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Analysis of the load-carrying capacity of a bolted connection between a steel floor beam and a column

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ABSTRACT:
The paper analyses the load-carrying capacity of a bolted overlapping connection between a floor beam and a column. Three variants of the connection were considered: without the support seat and with support in the form of an angle bracket and a plate. The value of force acting on the connection was determined based on calculations made for the adopted conditions. The load-carrying capacity of bolts and plates for the assumed load was evaluated and the values of stress in the contact zone were compared for the analysed cases. It was demonstrated that the load-carrying capacity of bolted overlapping connections of the beam/column type depends on the adopted solution in terms of contact shape (presence or absence of a support seat), the type of support seat (if any) and the number, class and spacing of bolts. The results of the calculations showed that the most effective method of connection for the adopted assumptions is the connection with the support seat capital in the form of an angle bracket. The use of this type of beam support significantly reduces bolt tension and reduces the stresses occurring in the contact zone of the connected elements.

KEYWORDS:
steel constructions; bolt connections; designing

1. Introduction

An important issue related to the design of buildings with steel frame structures is the correct shaping of connections between individual structural elements. These connections are made by welded or bolted connections. When mounting connections, bolted connections are usually used as they are easier to form under construction conditions compared to welded connections. The type of connection used depends, among other factors, on the static diagram of the beam. In the case of floor beams, two situations are most common: a rigid connection to the column (restraint) or an articulated connection. This study analysed the load-carrying capacity of a freely supported, articulated beam bolted to a column. It determined the load-carrying capacity of the connection and compared the values of stress and deformation of the elements in the contact area for the joint variants considered.

With the constant development of steel cubic structures, the emergence of new materials and technology and the strive to increase efficiency and reduce investment costs, actions are being taken to improve existing solutions and propose new techniques in the field of shaping bolted connections of steel structural elements.

A common solution in the design of screw contacts is the use of angle brackets as connecting elements. In studies [1, 2], the author presented the results of studies into experimental bolted

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connections, in which rolled angle bars were used. The result of this research was the development of a new mathematical model that more accurately reflected the actual operation of the connection and improved the design procedures used in its dimensioning. The problems related to the evaluation of the load-carrying capacity of bolted contacts made with rolled angle bars were also discussed in the following paper [3]. A mechanical model (spring) was developed to assess the behaviour of shear steel connections under failure conditions caused by the sudden removal of the column. A similar solution, referring to the spring mechanism MSC (multi-spring component), used for the evaluation of the rotational stiffness of semi-rigid beam-to-column connections was also proposed in this paper [4]. Issues related to the improvement of the existing methods of bolt connection dimensioning by creating new and more accurate models of their operation using numerical analysis were also presented in the studies [5, 6].

An important issue related to the design of steel frame buildings is the behaviour of the structure at elevated temperatures. The study [7] analysed typical beam/column connections in fire conditions. A numerical model was developed, allowing for the evaluation of the contact load-carrying capacity at temperatures up to 900°C. In the study [8], the behaviour of a bolted end-plate joint with a diagonal plate was examined, showing its higher resistance to elevated temperatures compared to the traditional contact with vertical plate.

The problems related to the design of bolted overlapping beam/column connections in terms of the load-carrying capacity of a connecting plate welded to the column were discussed in the study [9]. The study presented results of previous research and a research program aimed at the development of improved design recommendations for this type of connections.

Since steel frame structures of steel buildings quite often contain articulated beam/post connections, this work attempts to analyse three different variants of such a solution.

2. Goal and scope of work

The aim of the work was to perform an analysis of three variants of bolted connection (Figs. 1-3) in order to evaluate load-carrying capacity and determine the values of stress in the connected elements in the contact area.

