigating the brittle fracture of welds at the beam-to-column connection [41]. Based on this concept, Yu *et al.*, [42] proposed a Welded Upper Flange and Bolted Lower Flange Connection (WUFBLC) for beam-to-column connections, utilizing frictional slip between the splice plate and the frame beam to dissipate energy [42]. The sliding of bolts under lateral loads can be categorized into three states: complete contact state, viscous state, and complete sliding state [43]. The hysteresis behaviour of friction connections depends on the ratio of hardness between the bolt spacer and the connecting plate [44]. Concerning frictional resistance in connections, square groove specimens exhibit the highest frictional resistance, while painted specimens display the lowest frictional resistance [45].

In summary, the seismic performance of steel structure connections, particularly those involving H-profile beams and columns, is a multifaceted domain that encompasses a wide array of design considerations, from connection type and joint configuration to material selection and geometric parameters. The ongoing research in this field continues to provide valuable insights that inform and refine seismic design practices, aiming to enhance the structural integrity and resilience of steel frameworks against seismic forces.

3.2 Connections of H-profile Beam and Box-profile Column

Box-profile columns are known for their superior seismic performance, particularly in terms of bending, compression, and torsion resistance, when compared to their H-profile counterparts [46]. This section explores the connections between H-profile beams and box-profile columns, focusing on the challenges and innovative solutions proposed to enhance their seismic resilience.

3.2.1 Challenges in moment transfer efficiency

The moment transfer efficiency in connections between H-profile beams and box-profile columns often falls short of that observed in H-profile column connections. The primary reasons for this shortfall include out-of-plane deformation of column flanges and strain concentration in beam flanges, which collectively lead to a diminished deformation capacity in connections involving box-profile columns [47].

Employing appropriate strengthening components can impact stress distribution within the connection, enhancing the ultimate moment capacity [48]. Connections with strengthened web

connections between H-profile beams and box-profile columns exhibit higher moment capacity and dissipate more plastic energy compared to connections with reduced flange section connections. Reduced flange section connections facilitate plastic hinge outward [49-50]. Building upon this, Chang *et al.*, [51] introduced a novel connection between an H-profile beam and a box-profile column, characterized by a reduced web section and an elongated circular hole in the beam's opening. This design strategically relocates plastic hinges away from the column, resulting in improved seismic performance [51].

3.2.2 Innovation in connection design

Several researchers have introduced novel designs to further enhance the seismic performance of these connections. Single-sided bolted end-plate connections with box-profile columns is among the innovative design in this area. The end plate enhances the overall stiffness, energy dissipation capacity, and ductility of the connection [52]. When either the end plate or the column flange has weaker stiffness, the connection behaves semi-rigidly; when both the end plate and the column flange have stronger stiffness, the connection becomes rigid [34].

Núñez *et al.*, [53] conducted numerical research on a novel connection between H-profile beams and box-profile column end plates, demonstrating reliable seismic performance for such connections [53]. In another study, Núñez-Castellanos *et al.*, [54] studied the performance of optimized end-plate bolted connections between H-profile beams and box-profile columns under unidirectional and bidirectional loads, showing that connections under unidirectional loads exhibit better stiffness and bearing capacity [54]. Therefore, considering the bidirectional effects of seismic actions and axial load levels is essential to avoid forming column hinge brittle failure mechanisms [55].

Derakhshan and Shekastehband [56] investigated the seismic performance of external continuous plates connected with T-stubs. The study analysed parameters such as the beam-to-column moment ratio, the number of continuous plates, pre-embedded stiffeners on the beam, and the use of high-strength materials, aiming to understand their influence on seismic performance of the connection.

Building on traditional designs, several researchers have introduced innovative connections to enhance seismic resilience. Yang *et al.*, [57] proposed a bolted connection for H-profile beams and box-profile columns, utilizing angle steel with ribs and a web connection plate. They analysed that a higher rib height significantly improves the connection's bearing capacity. Similarly, Zhang *et al.*, [58] explored the seismic performance of all-bolted prefabricated steel frame structures, while Chan and Koetaka [59] developed a numerical model that captures the three-dimensional elastic-plastic behaviour of beams, columns, and panel areas under multi-directional loads. Furthering this innovation, Serrano-López *et al.*, [60] designed a novel connection by welding threaded bolts onto the front face of box-profile columns and securing angle steel cleat legs to the column with these bolts, enhancing the overall connection strength. Liu *et al.*, [61] introduced a bolted connection between H-profile beams and square steel tube columns, reinforced with diagonal braces for added stability. These advancements, including the use of supplementary plates, not only prevent fracture failures but also significantly increase energy dissipation capacity, offering a promising direction for future seismic-resistant steel constructions.

To eliminate internal stiffeners in box-profile columns at the beam-to-column connection, Paghaleh *et al.*, [63] proposed three through-beam connections for box-profile column connections. These connections are illustrated in Figure 2. Notably, all three proposed connections demonstrated favourable seismic performance, with the through-hole curved rib stiffener plate connection showcasing the most promising outcomes [63].

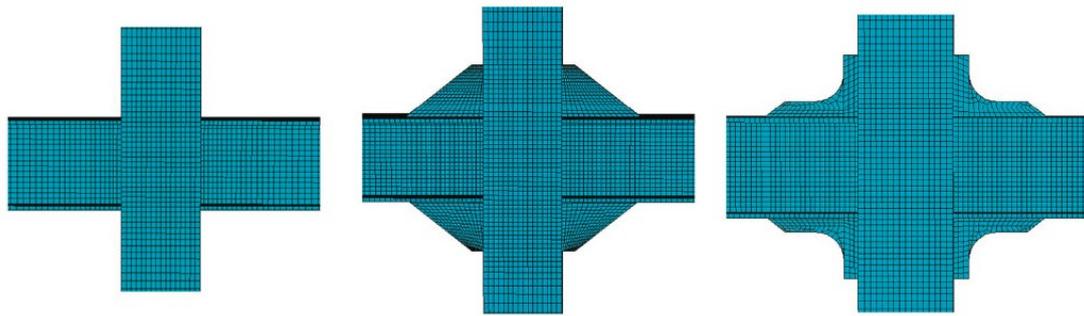


Fig. 2. Through-beam Connections for Box-profile Column Connections [63]

The seismic resilience of connections between H-profile beams and box-profile columns is a focal point of ongoing research. Innovations in connection design, from enhanced end-plate configurations to novel through-beam connections, underscore the commitment to improving the seismic performance of steel structures. By addressing the unique challenges presented by these connections, researchers continue to push the boundaries of structural engineering to ensure greater safety and reliability in the face of seismic events.

3.3 Connections of L-profile

L-profile section connections are essential in the construction of transmission towers and trusses, offering unique advantages and challenges. Taha *et al.*, [65] have investigated the complexities of bolted lap connections within lattice steel transmission towers, uncovering the multiple stages these connections undergo under axial loads, from pre-sliding to plastic deformation. Their study highlights a critical limitation: the failure of these connections often stems from the insufficient bearing capacity of angle steel members or splice plates, emphasizing the importance of robust connection design to prevent structural failures.

3.3.1 Advances in connection slip modelling

The failure of bolted lap connections occurs due to inadequate bearing capacity of angle steel members or splice plates [64-65]. The slip model of connections is a crucial parameter for predicting deflection in angle steel transmission tower structures. Influenced by factors like the number of bolts, bolt diameter, bolt arrangement, and angle steel section dimensions,

Gan *et al.*, [66] proposed single-leg bolt connections and bolted lap connection models for predicting structural deflection [66]. Bolted connections in transmission towers should consider rotational and axial stiffness due to slip [67]. Neglecting bolt slip can lead to underestimating the seismic response of transmission towers, consequently overestimating their seismic performance. This effect becomes more pronounced with higher levels of seismic activity [68].

Researchers have developed a finite element model for galvanized lattice steel structures to accurately simulate connection slip, enhancing the reliability and safety of structural designs [69-70]. The use of a second-order direct analysis method, which considers both bolt slip and semi-rigid connections, has underscored the significant impact of connection slip on the structural deflection and axial forces in transmission towers [71]. This effect becomes more pronounced as axial tension increases, leading to highly nonlinear behavior in the axial stiffness and elastic deformation of bolted connections [72]. Therefore, comprehensive modeling and analysis of transmission towers should include considerations of geometric and material nonlinearities alongside connection slip effects

[73]. A new model for connection slip, considering factors such as bolt pre-tension, contact friction, dimensions of angle steel, plate thickness, grades of steel and bolts, the quantity of bolts, and hole tolerances, has been proposed for enhanced accuracy in the second-order direct analysis of transmission towers [74-75].

3.3.2 Innovation in connection design

Li *et al.*'s examination of K-type connections in transmission towers provides valuable insights into their mechanical performance and vulnerability to damage. This study reveals how factors like bolt grade and steel strength dictate the connection's resilience, with precise manufacturing of bolt holes and reduced clearances being key to minimizing deformation [76, 77].

The exploration of novel connection designs, as presented by Ma *et al.*, [78], introduces a unique steel transmission connection that combines single-angle and double-angle configurations, as illustrated in Figure 3. This innovative approach could significantly influence the stress distribution and deformation characteristics of transmission towers, potentially leading to more resilient structures.

