Modern Methods for Modelling Bolted Joints at the Assembly Stage – A Systematic Review

RAFAŁ GRZEJDA
Faculty of Mechanical Engineering and Mechatronics,
West Pomeranian University of Technology in Szczecin,
19 Piastow Ave., 70-310 Szczecin,
POLAND

Abstract: - The main aim of the paper is to catalog ways of modeling bolted joints and introducing bolt preload using the finite element method. The paper presents models of bolted joints published in the current decade (i.e. after 1 January 2021 and up to 10 May 2023) in journals of the world's largest scientific publishers, such as: Elsevier, Springer, and MDPI, among others. Reporting of the systematic review was carried out based on PRISMA guidelines. The databases were searched with the EBSCO multi-search engine for the following keywords: bolted joint model, bolted connection model, preload, and finite element method. Additionally, the search results were narrowed down to peer-reviewed papers from the discipline of engineering and written in English. This yielded 2,712 records for further analysis. After removing duplicates from this group, screening was carried out, based on which 1,476 records were excluded from the study. For the remaining group of reports, an eligibility assessment was performed, after which a further 210 reports were excluded from the study. Finally, 86 papers were included in the review. As a result of their examination, six groups of simplified fastener models currently used in the modeling of bolted joints at the assembly stage were described.

Key-Words: - bolted joints, fastener, FE-modelling, assembly stage, preload

Received: May 23, 2022. Revised: July 24, 2023. Accepted: August 26, 2023. Published: September 27, 2023.

1 Introduction

Modern machines and the assemblies that make them up are consistently built with components that are joined inseparably (mainly by bonding techniques) and separably (using components such as keys, pins, or bolts). Among the most common such connections are bolted and multi-bolted joints, used in a wide range of industries, [1], [2], [3], [4].

The bolted joints practically applied in machine building most often work in two stages. The first of these is the assembly stage, which precedes the operational stage, [5], [6]. The correct performance of a bolted joint is closely linked to the well-designed preload of the bolts forming the joint, [7]. Depending on the type of joint, or the type of machine in which the bolted joint is installed, standards can be used to determine the correct preload and how it should be introduced, [8]. However, the normative recommendations only apply to typical bolted joints and are not comprehensive of all design cases for these joints. Therefore, scholars are still looking for new models of bolted joints and a better way to preload them.

The peculiarity of bolted joints due to the interdependence of the stiffness of their components determines that once applied, the preload in the bolt changes both when subsequent bolts in the system are tightened, [9], and when an external load is applied to the preloaded joint, [10]. This variation can even continue after the bolted joint is relieved, [11], but may be less when preloading is conducted in several passes, [8], [12]. Loss of preload is also affected by multiple reuse of threaded fasteners, [13]. Therefore, it is important to select the preload correctly so that the joint does not lose its load-bearing capacity during operation and remains safe for its users.

Observation of the content of papers on bolted joints shows that they are most often modeled using the finite element method (FEM), and less often using other methods, such as the component method, [14]. This systematic review considers papers on modeling using FEM, which should be recognized as the most popular modeling method in recent years, [15], [16], [17], [18].

2 Methods

The EBSCO multi-search engine for scientific journal databases was used to perform a systematic review of papers published in the current decade (i.e. after 1 January 2021 and up to 10 May 2023).

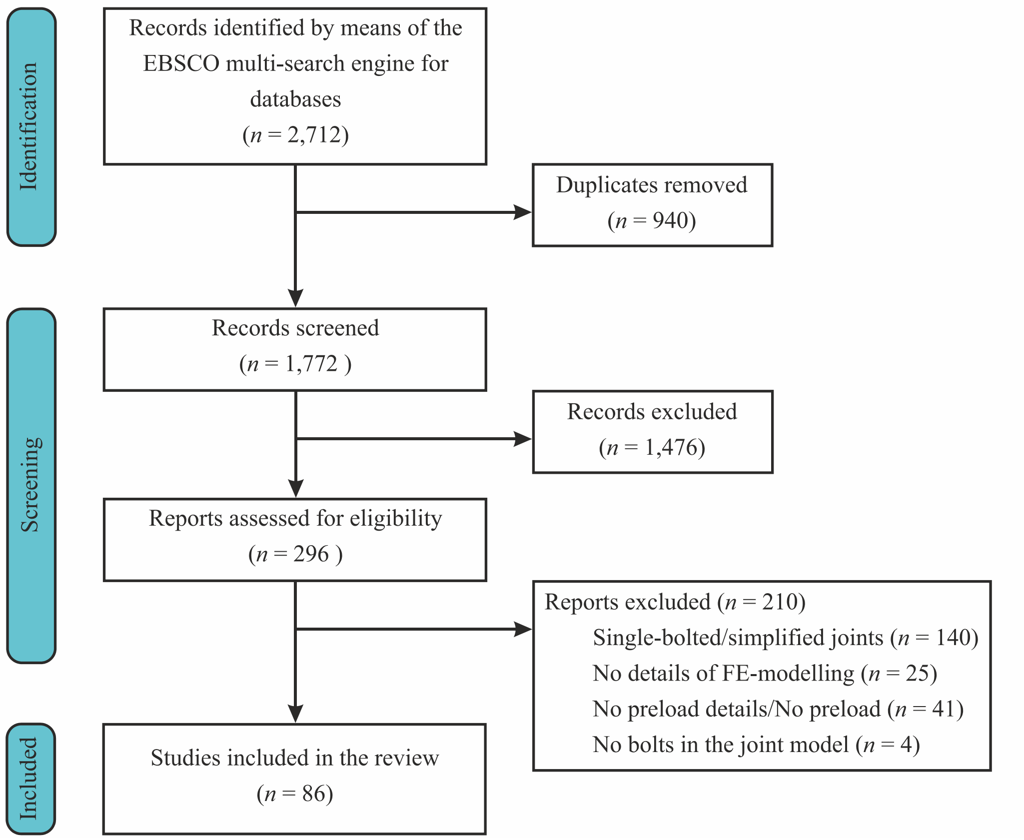

Fig. 1: PRISMA 2020 flow diagram of search strategy results from initial search to included studies.