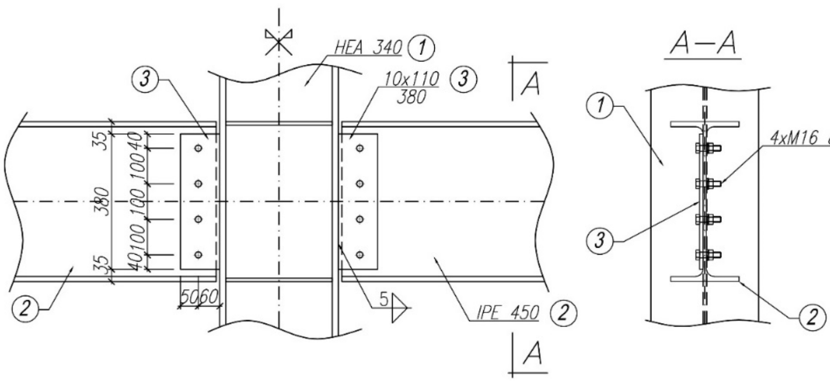

Fig. 1. Connection without support seat: variant 1

The following assumptions were made for the purposes of the calculations:

- useful load of 5 kN/m^2 , category D2 [10]
- span of floor beams: 6.0 m
- spacing of floor beams: 3.0 m
- bolts: M16 kl. 8.8
- support seat (variant 2) – sheet metal 30x50x200
- weld fixing the support seat (variant 2): fillet weld, thickness: 5 mm
- support seat (variant 3) – angle bracket 160x160x15

- weld fixing the support seat (variant 3): fillet weld, thickness: 10 mm
- connection plate with dimensions of 10x110x380
- connection sheet weld: double-sided fillet weld, thickness: 5 mm
- steel – S235
- reinforced concrete floor slab, thickness: 20 cm
- due to the industrial purpose of the building, it was assumed that the ceiling finishing layer would be smooth-trowelled floor slab.

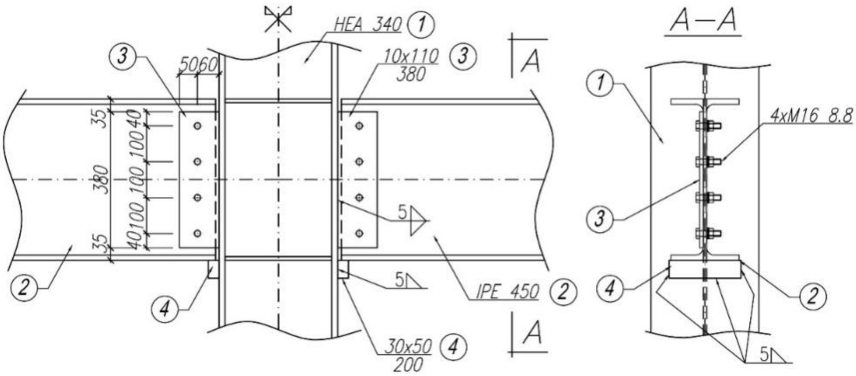

Fig. 2. Connection with support seat in the form of sheet metal: variant 2

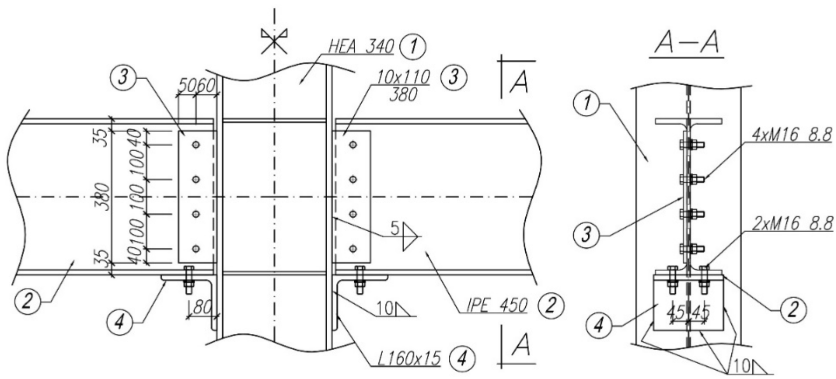

Fig. 3. Connection to the support seat in the form of an angle bracket: variant 3

For the above assumptions, the Advance Design program was used for performing static calculations to determine the size of floor beam and column profiles (Figs. 1-3) and the value of transverse force acting on the connection, which was 138.1 kN. Then, using the IdeaStatica program, calculations were made for the numerical model of connection variants.

