MODELLING OF PRELOAD DISTRIBUTION IN BOLTED JOINTS WITH THE SPIDER BOLT MODEL

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Abstract: *The paper is a part of wider research based on the system approach to the problem of modelling and calculations of bolted flange connections. With this approach it is possible to independent consideration of each system's element in order to find the best model of this element. The aim of this study is to develop a model of the single-bolted joint separated from the bolted flange connection.*

An analysis is conducted for the spider bolt model which is an equivalent model corresponding to the spatial bolt model. The key problem in the case of modelling bolts with the spider bolt model is adequate distribution of the preload on the bolt head. Accuracy of modelling bolts using the spider bolt model strongly depends on the way of this distribution. The effect of preload distribution in the spider bolt model on stiffness values of the element fastened in the bolted joint has been examined. The result of actions described in the paper is proposal distribution of the preload on nodes belonging to the bolt head which guarantees the best effects of spider bolt model application.

Keywords: BOLTED JOINT, SPIDER BOLT MODEL, PRELOAD, FINITE ELEMENT METHOD

1. Introduction

The primary task of the machine modelling phase is to find a compromise between the level of model simplification and the expected accuracy of modelling. This is particularly important for modelling complex systems with many elements being in a contact such as bolted connections [2, 8].

The bolted connection can be regarded as a system consisting of subsystems (which are the elements of the connection) [3]. In the case of the bolted flange connection (Fig. 1), these subsystems include: bolts, the flange element, the rigid support and the contact layer between joined elements. With this approach, each of these subsystems can be developed and modeled separately using different methods for modelling.

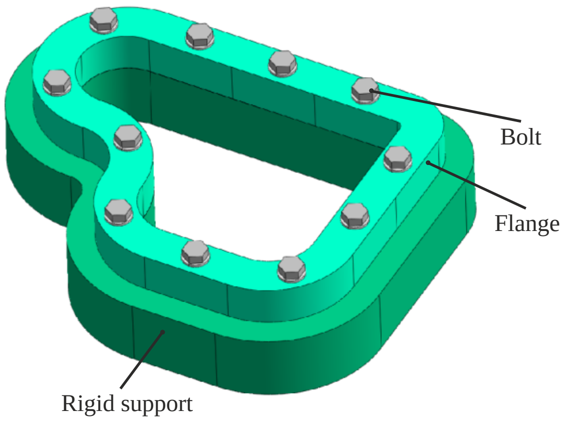

Fig. 1 *Example of a bolted flange connection*

The most common method of modelling complex structures is currently the finite element method (FEM) [12]. In the papers [4, 6, 7] several different FE-models of bolts are presented, which can be used for modelling bolted flange connections. These include:
- the no-bolt model,
- plane models,
- the coupled bolt model,
- the rigid body bolt model,
- the spider bolt model,
- spatial bolt models.

In the present study, the spider bolt model (SB model) is assumed as the model of the bolt. This is an equivalent model corresponding to the reference spatial bolt model (3DB model), which according to experimental tests deliver the best accurate results of modelling [11].

One of the fundamental aspects of modelling bolts with the SB model is adequate distribution of the preload on the bolt head. It has a significant impact on the accuracy of joint modelling. The aim of this study is to investigate the effect of preload distribution in the SB model on stiffness of the flange element fastened in the bolted joint. As a result of the research proposal distribution of the preload on nodes belonging to the bolt head which guarantees the best effects of SB model application is presented. All calculations were conducted with use of the Midas NFX 2014 finite element software.

2. Models of the bolted joint

The tests were performed on the example of a fragment of the bolted flange connection shown in Fig. 1. The considered joint consists of a deformable flange element mounted with a single bold M10 made in the mechanical property class 10.9 to a rigid support. Thickness of the flange element h is equal to 30 mm. The preload of the bolt F_m is equal to 17,2 kN and it was set down based on Polish Standard PN-EN 1591-1 [9]. The surface area of preload acting A_m is equal to 69,75π mm^2 and it was set down on the base of Polish Standard PN-EN ISO 7091 [10].

In the FEM-based models of the joint, occurrence of the contact layer between connected elements is omitted. For the construction of discrete models standard finite elements are used. The joined element model and the spatial bolt model are created with 3D finite elements. In contrast, in the SB model the plain part of the bolt and its head are modeled with use of beam elements but the total volume of beam elements for the head is assumed to be equal to the volume of the head of the bolt in the 3DB model. Developed discrete models of the bolted joint are shown respectively in Fig. 2 and Fig. 3.

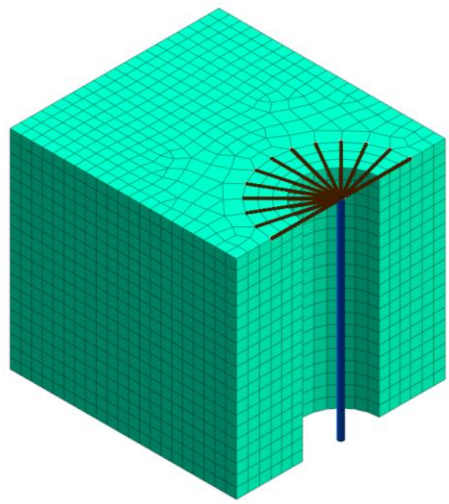

Fig. 2 *Bolted joint with the spider bolt model*

Methods of models loading are shown in Fig. 4. In this figure the following new designations are used:

F_h – part of the preload F_m applied to the head of the bolt,
F_p – part of the preload F_m applied to the plain part of the bolt.

