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Thermal strength analysis of a steel bolted connection under bolt loss conditions

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Highlights

- FEM-based studies of an asymmetric bolted connection are presented.
- Six different tensioning orders of the bolts were tested.
- The failure of selected bolts in a connection loaded with temperature was simulated.
- The influence of tensioning order on the bolt forces in a damaged connection was probed.

Abstract

The aim of the paper is to analyse an exemplary bolted connection under the conditions of loss of bearing capacity of some fasteners in the connection. The presented tests are numerical and concern an asymmetric bolted connection. The joined elements in the connection were modelled as 3D finite elements, and the fasteners were treated as hybrid models consisting of rigid heads and nuts, and flexible beams between them. The bolted connection was first preloaded according to six different tensioning orders using a standardised force. After all bolts were tensioned, the selected bolts were removed, simulating bolt damage. The connection was then tested for external loads with temperatures ranging from 20 to 600°C. The influence of loosening the connection on the load in the remaining bolts at the operational stage of the connection was investigated. The calculation results were compared with the test results for a healthy bolted connection. It was shown that the bearing capacity of the connection in the damaged state decreased by 13%.

Keywords

bolted connection; thermal strength; non-linearity; finite element method; preload.

1. Introduction

Steel bolted connections are used in many engineering, mechanical and building structures that can be subjected to a wide variety of thermal loads [11, 28]. As a result of these loads, the preload of bolts changes, which may be an unfavorable phenomenon [27, 51]. It has been observed that, in the case of moment connections, the tensile force in the bolts tends to decrease with increasing temperature. However, in the case of shear connections, the force in the bolts tends to increase with temperature [44]. At elevated temperatures, the mechanical properties of the bolts also drop significantly, which directly affects the safety and reliability of steel structures [3, 34, 53].

Many experimental studies with the use of testing machines have shown that temperature loads quickly lead to a significant decrease in the load capacity of bolted connections and affect their failure modes [22, 55, 62]. In order to prevent bolted connections from being failure by elevated temperatures, a series of experimental studies have been carried out, which have resulted in the development of special design rules, for example, for additional protection of bolts [7, 18, 23, 61].

In the papers written so far, the behaviour of bolted connections at elevated temperatures is sometimes analysed on the basis of the component method [2, 20, 46, 58, 63]. The still poor knowledge of some elements, especially the elements in shear, limits the wider application of this method. However, much more often it is modelled and described using the finite element method (FEM). Towarnicki and Grzejda [49] presented an analysis of the influence of the temperature load on the stress state in the joint separated from the bolted flange connection. They demonstrated the usefulness of using a simplified bolt model for modelling bolted connections in order to determine the forces acting on the bolt. The influence of the thread length on the failure of bolted connections at elevated temperatures was discussed by Shaheen et al. [45]. Schaumann and Kirsch [42] simulated a flush endplate connection at elevated temperatures taking into account non-linearities, e.g. temperature dependent material. Lim and Young [25] investigated the influence of elevated temperatures on bolted moment-connections between cold-formed steel members and proposed some simple design rules that allow for this influence to be taken into account. Abid et al. [1] studied the strength and sealing performance of a preloaded gasketed bolted flange connection at combined pressure, axial and thermal loading to show its safe and unsafe operating limits. Similar thematic considerations were presented by Wang et al. [56]. The fracture behaviour of high-strength bolted steel connections

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at elevated temperatures and also loaded with shear forces was described by Cai et al. [5]. Li and Zhao [24] conducted an analytical tests of beam-to-column connections at elevated temperatures and the verification of these tests with the use of FEM.

There are also many papers on the determination of the behaviour of bolted connections under fire conditions [12, 13, 19, 21, 37-39] and several on the behaviour of bolted connections at reduced temperatures [29, 47, 50] using FEM.

Only a few studies dealt with the issue of changing the stress distribution in a bolted connection subjected first to failure and then to temperature loads. Most often they concern the analysis of connections with properties changed by the earthquake, and therefore different from those designed for a given structure and then subjected to fire. Della Corte et al. [9] investigated the post-earthquake fire resistance of steel moment resisting frames, which confirmed that the fire resistance of structures can be significantly reduced depending on the damage caused by seismic action. Xu et al. [59] came to similar conclusions, but in the case of bolted end-plate connections with end-plate and web stiffeners. Tartaglia et al. [48] described the behaviour of seismically damaged extended stiffened end-plate connections at elevated temperature. They presented the results in terms of moment-rotation-temperature characteristics and pattern of plastic deformations, which indicate under what conditions the type of cyclic damage may affect the performance of the connection under high temperature. An example of a test stand and test procedure to analyse the behaviour of steel beam to column end-plate bolted connections under the post-earthquake fire action was published by Petrina [35].