Using this search engine, it is possible to browse papers released by major global publishers such as: Elsevier, Springer, MDPI, Wiley, SAGE Publications, Taylor & Francis, Emerald Publishing, and many others. To identify the group of articles to perform the study, the databases were searched for the following keywords: bolted joint model, bolted connection model, preload, and finite element method. In addition, the search results were narrowed down by limiting them to peer-reviewed papers from the discipline of engineering and written in English. For the search conditions specified in this way, 2,712 records were obtained for further analysis, which was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, [19]. A flow diagram of this analysis is shown in Figure 1.

In the identification process, 940 duplicate records were removed from the group of records found. Through this, 1,772 records were included in the screening process. After a preliminary analysis of the titles and contents of the papers, 1,476 records were excluded from the identified collection that concerned preprints or were considered ineligible (e.g. were written in English only in part, contained only citations of other papers on bolted joints, did not deal with numerical studies, treated threaded connections or bolts separated from a bolted joint). The reports assessed for eligibility are grouped in Table 1 according to the publisher of the journal in which the report was disseminated to the public.

Table 1. Characteristics of the reports assessed for eligibility

Publisher	Number of reports
Elsevier	137
Springer	64
MDPI	33
Wiley	25
SAGE Publications	8
Others	29
Totally	296

In the process of assessing the reports for eligibility, reports that dealt with single-bolted joints or simplified joints (including primarily: segments cut from full multi-bolted joints, lap joints, and T-stub joints) were excluded from the analysis. In addition, the group of these reports was narrowed down for the following reasons:

- no description of the details of FE-modelling;
- no information on the method of bolt preloading or lack of bolt preloading;
- exclusion of bolts from the joint model.

The studies included in the review are listed in Table 2 according to the publisher of the journal in which the report was publicly disseminated. Finally, the review concerns 86 papers on FE modeling of multi-bolted joints. Most of them deal with experimental verification of the bolted joint models in addition to modeling.

Table 2. Characteristics of the studies included in the review

Publisher	Number of reports
Elsevier	37
Springer	22
MDPI	11
Wiley	5
SAGE Publications	2
Others	9
Totally	86

3 Results and Discussion

In contrast to the case of single-bolted joints, where fastener models are often very detailed, [20], only simplified fastener models are almost always used for multi-bolted joints, with varying degrees of simplification. Such a practice is often justified, as it leads to improved computing performance, [21]. In this section, the ways of FE-modelling of the fasteners, the ways of modeling the material from which they are made, and the ways of modeling the contact connections occurring in a bolted joint, as established by the review, are presented. The vast majority used commercial finite element systems to model the bolted joints, such as Abaqus, ANSYS, and Midas NFX, among others.

3.1 FE-Based Fastener Models

The adoption of a solid fastener model with a cylindrical bolt head and nut in a bolted flange joint model, but including a helical thread outline between them, has only been found in one paper, [22]. Its authors attempted to simulate and predict the local stresses and contact state on the thread between the bolt and nut using such a model. The authors of the other papers used various types of simplification in the modeling of the fasteners.

In the first level of simplification, bolts, and nuts are modeled with equivalent cylinders using solid finite elements, while the effect of the threaded connection is achieved by applying a simplified linkage between the bolt shank and the nut. The coupling and reference point option (available in the software Abaqus) is used for this purpose. A fastener model of this type, adopted as Model A, was implemented in the case of two papers by, [23], [24]. The first variation of Model A is a fastener model consisting of a hexagonal-head bolt and a hexagonal nut connected by tie constraints (an option also available in the Abaqus software, [25]). A second variation of Model A is a fastener model composed of a cylindrical bolt and a cylindrical nut connected as a contact pair (using TARGE170 and CONTA174 elements available in the ANSYS software, [26]).

In the second level of simplification, bolts, and nuts are fused into a single component and are modeled using solid finite elements, retaining the hexagonal shape of the head and nut (if it exists in the model). In this fastener model, referred to as Model B, no threads are taken into account by fusing the bolt and nut. The studies, [27], [28] applied this approach to modeling the preloading process of a multi-bolted flange joint, and, [29], applied it to modeling a flanged sealing structure. Model B was also used by, [30], to calculate the resistance of the bolted joint between the beam and column in a progressive collapse scenario and by, [31], [32], [33], to model different types of beam-to-column end-plate joints. A recent example of the application of Model B is the modeling of a selected thin-walled steel bolted joint described by, [34]. A variation of Model B is a model consisting only of a bolt with a hexagonal head and without a nut. In this model, only the upper part of the bolt comprising the thread run-out (represented by the circular groove) and the bolt shank are included, [35].

In the third level of simplification, bolts, and nuts are fused into a single component and are modeled using three (or much less frequently four) cylindrical solid elements. In this fastener model, referred to as Model C, the threads are also not considered due to the bolt and nut being fused, as mentioned above. This is the most common fastener model used in the studies included in this review and is applied to simulate the behavior of the following bolted joints:

- beam-to-column joints, [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66],

[67], [68], [69], [70], [71], [72], [73], [74], [75], [76];
- lap joints, [77], [78], [79];
- flange joints, [80], [81], [82], [83], [84], [85], [86], [87], [88];
- other types of special connections, such as an aircraft fitting joint, [89], gusset joints, [90], [91], [92], composite truss, [93] and beam joints, [94], [95], [96], [97].

