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Possibility of using CAD package and FEM analysis for rapid prototyping of design variants of semi-rigid furniture joints with dowel and eccentric connector

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Abstract: *Possibility of using CAD package and FEM analysis for rapid prototyping of design variants of semi-rigid furniture joints with dowel and eccentric connector.* The research focused on investigating the possibility of using CAD and FEM modelling and analysis of structural connections furniture constructed from the use of eccentric connector and dowel. FEM software makes possible is to select the variant that has the most preferred distribution of stresses and displacements as small as possible. Numerical analysis confirmed the possibility of structural analysis and enabled the option to select the most favourable construction

Keywords: Computer-aided design (CAD), Finite element method (FEM), furniture joint, rapid prototyping,

INTRODUCTION

Computer numerical simulations is widely used in wood technology. There are many literature references in this topic. Mackerle (2005) describe literature review of Finite Element Methods (FEMs) used in the analysis of wood and wood based products. There are 300 references to papers and conference proceedings between 1994 and 2004. The references was classified into the main topics: Wood as a construction material, material and mechanical properties, wood joining and fastening, fracture mechanics problems, drying process, thermal properties and other topics. Computer numerical simulation methods are successfully used to analyse of behaviour of semi-rigid furniture joints in furniture, both box and frame construction. Smardzewski (2011) presented alternative method to simulate semi-rigid furniture connections. A nonlinear finite element analysis was also successfully adapted for timber joints (Sawata and Yasumura 2003). Mohamadzadeh et al. (2012) used ABAQUS finite element (FE) software for simulation wood plastic composites (WPC). Experiments were conducted according to ASTM D-1037 standard.

The use of CAD - Computer-aided design program and FEM analysis can reduce the time for product development and improve the quality of the products (Pousette 2003). The aim of this paper is to test the possibility of using CAD package and FEM analysis for rapid prototyping of design variants of semi-rigid furniture joints with dowel and eccentric connector.

MATERIALS AND METHODS

In investigations was used specimens from two 16mm particleboard EN 312-P2 panels. First 150x458x16mm panel, second 134x458x16mm. Basic geometry of analysed specimens was shown on Fig 1.

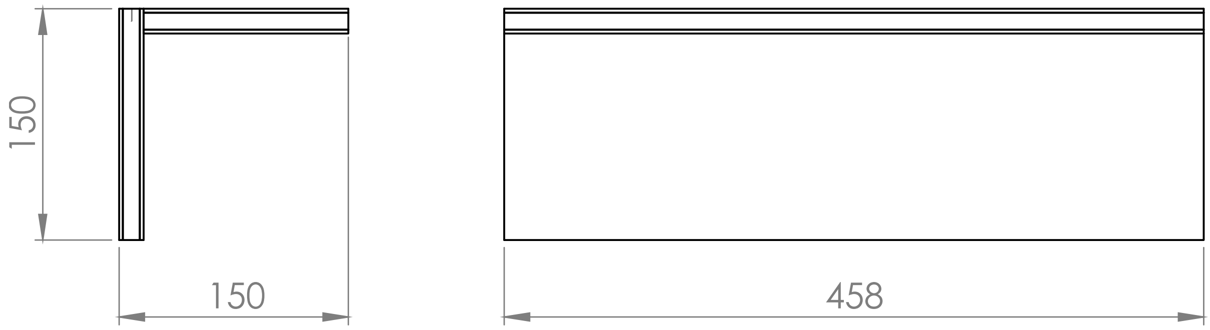

Fig 1. Basic geometry of analysed specimens

In investigations was used Ø8x30mm dowel type connection and classical eccentric type connection based on Hettich Rastex 15 with Twister 232.

