Analysis of Selected Methods of Machine Seating using Multi-Bolted Foundation Connections

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Abstract: - Finite element modeling of multi-bolted foundation connections applied in the case of seating of heavy machines or devices is reported. Connections performed by means of 3 different types of chocks were investigated. Characteristics of stiffness for the assumed models of multi-bolted foundation connections at the assembling phase were outlined and discussed. Conclusions of great relevance to engineering design were presented.

Key-Words: - machine seating, multi-bolted foundation connections, foundation chocks, assembly, pre-tension, FE analysis.

Received: April 7, 2024. Revised: August 16, 2024. Accepted: September 18, 2024. Published: November 15, 2024.

1 Introduction

In the engineering industry, it is repeatedly necessary for machines to have a proper foundation, without which their correct operation is not possible. Correctly sited machines can determine the operational safety of entire production lines, their durability, the absence of vibration, the proper functioning of bearings, as well as the safety of the people working on the production site, [1], [2], [3].

The seating of heavy machines or devices on foundations is commonly achieved using multi-bolted connections, which as a rule must be pre-tensioned, [4], [5]. As a result of various factors (including geometric imperfections of flanges), the surfaces of the components to be joined do not adhere tightly to each other, [6], [7]. To enable machines and devices to be installed, special foundation chocks are used in such connections. There are 3 types of these chocks, [8], [9], [10]:

- steel chocks (SCs),
- polymer chocks (PCs),
- polymer-steel chocks (PSCs).

The earliest known method of machine seating is that in which SCs (mainly rigid chocks, but also wedge chocks and adjustable chocks, [11]) are used. This seating is associated with two inconveniences when assembling the multi-bolted foundation connections (MBFCs). The first is the necessity to guarantee an even distribution of contact pressure on all chocks by matching their surfaces to the retaining surfaces of the machine being assembled and the foundation. Such measures are challenging, and time-consuming. Furthermore, in this case of seating, applying the preload of the foundation bolts causes significant contact deformations between the components to be joined, [9].

The second method of machine seating is the seating on cast PCs. With this method, precise machining surfaces of the components to be joined is not necessary. Moreover, the direct casting of the chocks underneath the machine base ensures that the joined surfaces of these components adhere closely together. Unevenness due to the roughness of the joined surfaces is infilled with polymer, making the pressure distribution on these surfaces more beneficial than when seated with SCs, [12]. But the drawback of seating on PCs is that they creep under operational conditions, causing pre-tension relaxation in the foundation bolts, [8], [13].

The third and most recent method to perform machine seating is polymer-steel chock seating. It combines the strengths of seating under the two above-mentioned methods and minimizes the shortcomings occurring there. In connections made with PSCs, chock creep is significantly reduced. At the same time, the abutment surfaces of the joined components fit tightly together and there is no need to adjust them. Additionally, with this type of multi-bolted foundation connection, SCs with identical thickness can be used throughout the connection area.

MBFCs often have a considerable influence on the vibration, dependability, and sustainability of whole mechanic systems. Thus, knowledge of their behavior under assembly and operating conditions is required to analyze the problems they present. To find out about this behavior, the corresponding stiffness characteristics are usually specified.

Investigations concerning MBFCs with steel and PCs are reported in [14] and [15], among others. On the other hand, investigations of foundation multi-bolted connections with PSCs are provided, for instance, in [8], [11]. The present article is a further study of foundation multi-bolted connections, with the main purpose of determining the stiffness characteristics of the components joined during the assembly of the multi-bolted foundation connection for all its types mentioned above, including steel, polymer, and polymer-steel chocks.

The subjects of this study are symmetrical segments of a multi-bolted foundation connection formed by two rectangular slabs and a rectangular chock placed between the slabs. It was assumed that the chock could be of any of the 3 types mentioned above. Layoutsseparated in this way were modeled using the finite element method (FEM) in order to obtain characteristics of the stiffness of the joined components in the state of assembly. EPY resin, [16], [17], was chosen as the polymer chock material. The study resulted in findings of great relevance to engineering design.