In the fourth level of simplification, fasteners are modeled using finite beam elements. Thus, in these fastener models, named Models D, the threads are not included. The following beam models of fasteners are distinguished:
- models with a flexible stud modeled as a beam and with flexible washers and nuts, and a rigid region established at the end surfaces of the stud and nuts, [98];
- models with a flexible shank modeled as a beam and with a rigid head and a rigid nut, [8], [99], [100];
- CBEAM element (available in the HyperMesh software, [101]).

In the fifth level of simplification, fasteners are modeled using the discrete fastener option (available in the Abaqus software, [102], [103], [104]). Thus, in these fastener models, called Models E, threads are also not considered.

The last group of models referred to as Models F, includes equivalent models in which the behavior of entire preloaded bolted joints is modeled by means of a single beam element, [105], [106].

Among the papers on bolted joint models excluded from the group of studies considered in this review, but included in the group of reports assessed for eligibility, other fastener models are also described, however, in which no preload was applied. These include:
- solid fasteners (such as in Model C), but integrated into the model using the embedded region (available in the Abaqus software, [107]);
- solid elements (cylinders) replacing only the bolt shanks, [108];
- CBUSH element (available in the Nastran software, [109]) that simulates the stiffness of the fastener by defining six directional stiffnesses, i.e. axial stiffness, shear stiffness in planes perpendicular to the fastener axis, and three rotational stiffnesses;
- linear translational SPRING2 element (available in the Abaqus software, [110]).

Depending on the type of fastener model among those mentioned above and the software in which the bolted joint model is executed, different ways of applying bonds to the fastener model are available. It is paramount that contact in the normal and tangential directions is established at the interface between the joined components. As the vast majority of the models from the studies considered in the review were made in the Abaqus software, for example, the modeling of contact connections in this particular software is described in this subsection. In a typical approach, the normal contact of the surfaces of the joined components is set to 'hard contact'. This means that the contact constraint is applied when the separation distance between the two contact surfaces is zero. The tangential contact, on the other hand, is defined by penalty function, with a given penalty factor μ. This indicates that if the contact pressure between the two surfaces is equal to P and then the friction limit between the contact surfaces is equal to μP, when the shear stress at the interface reaches the limit, relative sliding occurs at the contact surface, [111].

3.2 Methods of Preloading Bolted Joints

In general, bolt preloading in a bolted joint model can be done in two ways. It is most commonly realized by appropriately applying a force load to the bolt model, while less commonly it is achieved by introducing a temperature load to the bolt model. The choice between the indicated methods of bolt preloading is strictly determined by the bolt and bolted joint model selected from those cataloged in Section 3.1.

Most often, bolt preloading is carried out simultaneously, with the possibility of loading in two steps. First, the bolts are loaded slightly to establish the contact relationship between various surfaces smoothly, and then the bolts are loaded to the full preload value, [29]. However, on some models, it is possible to apply preloading according to a specific sequence, in one or more passes, [8], [27], [99].

In the case of a bolted joint model based on detailed modeling of the threads on the bolt shank and inside the nut, it is possible to introduce preload by rotating the nut, [22].

In solid fasteners, preload is most often simulated by adding a 'cut surface' at the midpoint of the bolt shank and subjecting it to a tensile load, [67], [73]. It is also possible to apply pressure to the upper and lower surfaces of the fasteners to provide a preloading effect, [30]. Another approach to achieve joint preload is to apply a temperature change to the bolt shank, [46] or to the washer, [97].

In beam fasteners, preload is most often realized by adding a 'pretension' option to the model (in the

Midas NFX software, [100]) or by adding an element (for example, the PRETS179 element available in the ANSYS software, [98]).

In the discrete fastener approach, the displacement and rotation of each fastener point are coupled to the average displacement and rotation of the surface nodes within a certain interaction radius. The preload is modeled by assigning appropriate friction conditions, [104].

4 Conclusion

The paper presents methods for modeling and preloading bolted joints using the finite element method identified in reviewing 86 studies selected according to PRISMA guidelines from papers published in the current decade. It has been shown that the most popular approach is one in which fasteners are modeled with various types of simplification. A list of such models and corresponding preloading methods has been created and is presented in Section 3. It can be very useful for researchers who are modeling bolted joints using the finite element method.

In the vast majority of the papers cited in this review, the joined components in the bolted joint models were replaced by solid finite elements. The exceptions are the model shown in the paper, [109], in which plate elements were used, and the model described in the paper, [34], in which the joined components were modeled by solid elements (near the fasteners) and by shell elements (in the other regions) and the equivalent models in which the behavior of entire preloaded bolted joints was modeled by means of a single beam element, [105], [106]. Consequently, fastener models were used in the bolted joint models, which apply to the joined components treated as solids that can be created using 3D CAD systems, [112], [113]. These primarily include solid and beam models of the fasteners. The fastener models were preloaded depending on the capabilities of the respective software, according to the type of finite elements applied to the fastener modeling. This preloading can be implemented either by imposing a force load or by imposing a temperature load.

References:

[1] P. Palenica, B. Powałka, R. Grzejda, Assessment of modal parameters of a building structure model, *Springer Proceedings in Mathematics & Statistics*, Vol. 181, 2016, pp. 319-325.

[2] S. Duda, O. Dudek, G. Gembalczyk, T. Machoczek, Determination of the kinematic excitation originating from the irregular envelope of an omnidirectional wheel, *Sensors*, Vol. 21, No. 20, 2021, Paper No. 6931.

[3] L. Rakotondrainibe, J. Desai, P. Orval, G. Allaire, Coupled topology optimization of structure and connections for bolted mechanical systems, *European Journal of Mechanics – A/Solids*, Vol. 93, 2022, Paper No. 104499.