Likewise, there are few papers on the effect of the number and arrangement of bolts in a bolted connection on its performance under the influence of high temperatures. Wang et al. [57] conducted an experimental study of the relative structural fire behaviour and robustness of different types of bolted steel connections in restrained steel frames. Wang and Wang [54], and Yahyai and Rezaeian [60] presented numerical analyses verified experimentally on essentially similar issues. However, they did not investigate the effect of bolts loss on the bolted connection behaviour.

There are also several papers on the evaluation of the reliability of bolted connections, or larger structures with these connections. However, they do not take into account the influence of temperature on reliability, but rather relate to the assessment of fatigue reliability [26, 30, 41].

According to the conducted review of the state of knowledge, few scientists have so far dealt with the health assessment of the bolted connections under conditions of elevated temperatures and after the failure occurred earlier in the connection. Therefore, this theme was taken up by the author of the featured paper. The paper concerns a bolted connection, some experimental tests of which have been described in [14-16]. The novelty in relation to the above-cited articles is that in the current paper an asymmetrical connection was modelled under bolt loss conditions. The failure of the connection was simulated by removing the selected bolts from the connection, similarly to the explicit finite element analysis using element erosion, in which the elements are removed from the analysis after meeting certain failure criteria [43]. The calculations were made for an exemplary bolted connection using the finite element system called Midas NFX 2020 R2, and their results are the courses of force changes in bolts remaining in the connection, which was pretensioned and then subjected to variable temperature loads.

2. Material and methods

The subject of research and analysis is the bolted connection presented in Fig. 1a. The tested connection is made of a pair of plates joined with i fasteners shown in Fig. 1b (for i = 1, 2, …, 7). The fasteners are of the M10x1.25 type and consist of a bolt and a nut as one solid [52]. The joined plates are welded to the top and bottom bases. The thickness of the joined plates and the bases is equal to 28 mm. The connection is sloped to the horizontal at an angle of 60 deg (for comparison, see [8]). The total heigh of the structure is approximately 266 mm. The plates and bases are performed of 1.0577 steel. After machining, the bolts and nuts have been tempered to achieve the characteristics for the class of mechanical property 8.8 and 8, respectively.

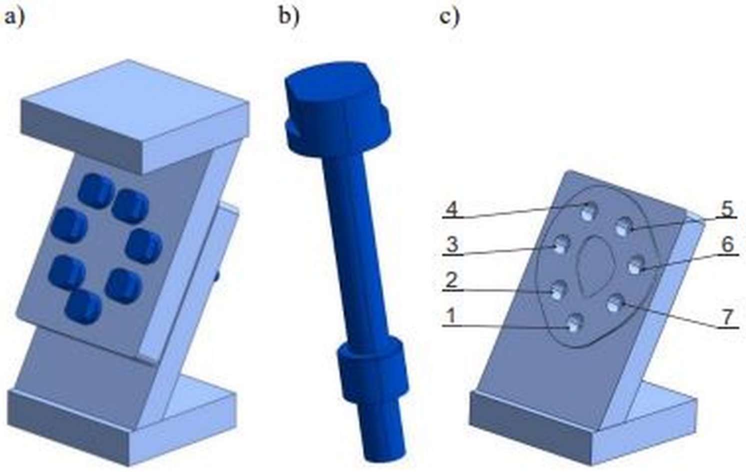


Fig. 1. Model of the connection: (a) model 3D, (b) model 3D of the single fastener, (c) outline of the surface at the contact of the joined plates and assumed numbering of the bolts

The contact surface area between the joined plates and the assumed numbering of the bolts are presented in Fig. 1c. This area fits in a circle with a radius of 90 mm, and its outline does not exceed 90 cm^2.

Using the Midas NFX 2020 R2 finite element system tools, a model of the bolted connection was made, shown in Fig. 2. The joined plates were divided into 3D finite elements, while the fasteners were modelled as flexible beams with rigid heads and nuts (for comparison, see [32, 33]). All connection parts were assigned the properties of isotropic linear steel materials. The constitutive relationships in this case can be described by Hooke's law [10].

General surface-to-surface contact elements were applied between the joined plates. They allow for non-linear analysis taking into consideration the possibility of separating the joined plates in the vertical direction and the occurrence of sliding in the horizontal direction. The following values of the contact layer parameters were adopted:

- normal stiffness ratio equal to 10,
- tangential stiffness ratio equal to 1,
- static friction factor equal to 0.14 [17].