2 Fundamentals of Research

One of the major issues addressed in the computations of MBFCs concerns the stiffness analysis of their components. Regarding bolts to be linear elements, their elastic flexibility can be defined either with the guidelines provided in VDI 2230, [18] or with a simplified method, [19]. There is no similarly simple method to identify the elastic flexibility of components joined in MBFCs. For this reason, FEM is normally used to specify it accurately.

For analyzing the aforementioned seating methods, computations were made for the models labeled as:

- FEM-S – FE-based model that uses the steel chock,
- FEM-P – FE-based model that uses the polymer chock,
- FEM-PS – FE-based model that uses the polymer-steel chock.

This article investigates a segment of a multi-bolted foundation connection, with the dimensions of a single joint illustrated in Figure 1, Figure 2 and Figure 3. The single joint was formed with a pair of steel slabs (2) and (4) representing segments of the base of the machine and the ground footing. A chock (3) or (6) was placed between the slabs, appropriate to the seating method used. As the aim of this article was to analyse the stiffness of the joined components, the full model of the bolt was not considered in the connection.

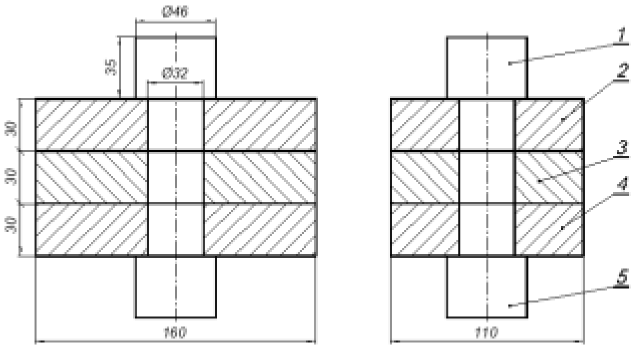

Fig. 1: Dimensions of the FEM-S model: 1 – upper-pressure punch, 2 – upper slab, 3 – steel chock, 4 – lower slab, 5 – lower pressure punch

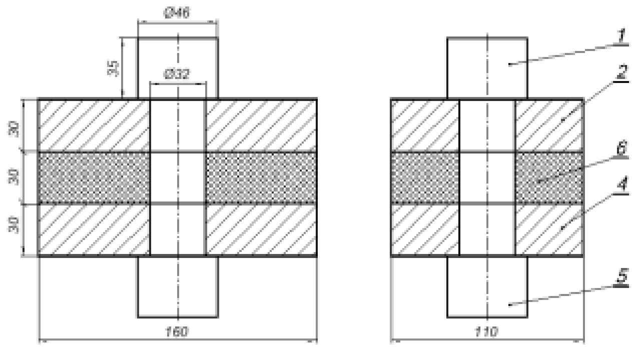

Fig. 2: Dimensions of the FEM-P model: 1 – upper-pressure punch, 2 – upper slab, 4 – lower slab, 5 – lower pressure punch, 6 – polymer chock

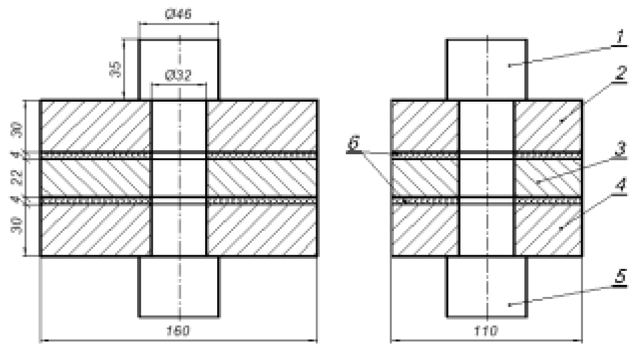

Fig. 3: Dimensions of the FEM-PS model: 1 – upper-pressure punch, 2 – upper slab, 3 – steel chock, 4 – lower slab, 5 – lower pressure punch, 6 – polymer chock

The bolt in this case was represented by two steel punches (1) and (5), with which the pressure from the nut and bolt head was introduced. The diameter of the punches was 46 mm and corresponded to the area of pressure of the M30 nut.