[4] E. Nezirić, S. Isić, I. Karabegović, Vibration quantity share of multiple faults with similar frequency spectrum characteristics in rotational machinery, *Periodica Polytechnica Mechanical Engineering*, Vol. 66, No. 3, 2022, pp. 213-218.

[5] R. Grzejda, Modelling nonlinear multi-bolted connections: A case of operational condition, in Proceedings of the 15th International Scientific Conference ‘Engineering for Rural Development 2016’, Jelgava, Latvia, 25-27 May 2016, pp. 336-341.

[6] R. C. Cardoso, B. L. Nascimento, F. de Freitas Thompson, S. Griza, Study of bolted joint axial stiffness using finite element analyses, experimental tests, and analytical calculations, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, Vol. 234, No. 23, 2020, pp. 4671-4681.

[7] R. Grzejda, Modelling nonlinear multi-bolted connections: A case of the assembly condition, in Proceedings of the 15th International Scientific Conference ‘Engineering for Rural Development 2016’, Jelgava, Latvia, 25-27 May 2016, pp. 329-335.

[8] R. Grzejda, M. Warzecha, K. Urbanowicz, Determination of pretension in bolts for structural health monitoring of multi-bolted connection: FEM approach, *Lubricants*, Vol. 10, No. 5, 2022, Paper No. 75.

[9] I. Coria, M. Abasolo, J. Aguirrebeitia, I. Heras, Study of bolt load scatter due to tightening sequence, *International Journal of Pressure Vessels and Piping*, Vol. 182, 2020, Paper No. 104054.

[10] O. M. U. Eraliev, Y.-H. Zhang, K.-H. Lee, C.-H. Lee, Experimental investigation on self-loosening of a bolted joint under cyclical temperature changes, *Advances in*

Mechanical Engineering, Vol. 13, No. 8, 2021, DOI: 10.1177/16878140211039428.

[11] R. Grzejda, A. Parus, K. Kwiatkowski, Experimental studies of an asymmetric multi-bolted connection under monotonic loads, *Materials*, Vol. 14, No. 9, 2021, Paper No. 2353.

[12] R. Grzejda, A. Parus, Health assessment of a multi-bolted connection due to removing selected bolts, *FME Transactions*, Vol. 49, No. 3, 2021, pp. 634-642.

[13] M. Whitelaw, Bolted joint preload decay and the effect of multiple reuse, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, Vol. 237, No. 9, 2023, pp. 2213-2224.

[14] L. Guo, J. Wang, W. Wang, Y. Liu, Experimental and numerical investigation on non-welding CFDST joint for seismic evaluation of moment resisting frame, *Archives of Civil and Mechanical Engineering*, Vol. 21, No. 2, 2021, Paper No. 47.

[15] H. Debski, S. Samborski, P. Rozylo, P. Wysmulski, Stability and load-carrying capacity of thin-walled FRP composite Z-profiles under eccentric compression, *Materials*, Vol. 13, No. 13, 2020, Paper No. 2956.

[16] P. Wysmulski, Load eccentricity of compressed composite Z-columns in non-linear state, *Materials*, Vol. 15, No. 21, 2022, Paper No. 7631.

[17] P. Wysmulski, The effect of load eccentricity on the compressed CFRP Z-shaped columns in the weak post-critical state, *Composite Structures*, Vol. 301, 2022, Paper No. 116184.

[18] P. Wysmulski, Non-linear analysis of the postbuckling behaviour of eccentrically compressed composite channel-section columns, *Composite Structures*, Vol. 305, 2023, Paper No. 116446.

[19] M. J. Page, J. E McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, J. M. Tetzlaff, E. A. Akl, S. E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M. M. Lalu, T. Li, E. W. Loder, E. Mayo-Wilson, S. McDonald, L. A. McGuinness, L. A. Stewart, J. Thomas, A. C. Tricco, V. A. Welch, P. Whiting, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, *BMJ*, Vol. 372, 2021, Paper No. 71.

[20] Z. Zheng, X. Miao, X. Huang, P. Ding, Fastening reliability analysis of bolted joint anti-self-loosening, *Journal of Constructional Steel Research*, Vol. 202, 2023, Paper No. 107776.

[21] L.-H. Han, T.-Y. Song, S. Li, Post-fire seismic performance of concrete-filled steel tubular column to steel beam joints with blind-bolted connections: Experiment and simulation, *Engineering Structures*, Vol. 283, 2023, Paper No. 115892.

[22] W. Sun, Z. Guan, Y. Chen, J. Pan, Y. Zeng, Modeling of preload bolted flange connection structure for loosening analysis and detection, *Shock and Vibration*, Vol. 2022, 2022, Paper No. 7844875.

[23] D. Kukla, A. Kozłowski, T. Siwowski, Numerical analysis of steel double side joints with flush and extended end plate under accidental situation, *ce/papers*, Vol. 4, No. 2-4, 2021, pp. 77-84.

[24] F. Plaitano, A. Stratan, E. Nastri, Simplified modelling of failure in high strength bolts under combined tension and bending, *Journal of Composites Science*, Vol. 6, No. 10, 2022, Paper No. 302.

[25] X. Qiang, Y. Shu, X. Jiang, Experimental and numerical study on high-strength steel flange-welded web-bolted connections under fire conditions, *Journal of Constructional Steel Research*, Vol. 192, 2022, Paper No. 107255.

[26] Z. Li, Y. Zhang, C. Li, M. Xu, W. Dai, Z. Liu, Modeling and nonlinear dynamic analysis of bolt joints considering fractal surfaces, *Nonlinear Dynamics*, Vol. 108, No. 2, 2022, pp. 1071-1099.