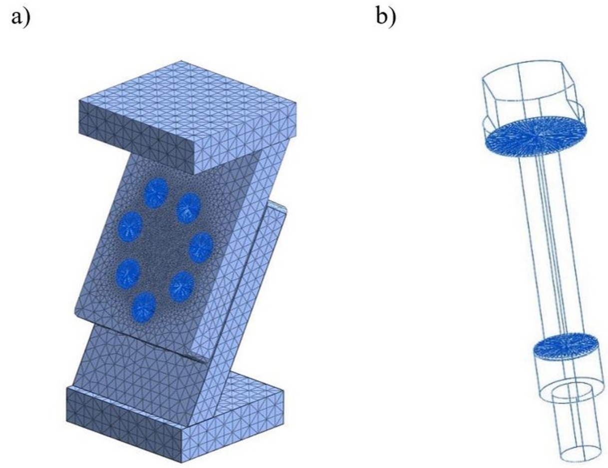


Fig. 2. FE-model of the bolted connection: (a) entire connection, (b) single fastener

Welded type contact elements were used between the plates and the bases, preventing the elements from moving relative to each other in any direction.

The bolted connection model was created with a total of 78750 elements and 133162 nodes. The maximum size of the side length of a finite element in the mesh does not exceed 10 mm. The mesh has been significantly densified at the point of contact between the joined plates and at the point of contact between the fasteners and the joined plates (for comparison, see [4]). The model was constrained by taking away all degrees of freedom on the underside of the bottom base. The preload of the bolts was applied via the "pretension" function built into the Midas NFX 2020 R2 system. A non-linear static analysis was chosen as the type of FE-analysis. The mathematical description of the temperature distribution in this case can be done using the Fourier-Kirchhoff partial differential equation for stationary isotropic bodies [40].

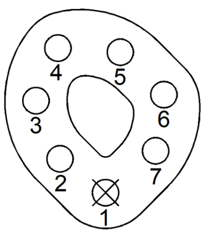
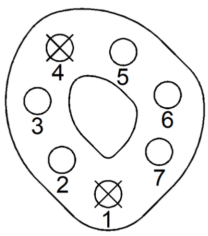
The research was divided into the following stages:

1. Pretensioning the bolted connection according to one of the six adopted tensioning orders presented in Table 1 with a pretension F_p equal to 22 kN.
2. Performing calculations of forces in the bolts in the connection subjected to thermal loads in the range from 20 to 600°C (temperature boundary conditions were assigned to all model nodes as uniform prescribed nodal temperature [6]).
3. Entering the failure states according to the diagram shown in Table 2 (after each way of tensioning the bolted connection).
4. Designation of changes in the value of forces in the bolts remaining in the connection.
5. Duplication the above steps for all connection tensioning orders.

Table 1. Orders of bolt tensioning

Queue No.	Order of bolts	Queue No.	Order of bolts
1	1-2-3-4-5-6-7	4	1-5-2-6-3-7-4
2	1-3-5-7-2-4-6	5	1-6-4-2-7-5-3
3	**1-4-7-3-6-2-5**	6	1-7-6-5-4-3-2

Table 2. Connection failure states

1	2
	

3. Results and discussion

The obtained courses of the bolt forces variation for individual types of pretensioning of the connection are qualitatively very similar. Since their quantitative comparison also gives a high similarity, this paper presents a set of diagrams for an example type of pretensioning of the connection, which is the queue No. 3, marked with bold letters in Table 1.

The graphical presentation of the calculation results is shown in Fig. 3. The values of the operating forces in the bolts remaining in the connection after the introduction of two successive states of failure and those obtained for the healthy connection were compared. The operating forces were related to the preload of the bolts to improve the readability of the graphs.

The forces in the bolts tend to increase with temperature, which is inherent in shear connections [44]. In general, increments in operating bolt forces due to temperature decrease as the number of bolts