3 Computational Models

The computations were conducted for the geometry of the components shown in Figure 1, Figure 2 and Figure 3, respectively. Based on the work, [10], the EPY resin compound behaves as a linear material. The constants of the materials involved in the models, namely Young's modulus E and Poisson's ratio ν, are summed up in Table 1.

Table 1. Foundation chock material characteristics

Material	E, GPa	ν
EPY	7.5	0.376
Steel	210	0.3

Due to the plane of symmetry present in the segment of the multi-bolted foundation connection under consideration, only half of the connection was included in the computations (Figure 4).

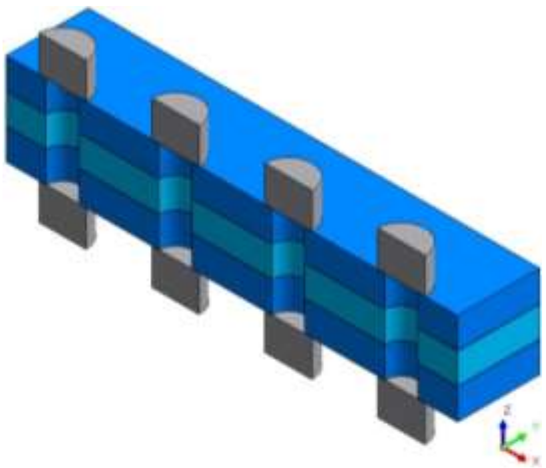

Fig. 4: Computational model of the multi-bolted foundation connection with the steel chock

The discrete connection models formed in Midas NFX 2023 R1, [20], are presented for all the seating methods assumed in Figure 5, Figure 6 and Figure 7. In the models, between the steel components, a 'rough' contact joint model was used. At the same time, a 'welded' contact joint model was used between the steel joint components and the polymer chock.

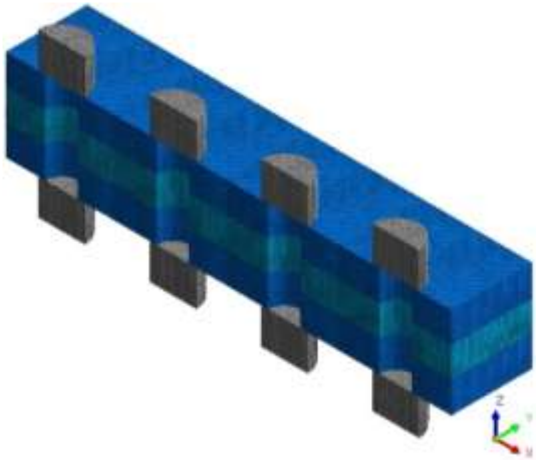

Fig. 5: FEM-S model of the foundation connection

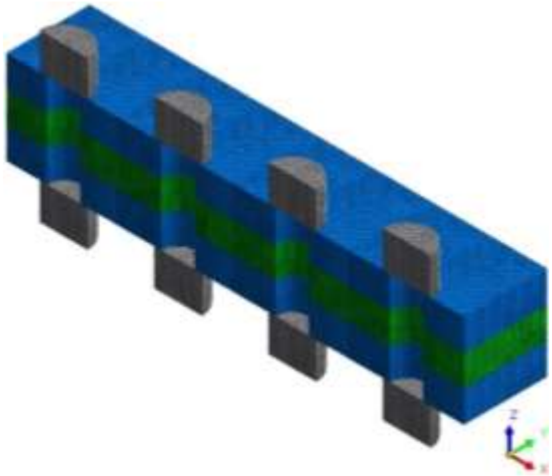

Fig. 6: FEM-P model of the foundation connection

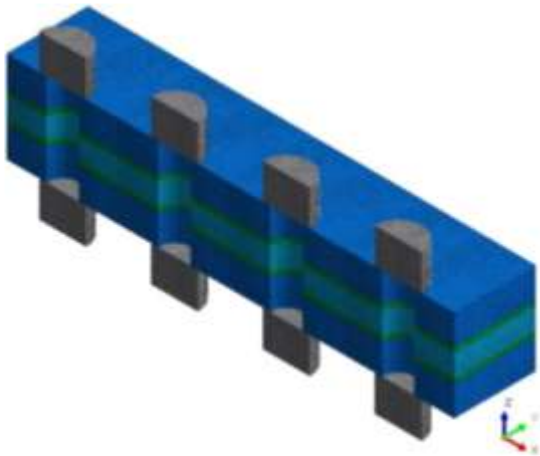

Fig. 7: FEM-PS model of the foundation connection

The following parameters were assumed for the 'rough' contact joint model:

- scaling factor of normal stiffness – 10,
- scaling factor of tangential stiffness – 1,
- static friction coefficient – 0.6.