[27] L. Zhu, A.-H. Bouzid, J. Hong, A method to reduce the number of assembly tightening passes in bolted flange joints, *Journal of Manufacturing Science and Engineering*, Vol. 143, No. 12, 2021, Paper No. 121006.

[28] S.-Z. Li, H. Li, X.-H. Zhou, Y.-H. Wang, X.-H. Li, D. Gan, R.-H. Zhu, Damage detection of flange bolts in wind turbine towers using dynamic strain responses, *Journal of Civil Structural Health Monitoring*, Vol. 13, No. 1, 2023, pp. 67-81.

[29] X. Lin, Z. Du, Study on leakage model of typical penetration of closed structures based on porous media seepage theory, *Mathematical Problems in Engineering*, Vol. 2022, 2022, pp. 6901534.

[30] X. Rong, X. Xu, Y. Du, Research on the resistance of modified bolted connection under progressive collapse scenario, *Advances in Structural Engineering*, Vol. 24, No. 11, 2021, pp. 2555-2571.
[31] M. Senthil Pandian, M. Helen Santhi, B. Gopalan, Extended end plate long bolted joint using cold formed steel hollow and concrete filled column, *International Journal of Steel Structures*, Vol. 21, No. 2, 2021, pp. 613-625.
[32] S. H. Boukhalkhal, A. N. T. Ihaddoudène, L. F. Costa-Neves, W. Madi, P. C. G. Vellasco, L. Lima, Numerical modelling of CFST column to I beam end plate joints, *ce/papers*, Vol. 4, No. 2-4, 2021, pp. 989-994.
[33] S. M. R. Tekieh, A. P. Zandi, M. H. Pashaei, Numerical and experimental study of the BUEEP connection using an inner box, *Journal of Constructional Steel Research*, Vol. 193, 2022, Paper No. 107264.
[34] J. Ye, G. Quan, X. Yun, X. Guo, J. Chen, An improved and robust finite element model for simulation of thin-walled steel bolted connections, *Engineering Structures*, Vol. 250, 2022, Paper No. 113368.
[35] A. K. A. Jawwad, N. Al Shabatat, M. Mahdi, The effects of joint design, bolting procedure and load eccentricity on fatigue failure characteristics of high-strength steel bolts, *Engineering Failure Analysis*, Vol. 122, 2021, Paper No. 105279.
[36] A.-L. Zhang, X.-C. Liu, Y. Wang, C. Yu, Z.-X. Bai, H. Tran, Static performance of slidable bolt-assembly truss-to-column connection with oversized bolt holes, *Journal of Constructional Steel Research*, Vol. 176, 2021, Paper No. 106374.
[37] M. A. Naghsh, A. Shishegaran, B. Karami, T. Rabczuk, A. Shishegaran, H. Taghavizadeh, M. Moradi, An innovative model for predicting the displacement and rotation of column-tree moment connection under fire, *Frontiers of Structural and Civil Engineering*, Vol. 15, No. 1, 2021, pp. 194-212.
[38] S. Jovasevic, J. Correia, M. Pavlovic, R. Dantas, C. Rebelo, M. Veljkovic, A. M. P. de Jesus, Alternative steel lattice structures for wind energy converters, *International Journal of Structural Integrity*, Vol. 12, No. 1, 2021, pp. 48-69.
[39] X.-X. Zhan, X.-C. Liu, S. Feng, C. Yu, Seismic performance of a square HSS column to H-section beam bolted connection with double cover plate, *Engineering Structures*, Vol. 231, 2021, Paper No. 111729.
[40] B. Mou, Y. Liu, P. Wei, F. Zhao, W. Chenglong, N. Ning, Numerical investigation and design method of bolted beam-column joint panel with eccentricity in beam depths, *Journal of Constructional Steel Research*, Vol. 180, 2021, Paper No. 106568.
[41] J. Wang, Z. Hu, L. Guo, B. Wang, Y. Yang, Analytical performance and design of CECFST column assembled to PEC beam joint, *KSCE Journal of Civil Engineering*, Vol. 25, No. 7, 2021, pp. 2567-2586.
[42] F.-X. Ding, Y.-B. Chen, L. Wang, Z.-C. Pan, C.-Y. Li, T. Yuan, C. Deng, C. Luo, Q.-W. Yan, C.-B. Liao, Hysteretic behavior of CFST column-steel beam bolted joints with external reinforcing diaphragm, *Journal of Constructional Steel Research*, Vol. 183, 2021, Paper No. 106729.
[43] H. Ketabdari, A. S. Daryan, N. Hassani, M. Safi, Fire response of steel connections using gene expression programming and finite element method, *The Structural Design of Tall and Special Buildings*, Vol. 30, No. 11, 2021, Paper No. e1862.
[44] F. F. Almutairi, K. D. Tsavdaridis, The effect of degree of composite action on reduced web section (RWS) connections, *ce/papers*, Vol. 4, No. 2-4, 2021, pp. 843-849.
[45] R. Tartaglia, M. D'Aniello, A. Campiche, M. Latour, Symmetric friction dampers in beam-to-column joints for low-damage steel MRFs, *Journal of Constructional Steel Research*, Vol. 184, 2021, Paper No. 106791.
[46] Y. Song, J. Wang, B. Uy, D. Li, Behaviour and design of stainless steel-concrete composite beam-to-column joints, *Journal of Constructional Steel Research*, Vol. 184, 2021, Paper No. 106800.
[47] A. A. Osman, S. A. Mourad, Performance of extended end-plate bolted connections subjected to static and blast-like loads, *Journal of Engineering and Applied Science*, Vol. 68, 2021, Paper No. 8.
[48] J. Xu, J. Wang, H. S. Mohamed, J. Han, Z. Han, J. Tu, Z. Li, Post-earthquake fire resistance of bolted end-plate connection joint with end-plate and web stiffeners, *Journal of Constructional Steel Research*, Vol. 185, 2021, Paper No. 106835.
[49] X.-C. Liu, M.-L. Chen, X. Chen, Y.-M. Li, Y. Wang, L. Xu, Seismic behavior of bolted truss-to-column joint with oversized or slotted

bolt hole, *Engineering Structures*, Vol. 247, 2021, Paper No. 113110.