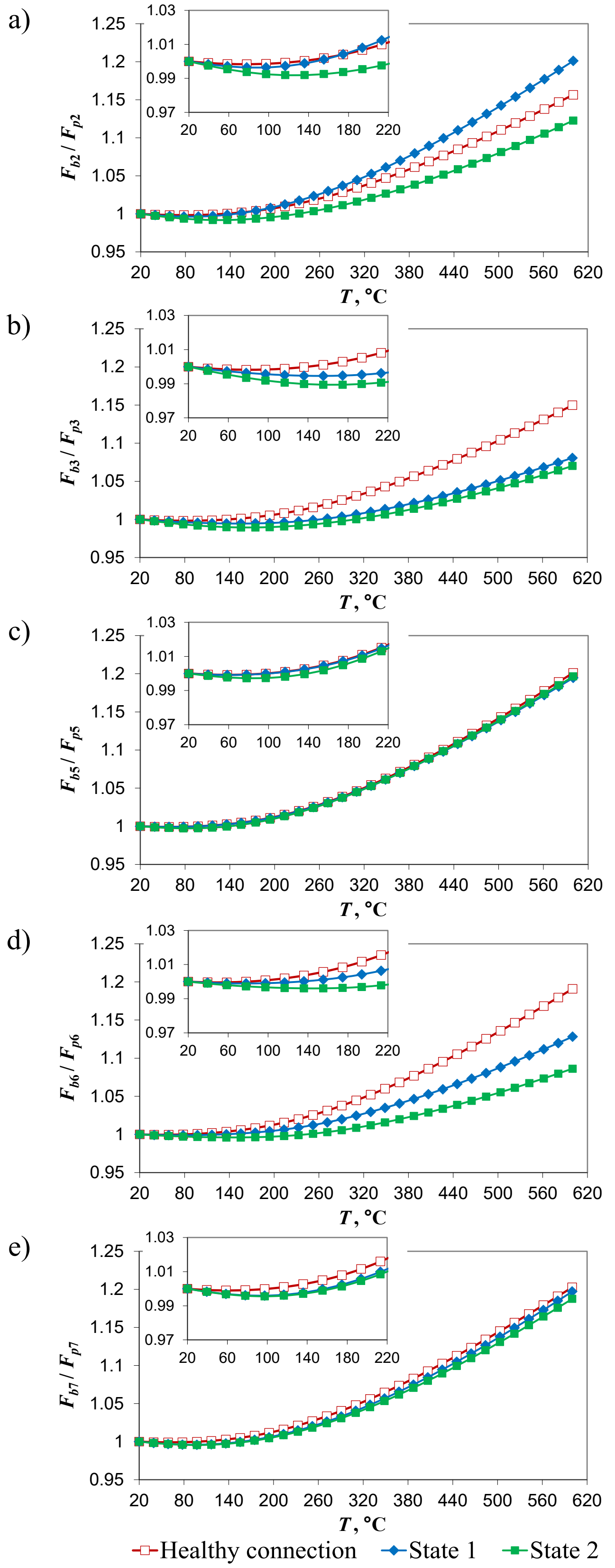


Fig. 3. Distributions of bolt forces in the connection pretensioned according to the queue No. 3: a) bolt No. 2, b) bolt No. 3, c) bolt No. 5, d) bolt No. 6, e) bolt No. 7

removed from the connection increases. However, due to the asymmetry in the arrangement of bolts in the connection, there is no single relationship to determine the magnitude of the force decrease in bolts compared to the healthy connection, as a function of the number of bolts lost. Its search may be the subject of a separate publication,

Table 3. Z_1 indicator values

Queue No.	Z_1, %														
	Healty connection					State 1					State 2				
	Bolt number					Bolt number					Bolt number				
	2	3	5	6	7	2	3	5	6	7	2	3	5	6	7
1	15.7	15.0	20.1	19.1	20.2	20.1	8.1	19.4	12.8	19.7	12.3	7.0	19.6	8.6	18.8
2	16.0	14.6	19.7	19.5	19.9	20.6	7.9	19.0	13.1	19.3	12.7	6.6	18.9	8.8	18.5
3	16.1	15.0	20.6	19.1	19.7	20.6	8.1	19.9	12.9	19.1	12.5	7.2	20.4	8.6	18.1
4	15.7	15.0	19.6	19.1	20.3	20.1	8.1	18.9	12.8	19.8	12.3	6.9	18.9	8.6	18.9
5	15.8	15.3	20.5	18.6	20.2	20.3	8.2	19.9	12.4	19.7	12.3	7.4	20.4	8.3	18.6
6	16.0	15.1	20.2	19.1	19.7	20.6	8.1	19.5	12.8	19.2	12.6	7.1	19.8	8.6	18.2

which would take into account other types of connections, with a different number of bolts.

The force increments in bolts for individual load conditions of the connection are summarised in Table 3. They are expressed using the following Z_1 indicator:

$$Z_1 = \left| \frac{F_{bi}^T - F_{bi}^p}{F_{bi}^p} \right| \cdot 100 \tag{1}$$

where: F_{bi}^T is the operating force in the *i*-th bolt at the end of the connection heating process as a function of the type of tensioning, and F_{bi}^p is the preload of the i-th bolt.

In most cases, the force increments in bolts under the influence of temperature acting on the damaged connection are smaller than for the healthy connection. The exceptions are the increments in force in bolt No. 2 in the first stage of failure, when they are greater than corresponding increments for the healthy connection. The force in this bolt then increases by about 20% for all tensioning cases. This does not exceed the permissible value of the preload according to Eurocode 3 [36], which for the M10x1.25 bolt in the class 8.8 is 31 kN. On the other hand, it may pose a threat due to the high pressure on the contact surface of the nut and the joined plate.