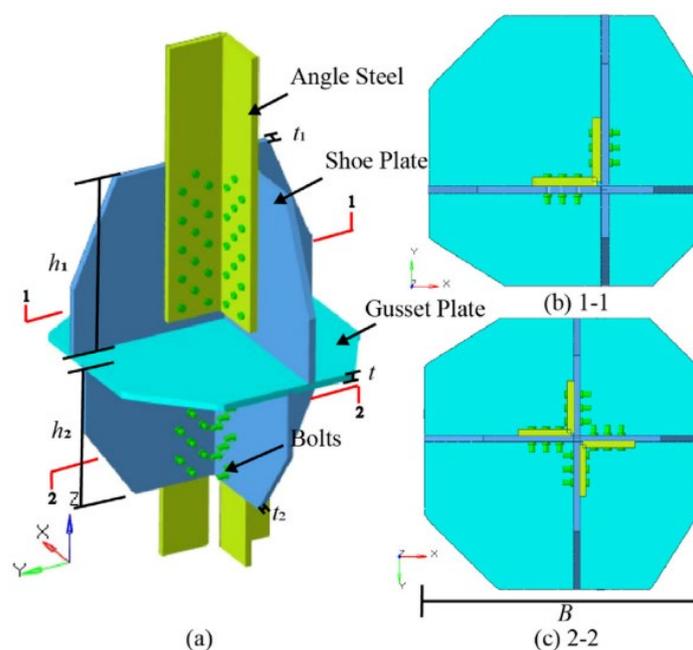


Fig. 3. A Novel Steel Transmission Connection [78]

In another study, Liu *et al.*, [79] conducted a study on the axial performance of single-angle steel bolt connections at elevated temperatures. They analysed parameters such as angle steel dimensions, load directions, bolt grades, size variations, and numbers. Research on angle steel connections in transmission tower structures located in areas with moderate to heavy icing conditions concluded that the deformation of the connections is controlled by vertical loads. In tension tower structures, the deformation of the connections is influenced by tensile forces, which in turn affect the bolts [78].

In summary, L-profile connections play a crucial role in the structural integrity of transmission towers and trusses. Current research efforts are focused on enhancing the understanding of bolted connections, from their basic mechanical behaviour to advanced modelling techniques. The purpose is to ensure that these structures can withstand a wide range of loading conditions, including seismic forces.

4. Initial Defects

4.1 Initial Defects in Weld Connection

Initial defects in beam-to-column connections diminish the seismic performance of steel frame structures and amplifying the probability of structural failure. In the welded connection, damage concentration and fractures tend to occur near welding holes in the beam flange plate, leading to insufficient connection ductility [80, 81]. Liao *et al.*, [82] investigated how the location, length, initial notch radius, and welding hole configuration of initial defects affect the fracture characteristics of the structure. It was also found that the primary damage model in the welded box beam-to-column connections is the fracture of the welding seam at the beam flange. In this section, the damage model of this connection will be reviewed and a summary will be provided at the end of the section to enhance reader comprehension.

4.1.1 Residual welding stress

Residual welding stress is generated during the welding process due to localized rapid heating and cooling, resulting in thermal stresses. Residual welding stresses also contribute to an increase in the equivalent plastic strain at the welds, thereby causing premature connection failure [83]. The distribution and magnitude of welding residual stress are influenced by factors such as connection type, welding conditions, and restraint conditions. There are also uncertainties that occasionally arise from welding process. To mitigate these uncertainties, non-welded artificial notched specimens with geometric and metallurgical notches can be utilized to examine the plastic deformation capacity of welded connections under stochastic loading conditions [84].

In another study, Jin *et al.*, [85] investigated the influence of welding on the strength and stiffness of Y-type and K-type connections in concrete-filled steel tubes. When weld toe dimensions are reduced, there is a moderate decline in connection strength and stiffness, accompanied by the occurrence of lower and smaller residual stress zones. Meanwhile, Park *et al.*, [86] studied the effects of component thickness, yield stress, transverse constraint, and bending constraint on welding residual stress in butt welding and established predictive factors for welding residual stress. Moreover, in comparison to longitudinal stress, the influence of welding methods on transverse stress is more pronounced [87, 88].

4.1.2 Welding deformation

Raftar *et al.*, [89] studied the welding deformation and residual stress characteristics of cruciform fillet weld connections, as well as the influence of plate thickness and welding sequence on welding deformation [89]. Residual deformation is directly proportional to the weld leg height, with the greatest impact on diagonal weld shear strength [90]. For T-type welded connections, compressive residual stress gradually increases from single-pass to double-pass and triple-pass welding, leading to an improved fatigue life. Therefore, multi-pass welding in different directions should be adopted [91].

Extensive research on longitudinal residual stress distribution in T-type welded connections subjected to various factors like hot rolling, flame cutting, pre-stressing, and welding revealed stress peaks near welds that often exceeded the yield strength of the base material [87]. To mitigate deformation during welding, selecting filler metal with mechanical properties similar to the base material, particularly in terms of yield strength, is essential [92]. Furthermore, residual welding stress

has a significant impact on the flexural stiffness of welded hollow spherical connections, reducing it by over 10 %. However, its influence on ultimate flexural capacity is minimal [93].

The hindrance of adjacent base metals to the contraction of welded metal introduces inevitable residual stresses and deformations to welded components. However, the proper selection of welding processes can mitigate the extent of tensile residual stresses and deformations. The degree of external constraint also significantly affects the distribution of residual stresses and the magnitude of deformations [94]. Due to metallurgical and mechanical melting effects, the initial residual stresses in the welding zone are entirely eliminated, having no impact on residual welding stresses [95]. Furthermore, post-production hot-dip galvanization alters the magnitude and distribution of residual stresses in the components, influencing their axial compression and bending performance [96].

4.1.3 Fracture defect in welded connection

Researchers have also conducted investigations into fracture defects caused by welding at connections. Matos simulated welding of the lower flange of beam-to-column connections, considering parameters such as the arrangement of stiffeners, root pass width, and semi-elliptical cracks. Their proposed calculation method for J-integral stress intensity factors indicated that, prior to applying structural loads, high demands are placed on fracture toughness due to residual stresses. The placement of stiffeners below the weld root significantly reduces these fracture toughness requirements by relocating the weld root pass [97].

During the assembly of steel structures, unacceptable welding defects might be encountered. When local grinding and re-welding are performed on the welds, an increase in transverse residual stresses within the welded metal and heat-affected zone is observed with increased lateral constraint strength, where it can potentially lead to cracking [98].

In 2023, Ke *et al.*, [99] conducted experimental and probabilistic studies on the fatigue crack growth behaviour of Q345qC steel by considering the stress ratio effects and the dispersion of fatigue test results. It was found that hot-rolled steel plates often exhibit anisotropy, which also manifests in their fatigue crack growth behaviour. As the load ratio increases, longitudinal cracks propagate faster compared to transverse cracks [100-101]. Additionally, initial cracks accelerate local buckling, altering the load-carrying capacity and deformation capability of components [102-103].

Based on these outcomes, it is evident that in beam-to-column rigid connections, damage concentration and fracture occur in the vicinity of the welding holes in the beam flange. It is essential to control the structural requirements around the welds, and the addition of stiffeners at the welding holes may potentially reduce the concentration of damage and fracture in the connection [81]. Additionally, the ductility against bottom flange fracture can be improved by welds at the bottom and tail of the stiffener [104].

In another study, Song *et al.*, [105] investigated the low-cycle fatigue crack growth behaviour of steel from the perspective of crack opening displacement. They considered accumulated strain, crack initiation displacement, and changes in crack growth life, ultimately proposing a simplified method for calculating crack growth rate. In addition to that, Wang and Qian [106] studied the welding residual stress and relaxation in both surface and thickness directions of fillet welds under fatigue loading. Residual stress and its relaxation can affect the stress ratio but do not alter the cyclic stress range.

4.1.4 Effect of corrosion on the steel connections

Corrosion significantly diminishes the fatigue resistance of steel structures due to the localized stress concentration and material embrittlement caused by pitting corrosion. Corrosion also exerts substantial influence on the welding geometries. The fatigue strength of welds depends not only on geometric shapes and their corrosion degradation, but to a larger extent on the residual stresses after corrosion [107]. Similarly, corrosion detrimentally impacts steel structural connections. The hysteresis loop of rusted beam-to-column connections tends to be wider, indicating more energy dissipation, but this also comes with a noticeable decrease in the stiffness during loading and unloading, as well as in the total energy absorbed, and the number of cycles the connection can endure before failure. [108]. The corrosion fatigue performance of steel is also influenced by multiple factors such as maximum applied load, loading frequency, and stress ratio [109]. In seawater environments, the initiation and initial propagation mechanisms of corrosion fatigue cracks alter with increasing peak stress levels [110].

The summary of this review on the welded connections is as summarized in Table 1. Initial defects in welds within connections encompass initial cracks, residual stress, residual deformation, and stress concentration. These factors will diminish the seismic performance and fatigue strength of the connection. Sufficient attention should be given to these aspects during the design of the connection.

Table 1
 Summary of Previous Research in the Welded Steel Connection

Author	Steel Profile	Outcome
Zuo <i>et al.</i> , 2019 [80]	H - beam to H - column	Defects in the welded connection showed a weakening development after earthquake.
Liao <i>et al.</i> , 2022 [82]	H - beam to H - column	Initial defect location, initial defect length, initial notch radius, and welding hole shape affect the fracture index.
Park <i>et al.</i> , 2023 [86]	H - beam to H - column	Welding residual stresses affect fatigue strength, fracture strength and buckling strength.
Wang & Qian, 2022 [106]	H - beam to H - column	Residual stress and its relaxation will affect the fatigue stress ratio.
Raftar <i>et al.</i> , 2023 [89]	H - beam to Box - column	Welding deformation and residual stress characteristics of cruciform fillet weld connections.
Pan <i>et al.</i> , 2017 [83]	Box - beam to Box - column	Welding residual stress can cause premature failure of the connection.