[50] X.-C. Liu, Y.-L. Tao, X. Chen, F.-Y. Cui, Seismic performance of welded-bolted joint between double channel beam and CFST column, *Engineering Structures*, Vol. 247, 2021, Paper No. 113202.

[51] M. S. Ghobadi, B. Mirzaie Abar, Development of new fully restrained bolted bracket moment connections for strong joints, *Archives of Civil and Mechanical Engineering*, Vol. 21, No. 4, 2021, Paper No. 145.

[52] G. Liang, Z. Lu, H. Guo, Y. Liu, D. Yang, S. Li, X. Pan, Experimental and numerical investigation on seismic performance of extended stiffened end-plate joints with reduced beam section using high strength steel, *Thin-Walled Structures*, Vol. 169, 2021, Paper No. 108434.

[53] H. Nazaralizadeh, H. Ronagh, P. Memarzadeh, F. Behnamfar, A practical design approach to bolted end-plate vertical-slits RWS connection, *Bulletin of Earthquake Engineering*, Vol. 20, No. 1, 2022, pp. 547-586.

[54] M. R. El-Hadary, I. M. El-Aghoury, S. A.-B. Ibrahim, Behavior of different bolted connection configurations in frames composed of cold-formed sections, *Ain Shams Engineering Journal*, Vol. 13, No. 1, 2022, Paper No. 101500.

[55] Z. Xie, Y. Chen, Numerical study of the robustness of steel moment connections under catenary effect, *Engineering Structures*, Vol. 252, 2022, Paper No. 113658.

[56] S. Li, D. Zhao, Y. Zhou, Research on seismic performance of prefabricated concrete-filled steel tubular frame joints, *International Journal of Structural Integrity*, Vol. 13, No. 2, 2022, pp. 327-347.

[57] O. Yılmaz, S. Bekiroğlu, Biaxial cyclic behavior of bolted end-plate connection to I-column reformed by box-plates, *Engineering Structures*, Vol. 255, 2022, Paper No. 113955.

[58] J. Xu, J. Wang, J. Han, Z. Han, J. Tu, Z. Li, Fire resistance numerical simulation of extended end-plate steel connection joints with different strengthening strategies under fire, *KSCE Journal of Civil Engineering*, Vol. 26, No. 4, 2022, pp. 1826-1845.

[59] X.-C. Liu, Y.-N. Zhu, X. Chen, Y.-M. Li, Seismic performance of bolted double-web T-stub connections with T-shaped steel column, *Journal of Constructional Steel Research*, Vol. 191, 2022, Paper No. 107168.

[60] T. Lin, Z. Wang, F. Hu, P. Wang, Finite-element analysis of high-strength steel extended end-plate connections under cyclic loading, *Materials*, Vol. 15, No. 8, 2022, Paper No. 2912.

[61] R. Tartaglia, A. Milone, A. Prota, R. Landolfo, Seismic retrofitting of existing industrial steel buildings: A case-study, *Materials*, Vol. 15, No. 9, 2022, Paper No. 3276.

[62] Y.-L. Xu, J.-P. Hao, Y.-X. Su, Y.-F. Shang, Seismic performance of column-tree moment connections with slit dampers, *KSCE Journal of Civil Engineering*, Vol. 26, No. 6, 2022, pp. 2789-2798.

[63] C. Arunkumar, N. Umamaheswari, Numerical study on the behaviour of resilient beam-column end plate connection with dual structural fuse, *Innovative Infrastructure Solutions*, Vol. 7, No. 3, 2022, Paper No. 222.

[64] C. Arunkumar, N. Umamaheswari, Numerical approach on moment rotation behaviour of beam-column end plate connection, *Journal of the Balkan Tribological Association*, Vol. 28, No. 2, 2022, pp. 173-184.

[65] Y. O. Özkılıç, Cyclic and monotonic performance of stiffened extended end-plate connections with large-sized bolts and thin end-plates, *Bulletin of Earthquake Engineering*, Vol. 20, No. 13, 2022, pp. 7441-7475.

[66] V. L. Tran, Investigating the behavior of steel flush endplate connections at elevated temperatures using FEM and ANN, *International Journal of Steel Structures*, Vol. 22, No. 5, 2022, pp. 1433-1451.

[67] H. Yuan, J. Gao, M. Theofanous, Numerical modelling and design of stainless steel double extended end-plate beam-to-column joints, *International Journal of Steel Structures*, Vol. 22, No. 6, 2022, pp. 1743-1759.

[68] W. Yi, L. Zuo, T. Chen, M. Wang, H. Sun, L. Zhu, X. Chen, Bearing capacity of steel square tubular column I-shaped beam joints connected by new elliptical one-sided bolts, *International Journal of Steel Structures*, Vol. 22, No. 6, 2022, pp. 1829-1840.