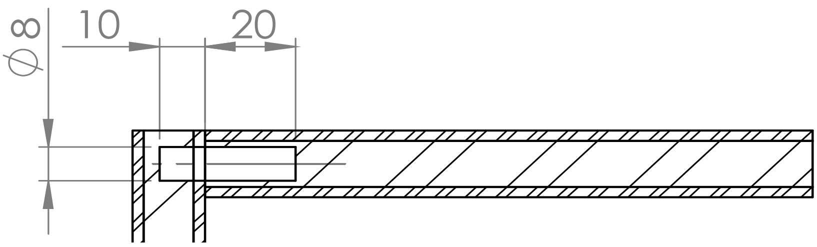

Fig. 2. Geometry of dowel – non glued dowel 8x30

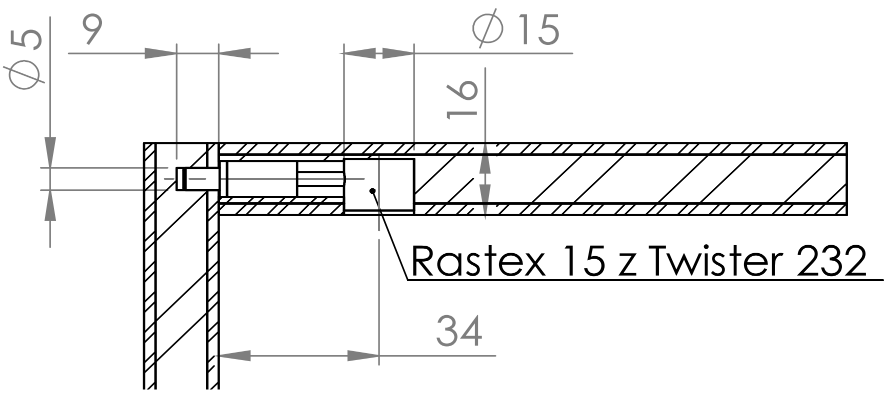

Fig. 3. Geometry of eccentric connector

Two types of connectors are used to create a six variants of connection. Table 1 shows distribution of connectors in analysed six design variants. 0 position is away from the edge of 37mm. Together there are 13 positions separated by 32mm (Fig 4).

Tab.1 Distribution of fasteners in different design variants (D – Dowel, EC – Eccentric connector)

	0	32	64	96	128	160	192	224	256	288	320	352	384
1.	D	EC	D	-	-	-	-	-	-	-	D	EC	D
2.	D	EC	-	-	-	-	-	-	-	-	-	EC	D
3.	D	-	-	-	-	-	EC	-	-	-	-	-	D
4.	D	EC	D	-	-	D	EC	D	-	-	D	EC	D
5.	D	EC	D	-	D	-	D	-	D	-	D	EC	D
6.	D	EC	-	-	D	-	-	-	D	-	-	EC	D