The bolt tensioning method has a slight effect on the Z_1 indicator values.

The last comparisons of the calculation results presented in Table 3 were aimed at determining the value of the temperature T at which the operating forces in the bolt No. 2 in the first state of connection failure reach the values corresponding to the final load condition in the healthy connection. The results of these analyses are summarised in Table 4.

The bearing capacity of bolt No. 2 in the failure state No. 1 decreased by approx. 13%. The bolt tensioning method has a slight effect on the value of the bearing capacity of the connection.

The total bolts tension at the end of the connection loading process was compared on the basis of the proposed Z_2 indicator described by the formula:

$$Z_2 = \left| \frac{F_t^h - F_t^d}{F_t^h} \right| \cdot 100 \tag{2}$$

where: F_t^h is the total force in the bolts in the considered distribution of forces at the end of the process of loading the healthy connection, and F_t^d is an analogous force in the case of the damaged connection.

The greatest drops in total force do not exceed 2% for failure state No. 1 and 5% for failure state No. 2, for all methods of tensioning the bolted connection (Table 5). The bolt tensioning method has a slight effect on the differences in these drops.

Table 4. Limit values of the temperature T

Queue No.	T, °C
1	527.1
2	526.4
3	526.8
4	527.1
5	526.6
6	526.8

Table 5. Z_2 indicator values

Queue No.	Z_2, %	
	State 1	State 2
1	1.69	4.04
2	1.68	4.07
3	1.70	4.03
4	1.69	4.06
5	1.68	3.99
6	1.69	4.04

In the literature cited in the introduction, the differences in the displacements of the joined elements as a result of the removal of selected bolts were studied rather than the differences in the values of forces in the bolts not removed from the connection. In this sense, the presented research and their results supplement the state of knowledge on the behaviour of damaged bolted connections at elevated temperatures.

4. Conclusions

The paper presents a method of modelling preloaded asymmetric bolted connections in conditions of failure and load with increased temperature. This method can be used in assessing the health of bolted connections. The results of the study lead to the following conclusions:

1. The increments in operating forces in a damaged connection subjected to elevated temperature may be greater than in the case of a healthy connection. In extreme cases, the differences in the values of the operating forces can be as high as 20%.
2. The bearing capacity of a damaged connection may be reduced by approx. 13%.
3. The method of tensioning the connection has a slight effect on the magnitude of increments in the values of bolt forces and the bearing capacity of the connection in its failure state.
4. The described tests can be extended to determine the universal load-strength interference [31] allowing the assesment of the

health condition of bolted connections subjected to temperature loads.