3. Results and discussion

The results of the calculations conducted in accordance with [11] for checking the load-carrying capacity of the bolts for the connections analysed (for the most heavily loaded bolt in each variant) are given in Table 1.

In the connections analysed in the study, the bolts work mainly in shear conditions, with very small proportion of extension and occurring only when the lower beam flange is fixed to the support seat by means of bolts. Therefore, the decisive factor for the correct selection of bolts will be their use in shear. The failure to meet the load-carrying capacity conditions while taking into account the shear and tensile interaction for variant 1 and 2 is caused by the excessive disproportion between the shear force per bolt and its shear load-carrying capacity expressed as U_{ts}.

Table 1
Bolt tension in the connections studied

Connection type	Use in shear U_{ts} [%]	Use in extension U_{tt} [%]	Shear and tensile interaction U_{tts} [%]
Variant 1	173.1	0	173.1
Variant 2	104.4	0	104.4
Variant 3	84.1	7.5	89.4

The total tension for the most heavily loaded bolt for variant 1 is 66% higher than for variant 2 and 94% higher than for variant 3. This is due to the fact that both the vertical force and the bending moment (resulting from the eccentric effect of the force in relation to the axis of the connectors) for the connection without the support seat is transmitted by the bolts. In variants 2 and 3, the bolts carry only the component from the bending moment, whereas the vertical force is applied to the support seat (together with the weld that fixes it to the column). In order to ensure the required load-carrying capacity for variant 1 of the connection in consideration for the very large gap between the actual and required load-carrying capacity, the number of bolts (with the same class and diameter) should be increased, which, with contact geometry, would make it necessary to place them in two rows.

The use of bolts for variant 2 slightly exceeds the permissible value (by less than 5%); also in this case it is necessary to correct the adopted bolts. As the excess is relatively small to ensure that the load-carrying capacity conditions are met, the diameter of the bolt can be increased (while maintaining the number and class) from M16 to M20.

For variant 3, all the required load-carrying capacity conditions are met. This results from the fact that the force applied to the connection is distributed not only to the bolts fixing the beam web to the column, but also to the bolts fixing the bottom flange of the beam to the support seat in the form of a support seat.

Figures 4-6 show the stress distributions in the walls of individual elements in the contact zone.

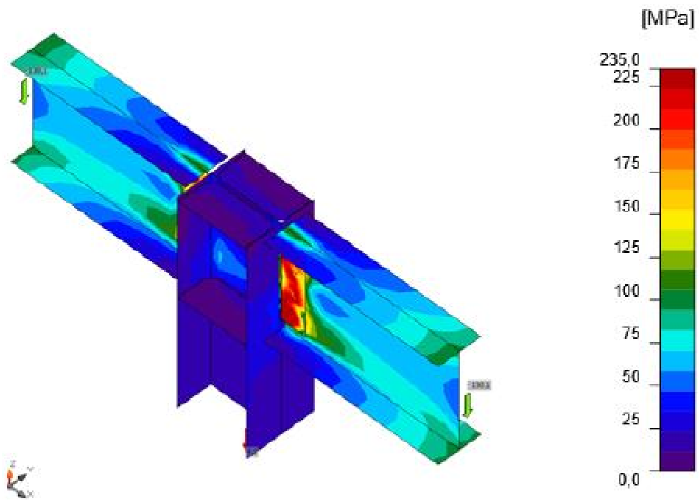

Fig. 4. Distribution of equivalent stresses in the contact zone: variant 1 (without the support seat)