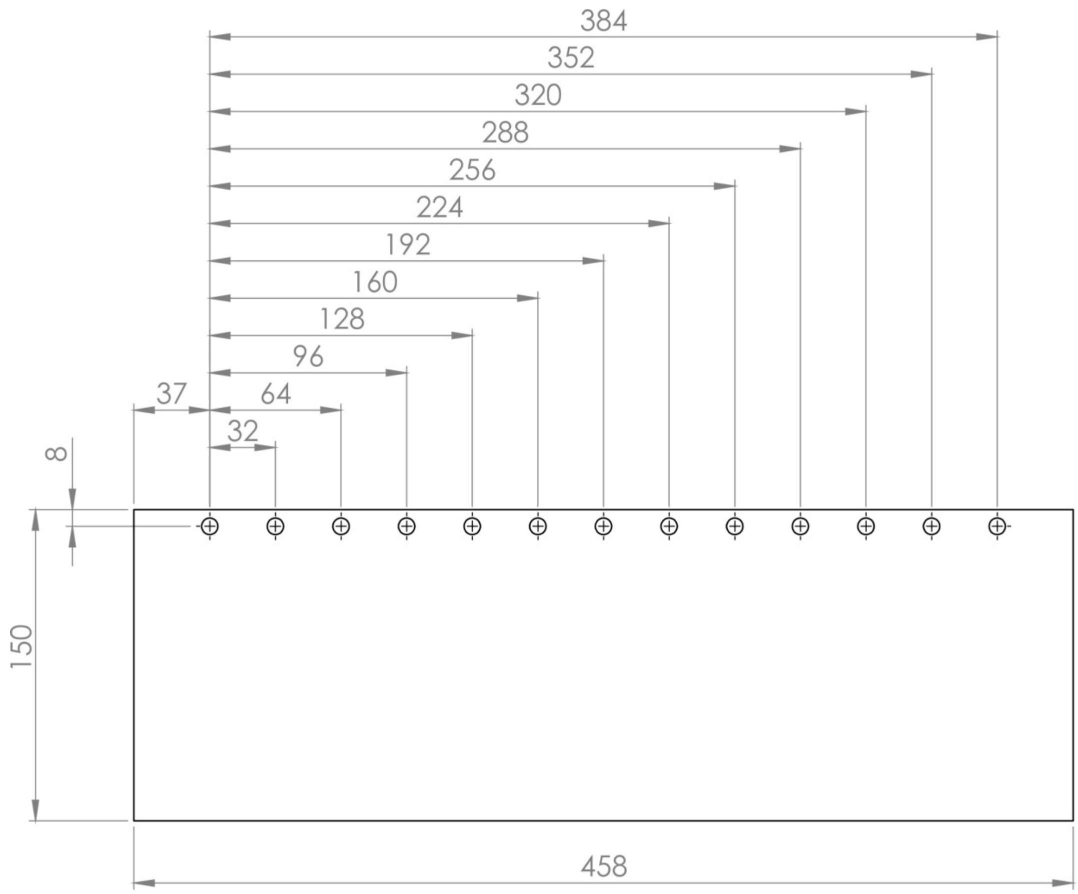

Fig 4. Positions of fasteners in joint

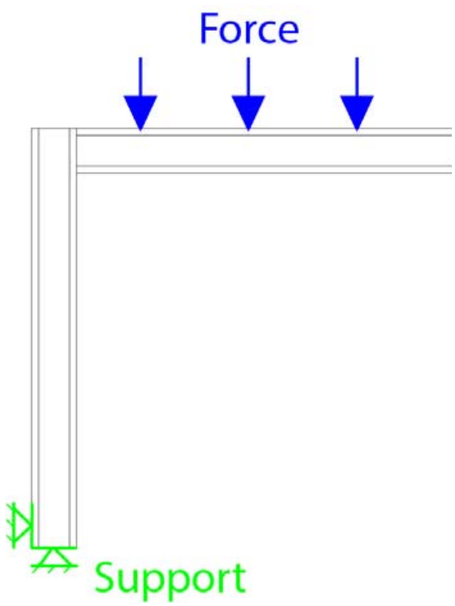

Fig. 5. Load distribution used in numerical simulations.

Load for connections was taken from Smardzewski (2008)– it is load for shelves at 1500 N/mm^2. Additionally, half of its load was calculated – 750 N/m^2.

SolidWorks Simulation 2012 was used in numerical simulations. It was used a linear static analysis module. Basic material for joints is 16mm particleboard that meet requirements of the PN-EN 312 – P2. Particleboard was modelled as three layer material with two 2,5mm face layer and one 11mm core layer (Archanowicz and Beer 2012). Beech isotropic material model was used for dowels. Simplification is connected with that we cannot determine equal localization of longitudinal and tangential sections for dowels. Steel, Zamak No.2, PP was taken from SolidWorks material library. Steel material was used for eccentric dowels. Zamak No.2 for eccentric cam, PP for sleeve on eccentric dowels.

Tab. 2. Mechanical constants used in numerical simulations

	Particleboard – Face Layer	Particleboard – Core Layer	Steel	ZAMAK 2	PP (Polypropylene)	Beech (Dowel)
E_X	3046	1486				
E_Y	2717	1464	210 000	85 500	1 790	13 970
E_Z	419	172				
ν_{YX}	0,206	0,249				
ν_{ZX}	0,040	0,041	0,280	0,300	0,300	0,300
ν_{ZY}	0,045	0,049				
G_{XY}	1216	562				
G_{XZ}	989	549	79 000	38 800	665	5 370
G_{YZ}	156	66				

In view of the fact that the thread geometry is consume a lot of computer resources, extending simulation time several times. It consists of that thread have curvilinear helical shape. Thread was not modelled, since the overall strength and stiffness of joints will not be due to the existence of this thread in the model. Simplified connection of thread rod with a particleboard, replacing it with the contact of two walls - bound without clearance. Local stresses in subsequent rolls of thread on this scale simulations that were difficult to model. Thread was modelled as the inner diameter of the thread - 5mm. The table below shows the material constants used in the analysis.

Computer resources: Intel quad core mobile processor i7-3610, 16GB RAM, nVidia mobile workstation graphic Quadro K1000M, SSD Samsung 840 Pro hdd drive.

RESULTS

Stress distribution and displacement

To allow comparison of applied stress between all the variants of specimens, used equal scale stresses in each case. Each graph of reduced Von Misses stress, the maximum stress was set at 5 MPa.

