Study of the Distribution of Bolt Forces in a Multi-Bolted System under Operational Normal Loads

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Abstract. The paper is related to modelling of multi-bolted joints treated as a system. The model of the joint with various substitute models of bolts is presented. The system was preloaded and externally loaded with normal forces. Calculations were made for an exemplary asymmetric joint. As a result of these calculations, the distribution of operating forces in the bolts is shown.

INTRODUCTION

In many engineering applications to connect components multi-bolted joints are used [1]. In order to provide such joints sufficient load-carrying ability in operating conditions, they are usually preloaded [2].

Various analyzes of multi-bolted joints in operating condition have so far been presented in several papers. They mostly concerned traditional types of bolted connections: flange joints [3], beam-to-column joints [4] and lap joints [5]. All these publications are based on the finite element method (FEM) and are related to FE-models of steel preloaded and externally loaded joints, however in none of them a systemic approach to modelling is not included.

By treating the multi-bolted joint as a system, it is possible to separate subsystems from this system and their individual modelling. One of them is a set of bolts, which can be replaced with very different models [6].

The subject of modelling nonlinear preloaded multi-bolted systems on the operational state has been initiated in [7], and the current paper is an extension of this subject. The aim of the study is to compare the values of operating bolt forces determined for two FE-models of a steel multi-bolted joint with different types of bolt models [6]: rigid body bolt models (RBB models) and spider bolt models (SB models).

METHODOLOGY FOR CREATING A MULTI-BOLTED SYSTEM

The structure of the multi-bolted system is based on the model of subsystems shown schematically in Fig. 1.

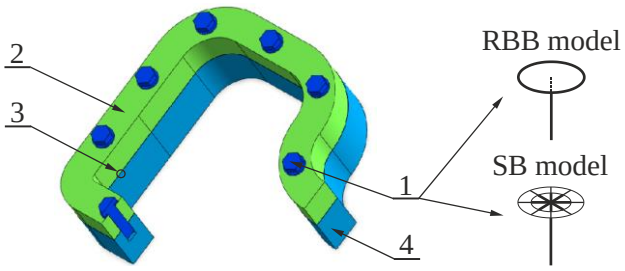


FIGURE 1. Multi-bolted system (1 – subsystem **B**, a set of the bolts, 2 – subsystem **F**, the flexible flange element, 3 – subsystem **C**, the contact layer, 4 – subsystem **S**, the flexible support)

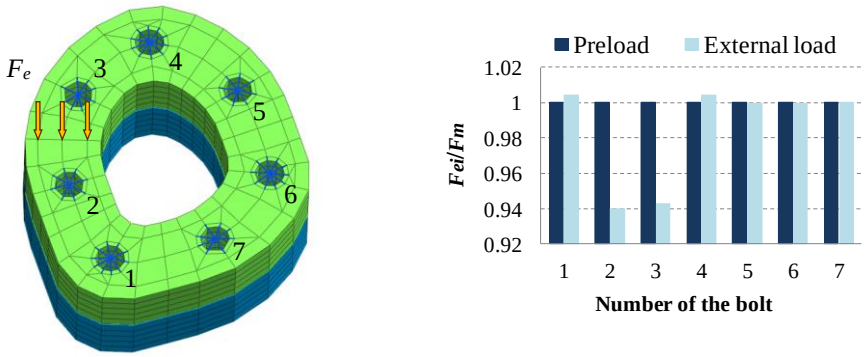
The set of equations of equilibrium of the multi-bolted system shown in Fig. 1 can be written in the form:

$$\begin{bmatrix} \boldsymbol{K}_{BB} & \boldsymbol{K}_{BF} & \boldsymbol{0} & \boldsymbol{K}_{BS} \\ \boldsymbol{K}_{FB} & \boldsymbol{K}_{FF} & \boldsymbol{K}_{FC} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{K}_{CF} & \boldsymbol{K}_{CC} & \boldsymbol{K}_{CS} \\ \boldsymbol{K}_{SB} & \boldsymbol{0} & \boldsymbol{K}_{SC} & \boldsymbol{K}_{SS} \end{bmatrix} \cdot \begin{bmatrix} \boldsymbol{q}_B \\ \boldsymbol{q}_F \\ \boldsymbol{q}_C \\ \boldsymbol{q}_S \end{bmatrix} = \begin{bmatrix} \boldsymbol{p}_B \\ \boldsymbol{p}_F \\ \boldsymbol{p}_C \\ \boldsymbol{p}_S \end{bmatrix}, \tag{1}$$

where: $\boldsymbol{K}_{ii}$ – stiffness matrices of individual subsystems, $\boldsymbol{K}_{ij}$ – matrices of elastic couplings between separated subsystems, $\boldsymbol{q}_i$ – displacements vector of the i-th subsystem, $\boldsymbol{p}_i$ – loads vector of the i-th subsystem (i, j – symbols of subsystems, $i \in \{B, F, C, S\}$, $j \in \{B, F, C, S\}$, for comparison, see Fig. 1).

RESULTS OF CALCULATIONS

Exemplary calculations were made for a selected asymmetrical multi-bolted system shown in Fig. 2a. The thickness of the connected flanges is equal to 20 mm. The joint is fastened by means of seven M10 bolts with the preload F_m equal to 20 kN. The set of bolts is made of the rigid body bolt models. The preloaded multi-bolted system is subjected to an external normal force F_e equal to 30 kN and applied in the manner shown in Fig. 2a. The distribution of operating forces in the bolts for the multi-bolted system loaded externally with the force F_e is illustrated in Fig. 2b.



(a) (b)

FIGURE 2. Example of calculations: a) FEM-based model of the multi-bolted system and numbering of the bolts, b) distribution of operating forces in the bolts for the multi-bolted system loaded externally

CONCLUSIONS

In the paper a general systemic approach to modelling and calculations of arbitrary multi-bolted systems is presented. It can be implemented in the operational state of the system adopted for various bolt models.

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