4.2 Initial Defects in Bolts Connection

The main initial defects in bolted end plate connections often arise from discrepancies in the thickness of the end plate and column flange. Considering the influence of these initial defects, such connections are usually characterized as semi-rigid. The thickness of the end plate significantly affects the safety of steel structure, for example steel gabled frames [111]. A study by Abdallah *et al.*, presented the effect of various gap angles as the initial defects in the bolted connection to the reduction of bearing capacity and stiffness of the connection [112]. Gil *et al.*, [113] also conducted a study on bolted connections with double extended end plates, taking into account initial defects, to capture potential buckling failure modes in the column web and beam flange regions.

4.2.1 Fatigue strength of bolt connection

The fatigue strength of bolted connections increases with the strength of the steel material. The pre-tensioning of bolts reduces stress concentration around the hole, preventing the formation of fatigue cracks at the net section. As the number of fatigue cycles increases, damage accumulates, leading to a reduction in effective bearing area and capacity, eventually resulting in sudden fracture. Apart from steel strength and stress concentration, factors such as loading stress amplitude, bolt arrangement, pre-tension force, bolt diameter, bolt hole diameter, and surface treatment also affect the fatigue strength of bolts [114]. Frictional fatigue damage on contact surfaces significantly diminishes the fatigue life of high-strength bolt connections under cyclic loads. Therefore, a numerical model has been proposed to estimate frictional fatigue damage under high-cycle conditions by considering the pre-stressing effect and contact characteristics of bolted overlapping connections [115].

4.2.2 Fracture damage in bolt connection

Fatigue fracture typically occurs at the first threaded connection between the bolt and nut. At low stress levels, the contact pressure formed by end plate compression reduces the fatigue life of the bolt [116]. Corrosion also affects the non-contact surfaces of bolt connections. Corrosive environments have a significant impact on slip loads, slip coefficients, and bolt pre-tension forces in bolted connections [117].

Cracking damage in stiffeners can affect their failure mode and stress distribution, leading to a reduction in their ultimate strength. The decrease in ultimate strength increases with the growth of crack length [118-119]. In bolted connections of steel gabled frames, stiffeners are commonly employed at beam-to-column connections. If the length of stiffeners attached to the column web is insufficient, it affects the shear resistance of the web but has less impact to the other parts of the connection [120].

The summary of this review on the bolted connections is as summarized in Table 2. Initial defects in bolts primarily encompass bolt over-tensioning, geometric deviations of the plate components, and corrosion. These factors will impact the bearing capacity, fatigue performance, and ductility of bolted connections. Attention should also be directed towards these aspects during the design of the connection.

Table 2
 Summary of Previous Research in the Bolted Steel Connection

Author	Steel Profile	Outcome
Duan <i>et al.</i> , 2011 [111]	H – beam to H – column	The thickness of the end plate significantly affects the safety of steel gabled structures.
Guo <i>et al.</i> , 2019 [114]	H - beam to H - column	Load stress amplitude, bolt arrangement, bolt preload force, bolt diameter, hole diameter, and surface treatment all affect the fatigue strength of bolts.
Venugopal Poovakaud <i>et al.</i> , 2020 [115]	H - beam to H - column	Contact surface friction fatigue damage significantly reduces the fatigue life of the connection.
Nie <i>et al.</i> , 2023 [117]	H – beam to H - column	Corrosive environments significantly reduce the slip load, coefficient of friction, and bolt preload of bolted connections.
Kövesdi <i>et al.</i> , 2023 [120]	H – beam to H - column	The insufficient length of the flange stiffener only affects the shear performance of the flange plate.
Zhang <i>et al.</i> , 2023 [116]	Box - beam to H - column	Contact pressure formed by end plate compression reduces the bolt fatigue life.

4. Damage Mechanism

4.1 Damage Mechanism in Welded Connection

For H-profile beam-to-column connection that is welded on both strong and weak axes, the predominant damage model is characterized by continuity plate crippling, local buckling of flanges and webs, and weld cracking at the edge of the continuity plate and the flange slope [25], [42]. The mechanisms are illustrated in Figure 4.

In contrast, traditional H-profile beam and box-profile column bolt-welded connections typically experience tension failure of the beam end flange plate. Small cracks appear at the top of the end plate or the toe of the beam weld (weld hole), and these cracks gradually propagate and connect as the load cycles, ultimately leading to tension failure. Local buckling also occurs in the upper and lower flange plates and the web of the beam [48,62].

However, in the novel connection proposed by Serrano-López *et al.*, [60] for H-profile steel beams and box-profile columns, the primary damage model is characterized by shear punching failure around the front face of the box at the end of the bolt and tensile fracture of the welded bolt. This indicates insufficient shearing capacity at the column connection and inadequate tensile capacity of the welded bolt [60].



Fig. 4. Damage Model of H-profile of Beam-to-column Connection[25]

For strengthened cover plate beam-to-column connections, four primary damage models are identified: (i) full-penetration weld fractures between the flange (especially the bottom) and the column flange; (ii) weld fractures between the continuous plate and the column; (iii) local weld fractures between the column flange and the web in the connection region; and (iv) local fractures of the column flange [16,22]. Additionally, the hysteresis damage index for connections using beam flange reinforced cover plates and beam web weakening can be determined using Eq. (1) [19].

$$D = \int_0^t d\theta / \theta_{e,a} \quad (1)$$

where $\int_0^t d\theta$ represents the cumulative plastic rotation deformation experienced by the steel connection from the beginning to time t , and $\theta_{e,a}$ represents the average elastic rotation angle of the steel connection.

The damage model for fillet welds varies by their position: transverse fillet welds primarily suffer from overall fractures, whereas longitudinal fillet welds show both local and overall cracking [90]. In welded cruciform beam-to-column connections, damage typically occurs as fractures in the base material of the beam flange or the welded material near the weld hole. Nevertheless, this ductility

issue can be mitigated by modifying the weld hole shape [121]. The summary of this review on the welded connections is as summarized in Table 3.

Table 3
 Summary of Previous Research in the Welded Beam Column Connection

Author	Steel Profile	Outcome
Somarriba <i>et al.</i> , 2022 [25]	H - beam to H - column	The main failure modes are continuous plate failure, local buckling of the beam, and cracking of the flange weld.
X. Chen & Shi, 2019 [22]	H - beam to H - beam	The failure modes of strengthened beam-column connections with cover plates include four types.
Y. Y. Chen & Chen, 2022 [90]	H – beam to H - beam	The failure modes of longitudinal and transverse angle welds are different.
Liao, Li, <i>et al.</i> , 2022 [121]	H – beam to H - beam	The failure mode of welded cruciform beam-to-column connections is the fracture of the beam flange weld.
Abdolwahab <i>et al.</i> , 2022 [48]	H – beam to Box - column	The failure mode includes tension failure of the beam flange plate, cracking of the weld, and local buckling of the beam.

4.2 Damage Mechanism in Bolted Connection

In bolted connections, different damage models include shear failure of bolts, shear failure of plates, bearing failure of bolts, bearing or crushing of plates (end failure), failure due to excessive tensile stretching of bolts, and tearing of plates [45], [64]. These damage models are illustrated in Figure 5. In the following review, the damage mechanism of bolted connections is further explored.

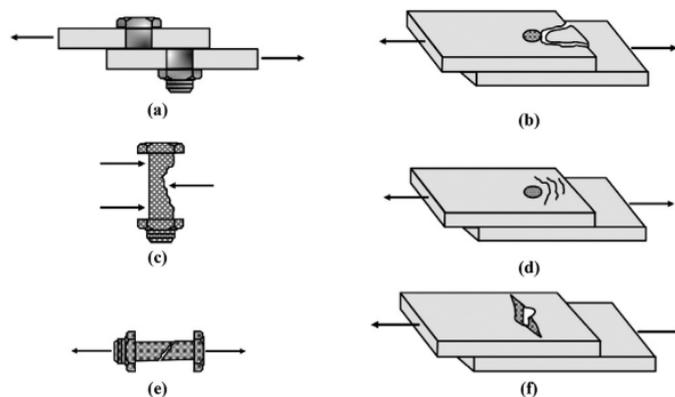


Fig. 5. Damage Models of Bolt Connection[45]

4.2.1 Failure in end plate connections

In traditional end plate connections without column stiffeners, yielding predominantly occurs in the column flange and end plate, significantly impacting connection performance due to the beam's flexural strength being twice that of the column. These connections are best categorized as semi-rigid connections [34]. When sufficient stiffness is present in the column connection region, the connection will experience beam flange buckling and bolt failure until it fails. For connections with a reduced beam section, initial cracking will occur at the reduced flange's section, and widespread cracking will happen at the flange and web until it fails. Cover plate connections with reduced beam sections also exhibit a similar damage model to reduced beam sections, culminating in the formation of an outward plastic hinge [15,36,52,122].

For H-profile beams and box-profile columns with optimized end plate bolted connections, the predominant damage model, applicable under both unidirectional and bidirectional loads, is

characterized by ductile failure due to beam yielding [53,54]. In inclined end plate beam-to-column connections, damage typically begins at the stiffeners, progressing to the end plate and column flange [35]. Meanwhile, weak-axis welded beam-to-column connections featuring end plates often suffer from local buckling of the column flange, beam flange buckling, and fractures at the welding joints [28].