The 'welded' contact elements used between the steel joined components and the polymer chock prevented the components from moving relative to each other in any direction, in line with the real realizationof the multi-bolted foundation connection.

The models were restrained at nodes on the back side of the lower pressure punch in the bolt axis direction and then subjected to normal forces at nodes on the top surface of the upper-pressure punch. The models also introduced boundary conditions due to the symmetry of the connections. By applying the aforementioned conditions, the joined components in the multi-bolted foundation connection models were in compression, conforming to the real operation of this type of connections.

The computations were carried out with a non-linear solver in ten load steps associated with an incremental preload of the connection from 0 to 200 kN.

4 Results of Computations

Example results of computations for the assumed FEM-based models in terms of displacements in the Z0X plane induced by a preload of 200 kN are illustrated in Figure 8. Displacement values are shown on the diagrams in mm.

To benchmark the results of the computations, an appropriate comparison of these results achieved for the adopted models of the tested connection was made (Figure 9).

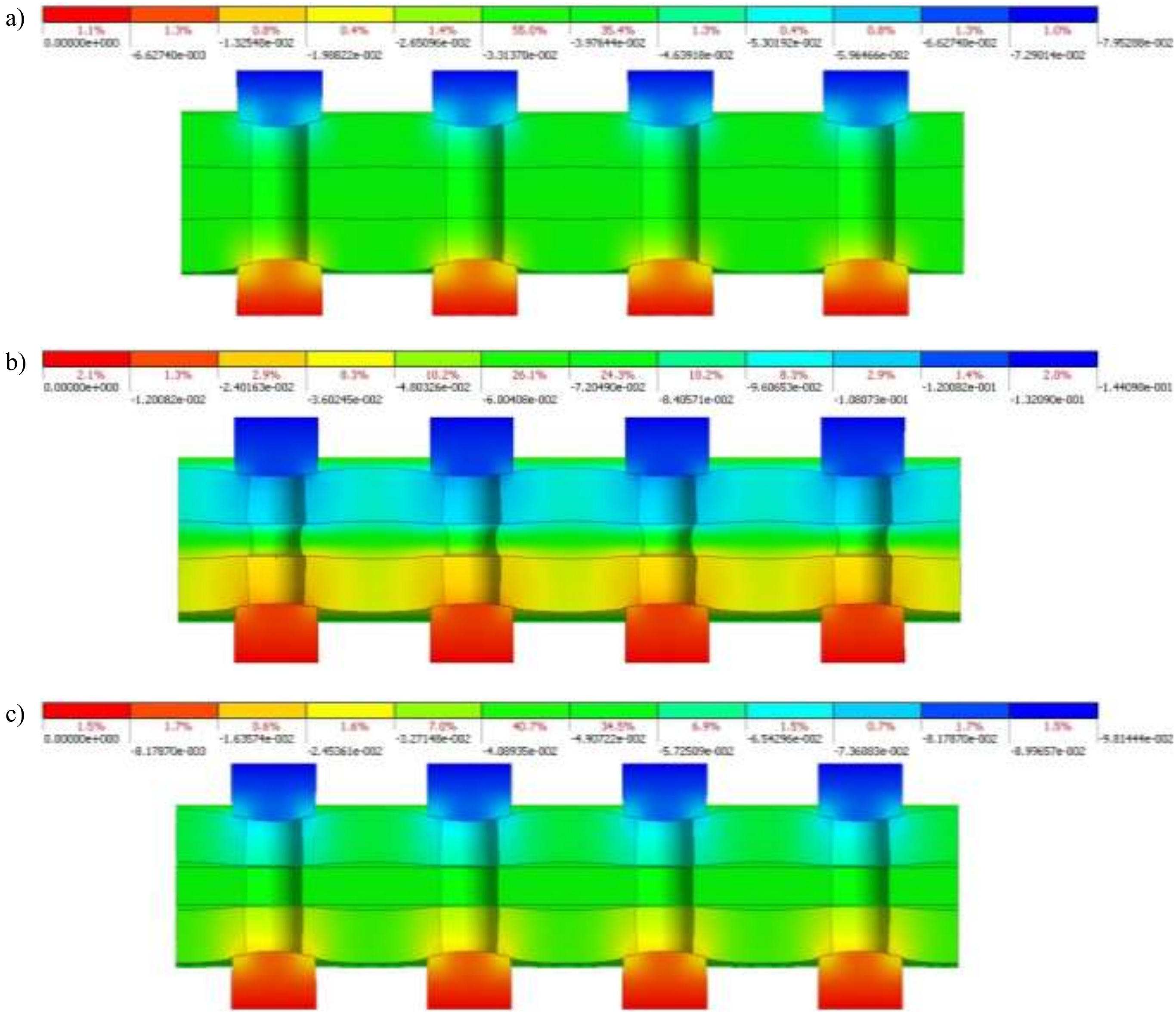

Fig. 8: Displacements in the Z0X plane of the connection model under consideration induced by a force of 200 kN for: a) FEM-S model, b) FEM-P model, c) FEM-PS model

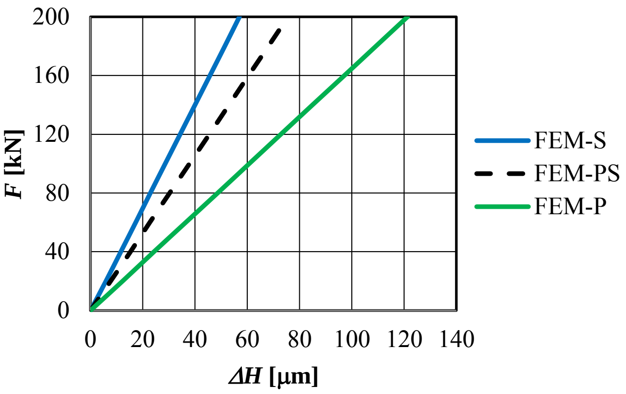

Fig. 9: Characterization of the stiffness of components joined in the multi-bolted foundation connection

Subsequently, the displacements of the joined components in the multi-bolted foundation connection ΔH , representing the maximal value of the preload , were identified.The last quantity assumed for the quantitative comparison of the computational models was the stiffness of the connected components *k*, defined in the form:

$$k = \frac{F}{\Delta H} \quad (1)$$

The values of the joined components' stiffness achieved for the assumed multi-bolted foundation connection models are listed in Table 2.

Table 2. Values of stiffness of joined components for individual models

Model	k, kN/µm
FEM-S	3.51
FEM-P	1.65
FEM-PS	2.65

The obtainedresults of computations lead to the conclusion that with the use of PSCs the following can be achieved:

- considerable increase in the stiffness of MBFCs in comparison with connections with PCs,
- obtaining MBFCs with a stiffness comparable to that of connections with SCs.

It should also be noted that observations of the stresses present in the FEM-P and FEM-PS models (not included in this article) show that, in the case of the EPY resin compound, the stresses did not overcome the compressive strength for this material.

5 Findings and Further Research

This article analyses MBFCs performed in 3 methods. It was demonstrated that MBFCs with PSCs can offer characteristics of stiffness comparable to MBFCs with SCs. Meanwhile, these connections have the benefits inherent in connections with PCs, the most important of which are the unnecessary precision machining and the close adhesion of the chock to the rough surfaces of the machine and foundation components over the entire nominal area of their contact.

The research presented in this article was continued to investigate the influence of the polymer layer thickness in PSCs on the stiffness characteristics of the joined components in MBFCs performed using such chocks, [].

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)
The author contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself
No funding was received for conducting this study.

Conflict of Interest
The author has no conflicts of interest to declare.