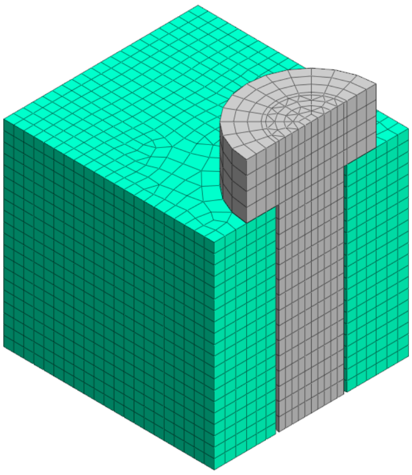

Fig. 3 *Bolted joint with the spatial bolt model*

Between F_h, F_p and F_m occur the following dependences

$$F_m = F_h + F_p \tag{1}$$

$$F_h = \alpha \cdot F_m \tag{2}$$

$$F_p = \beta \cdot F_m \tag{3}$$

where α – constant of load proportionality for the head of the bolt, β – constant of load proportionality for the plain part of the bolt (wherein $\alpha + \beta = 1$).

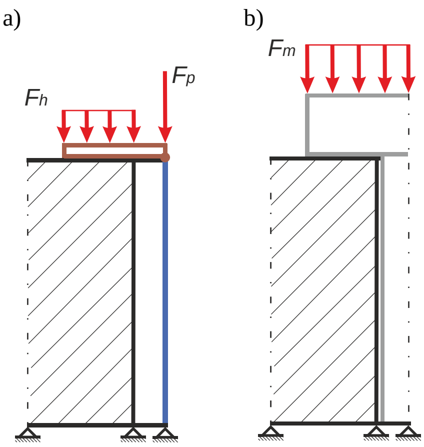

Fig. 4 *Scheme of bolted joint loading: a) in the case of the SB model, b) in the case of the 3DB model*

3. Results of bolted joint calculations

Treating the bolt as a linear element, its stiffness k_b can be easily and correctly determined as inverse of elastic flexibility e_b

$$k_b = \frac{1}{e_b} \tag{4}$$

Elastic flexibility e_b is the sum of elastic flexibility of individual fragments of the bolts e_{bi}

$$e_b = \sum_i e_{bi} \tag{5}$$

Elastic flexibility e_{bi} can be calculated with use of the Hooke's law [1] converted into the form

$$e_{bi} = \frac{l_i}{E \cdot A_i} \tag{6}$$

where E – modulus of elasticity, A_i – cross-sectional area of the i-th bolt's fragment, l_i – length of the i-th bolt's fragment.

There is no simple formulas for calculating stiffness of the joined flange element $k_{f,j}$. To designate it the most frequently the finite element method is used. Then stiffness of the joined flange element can be defined based on the relationship (for a review, see [5])

$$k_{f,j} = \frac{F_m}{\delta_{sum}} \tag{7}$$

where δ_{sum} – average normal displacement of nodes lying in the surface area A_m under the action of the preload F_m, j – symbol of the model of the joint, $j \in \{SB, 3DB\}$.

Stiffness values of the joined flange element for both models are given in Table 1.

Table 1*: Stiffness of the joined flange element as a function of the bolt load*

α	β	$k_{f,SB}$ [MN/mm]	$k_{f,3DB}$ [MN/mm]
1,0	0	2,22	
0,9	0,1	2,47	
0,85	0,15	2,61	
0,8	0,2	2,78	2,90
0,75	0,25	2,96	
0,7	0,3	3,18	
0,6	0,4	3,70	

The relative difference between the $k_{f,SB}$ and $k_{f,3DB}$ values can be analyzed on the basis of the W index

$$W = \frac{k_{f,SB} - k_{f,3DB}}{k_{f,3DB}} \cdot 100 \tag{8}$$

Calculated W index values are summarized in Table 2. Based on these results it can be concluded that the 3DB model in the best way may be replaced by the SB model, when

$$\frac{\alpha}{\beta} \in (3 \div 4) \tag{9}$$

Table 2*: W index values as a function of the bolt load*

α	β	W [%]
1,0	0	-23,45
0,9	0,1	-14,95
0,85	0,15	-9,94
0,8	0,2	-4,31
0,75	0,25	2,06
0,7	0,3	9,35
0,6	0,4	27,58

4. Conclusions

In the paper an analysis of the bolted flange connection for named models created with use of the finite element method was carried out. Two types of the connection were examined: with a bolt modeled using spatial elements and with a bolt modeled as the spider bolt model. It has been shown that the spider bolt model can be successfully applied as a substitute model for the reference spatial model by adopting the appropriate preload distribution.

Investigations of bolted flange connections are often conducted in the aspect of the selected problems. Then knowledge of the distribution of stress and strain levels in all elements of the connection is not needed. In the case of FEM analysis of stiffness of bolted flange connections, it is better to use simplified models of bolts and bolted flange connections, as demonstrated in this paper.

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