In bolted angle beam-to-column connections, adding stiffeners alters the buckling behaviour of the stiffeners from single-wave to multi-wave patterns and shifts the primary damage from fracturing of the angle steel to fracturing of the stiffeners. Buckling of stiffeners, induced by these additional components, specifically occurs with edge stiffeners, with the position of stiffeners also significantly affecting the overall damage of the connection [29].

4.2.2 Failure in the beam-to-column connections

In cantilever beam spliced beam-to-column connections, the failure often occurs at the weld of the beam-to-column connection earlier than the bolted connection at the splice region. These spliced connections demonstrate enhanced energy dissipation and facilitate the formation of plastic hinges in the splice region, thus enabling the design of semi-rigid connections [41].

When it comes to weak-axis bolted connections in beam-to-column joints, the prevalent damage model involves shear failure of either the flange or the connection plate [24]. In contrast, bolted angle steel semi-rigid beam-to-column connections primarily experience damage through angle leg fractures, column leg fractures, bolt fractures, and net section fractures at the angle-column bolt locations [31].

For H-profile beams connected to box-profile columns using ribbed angles and connecting plates, as outlined by Yang *et al.*, [57], the main damage models include local buckling of steel tubes, cracking of double L-type connection welds, fracture of high-strength bolts, and bending buckling of H-profile beams [57]. Additionally, in semi-rigid beam-to-column connections featuring T-stubs components, the observed damage models encompass bolt fracture, yielding of the end plate, and partial yielding of the column flange [123]. Kalash and Hantouche [123] employed two ductile damage models in ABAQUS, namely SMCS and Hooputra models, to simulate ductile failures in bolted connections and validated their effectiveness particularly in scenarios involving double T-stubs and extended end plate connections [123].

4.2.3 Failure in the bolted lap connection

In steel structures with friction-type connections, single lap connections exhibit notably lower fatigue strength compared to double lap connections. The fatigue behaviour of single lap connections is influenced by the number of bolts, steel grade, and the hole-making process. Conversely, the fatigue behaviour of double lap connections is predominantly affected by bolt preload, slip coefficient, main plate thickness, steel grade, and the hole-making process [124]. The presence of preload on bolts would reduce the tensile stress concentration at hole edges. This reduction in stress concentration facilitates the onset of fatigue cracks at the hole's leading edge. Consequently, failures in bolt connections typically originate at the first row of bolt holes, with fatigue cracks progressively extending along the front main plate of bolt hole [114,125].

The damage model of high-strength bolts in an oversized or super-tensioned configuration is characterized by typical bolt shear failure, accompanied by deformation of the cover plate and compression deformation of the bolt holes. Increasing the number of super-tensioned bolts and their preload can enhance the resistance to sliding capacity. The ductility of the connection is inversely

proportional to the number of bolts and preload. However, factors like plate thickness and the position of super-tensioned bolts do not significantly affect the resistance to sliding capacity. The shear ultimate bearing capacity of a group of high-strength bolts in a super-tensioned configuration remains relatively unchanged [126].

For the bolted connections in transmission tower L-profile angle steel legs, the primary damage models are tensile fracture caused by inadequate strength of the angle steel and shear failure of the end bolts [72]. As for lap bolted connections, under compression loading, the damage model involves the bearing failure of the angle steel members and splice plates, without any bolts being sheared [65]. The damage model of K-type connections in transmission towers is influenced by bolt grade and component strength. The most critical loading scenario is when one side is under tension and the other side is under compression, resulting in a torsional shear state of the connection [76]. Furthermore, the slip characteristics of galvanized bolted connections consist of three regions: elastic, sliding, and shear elastic regions [70].

In transmission tower with L-profile angle steel legs, the primary damage models for bolted connections include tensile fractures due to inadequate strength of angle steel and shear failure at the end bolts [72]. For lap bolted connections under compression loading, damage typically occurs as bearing failure in the angle steel members and splice plates, with bolts remaining intact [65]. K-type connections in transmission towers face a unique challenge when one side is under tension and the other under compression, leading to a torsional shear state that significantly affects the connection [76]. In addition to that, galvanized bolted connections also often experience slip incident that are generally categorized into three distinct regions: elastic, sliding, and shear elastic [70], each influencing the connection's performance under stress. The summary of this review on the bolted connections is as summarized in Table 4.

Table 4
 Summary of Previous Research in the Bolted Steel Connection

Author	Steel Profile	Outcome
Cai <i>et al.</i> , 2022 [52]	H - beam to H - column	Connection experiences beam flange buckling, bolt failure, until connection failure.
Miryahyavi <i>et al.</i> , 2023 [35]	H – beam to H - column	Damage initiates from the stiffeners and extends to end plate and column flange.
Jiang <i>et al.</i> , 2023 [124]	H – beam to H - column	Fatigue is significantly influenced by bolt preload, slip coefficient, plate thickness, steel grade, and hole-making process.
Zhang <i>et al.</i> , 2023 [126]	H – beam to H - column	The failure mode of high-strength bolts under tension is typically characterized by shear failure of the bolt.
An <i>et al.</i> , 2019 [72]	L – beam to L - column	Damage models are tensile fracture caused by inadequate strength of angle steel and shear failure of the end bolts.
J. X. Li <i>et al.</i> , 2021 [76]	L – beam to L - column	Failure mode of the K-type connection is related to the bolt grade and component strength.

5. Future Work

Future research in the field of steel connection should broaden its scope to encompass various profiles of steel components commonly utilized in the construction of buildings and infrastructure, such as H-profile, box-profile, and L-profile, especially when these components are subjected to seismic loads. It is crucial to account for common initial defects, including initial cracks, welding residual stresses, bolt loosening, and manufacturing imperfections. An area of significant interest is the investigation of the effects of varying intensity levels of seismic forces directly impacting the connections. This exploration should meticulously examine key aspects such as bearing capacity,

ductility, stiffness, energy dissipation capacity, and damage models associated with these connections. The findings from such research are anticipated to be instrumental in refining and enhancing existing design codes related to steel structure connections, contributing to the advancement of structural engineering practices and the construction of safer, more resilient infrastructures within the broader scientific community.

6. Conclusion

The rapid economic growth, supported by governmental policies, is leading to an escalation of steel structures within the construction sector. As a result, the seismic performance of steel structure connections is becoming increasingly critical. This study has conducted a comprehensive review of various steel component connection configurations, examining advancements in their seismic performance, particularly in terms of bearing capacity, stiffness, and ductility. It also evaluated potential initial defects in connections, such as initial cracks, welding residual stresses, manufacturing imperfections, and stress concentrations. Additionally, it has reviewed various damage models related to connections, including weld fractures, bolt failures, and local plate buckling.

However, most research to date has focused on monotonic and cyclic loading scenarios, with limited studies exploring seismic performance of connections under actual seismic loading. Addressing this gap, future research efforts should aim to investigate the seismic response and damage models of connections under seismic loading, considering the initial defects present in these connections. This research direction is expected to greatly enhance the design of steel structure connections, improving safety during seismic events.

Acknowledgement

This research was supported by the Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS) (FRGS/1/2022/TK01/UTHM/02/4).

References

- [1] X. N. Agency, "Outline of the Fourteenth Five-Year Plan for the National Economic and Social Development of the People's Republic of China and the Visionary Goals for 2035."
- [2] Eguchi, Ronald T., James D. Goltz, Craig E. Taylor, Stephanie E. Chang, Paul J. Flores, Laurie A. Johnson, Hope A. Seligson, and Neil C. Blais. "Direct economic losses in the Northridge earthquake: A three-year post-event perspective." *Earthquake Spectra* 14, no. 2 (1998): 245-264. <https://doi.org/10.1193/1.1585998>
- [3] Horikawa, Kousuke, and Yoshihiro Sakino. "Damages to steel structures caused by the 1995 Kobe earthquake." *Structural engineering international* 6, no. 3 (1996): 181-182. <https://doi.org/10.2749/101686696780495617>
- [4] Ye, Shanshan, Guofang Zhai, and Jiyuan Hu. "Damages and lessons from the Wenchuan earthquake in China." *Human and Ecological Risk Assessment* 17, no. 3 (2011): 598-612. <https://doi.org/10.1080/10807039.2011.571086>
- [5] Gould, P. L., B. J. Goodno, N. C. Gould, and P. Caldwell. "Behavior of engineer constructed facilities in the Haitian earthquake of January 12, 2010." *Procedia engineering* 14 (2011): 23-31. <https://doi.org/10.1016/j.proeng.2011.07.003>
- [6] LHalder, Lipika, Sekhar Chandra Dutta, Richi Prasad Sharma, and Subhamoy Bhattacharya. "Lessons learnt from post-earthquake damage study of Northeast India and Nepal during last ten years: 2021 Assam earthquake, 2020 Mizoram earthquake, 2017 Ambasa earthquake, 2016 Manipur earthquake, 2015 Nepal earthquake, and 2011 Sikkim earthquake." *Soil Dynamics and Earthquake Engineering* 151 (2021): 106990. <https://doi.org/10.1016/j.soildyn.2021.106990>
- [7] Naik, Sambit Prasanajit, Asmita Mohanty, Valkaniotis Sotiris, Himanshu Mittal, Sabina Porfido, Alessandro Maria Michetti, Ohsang Gwon et al. "28th September 2018 Mw 7.5 Sulawesi Supershear Earthquake, Indonesia: Ground effects and macroseismic intensity estimation using ESI-2007 scale." *Engineering Geology* 317 (2023): 107054. <https://doi.org/10.1016/j.enggeo.2023.107054>

