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Author: Rafał Grzejda

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MODELLING OF BOLTS IN MULTI-BOLTED CONNECTIONS USING MIDAS NFX

Rafał Grzejda

Department of Mechanics and Fundamentals of Machine Design
West Pomeranian University of Technology, Szczecin
19 Piastów Ave., 70-310 Szczecin, Poland
e-mail: rafal.grzejda@zut.edu.pl
phone: +48 91 4494969
fax: +48 91 4494564

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Abstract

In the paper a fragment of research on development of modelling methods of asymmetrical multi-bolted flange connections is presented. The effect of the bolt modelling method in a single bolted joint on both the stiffness characteristics of elements joined in the multi-bolted flange connection and bold forces have been examined. An analysis of the multi-bolted flange connection is carried out for selected models created using the finite element method (FEM). Guidelines for the selection of the bolt modelling method in the case of both the stiffness analysis and the load analysis of multi-bolted flange connections have been pointed out.

Introduction

Starting a process of designing the mechanical system, the designer needs to find a compromise between the level of model simplification and the required accuracy of performed calculations results (for a review, see SZABRACKI, LIPIŃSKI 2014). This applies particularly to FE-modelling of systems of many bodies being in a contact, an example of which are multi-bolted connections (Fig. 1).

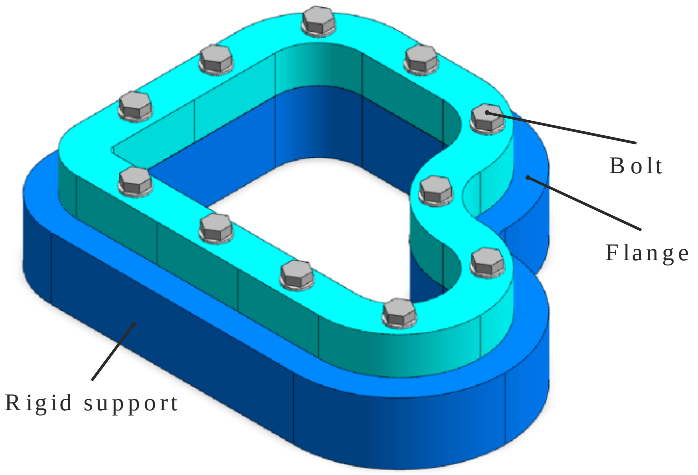

Fig. 1. Multi-bolted flange connection

In the papers (GRZEJDA 2013, WITEK, GRZEJDA 2006) modelling and calculations of selected multi-bolted flange connections were presented. The described models of these connections can be used to calculate asymmetrical systems, in which a flange element is joined with a rigid support. The most important feature of the proposed method of modelling is the treatment of the multi-bolted connection as a system composed of three subsystems, which are: bolts, the flange element and the contact layer between the flange element and the rigid support. Through this approach each subsystem can be modeled and developed separately.

In the paper (GRZEJDA 2014) the effect of the method of single bolted joint modelling on stiffness values of elements joined in this connection was investigated. Continuing with this work is the current paper, dedicated to developing the subsystem of bolts as a part of the multi-bolted system. Considerations are limited to testing the effect of simplifications of the single bolted joint model on both the stiffness characteristics of the connection and forces in the bolds. All analyses were carried out using the Midas NFX 2014 program.

Basics of the analysis

One of the important problems considered in the case of calculations of multi-bolted connections is the stiffness analysis of its elements. Treating the bolts as linear elements, their elastic flexibility can be easily and correctly determined by the instructions given in the standard VDI 2230 (GRUDZIŃSKI 2012) or by using the simplified method (BOUZID, BEGHOUL 2003). However, to determine the elastic flexibility of elements joined in multi-bolted connections, the finite element method is increasingly applied (for a review, see PEDERSEN, PEDERSEN 2008).

Analyzing publications on FE-modelling of bolted connections, it can be concluded that the following models are most commonly used by researchers:

- models without any bolts, but with the influence of the preload (CALISKAN 2006, TIROVIC, VOLLER 2005),
- plane models (TENMA et al. 2011),
- models, wherein the plain part of the bolt is modeled as a beam and its head as a rigid or deformable element (MONTGOMERY 2002, MONTGOMERY 2006),
- spatial models (NAGATA et al. 2011, WANG et al. 2013).