[69] P. Chen, J. Pan, F. Hu, Z. Wang, Numerical investigation on seismic resilient steel beam-to-column connections with replaceable buckling-restrained fuses, *Journal of*

Constructional Steel Research, Vol. 199, 2022, Paper No. 107598.
[70] Z. Mo, Q.-T. Feng, B.-L. Lai, W.-Q. Jiang, Y. Feng, Resilient performance of super-elastic SMA bolted connection equipped with extended end plate and shear tab, *Journal of Constructional Steel Research*, Vol. 199, 2022, Paper No. 107626.
[71] C. Arunkumar, N. Umamaheswari, Seismic performance of steel frame equipped with structural fuse, *Innovative Infrastructure Solutions*, Vol. 8, No. 2, 2023, Paper No. 83.
[72] K. Ma, X. Ye, H. Yu, R. Wu, Y. Li, W. Li, Study on seismic behavior and influencing factors of composite connection in moment-resisting steel frame, *KSCE Journal of Civil Engineering*, Vol. 27, No. 3, 2023, pp. 1093-1106.
[73] P. Lu, J. Yang, T. Ran, W. Wang, Experimental study on flexural capacity and fire resistance of high strength Q690 steel flush end-plate connections, *Thin-Walled Structures*, Vol. 184, 2023, Paper No. 110506.
[74] S.-Y. Zhai, Y.-F. Lyu, K. Cao, G.-Q. Li, W.-Y. Wang, C. Chen, Seismic behavior of an innovative bolted connection with dual-slot hole for modular steel buildings, *Engineering Structures*, Vol. 279, 2023, Paper No. 115619.
[75] X. Liu, C. Xu, S. Peng, B. Zhou, Influence of staggered floor and unequal height of left and right beam on seismic behavior of CFSST column-to-HSS beam composite frames, *Journal of Building Engineering*, Vol. 66, 2023, Paper No. 105878.
[76] Z. Shu, B. Ning, H. Dong, Z. Li, Z. Peng, Y. Yang, Glulam beam-to-column connection with coupled steel rods with screwheads: Concept and experimental verifications, *KSCE Journal of Civil Engineering*, Vol. 27, No. 6, 2023, pp. 2570-2585.
[77] C. Wang, A. Rudman, R. Tremblay, C. A. Rogers, Numerical investigation into I-shape brace connections of conventional concentrically braced frames, *Engineering Structures*, Vol. 236, 2021, Paper No. 112091.
[78] E. Bernatowska, L. Ślęczka, Experimental and numerical investigation into failure modes of tension angle members connected by one leg, *Materials*, Vol. 14, No. 18, 2021, Paper No. 5141.
[79] J. Kennaway, A. Rajabipour, D. Huang, M. Bazli, S. Tang, J. Wang, H. Zanker, F. Su, Connection confinement of bolted fibre-reinforced polymer bamboo composite, *Polymers*, Vol. 14, No. 10, 2022, Paper No. 2051.
[80] P. Jaszak, Prediction of the durability of a gasket operating in a bolted-flange-joint subjected to cyclic bending, *Engineering Failure Analysis*, Vol. 120, 2021, Paper No. 105027.
[81] K. Zhao, N. Jiang, C. Zhou, H. Li, Z. Cai, B. Zhu, Dynamic behavior and failure of buried gas pipeline considering the pipe connection form subjected to blasting seismic waves, *Thin-Walled Structures*, Vol. 170, 2022, Paper No. 108495.
[82] P. Jaszak, J. Skrzypacz, A. Borawski, R. Grzejda, Methodology of leakage prediction in gasketed flange joints at pipeline deformations, *Materials*, Vol. 15, No. 12, 2022, Paper No. 4354.
[83] H. Zhang, M. Wang, W. Deng, J. Zhao, J. Zhou, X. Ma, L. Yao, M. Wang, Semi-physical simulation optimization method for bolt tightening process based on reinforcement learning, *Machines*, Vol. 10, No. 8, 2022, Paper No. 637.
[84] X.-C. Liu, Y.-L. Tao, X. Chen, M. L. Chen, Seismic performance of bolted flange splicing joints for CFST columns, *Journal of Constructional Steel Research*, Vol. 196, 2022, Paper No. 107412.
[85] Y.-L. Tao, X. Chen, X.-C. Liu, Seismic performance of CFST column bolted flange splice joints with connecting plates and rebar hooks, *Engineering Structures*, Vol. 267, 2022, Paper No. 114662.
[86] W. Zhao, X. Huang, M. Yang, H. Yang, H. Bi, Q. He, Z. Wang, Flow-induced dynamic behavior of head-cover bolts in a prototype pump-turbine during load rejection, *Machines*, Vol. 10, No. 12, 2022, Paper No. 1130.
[87] G. Nadeem, N. A. Safiee, N. A. Bakar, I. A. Karim, N. A. M. Nasir, Evaluation of slip behaviour of self-locking modular steel connection, *Journal of Constructional Steel Research*, Vol. 197, 2022, Paper No. 107467.
[88] T. Dograr, B. Sabuncuoglu, Development of a numerical model for the modal analysis of a gun control unit column with isolator, *Journal of Vibration Engineering & Technologies*, in press, 2022, https://doi.org/10.1007/s42417-022-00723-5.

[89] Y. Sun, O. G. Grebenikov, C. Li, Analysis of force distribution of four rows of bolts in aircraft fitting joint, *International Journal of Aerospace Engineering*, Vol. 2021, 2021, Paper No. 9962645.

[90] C. Zhao, G. Wang, T. Zheng, Research on the hysteretic performance of flower-gusset composite joints for single-layer aluminium alloy lattice shell structures, *Advances in Structural Engineering*, Vol. 25, No. 1, 2022, pp. 171-187.

[91] J. Wu, Y. Li, G. Sun, S. Chen, Experimental and numerical analyses of the hysteretic performance of an arched aluminium alloy gusset joint, *Thin-Walled Structures*, Vol. 171, 2022, Paper No. 108765.