- [8] AFAD, "Disaster and emergency management authority–Turkish earthquake data center system," 2023.
- [9] Vamvatsikos, Dimitrios, and C. Allin Cornell. "Incremental dynamic analysis." *Earthquake engineering & structural dynamics* 31, no. 3 (2002): 491-514. <https://doi.org/10.1002/eqe.141>
- [10] Calvi, G. Michele, Rui Pinho, Guido Magenes, Julian J. Bommer, L. Fernando Restrepo-Vélez, and Helen Crowley. "Development of seismic vulnerability assessment methodologies over the past 30 years." *ISET journal of Earthquake Technology* 43, no. 3 (2006): 75-104.
- [11] Gabbianelli, Giammaria, Daniele Perrone, and Emanuele Brunesi. "Influence of beam-to-column connections in seismic vulnerability assessment of steel structures." In *COMPADYN 2021-8th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering*. Athens, 2021. <https://doi.org/10.7712/120121.8629.19176>
- [12] Wu, Fahong, Wei Shi, Ping Zhu, and Weibing Ji. "Connection Strength of Bolt End Plate of Steel Structures Under Earthquake Action." *Russian Physics Journal* 64, no. 2 (2021): 323-332. <https://doi.org/10.1007/s11182-021-02332-3>
- [13] Yu, Haoran, and Weibin Li. "Comparison of steel frames with RWS and WFP beam-to-column connections through seismic fragility analysis." *Advances in Structural Engineering* 24, no. 8 (2021): 1583-1598. <https://doi.org/10.1177/1369433220977284>
- [14] Stenecker, Paul, and Lydell Wiebe. "Identifying and selecting critical connections for seismic response of steel moment resisting frames." *Engineering Structures* 242 (2021): 112634. <https://doi.org/10.1016/j.engstruct.2021.112634>
- [15] Li, Jianfen, Yan Wang, Zuojie Zhang, and Ben Mou. "Seismic behavior of steel frames with different joints: Shaking table test and finite element analysis." *Journal of Building Engineering* 70 (2023): 106377, <https://doi.org/10.1016/j.jobe.2023.106377>
- [16] Zhang, Xiaohui, Shansuo Zheng, and Xuran Zhao. "Seismic performance of steel beam-to-column moment connections with different structural forms." *Journal of Constructional Steel Research* 158 (2019): 130-142. <https://doi.org/10.1016/j.jcsr.2019.03.028>
- [17] Erfani, Saeed, Vahid Akrami, and Arash Mohammad-nejad. "Lateral load resisting behavior of steel moment frames with reduced web section (RWS) beams." In *Structures*, vol. 28, pp. 251-265. Elsevier, 2020. <https://doi.org/10.1016/j.istruc.2020.08.060>
- [18] Sepasdar, R., Mo R. Banan, and Ma R. Banan. "A numerical investigation on the effect of panel zones on cyclic lateral capacity of steel moment frames." *Iranian Journal of Science and Technology, Transactions of Civil Engineering* 44 (2020): 439-448. <https://doi.org/10.1007/s40996-019-00274-y>
- [19] Xu, Qiang, Haoran Chen, Wenyang Li, Shansuo Zheng, and Xiaohui Zhang. "Experimental investigation on seismic behavior of steel welded connections considering the influence of structural forms." *Engineering Failure Analysis* 139 (2022): 106499. <https://doi.org/10.1016/j.engfailanal.2022.106499>
- [20] Horton, Thomas Alexander, Iman Hajirasouliha, Buick Davison, and Zuhail Ozdemir. "More efficient design of reduced beam sections (RBS) for maximum seismic performance." *Journal of Constructional Steel Research* 183 (2021): 106728, <https://doi.org/10.1016/j.jcsr.2021.106728>
- [21] Fanaie, Nader, Zahra Nadalipour, Omid Sepasgozar Sarkhosh, and Shervin Safaei Faegh. "Elastic drift amplification factor in steel moment frames with double reduced beam section (DRBS) connections." *Journal of Building Engineering* 43 (2021): 102563. <https://doi.org/10.1016/j.jobe.2021.102563>
- [22] Chen, Xuesen, and Gang Shi. "Cyclic tests on high strength steel flange-plate beam-to-column joints." *Engineering Structures* 186 (2019): 564-581. <https://doi.org/10.1016/j.engstruct.2019.01.093>
- [23] Jazany, Roohollah Ahmady, and Mohammad Soheil Ghobadi. "Seismic evaluation and upgrading details of plate-reinforced moment-resisting connections." *Journal of Constructional Steel Research* 150 (2018): 230-248. <https://doi.org/10.1016/j.jcsr.2018.08.023>
- [24] Lim, Woo-Young, Dongkeun Lee, and Young-Chan You. "Partially restrained beam-column weak-axis moment connections of low-rise steel structures." *Structural Engineering and Mechanics* 76, no. 5 (2020): 663-674. <https://doi.org/10.12989/sem.2020.76.5.663>
- [25] Somarriba, Martin, Taichiro Okazaki, Junxian Zhao, and Kensuke Komatsu. "Cyclic-loading performance of steel beam-to-column moment connections to an I-section column." *Journal of Structural Engineering* 148, no. 4 (2022): 04022025. [https://doi.org/10.1061/\(asce\)st.1943-541x.0003310](https://doi.org/10.1061/(asce)st.1943-541x.0003310)
- [26] Elhout, Emad. "Location of semi-rigid connections effect on the seismic performance of steel frame structures." *Electronic Journal of Structural Engineering* 22, no. 3 (2022): 1-10. <https://doi.org/10.56748/ejse.223113>
- [27] Rigi, Abed, Behtash JavidSharifi, Mohammad Ali Hadianfard, and T. Y. Yang. "Study of the seismic behavior of rigid and semi-rigid steel moment-resisting frames." *Journal of Constructional Steel Research* 186 (2021): 106910. <https://doi.org/10.1016/j.jcsr.2021.106910>

- [28] Peker, Kerem, A. İlker Akgönen, and Nesrin Yardımcı. "Investigation on seismic performance of weak-axis moment connections with European profiles." In *Structures*, vol. 32, pp. 254-267. Elsevier, 2021. <https://doi.org/10.1016/j.istruc.2021.02.047>
- [29] Kang, Lan, and Cheng Zhang. "Cyclic behavior of steel beam-to-column connections with novel strengthened angle components." *Steel and Composite Structures, An International Journal* 42, no. 6 (2022): 791-804.
- [30] Wang, Feiliang, Jian Yang, and Zhufeng Pan. "Progressive collapse behaviour of steel framed substructures with various beam-column connections." *Engineering Failure Analysis* 109 (2020): 104399. <https://doi.org/10.1016/j.engfailanal.2020.104399>
- [31] Béland, Thierry, Cameron R. Bradley, Jessalyn Nelson, Joshua G. Sizemore, Ali Davaran, Robert Tremblay, Eric M. Hines, and Larry A. Fahnestock. "Experimental parametric characterization of bolted angle connection behavior." *Journal of Structural Engineering* 146, no. 8 (2020): 04020160. [https://doi.org/10.1061/\(asce\)st.1943-541x.0002662](https://doi.org/10.1061/(asce)st.1943-541x.0002662)
- [32] Li, Shen, Shihao Ding, Xiaolei Li, Hongchao Guo, and Lin Mu. "Experimental study and mechanical properties of prefabricated beam-column joint with L-shaped stiffeners." *Journal of Constructional Steel Research* 199 (2022): 107627. <https://doi.org/10.1016/j.jcsr.2022.107627>
- [33] Radmehr, Mostafa, and Peyman Homami. "The seismic reliability analysis of moment resisting frames with bolted end-plate connection." *Journal of Constructional Steel Research* 171 (2020): 106134. <https://doi.org/10.1016/j.jcsr.2020.106134>
- [34] Faridmehr, Iman, Mamood Md Tahir, Mohd Hanim Osman, and Mohammadamin Azimi. "Cyclic behaviour of fully-rigid and semi-rigid steel beam-to-column connections." *International Journal of Steel Structures* 20 (2020): 365-385. <https://doi.org/10.1007/s13296-019-00290-8>
- [35] Miryayyavi, Mirreza, Reza Khani, and Yousef Hosseinzadeh. "Evaluating the Cyclic Behavior of the Sloped Extended End-plate Beam-to-column Connections." *Periodica Polytechnica Civil Engineering* 67, no. 2 (2023): 552-560. <https://doi.org/10.3311/PPci.21260>
- [36] Masoudi, Mohammad Javad, and Pooyan Broumand. "Numerical assessment of an enhanced stiffened extended end-plate joint for composite frame structures." *Engineering Structures* 293 (2023): 116599. <https://doi.org/10.1016/j.engstruct.2023.116599>
- [37] Zhandong, Ni. "Research on seismic behavior of beam-column joints of new prefabricated steel structure." In *IOP Conference Series: Earth and Environmental Science*, vol. 560, no. 1, p. 012010. IOP Publishing, 2020. <https://doi.org/10.1088/1755-1315/560/1/012010>
- [38] Bezerra, Luciano M., Jorge Bonilla, Wellington A. Silva, and William T. Matias. "Experimental and numerical studies of bolted T-stub steel connection with different flange thicknesses connected to a rigid base." *Engineering structures* 218 (2020): 110770. <https://doi.org/10.1016/j.engstruct.2020.110770>
- [39] Bezerra, Luciano M., Jorge Bonilla, Cleirton S. Freitas, and Bruno Massicotte. "Behavior of T-stub steel connections bolted to rigid bases." *Journal of Constructional Steel Research* 192 (2022): 107242. <https://doi.org/10.1016/j.jcsr.2022.107242>
- [40] Qiang, Xuhong, Zhiyi Zhang, Xu Jiang, and Meng Wang. "Study on initial stiffness of high strength steel T-stubs considering bending stiffness of bolts." *Journal of Building Engineering* 76 (2023): 107273. <https://doi.org/10.1016/j.jobe.2023.107273>
- [41] L. Jin, Q. Li, and Y. Zhang, "Experimental study on seismic behavior of steel frame structures using cantilever beam splicing as energy dissipater," *Jianzhu Jiegou Xuebao/Journal Build. Struct.*, vol. 43, no. 2, pp. 43–51, 2022, <https://doi.org/10.14006/j.jzjgxb.2019.0760>
- [42] Yu, Yousheng, Aijia Zhang, Wei Pan, Ben Mou, and Xinyu Liu. "Seismic performance of beam-column connections with welded upper flange and bolted lower flange." *Journal of Constructional Steel Research* 182 (2021): 106697. <https://doi.org/10.1016/j.jcsr.2021.106697>
- [43] Gao, Dawei, Jiacheng Gong, Zhongling Tian, and Tengfei Zheng. "Research on bolt pre-tightening and relaxation mechanism under transverse load." *Advances in Mechanical Engineering* 12, no. 12 (2020): 1687814020975919. <https://doi.org/10.1177/1687814020975919>
- [44] Golondrino, Jose Christian Chanchi, Gregory Anthony MacRae, James Geoffrey Chase, Geoffrey William Rodgers, and George Charles Clifton. "Seismic behaviour of symmetric friction connections for steel buildings." *Engineering Structures* 224 (2020): 111200. <https://doi.org/10.1016/j.engstruct.2020.111200>
- [45] Mahmoudi, M., M. Kosari, M. Lorestani, and M. Jalili Sadr Abad. "Effect of contact surface type on the slip resistance in bolted connections." *Journal of Constructional Steel Research* 166 (2020): 105943. <https://doi.org/10.1016/j.jcsr.2020.105943>
- [46] Pawar, Gaurav D., and Vaishali B. Dawari. "Seismic design of bolted beam to column connections in tubular steel structures—A review." *Materials Today: Proceedings* (2023). <https://doi.org/10.1016/j.matpr.2023.03.150>