In the paper the usefulness of bolt models described in the literature for modelling of a set of bolts in multi-bolted connections is examined. For this purpose the following models of the separated bolted joint are chosen:

- the 3DB model, with the bolt modeled using cylindrical spatial elements,
- the SB model, in which 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,
- the RBB model, consisted of the flexible plain part of the bolt and the rigid head of the bolt.

FEM-based models of the multi-bolted connection

Research were executed on an example of the multi-bolted flange connection shown in Fig. 1. Calculations are carried out for the thickness of the flange h equal to 30 mm. The flange is fastened to a rigid support by means of eleven bolts M10 made in the mechanical property class 10.9. The preload of the bolt F_m is equal to 17,2 kN and it was set down on the base of Polish Standard PN-EN 1591-1. However, the total surface area of preload acting A_m is equal to 24,1 cm^2 and it was set down based on Polish Standard PN-EN ISO 7091. In the 3DB model of the connection, for modelling of the contact joint between the head of the bold and the flange default contact elements available in the Midas NFX 2014 program is used. In other models, contact elements are not included. Developed computational models of the multi-bolted connection are shown in Fig. 2.

a)
b)
c)

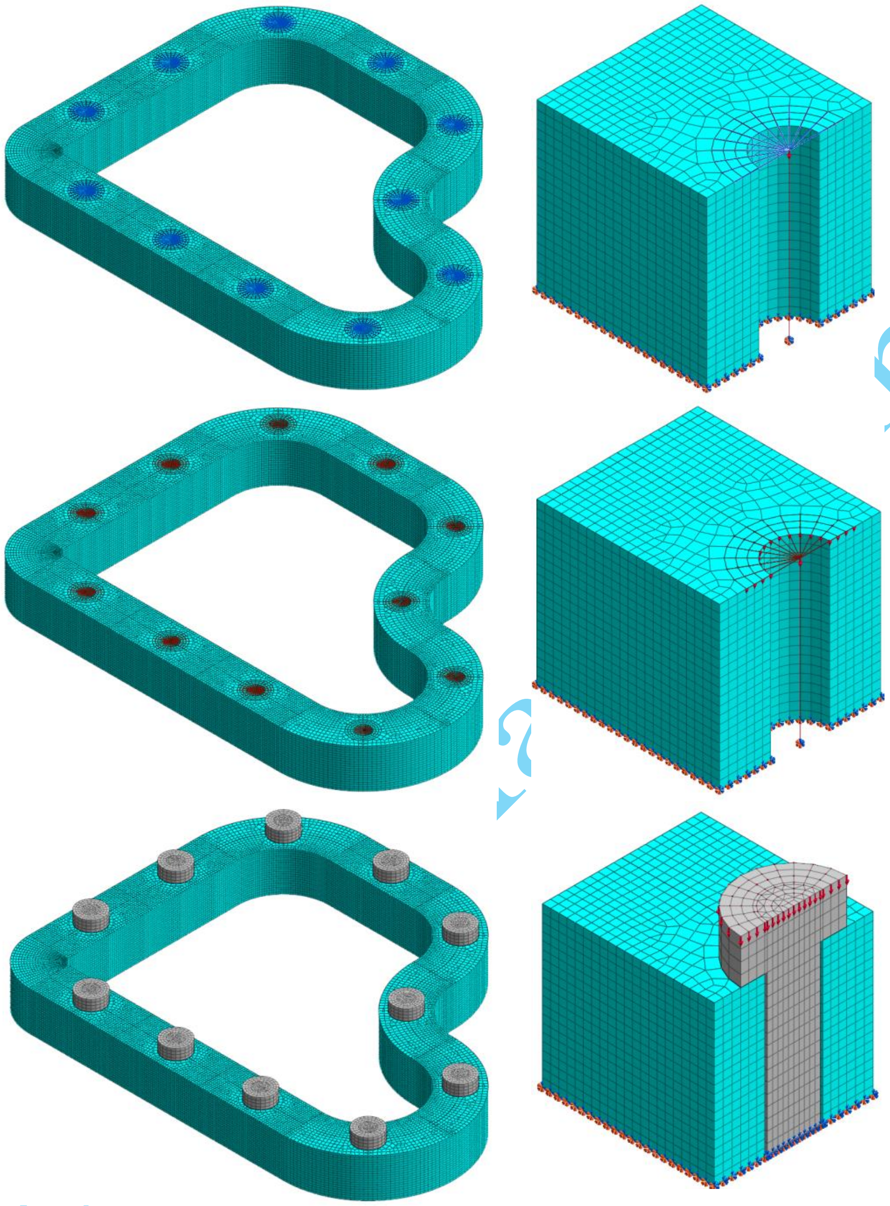

Fig. 2. Computational models of the multi-bolted connection:
a) RBB model, b) SB model, c) 3DB model