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References

1. Abid M, Nash DH, Javed S, Wajid HA. Performance of a gasketed joint under bolt up and combined pressure, axial and thermal loading – FEA study. International Journal of Pressure Vessels and Piping 2018; 168: 166-173, https://doi.org/10.1016/j.ijpvp.2018.10.014.
2. Al-Jabri KS, Davison JB, Burgess IW. Performance of beam-to-column joints in fire – A review. Fire Safety Journal 2008; 43(1): 50-62, https://doi.org/10.1016/j.firesaf.2007.01.002.
3. Ban H, Yang Q, Shi Y, Luo Z. Constitutive model of high-performance bolts at elevated temperatures. Engineering Structures 2021; 233: 111889, https://doi.org/10.1016/j.engstruct.2021.111889.
4. Buczkowski R, Kleiber M. A study of the surface roughness in elasto-plastic shrink fitted joint. Tribology International 2016; 98: 125-132, https://doi.org/10.1016/j.triboint.2016.02.021.
5. Cai W-Y, Jiang J, Li G-Q, Wang Y-B. Fracture behavior of high-strength bolted steel connections at elevated temperatures. Engineering Structures 2021; 245: 112817, https://doi.org/10.1016/j.engstruct.2021.112817.
6. Chinesta F, Ammar A, Lemarchand F, Beauchene P, Boust F. Alleviating mesh constraints: Model reduction, parallel time integration and high resolution homogenization. Computer Methods in Applied Mechanics and Engineering 2008; 197(5): 400-413, https://doi.org/10.1016/j.cma.2007.07.022.
7. Dai XH, Wang YC, Bailey CG. Effects of partial fire protection on temperature developments in steel joints protected by intumescent coating. Fire Safety Journal 2009; 44(3): 376-386, https://doi.org/10.1016/j.firesaf.2008.08.005.
8. Daniūnas A, Urbonas K. Influence of the semi-rigid bolted steel joints on the frame behaviour. Journal of Civil Engineering and Management 2010; 16(2): 237-241, https://doi.org/10.3846/jcem.2010.27.
9. Della Corte G, Landolfo R, Mazzolani FM. Post-earthquake fire resistance of moment resisting steel frames. Fire Safety Journal 2003; 38(7): 593-612, https://doi.org/10.1016/S0379-7112(03)00047-X.
10. Dovstam K. Augmented Hooke's law based on alternative stress relaxation models. Computational Mechanics 2000; 26(1): 90-103, https://doi.org/10.1007/s004660000157.
11. El Ghor AH, Hantouche EG, Morovat MA. Review of research on the fire behavior of simple shear connections. Fire Technology 2018; 54: 1149-1169, https://doi.org/10.1007/s10694-018-0736-9.
12. El Kalash S, Hantouche E. Mechanical modeling for predicting the axial restraint forces and rotations of steel top and seat angle connections at elevated temperatures. Journal of Structural Fire Engineering 2017; 8(3): 258-286, https://doi.org/10.1108/JSFE-05-2017-0033.
13. Fischer EC, Chicchi R, Choe L. Review of research on the fire behavior of simple shear connections. Fire Technology 2021; 57: 1519-1540, https://doi.org/10.1007/s10694-021-01105-1.
14. Grzejda R, Parus A. Experimental studies of the process of tightening an asymmetric multi-bolted connection. IEEE Access 2021; 9: 47372-47379, https://doi.org/10.1109/ACCESS.2021.3067956.
15. Grzejda R, Parus A. Health assessment of a multi-bolted connection due to removing selected bolts. FME Transactions 2021; 49(3): 634-642, https://doi.org/10.5937/fme2103634G.
16. Grzejda R, Parus A, Kwiatkowski K. Experimental studies of an asymmetric multi-bolted connection under monotonic loads. Materials 2021; 14(9): 2353, https://doi.org/10.3390/ma14092353.
17. Grzesik W. Effect of the machine parts surface topography features on the machine service (in Polish). Mechanik 2015; 88(8-9): 587-593, https://doi.org/10.17814/mechanik.2015.8-9.493.
18. Guo Z, Lu N, Zhu F, Gao R. Effect of preloading in high-strength bolts on bolted-connections exposed to fire. Fire Safety Journal 2017; 90: 112-122, https://doi.org/10.1016/j.firesaf.2017.04.030.
19. Hantouche EG, Sleiman SA. Response of double angle and shear endplate connections at elevated temperatures. International Journal of Steel Structures 2016; 16(2): 489-504, https://doi.org/10.1007/s13296-016-6019-8.
20. Heidarpour A, Bradford MA. Behaviour of a T-stub assembly in steel beam-to-column connections at elevated temperatures. Engineering Structures 2008; 30(10): 2893-2899, https://doi.org/10.1016/j.engstruct.2008.04.007.
21. Hu G, Engelhardt M. Studies on the behavior of steel single-plate beam end connections in a fire. Structural Engineering International 2012; 22(4): 462-469, https://doi.org/10.2749/101686612X13363929517497.
22. Hu G, Engelhardt MD. Experimental investigation of steel single plate beam end connections at elevated temperatures. Engineering Structures 2014; 58: 141-151, https://doi.org/10.1016/j.engstruct.2013.09.015.
23. Huang S-S, Davison B, Burgess IW. Experiments on reverse-channel connections at elevated temperatures. Engineering Structures 2013; 49: 973-982, https://doi.org/10.1016/j.engstruct.2012.12.025.
24. Li Y, Zhao J. Analytical investigation of beam-to-column endplate connections at elevated temperatures. International Journal of Steel Structures 2019; 19(2): 398-412, https://doi.org/10.1007/s13296-018-0127-6.
25. Lim JBP, Young B. Effects of elevated temperatures on bolted moment-connections between cold-formed steel members. Engineering Structures 2007; 29(10): 2419-2427, https://doi.org/10.1016/j.engstruct.2006.11.027.
26. Lochan S, Mehmanparast A, Wintle J. A review of fatigue performance of bolted connections in offshore wind turbines. Procedia Structural Integrity 2019; 17: 276-283, https://doi.org/10.1016/j.prostr.2019.08.037.
27. Nah H-S, Lee H-J, Kim K-S, Kim J-H, Kim W-B. Method for estimating the clamping force of high strength bolts subjected to temperature variation. International Journal of Steel Structures 2009; 9: 123-130, https://doi.org/10.1007/BF03249487.
28. Nakahara T, Hirohata M, Kondo S, Furuichi T. Paint coating removal by heating for high-strength bolted joints in steel bridge and its influence on bolt axial force. Applied Mechanics 2021; 2(4): 728-738, https://doi.org/10.3390/applmech2040042.
29. Noh M-H, Cerik BC, Han D, Choung J. Lateral impact tests on FH32 grade steel stiffened plates at room and sub-zero temperatures. International Journal of Impact Engineering 2018; 115: 36-47, https://doi.org/10.1016/j.ijimpeng.2018.01.007.
30. Novoselac S, Kozak D, Ergić T, Damjanović D. Fatigue damage assessment of bolted joint under different preload forces and variable amplitude eccentric forces for high reliability. Fracture at all Scales, Lecture Notes in Mechanical Engineering 2017: 239-268, https://doi.org/10.1007/978-3-319-32634-4_13.
31. O'Connor PDT. Variation in reliability and quality. Quality and Reliability Engineering International 2004; 20(8): 807-821, https://doi.