- [47] Kim, Young-Ju, and Sang-Hoon Oh. "Effect of the moment transfer efficiency of a beam web on deformation capacity at box column-to-H beam connections." *Journal of Constructional Steel Research* 63, no. 1 (2007): 24-36. <https://doi.org/10.1016/j.jcsr.2006.02.009>
- [48] Abdolwahab, Mohamed G., Ahmed H. Yousef, and Ehab H. Ahmed. "Seismic Performance of Tubular Square Column to Stiffened I-Beam." *Sci. Eng. Sci.*, vol. 6, no. January, pp. 94–106, 2022, [Online].
- [49] Ozkula, Gulen, Rupa Garai, Peter Lee, and Chia-Ming Uang. "Cyclic behavior of electroslag welded joints in beam-to-built-up box column steel moment connections." *Journal of Structural Engineering* 145, no. 12 (2019): 04019146. [https://doi.org/10.1061/\(asce\)st.1943-541x.0002409](https://doi.org/10.1061/(asce)st.1943-541x.0002409)
- [50] Ghassemieh, M., M. Hassani Sokhtesaraei, and S. R. Mirghaderi. "The behavior of welded moment connections in box-columns and investigating applied demands for different cyclic loading protocols." *International Journal of Steel Structures* 21, no. 2 (2021): 455-474. <https://doi.org/10.1007/s13296-020-00449-8>
- [51] Chang, Heui-Yung, Chu-Tsen Liao, Sin-Yu Kang, Sih-Yu Ho, and Chi-Ming Lai. "Seismic performance of RWS moment connections to steel box-columns and H-beams with general sections." *Journal of Constructional Steel Research* 201 (2023): 107691. <https://doi.org/10.1016/j.jcsr.2022.107691>
- [52] Cai, Min, Xinyu Liu, Qishuai Wang, Hangping Gu, Peijun Wang, Yuanjian Liu, and Fangzhou Liu. "Seismic performance of thread-fixed one-side bolts bolted extended endplate connection to HSST column with internal strengthening components." *Journal of Building Engineering* 45 (2022): 103615. <https://doi.org/10.1016/j.jobe.2021.103615>
- [53] Nuñez, Eduardo, Roberto Lichtemberg, and Ricardo Herrera. "Cyclic performance of end-plate biaxial moment connection with HSS columns." *Metals* 10, no. 11 (2020): 1556. <https://doi.org/10.3390/met10111556>
- [54] Nuñez-Castellanos, Eduardo, Juan Bustos-Figueroa, Ramón Mata-Lemus, Frank Sanhueza-Espinoza, and Pablo Lapeña-Mañero. "Cyclic behavior of 3D moment connections subjected to bidirectional load: Experimental approach." *Engineering Structures* 291 (2023): 116392. <https://doi.org/10.1016/j.engstruct.2023.116392>
- [55] Gallegos, Marco, Eduardo Nuñez, and Ricardo Herrera. "Numerical study on cyclic response of end-plate biaxial moment connection in box columns." *Metals* 10, no. 4 (2020): 523, <https://doi.org/10.3390/met10040523>
- [56] Derakhshan, H., and B. Shekastehband. "Seismic performance of bolted T-stub Beam-to-Box column connection." In *Structures*, vol. 56, p. 104873. Elsevier, 2023. <https://doi.org/10.1016/j.istruc.2023.104873>
- [57] Yang, Zhaoyuan, Wanlin Cao, Qiyun Qiao, and Jianwei Zhang. "Experimental and numerical study on the prefabricated double L-shaped beam-column joint with triangular stiffener." *Journal of Building Engineering* 69 (2023): 106315. <https://doi.org/10.1016/j.jobe.2023.106315>
- [58] Zhang, Ailin, Zhiqiang Xie, Yanxia Zhang, and Haipeng Lin. "Shaking table test of a prefabricated steel frame structure with all-bolted connections." *Engineering Structures* 248 (2021): 113273. <https://doi.org/10.1016/j.engstruct.2021.113273>
- [59] Chan, Iathong, and Yuji Koetaka. "Numerical model for 3D steel moment frames with H-shaped beams and hollow-section columns under multi-directional seismic ground motions." *Engineering Structures* 246 (2021): 112730. <https://doi.org/10.1016/j.engstruct.2021.112730>
- [60] Serrano-López, Miguel A., Carlos López-Colina, Yong C. Wang, Miguel Lozano, Ismael García, and Fernando L. Gayarre. "An experimental study of I beam-RHS column demountable joints with welded studs." *Journal of Constructional Steel Research* 182 (2021): 106651. <https://doi.org/10.1016/j.jcsr.2021.106651>
- [61] Liu, Xue-Chun, Xiaotong Wu, Yue Wang, and XiaoXiong Cui. "Seismic performance of bolted connection between H-section beam and SST column welded with inclined braces." *Journal of Building Engineering* 61 (2022): 105270. <https://doi.org/10.1016/j.jobe.2022.105270>
- [62] Jian, Wu, and Tong Wei Guang. "Experimental seismic behavior of RHS column-to-I beam connection with additional plates." *Iranian Journal of Science and Technology, Transactions of Civil Engineering* 46, no. 3 (2022): 2053-2065. <https://doi.org/10.1007/s40996-021-00770-0>
- [63] Paghaleh, Fatemeh Jamali, Mohammad Ali Hadianfard, and Hamed Saffari. "Seismic behavior of through beam connection to steel box-column." *Journal of Constructional Steel Research* 193 (2022): 107261. <https://doi.org/10.1016/j.jcsr.2022.107261>
- [64] Ma, Liyang, and Paolo Bocchini. "Hysteretic model of single-bolted angle connections for lattice steel towers." *Journal of Engineering Mechanics* 145, no. 8 (2019): 04019052. [https://doi.org/10.1061/\(asce\)em.1943-7889.0001630](https://doi.org/10.1061/(asce)em.1943-7889.0001630)
- [65] Taha, A. M., M. A. Dabaon, M. H. El-Boghdadi, and M. F. Hassanein. "Experimental testing and evaluation of real-scale lap-splice bolted connections used in typical lattice steel transmission towers." *Thin-Walled Structures* 171 (2022): 108790. <https://doi.org/10.1016/j.tws.2021.108790>
- [66] Deng, Hong-zhou, and Chao Li. "Simplified joint-slippage model of bolted joint in lattice transmission tower." In *Structures*, vol. 32, pp. 1192-1206. Elsevier, 2021. <https://doi.org/10.1016/j.istruc.2021.03.022>