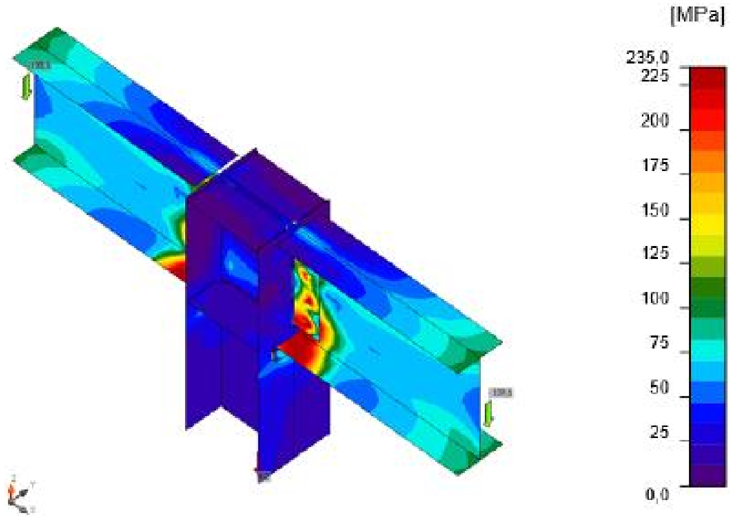

Fig. 5. Distribution of equivalent stresses in the contact zone: variant 2
(with the support seat in the form of a plate)

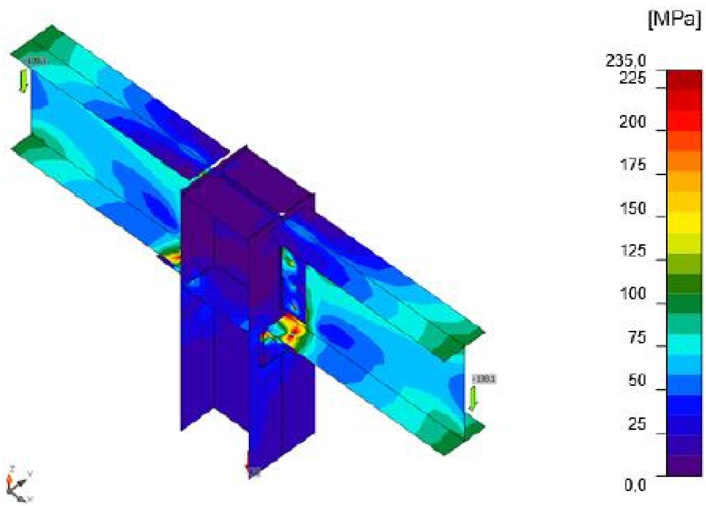

Fig. 6. Distribution of equivalent stresses in the contact zone: variant 3
(with the support seat in the form of an angle bracket)

The maximum stress for variant 1 is 244.4 MPa and exceeds the yield strength of the steel of which the individual components are made by 4%. The zone of maximum stress occurs in the beam web and connecting plate where the bolts are located. This is due to the fact of the lack of a support seat, with all the force acting on the connection transmitted through the outermost part of the web and by means of bolts to the connecting plate welded to the column.

The highest stress for variant 2 occurs in the connecting plate and beam web, near the bolt holes and in the bottom flange of the beam, and in the area of the support seat. The maximum value of these stresses is close to the yield strength of the steel (235 MPa) from which the components are made. The concentration of stresses in these locations results from the force of the bolts to the hole walls (in the web zone) and pressure of the lower flange to the support seat plate on which the beam is supported.

The highest stresses for variant 3 occur at the point where the beam is supported on the support seat, near the openings in the bottom flange of the beam and in the upper flange of the angle bar, and they amount to 235 MPa. The area of the zone of maximum stresses is much smaller than for the other variants. This is because the force acting on the connection is distributed over a larger number of connectors than in variants 1 and 2 and over a larger area of pressing at the contact between the lower beam flange and the support seat compared to variant 2.

4. Conclusions

In overlapping bolted connections of the beam/column type, the degree of shear tension in the bolt is the factor that determines the suitability of the adopted solution. In properly designed contacts, tensile forces are very low or do not occur at all.

The load-carrying capacity of bolted overlapping connections of the beam/column type depends on the adopted solution in terms of contact shape (presence or absence of a support seat), the type of support seat (if any) and the number, class and spacing of bolts.