org/10.1002/qre.596.
32. Omar R, Abdul Rani MN, Yunus MA. Representation of bolted joints in a structure using finite element modelling and model updating. Journal of Mechanical Engineering and Sciences 2020; 14(3): 7141-7151, https://doi.org/10.15282/jmes.14.3.2020.15.0560.
33. Palenica P, Powałka B, Grzejda R. Assessment of modal parameters of a building structure model. Springer Proceedings in Mathematics & Statistics 2016; 181: 319-325, https://doi.org/10.1007/978-3-319-42402-6_25.
34. Pang X-P, Hu Y, Tang S-L, Xiang Z, Wu G, Xu T, Wang X-Q. Physical properties of high-strength bolt materials at elevated temperatures. Results in Physics 2019; 13: 102156, https://doi.org/10.1016/j.rinp.2019.102156.
35. Petrina T. Steel connections post-earthquake fire tests setup. Procedia Engineering 2016; 161: 133-136, https://doi.org/10.1016/j.proeng.2016.08.510.
36. PN-EN 1993-1-8, 2006. Eurocode 3: Design of steel structures, Part 1–8: Design of joints.
37. Qiang X, Wu N, Jiang X, Luo Y, Bijlaard F. Experimental and numerical analysis on full high strength steel extended endplate connections in fire. International Journal of Steel Structures 2018; 18(4): 1350-1362, https://doi.org/10.1007/s13296-018-0130-y.
38. Rahnavard R, Thomas RJ. Numerical evaluation of the effects of fire on steel connections; Part 1: Simulation techniques. Case Studies in Thermal Engineering 2018; 12: 445-453, https://doi.org/10.1016/j.csite.2018.06.003.
39. Rahnavard R, Thomas RJ. Numerical evaluation of the effects of fire on steel connections; Part 2: Model results. Case Studies in Thermal Engineering 2019; 13: 100361, https://doi.org/10.1016/j.csite.2018.11.012.
40. Ranatowski E. Problems of welding in shipbuilding - an analytic-numerical assessment of the thermal cycle in haz with three dimensional heat source models in agreement with modelling rules, Part I: Theoretical basis of modelling and an analytical assessment of heat sources models. Polish Maritime Research 2010; 17(1): 75-79, https://doi.org/10.2478/v10012-010-0009-0.
41. Savkin AN. Assessing the reliability of thread joints under variable loads. Journal of Machinery Manufacture and Reliability 2007; 36(4): 336-340, https://doi.org/10.3103/S105261880704005X.
42. Schaumann P, Kirsch T. Simulation of a flush endplate connection at elevated temperatures including fracture simulation. Journal of Structural Fire Engineering 2013; 4(2): 103-112.
43. Seif M, Main J, Weigand J, McAllister TP, Luecke W. Finite element modeling of structural steel component failure at elevated temperatures. Structures 2016; 6: 134-145, https://doi.org/10.1016/j.istruc.2016.03.002.
44. Shaheen MA, Foster ASJ, Cunningham LS, Afshan S. Behaviour of stainless and high strength steel bolt assemblies at elevated temperatures – A review. Fire Safety Journal 2020; 113: 102975, https://doi.org/10.1016/j.firesaf.2020.102975.
45. Shaheen MA, Foster ASJ, Cunningham LS, Afshan S. Selecting suitable bolt parameters to achieve ductility at elevated temperatures. Ce/papers 2021; 4(2-4): 1191-1195, https://doi.org/10.1002/cepa.1411.
46. Spyrou S, Davison JB, Burgess IW, Plank RJ. Experimental and analytical investigation of the 'compression zone' component within a steel joint at elevated temperatures. Journal of Constructional Steel Research 2004; 60(6): 841-865, https://doi.org/10.1016/j.jcsr.2003.10.005.
47. Stranghöner N, Lorenz C, Feldmann M, Citarelli S, Bleck W, Münstermann S, Brinnel V. Brittle fracture of high-strength bolts of large diameters at low temperatures (in German). Stahlbau 2018; 87(1): 17-29, https://doi.org/10.1002/stab.201810559.
48. Tartaglia R, D'Aniello M, Wald F. Behaviour of seismically damaged extended stiffened end-plate joints at elevated temperature. Engineering Structures 2021; 247: 113193, https://doi.org/10.1016/j.engstruct.2021.113193.