- [67] Balagopal, R., Ananth Ramaswamy, G. S. Palani, and N. Prasad Rao. "Simplified bolted connection model for analysis of transmission line towers." In *Structures*, vol. 27, pp. 2114-2125. Elsevier, 2020. <https://doi.org/10.1016/j.istruc.2020.08.029>
- [68] Li, Jia-Xiang, Jin-Peng Cheng, Chao Zhang, Chun-Xu Qu, Xiao-Hong Zhang, and Wen-Qiang Jiang. "Seismic response study of a steel lattice transmission tower considering the hysteresis characteristics of bolt joint slippage." *Engineering Structures* 281 (2023): 115754. <https://doi.org/10.1016/j.engstruct.2023.115754>
- [69] Zhan, Yang, Benben Li, Zhangjian Wu, Lee S. Cunningham, Gang Wu, and Yaqiang Yang. "Modeling of galvanized lattice steel structures incorporating the effect of joint slip." *Journal of Constructional Steel Research* 173 (2020): 106252. <https://doi.org/10.1016/j.jcsr.2020.106252>
- [70] Li, Benben, and Yang Zhan. "A new joint-slippage model for galvanized steel bolted joints with slippage." In *Structures*, vol. 34, pp. 1034-1047. Elsevier, 2021. <https://doi.org/10.1016/j.istruc.2021.08.032>
- [71] Jiang, Wen-Qiang, Yao-Peng Liu, Siu-Lai Chan, and Zhang-Qi Wang. "Direct analysis of an ultrahigh-voltage lattice transmission tower considering joint effects." *Journal of Structural Engineering* 143, no. 5 (2017): 04017009. [https://doi.org/10.1061/\(asce\)st.1943-541x.0001736](https://doi.org/10.1061/(asce)st.1943-541x.0001736)
- [72] An, Liqiang, Jiong Wu, and Wenqiang Jiang. "Experimental and numerical study of the axial stiffness of bolted joints in steel lattice transmission tower legs." *Engineering Structures* 187 (2019): 490-503. <https://doi.org/10.1016/j.engstruct.2019.02.070>
- [73] Nezamolmolki, Davoud, and Ahmad Shoostari. "The effect of nonlinear behavior of bolted connections on dynamic analysis of steel transmission towers." *International Journal of Steel Structures* 21 (2021): 634-649. <https://doi.org/10.1007/s13296-021-00462-5>
- [74] Abdelrahman, Ahmed Hussain Ali, Yao-Peng Liu, and Siu-Lai Chan. "Advanced joint slip model for single-angle bolted connections considering various effects." *Advances in Structural Engineering* 23, no. 10 (2020): 2121-2135. <https://doi.org/10.1177/1369433220906226>
- [75] Pourshargh, Farshad, Frederic P. Legeron, Sébastien Langlois, and Kahina Sad Saoud. "A simple method for a reliable modelling of the nonlinear behaviour of bolted connections in steel lattice towers." *Advanced Steel Construction* 18, no. 1 (2022): 479-487. <https://doi.org/10.18057/IJASC.2022.18.1.6>
- [76] Li, Jia-xiang, Chao Zhang, Shu-hong Wang, and Sheng-qiang Yin. "Numerical Study on the Mechanical Properties of Transmission Tower K-Joints under Cyclic Loading." *Shock and Vibration* 2021, no. 1 (2021): 7403365. <https://doi.org/10.1155/2021/7403365>
- [77] Yang, Fengli, Binrong Zhu, and Zheng Li. "Numerical analysis and full-scale experiment on K-joint deformations in the crank arms of lattice transmission towers." *The Structural Design of Tall and Special Buildings* 27, no. 5 (2018): e1448. <https://doi.org/10.1002/tal.1448>
- [78] Ma, Ruijun, Liang Yu, Huihong Zhang, Lei Tan, Ahmad BH Kueh, Jian Feng, and Jianguo Cai. "Experimental and numerical appraisal of steel joints integrated with single-and double-angles for transmission line towers." *Thin-Walled Structures* 164 (2021): 107833. <https://doi.org/10.1016/j.tws.2021.107833>
- [79] Liu, Xinpei, Mark Bradford, and Jia Wang. "Load-slip behaviour of single-leg bolted angle steel connections at elevated temperatures." In *Structures*, vol. 43, pp. 1018-1041. Elsevier, 2022. <https://doi.org/10.1016/j.istruc.2022.07.014>
- [80] Zuo, Yuan, Weibin Li, and Menglu Li. "Seismic fragility analysis of steel frame structures containing initial flaws in beam-column connections." *International Journal of Steel Structures* 19 (2019): 504-516.
- [81] Tapia-Hernández, Edgar, Alejandro Santiago-Flores, and Héctor Guerrero-Bobadilla. "Performance of seismic steel beam-column moment joints." *Bulletin of Earthquake Engineering* 20, no. 12 (2022): 6741-6761. <https://doi.org/10.1007/s10518-022-01456-2>
- [82] Liao, Fangfang, Kaoshi Zhang, Wei Wang, Yiyi Chen, Shukai Tang, Xiao Xue, and Chao Li. "Fracture analysis of high-strength steel beam-column connections with initial defects." *Journal of Constructional Steel Research* 194 (2022): 107301. <https://doi.org/10.1016/j.jcsr.2022.107301>
- [83] Pan, Jianrong, Shizhe Chen, Zhichao Lai, Zhan Wang, Junqi Wang, and Huashen Xie. "Analysis and fracture behavior of welded box beam-to-column connections considering residual stresses." *Construction and Building Materials* 154 (2017): 557-566. <https://doi.org/10.1016/j.conbuildmat.2017.07.228>
- [84] Zhou, Z. G., M. M. Chen, and C. Z. Ma. "Stress-strain states of welded beam-to-column connections with geometrical and metallurgical notches." *Journal of Constructional Steel Research* 167 (2020): 105745. <https://doi.org/10.1016/j.jcsr.2019.105745>
- [85] Jin, Dengyiding, Chao Hou, and Luming Shen. "Effect of welding residual stress on the performance of CFST tubular joints." *Journal of Constructional Steel Research* 184 (2021): 106827. <https://doi.org/10.1016/j.jcsr.2021.106827>
- [86] Park, Jeongung, Gyubaek An, Ninshu Ma, and Seong-Joon Kim. "Prediction of transverse welding residual stress considering transverse and bending constraints in butt welding." *Journal of Manufacturing Processes* 102 (2023): 182-194. <https://doi.org/10.1016/j.jmapro.2023.07.043>

- [87] Kollár, D., I. Völgyi, and A. L. Joó. "Assessment of residual stresses in welded T-joints using contour method." *Thin-Walled Structures* 190 (2023): 110966. <https://doi.org/10.1016/j.tws.2023.110966>
- [88] Zhang, Yuelin, Xuchen Liu, Yi Zhou, and Yanlong Shi. "Influence of welding method on residual stress and metallography of a mild steel welded butt-joint plate." *Journal of Constructional Steel Research* 199 (2022): 107640. <https://doi.org/10.1016/j.jcsr.2022.107640>
- [89] Raftar, Hamidreza Rohani, Antti Ahola, Kalle Lipiäinen, and Timo Björk. "Simulation and experiment on residual stress and deflection of cruciform welded joints." *Journal of Constructional Steel Research* 208 (2023): 108023. <https://doi.org/10.1016/j.jcsr.2023.108023>
- [90] Chen, Yang-Yi, and Yu Chen. "Residual shearing strength of fillet weld connections after exposure to elevated temperature." *Journal of Constructional Steel Research* 188 (2022): 107049. <https://doi.org/10.1016/j.jcsr.2021.107049>
- [91] Samadi, Farzaneh, Jeetendra Mourya, Greg Wheatley, Mohammed Nizam Khan, Reza Masoudi Nejad, Ricardo Branco, and Wojciech Macek. "An investigation on residual stress and fatigue life assessment of T-shape welded joints." *Engineering Failure Analysis* 141 (2022): 106685. <https://doi.org/10.1016/j.engfailanal.2022.106685>
- [92] Khatib, Hamza. "Numerical analysis of the residual stress state and distortions generated by autogenous welding and shielded metal arc welding (SMAW)." *Materials Today: Proceedings* (2023). <https://doi.org/10.1016/j.matpr.2023.08.015>
- [93] Yan, Renzhang, Ziyang Yu, Shuai Wang, and Jiaqi Liu. "Influence of welding residual stress on bending resistance of hollow spherical joints." *Journal of Constructional Steel Research* 208 (2023): 108004. <https://doi.org/10.1016/j.jcsr.2023.108004>
- [94] Pavan, A. R., B. Arivazhagan, M. Vasudevan, and Govind Kumar Sharma. "Numerical simulation and validation of residual stresses and distortion in type 316L (N) stainless steel weld joints fabricated by advanced welding techniques." *CIRP Journal of Manufacturing Science and Technology* 39 (2022): 294-307. <https://doi.org/10.1016/j.cirpj.2022.08.010>
- [95] Sun, Jiamin, and Klaus Dilger. "Influence of initial residual stresses on welding residual stresses in ultra-high strength steel S960." *Journal of Manufacturing Processes* 101 (2023): 259-268. <https://doi.org/10.1016/j.jmapro.2023.06.011>
- [96] Jin, Ye, Min Sun, Kian Karimi, Ali Ziaeinejad, Kamran Tayyebi, and Michael Flores. "Effects of galvanizing on residual stresses and stress concentrations in RHS X-and T-Connections." *Engineering Structures* 284 (2023): 115984. <https://doi.org/10.1016/j.engstruct.2023.115984>
- [97] Matos, C. G., and R. H. Dodds Jr. "Modeling the effects of residual stresses on defects in welds of steel frame connections." *Engineering Structures* 22, no. 9 (2000): 1103-1120. [https://doi.org/10.1016/S0141-0296\(99\)00055-3](https://doi.org/10.1016/S0141-0296(99)00055-3)
- [98] Amadeus, Becker, Schroepfer Dirk, Kromm Arne, and Kannengiesser Thomas. "Determination of residual stress evolution during repair welding of high-strength steel components." *Forces in mechanics* 6 (2022): 100073. <https://doi.org/10.1016/j.finmec.2022.100073>
- [99] Ke, Lu, Youlin Li, Chuanxi Li, Zheng Feng, Furui Zhu, Longming Liang, and Shuyu Mei. "Experimental and probabilistic study of fatigue crack growth behavior of steel Q345qC under different stress ratios." *Construction and Building Materials* 393 (2023): 131986. <https://doi.org/10.1016/j.conbuildmat.2023.131986>
- [100] Chen, Chun-Jun, Mei-Ni Su, Yu-Hang Wang, and Rong-Hua Zhu. "Experimental investigation on anisotropic fatigue crack growth characteristics of Q420C steel." *Theoretical and Applied Fracture Mechanics* 124 (2023): 103815. <https://doi.org/10.1016/j.tafmec.2023.103815>
- [101] Tan, Hongmei, Xianqi Hu, Die Huang, and Yong Zeng. "Fatigue crack propagation performance of Q690 high-strength steel and butt welds." *Theoretical and Applied Fracture Mechanics* 126 (2023): 103988. <https://doi.org/10.1016/j.tafmec.2023.103988>
- [102] Qiao, Huiyun, Mingfeng Zhang, Zhongcun Liu, Yu Chen, Huasheng Qiu, and Zheng Wang. "Experimental investigation on square steel tubular columns with initial crack defects." In *Structures*, vol. 35, pp. 388-405. Elsevier, 2022. <https://doi.org/10.1016/j.istruc.2021.10.097>
- [103] Wang, Gang, Zhuxuan Li, Tao Chen, Peichen Peng, and Zhigang Xiao. "Numerical study on fatigue behavior and strengthening of steel pipes with a surface crack." *Theoretical and Applied Fracture Mechanics* 127 (2023): 104003. <https://doi.org/10.1016/j.tafmec.2023.104003>
- [104] Chen, Ying, Jingsi Huo, Wensu Chen, Hong Hao, and Ahmed Y. Elghazouli. "Experimental and numerical assessment of welded steel beam-column connections under impact loading." *Journal of Constructional Steel Research* 175 (2020): 106368. <https://doi.org/10.1016/j.jcsr.2020.106368>
- [105] Song, Yuelin, Ping Yang, Tian Xia, Ziya Peng, and Jiping Zhang. "The crack growth rate and crack opening displacement of EH-36 steel under low-cycle fatigue loading." *Ocean Engineering* 280 (2023): 114734. <https://doi.org/10.1016/j.oceaneng.2023.114734>