The use of the support seat significantly reduces bolt stresses and reduces those occurring in the contact zone of the connected elements. Consequently fewer bolts (with the same class and diameter) can be adopted compared to the case of contacts without the seat to ensure the required load-carrying capacity conditions.

The support seat, in the form of an angle bracket, allows the increase in the number of bolts fixing the beam to the column with unchanged geometry of the web contact (1 row of bolts), which leads to a reduction in the tension of the bolts fixed to the beam web and to a reduction in the size of the zone of maximum stresses occurring in the area of the web.

References

[1] Gong Y., Ultimate tensile deformation and strength capacities of bolted-angle connections, Journal of Constructional Steel Research 2014, 100, 50-59.

[2] Gong Y., Test, modelling and design of bolted-angle connections subjected to column removal, Journal of Constructional Steel Research 2017, 139, 315-326.

[3] Oosterhof S.A., Driver R.G., Shear connection modelling for column removal analysis, Journal of Constructional Steel Research 2016, 117, 227-242.

[4] Zhang J., Jiang J., Xu S., Wang Z., An investigation of the effect of semi-rigid connections on sudden column removal in steel frames, Structures 2018, 13, 166-177.

[5] Zhao Z., Liang B., Liu H., Li Y., Simplified numerical model for high-strength bolted connections, Engineering Structures 2018, 164, 119-127.

[6] Zeynali Y., Jafari Samimi M., Mazroei A., Asgari Marnani J., Rohanimanesh M.S., Experimental and numerical study of frictional effects on block shear fracture of steel gusset plates with bolted connections, Thin-Walled Structures 2017, 121, 8-24.

[7] Rahnavard R., Thomas R.J., Numerical evaluation of the effects of fire on steel connections; Part 2: Model results, Case Studies in Thermal Engineering 2019, 13.

[8] Zahmatkesh F., Osman M.H., Talebi E., Kueh A.B.H., Tahir M., Structural performance of steel beams and frames with slant end-plate connections at elevated temperature, Engineering Structures 2019, 187, 396-413.

[9] Thomas K., Driver R.G., Oosterhof S.A., Callele L., Full-scale tests of stabilized and unstabilized extended single-plate connections, Structures 2017, 10, 49-58.

[10] PN-EN 1991-1-1, Eurocode 1: Actions on structures, Part 1-1: General actions – Densities, self-weight, imposed loads for buildings, 2004 (in Polish).

[11] PN-EN 1993-1-8, Eurocode 3: Design of steel structures, Part 1-8: Design of joints, 2006 (in Polish).

Analiza nośności połączenia śrubowego stalowej belki stropowej ze słupem

STRESZCZENIE:
Dokonano analizy nośności śrubowego połączenia zakładkowego belki stropowej ze słupem. Rozpatrywano trzy warianty połączenia: bez stołeczka podporowego oraz z oparciem belki na stołeczku podporowym w postaci kątownika oraz blachy. Dla przyjętych założeń wykonano obliczenia, na podstawie których określono wartość siły działającej na połączenie. Sprawdzono nośność śrub i blach dla przyjętego obciążenia oraz porównano wartości naprężeń w strefie styku dla analizowanych przypadków. Wykazano, że nośność śrubowych połączeń zakładkowych typu belka/słup zależy od przyjętego rozwiązania w zakresie ukształtowania styku (występowanie lub brak stołeczka podporowego), typu zastosowanego stołeczka podporowego (o ile występuje) oraz ilości, klasy i rozstawu śrub. Wyniki przeprowadzonych obliczeń wykazały, iż najefektywniejszym sposobem połączenia, dla przyjętych założeń, jest styk ze stołeczkiem podporowym w postaci kątownika. Zastosowanie tego rodzaju podparcia belki znacznie obniża wytężenie śrub oraz powoduje zmniejszenie naprężeń występujących w strefie przystykowej łączonych elementów.

SŁOWA KLUCZOWE:
konstrukcje stalowe; połączenia śrubowe; projektowanie