Calculations of the multi-bolted connection

The elastic flexibility of the bolt e_s is calculated according to the standard VDI 2230 (GRUDZIŃSKI 2012) as the sum of the elastic flexibility of the individual fragments of the bolt e_{si}

$$e_s = \sum_i e_{si} \tag{1}$$

Calculated from the formula (1) the elastic flexibility of the bolt is adopted equal for all models of the multi-bolted connection. Its value is given in Table 1.

However, the elastic flexibility of the joined flange element $e_{p,j}$ is defined based on the relationship (for a review, see HAIDAR et al. 2011)

$$e_{p,j} = \frac{\delta_{\Sigma}}{F_m} \tag{2}$$

where:
δ_{Σ} – average normal displacement of nodes lying in the total surface area A_m, under the action of forces F_m;
j – symbol of the consecutive FEM model of the connection, j ={RBB, SB, 3DB}.
The elastic flexibility of the joined flange element for all models are given in Table 1.

Table 1. Elastic flexibility values of the joined flange element [mm/MN]

e_s	$e_{p,RBB}$	$e_{p,SB}$	$e_{p,3DB}$
2,91	0,177	0,188	0,184

The relative difference between the obtained elastic flexibility values is analyzed on the basis of the W_x index

$$W_x = \frac{e_{p,x} - e_{p,3DB}}{e_{p,3DB}} \tag{3}$$

where:
$e_{p,x}$ – flange elastic flexibility obtained for beam models of the connection (x = RBB lub SB),
$e_{p,3DB}$ – flange elastic flexibility received for 3D model of the connection.
Calculated W_x index values are summarized in Table 2.

Table 2. W_x index values [%]

W_{RBB}	W_{SB}
-4,16	1,72

In the case of the stiffness analysis of the multi-bolted connection, the best bolt model among the proposed equivalent bolt models in relation to the 3D model is the SB model. The assumption of this model of the multi-bolted connection may result in increased values of the elastic flexibility of the joined flange element by approximately 2 %.

The average value of the bolt force $F_{s,j}$ can be determined according to relations arising from the joint diagram in the form (JUVINALL, MARSHEK 2006)

$$F_{s,j} = F_m + F_e \cdot \frac{e_{p,j}}{e_{p,j} + e_s} \tag{4}$$

where:
F_e – external load.

It can be assumed that the external load F_e is proportional to the preload F_m

$$F_e = \alpha \cdot F_m \tag{5}$$

where:
α – ratio of the external load to the preload.
The $F_{s,j}$ values are set up in Table 3 for the parameter α adopted at the level of 0,5.

Table 3. Bolt force values [N]

$F_{s,RBB}$	$F_{s,SB}$	$F_{s,3DB}$
17692	17721	17713

The relative difference between the obtained bolt force values is analyzed on the basis of the Z_x index

$$Z_x = \frac{F_{s,x} - F_{s,3DB}}{F_{s,3DB}} \tag{6}$$

where:
$F_{s,x}$ – average bolt force obtained for beam models of the connection (x = RBB lub SB),
$F_{s,3DB}$ – average bolt force received for 3D model of the connection.
Calculated Z_x index values are summarized in Table 4.

In the case of the load analysis of the multi-bolted connection, the best bolt model among the proposed equivalent bolt models in relation to the 3D model is the SB model. The use of this model may cause a negligible increase of bolt force values up to 0,05 %.

Table 4. Z_x index values [%]

Z_{RBB}	Z_{SB}
-0,11	0,05

Conclusions

Studies on multi-bolted connections are often carried out in the aspect of the selected problems, in which knowledge of the distribution of stress and strain levels in all elements of the connection is not necessary. In the case of FEM analysis of the stiffness characteristics of multi-bolted connections or forces acting on the bolts in such connections, it is better to use simplified models of bolts and multi-bolted connections. Then the results of calculations can be obtained in shorter time and modelling becomes more efficient.

In the paper the load analysis is conducted based on the classical joint diagram, taking into account elastic flexibility values calculated using FEM. It is worthwhile to carry out a similar analysis based entirely on FEM. Results of this analysis will be described in a separate article.

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