- [106] Wang, Le, and Xudong Qian. "Welding residual stresses and their relaxation under cyclic loading in welded S550 steel plates." *International Journal of Fatigue* 162 (2022): 106992. <https://doi.org/10.1016/j.ijfatigue.2022.106992>
- [107] Shojai, Sulaiman, Tim Brömer, Elyas Ghafoori, Christian Woitzik, Moritz Braun, Markus Köhler, and Peter Schaumann. "Assessment of corrosion fatigue in welded joints using 3D surface scans, digital image correlation, hardness measurements, and residual stress analysis." *International journal of fatigue* 176 (2023): 107866. <https://doi.org/10.1016/j.ijfatigue.2023.107866>
- [108] Hao, W. A. N. G., X. U. Shanhua, L. I. U. Xiaogang, and W. A. N. G. Youde. "Experimental study on seismic performance of corroded steel frame beam-column connection under salt spray environment." *Journal of Building Structures* 43, no. 3 (2022): 68-80.
- [109] Zhong, Ying, Yongbo Shao, Xudong Gao, Xiafei Luo, and Hongmei Zhu. "Fatigue crack growth of EH36 steel in air and corrosive marine environments." *Journal of Constructional Steel Research* 210 (2023): 108104. <https://doi.org/10.1016/j.jcsr.2023.108104>
- [110] Zhao, Tianliang, Zhiyong Liu, Cuiwei Du, Chunduo Dai, Xiaogang Li, and Bowei Zhang. "Corrosion fatigue crack initiation and initial propagation mechanism of E690 steel in simulated seawater." *Materials science and engineering: A* 708 (2017): 181-192. <https://doi.org/10.1016/j.msea.2017.09.078>
- [111] Duan, H. J., J. C. Zhao, and Z. S. Song. "Effects of initial imperfection of bolted end-plate connections in the reliability of steel portal frames." *Procedia Engineering* 14 (2011): 2164-2171. <https://doi.org/10.1016/j.proeng.2011.07.272>
- [112] Abdallah, Mostafa Nour Eldin M., Emad Salem, Sherif M. Ibrahim, and Abdelrahim K. Dessouki. "Numerical Analysis of Initially Imperfect Pretensioned Bolted Connections." In *IOP Conference Series: Materials Science and Engineering*, vol. 1150, no. 1, p. 012020. IOP Publishing, 2021. <https://doi.org/10.1088/1757-899x/1150/1/012020>
- [113] Gil, Beatriz, Javier Gracia, and Eduardo Bayo. "Axial-moment interaction for 2D extended end plate bolted steel connections. Experimental investigation and assessment of the initial imperfections." *Journal of Building Engineering* 60 (2022): 105134. <https://doi.org/10.1016/j.jobe.2022.105134>
- [114] Guo, Hongchao, Kuanhong Mao, Yunhe Liu, and Gang Liang. "Experimental study on fatigue performance of Q460 and Q690 steel bolted connections." *Thin-Walled Structures* 138 (2019): 243-251. <https://doi.org/10.1016/j.tws.2019.02.011>
- [115] Poovakaud, Vishnu Venugopal, Carlos Jiménez-Peña, Reza Talemi, Sam Coppieters, and Dimitri Debruyne. "Assessment of fretting fatigue in high strength steel bolted connections with simplified Fe modelling techniques." *Tribology International* 143 (2020): 106083. <https://doi.org/10.1016/j.triboint.2019.106083>
- [116] Zhang, Shujia, Zichun Zhou, Guoqing Wang, Liang Zhang, Xuanzhe Ji, and Honggang Lei. "Variable-amplitude fatigue behavior of M30 high-strength bolts in end-plate connection joints." In *Structures*, vol. 56, p. 104903. Elsevier, 2023. <https://doi.org/10.1016/j.istruc.2023.104903>
- [117] Nie, Shidong, Hui Wang, Bo Yang, Zhenghang Cheng, Xiyu Ye, and Zhenye Chen. "Corrosion-induced mechanical properties of shear bolted connections in high-strength weathering steel." *Thin-Walled Structures* 190 (2023): 111013. <https://doi.org/10.1016/j.tws.2023.111013>
- [118] Margaritis, Y., and M. Toullos. "The ultimate and collapse response of cracked stiffened plates subjected to uniaxial compression." *Thin-Walled Structures* 50, no. 1 (2012): 157-173. <https://doi.org/10.1016/j.tws.2011.09.008>
- [119] Cui, Chong, Ping Yang, Chuang Li, and Tian Xia. "Ultimate strength characteristics of cracked stiffened plates subjected to uniaxial compression." *Thin-Walled Structures* 113 (2017): 27-38. <https://doi.org/10.1016/j.tws.2017.01.003>
- [120] Kövesdi, B., László Dunai, H. Pasternak, Z. Li, R. Oly, and P. Márai. "Design of partial height web stiffeners in beam-to-column joints and influence of residual stresses induced by welding." *Results in Engineering* 18 (2023): 101042. <https://doi.org/10.1016/j.rineng.2023.101042>
- [121] Liao, Fangfang, Xiaohong Li, Wei Wang, Yiyi Chen, Tianhua Zhou, Shaofeng Nie, and Gen Li. "Seismic performance study on Q460 high-strength steel welded cruciform beam-column connections." *Journal of Constructional Steel Research* 198 (2022): 107504. <https://doi.org/10.1016/j.jcsr.2022.107504>
- [122] TahamouliRoudsari, Mehrzad, AllahReza Moradi Garoosi, Ali Alipour, Morteza Torkaman, Hossein Moghadam Abrishami, Mehran Rambarzini, Alireza Doudman Koushki, Shahrokh Khodaparast, and Shahab Bonyadirad. "Comparing the seismic performances of shallow beam connections with accordion webs and reduced sections: An experimental study." In *Structures*, vol. 22, pp. 421-434. Elsevier, 2019. <https://doi.org/10.1016/j.istruc.2019.10.014>
- [123] El Kalash, Sana N., and Elie G. Hantouche. "Methodology and Application of Ductile Damage Modeling on Double Tee and Extended Endplate Connections." *Practice Periodical on Structural Design and Construction* 28, no. 2 (2023): 04022075. <https://doi.org/10.1061/ppscfx.sceng-1184>
- [124] Jiang, Chao, Wen Xiong, C. S. Cai, Xiaoyi Zhou, Yichen Zhu, and Yanjie Zhu. "Parametric study on fatigue behavior of steel friction connections in shear." *Journal of Constructional Steel Research* 207 (2023): 107951. <https://doi.org/10.1016/j.jcsr.2023.107951>

- [125] Riedel, T., U. Hähnel, H. Flederer, P. Hübner, and L. Sieber. "Fracture-mechanical crack growth parameters of historical mild steels." *Engineering Fracture Mechanics* 290 (2023): 109517. <https://doi.org/10.1016/j.engfracmech.2023.109517>
- [126] Zhang, Wanpeng, Zhiquan Xing, Zhihan Huang, Yu Chen, Yongbo Shao, Wei Chen, and Quan Lin. "Study on shear behavior of super-tightened high-strength bolted group connections." *Journal of Building Engineering* 76 (2023): 107308. <https://doi.org/10.1016/j.jobbe.2023.107308>
- [127] Wang, Dan, Terh Jing Khoo, and Zhangfei Kan. "Exploring the application of digital data management approach for facility management in Shanghai's high-rise buildings." *Progress in Energy and Environment* (2020): 1-15.