49. Towarnicki P, Grzejda R. Analysis of the impact of temperature load on the state of stress in a bolted flange connection. Proc. of the 2018 International Interdisciplinary PhD Workshop, IEEE Conferences 2018: 96-98, https://doi.org/10.1109/IIPHDW.2018.8388333.
50. Truong DD, Jung H-J, Shin HK, Cho S-R. Response of low-temperature steel beams subjected to single and repeated lateral impacts. International Journal of Naval Architecture and Ocean Engineering 2018; 10(6): 670-682, https://doi.org/10.1016/j.ijnaoe.2017.10.002.
51. Tu Y, Huang Y-K, Tu S-T. Real-time monitoring of bolt clamping force at high temperatures using metal-packaged regenerated fiber Bragg grating sensors. International Journal of Pressure Vessels and Piping 2019; 172: 119-126, https://doi.org/10.1016/j.ijpvp.2019.03.006.
52. Wang G, Ding Y. The interface friction in the friction-type bolted joint of steel truss bridge: Case study. The Baltic Journal of Road and Bridge Engineering 2020; 15(1): 187-210, https://doi.org/10.7250/bjrbe.2020-15.467.
53. Wang H, Hu Y, Wang X-Q, Tao Z, Tang S-L, Pang X-P, Chen YF. Behaviour of austenitic stainless steel bolts at elevated temperatures. Engineering Structures 2021; 235: 111973, https://doi.org/10.1016/j.engstruct.2021.111973.
54. Wang M, Wang P. Strategies to increase the robustness of endplate beam–column connections in fire. Journal of Constructional Steel Research 2013; 80: 109-120, https://doi.org/10.1016/j.jcsr.2012.09.017.
55. Wang P, You Y, Liu M, Zhang B, Zhou S, Chen J. Behavior of thread-fixed one-side bolted T-stubs with backing plates at ambient and elevated temperatures. Journal of Constructional Steel Research 2020; 170: 106093, https://doi.org/10.1016/j.jcsr.2020.106093.
56. Wang P, Zhang L, Wang L. Influence of temperature on the bolt loads and variation in a bolted flange for subsea pipeline connection. Mathematical Problems in Engineering 2021; 2021: 5636941, https://doi.org/10.1155/2021/5636941.
57. Wang YC, Dai XH, Bailey CG. An experimental study of relative structural fire behaviour and robustness of different types of steel joint in restrained steel frames. Journal of Constructional Steel Research 2011; 67(7): 1149-1163, https://doi.org/10.1016/j.jcsr.2011.02.008.
58. Xie B, Hou J, Xu Z, Dan M. Component-based model of fin plate connections exposed to fire - part II: Establishing of the component-based model. Journal of Constructional Steel Research 2018; 145: 218-231, https://doi.org/10.1016/j.jcsr.2018.02.018.
59. Xu J, Wang J, Mohamed HS, Han J, Han Z, Tu J, Li Z. Post-earthquake fire resistance of bolted end-plate connection joint with end-plate and web stiffeners. Journal of Constructional Steel Research 2021; 185: 106835, https://doi.org/10.1016/j.jcsr.2021.106835.
60. Yahyai M, Rezaeian A. Behavior of beams in bolted column-tree frames at elevated temperature. Fire and Materials 2016; 40(3): 482-497, https://doi.org/10.1002/fam.2305.
61. Yang K-C, Chen S-J, Ho M-C. Behavior of beam-to-column moment connections under fire load. Journal of Constructional Steel Research 2009; 65(7): 1520-1527, https://doi.org/10.1016/j.jcsr.2009.02.010.
62. You Y, Liu M, Liu Y, Wang P, Zhou S, Chen J. Experimental studies on thread-fixed one-side bolted T-stubs in tension at elevated temperatures. Journal of Constructional Steel Research 2020; 171: 106139, https://doi.org/10.1016/j.jcsr.2020.106139.
63. Yu H, Burgess IW, Davison JB, Plank RJ. Experimental investigation of the behaviour of fin plate connections in fire. Journal of Constructional Steel Research 2009; 65(3): 723-736, https://doi.org/10.1016/j.jcsr.2008.02.015.