[92] H. Wang, J. Li, P. Li, L. Zhong, X. Zhang, C. Li, Study on flexural performance of aluminum alloy gusset joints subjected to bending moment and shear force, *Materials*, Vol. 16, No. 7, 2023, Paper No. 2920.

[93] Q. Zhou, W. He, Z. Zhou, W. Guo, S. Liu, Experimental and theoretical studies on hysteretic behavior of friction energy dissipation composite chord under quasi-static tests, *Materials*, Vol. 16, No. 7, 2023, Paper No. 2885.

[94] Y. Yu, A. Zhang, W. Pan, B. Mou, X. Liu, Seismic performance of beam-column connections with welded upper flange and bolted lower flange, *Journal of Constructional Steel Research*, Vol. 182, 2021, Paper No. 106697.

[95] Q. Lin, Y. Lu, L. Hu, X. Zhao, Experimental and numerical study on fatigue behavior of RC beams strengthened with U-shaped steel casing, *International Journal of Steel Structures*, Vol. 22, No. 2, 2022, pp. 514-538.

[96] J. Fan, L. Yang, Y. Wang, H. Ban, Research on seismic behaviour of square steel tubular columns with deconstructable splice joints, *Journal of Constructional Steel Research*, Vol. 191, 2022, Paper No. 107204.

[97] O. Mijatović, A. Borković, M. Guzijan-Dilber, Z. Mišković, R. Salatić, R. Mandić, V. Golubović-Bugarski, Experimental and numerical study of structural damping in a beam with bolted splice connection, *Thin-Walled Structures*, Vol. 186, 2023, Paper No. 110661.

[98] R. Miao, R. Shen, F. Tang, W. Chen, M. Que, Nonlinear interaction effect on main cable clamp bolts tightening in suspension bridge, *Journal of Constructional Steel Research*, Vol. 182, 2021, Paper No. 106663.

[99] R. Grzejda, Thermal strength analysis of a steel bolted connection under bolt loss conditions, *Eksploatacja i Niezawodnosc – Maintenance and Reliability*, Vol. 24, No. 2, 2022, pp. 269-274.

[100] R. Grzejda, R. Perz, Compressive strength analysis of a steel bolted connection under bolt loss conditions, *Communications - Scientific Letters of the University of Žilina*, Vol. 24, No. 4, 2022, pp. B319-B327.

[101] E. Talay, C. Özkan, E. Gürtaş, Designing lightweight diesel engine alternator support bracket with topology optimization methodology, *Structural and Multidisciplinary Optimization*, Vol. 63, No. 5, 2021, pp. 2509-2529.

[102] S. M. Mojtabaei, I. Hajirasouliha, J. Ye, Optimisation of cold-formed steel beams for best seismic performance in bolted moment connections, *Journal of Constructional Steel Research*, Vol. 181, 2021, Paper No. 106621.

[103] S. M. Mojtabaei, J. Becque, I. Hajirasouliha, Behaviour and design of cold-formed steel bolted portal frame connections, *ce/papers*, Vol. 4, No. 2-4, 2021, pp. 432-437.

[104] I. Papargyriou, S. M. Mojtabaei, I. Hajirasouliha, J. Becque, K. Pilakoutas, Cold-formed steel beam-to-column bolted connections for seismic applications, *Thin-Walled Structures*, Vol. 172, 2022, Paper No. 108876.

[105] B. Ji, Q. Xiong, P. Xing, P. Qiu, W. Qu, Bolt loosening localization at flange joints using wind-induced response for high-rise tower, *International Journal of Steel Structures*, Vol. 21, No. 5, 2021, pp. 1790-1803.

[106] J. Hong, Z. Yang, Y. Wang, R. Cheng, Y. Ma, Combination resonances of rotor systems with asymmetric residual preloads in bolted joints, *Mechanical Systems and Signal Processing*, Vol. 183, 2023, Paper No. 109626.

[107] X. Wang, P. Su, J. Liu, Z. Chen, K. Khan, Seismic performance of light steel-natural timber composite beam-column joint in low-rise buildings, *Engineering Structures*, Vol. 256, 2022, Paper No. 113969.

[108] L. Roquete, M. M. de Oliveira, A. M. Cunha Sarmanho, E. Martins Xavier, V. Nicchio Alves, Design of sleeve connections with cross-bolted on circular hollow sections under

axial tension, *Engineering Structures*, Vol. 250, 2022, Paper No. 113393.

[109] B. Li, Y. Gong, H. Xiao, Y. Gao, E. Liang, A two-dimensional model for pin-load distribution and failure analysis of composite bolted joints, *Materials*, Vol. 14, No. 13, 2021, Paper No. 3646.

[110] X. Chen, M. Boston, D. Bell, J. Mares, K. Roy, J. B. P. Lim, Moment capacity of apex brackets of cold-formed steel portal frames, *Thin-Walled Structures*, Vol. 185, 2023, Paper No. 110574.

[111] Z. Xin, H. Wei, Y. Liu, G. Liang, Study on mechanical properties of press-bending members based on transmission towers diagonal member reinforcement in-situ, *International Journal of Steel Structures*, Vol. 22, No. 4, 2022, pp. 1025-1041.

[112] A. Lukaszewicz, K. Panas, R. Szczebiot, Design process of technological line for vegetables packaging using CAx tools, in Proceedings of the 17th International Scientific Conference 'Engineering for Rural Development 2018', Jelgava, Latvia, 23-25 May 2018, pp. 871-876.

[113] A. Łukaszewicz, K. Szafran, J. Józwik, CAx techniques used in UAV design process, in 2020 IEEE 7th International Workshop on Metrology for AeroSpace (MetroAeroSpace), Pisa, Italy, 22-24 June 2020, pp. 95-98.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The author contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The author has no conflicts of interest to declare.