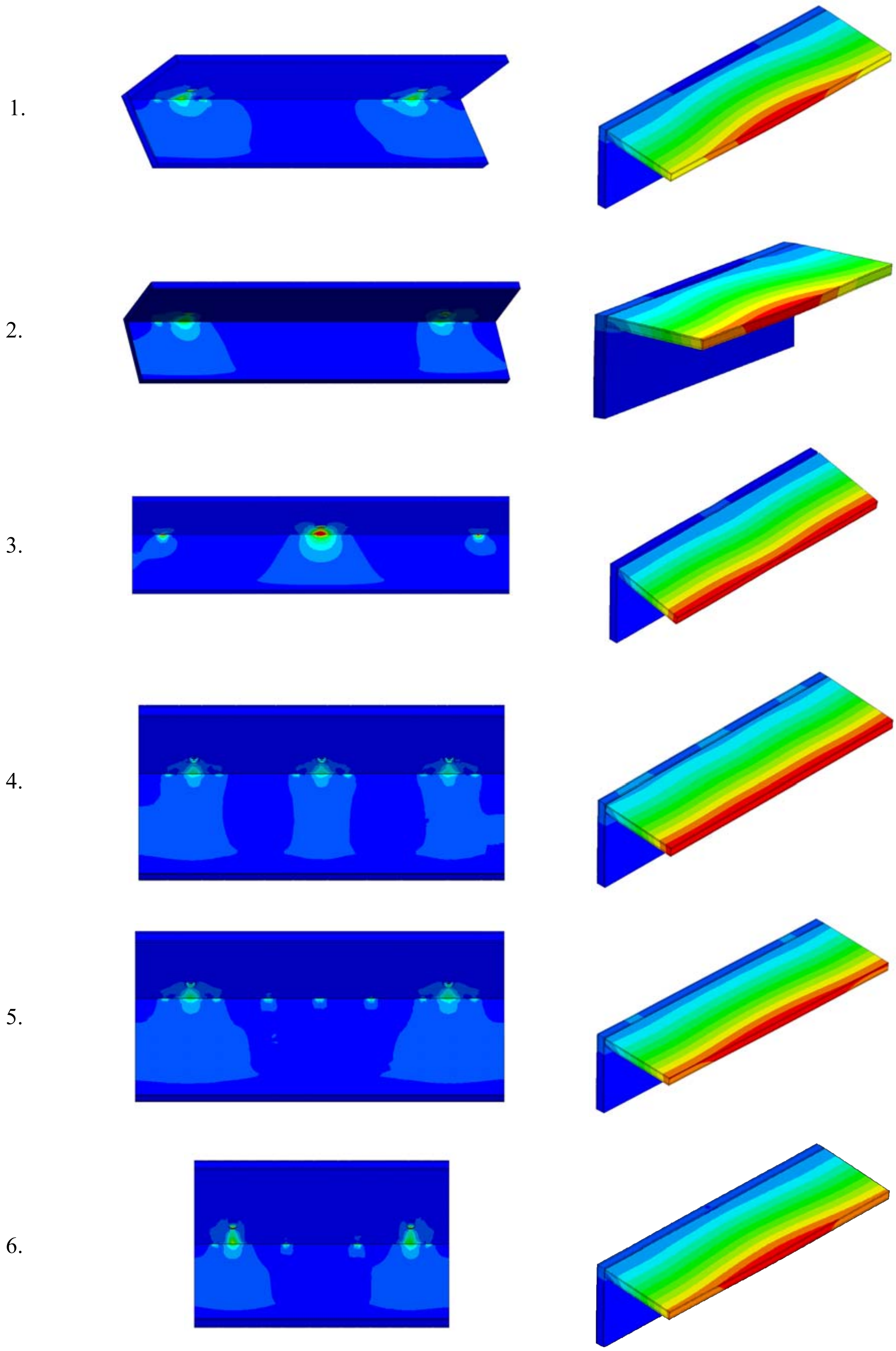

Fig. 6. Comparison of Stress distribution and displacements in analysed variants of connections

Variant 1

Variant 1 has the two dowels on one eccentric connector. This is the most common way to design eccentric joints. Maximum stress (6.43 MPa) in this variant occurs near drilling for eccentric joint. They can cause local exceeding the allowable stresses. However, they will not cause destruction of joints, due to their local character. Due to the arrangement of joints on the edges, the maximum displacement is located in the centre of specimen - is 1.86mm. Lack of dowels in the middle of specimen, results on the concentration of displacement in the middle of specimen.

Variant 2

Compared to variant 1, the second variant has one dowel for each eccentric connector, and therefore was removed one dowel. This variant would have to check necessity of the second dowel in eccentric joint. The maximum stress is 32 MPa, located on the upper surface of drilling for eccentric connector. Lack of the second dowels in eccentric joints causes a significant increase in stress in the joint. With increased load, area of distribution of increased stress may be a point of a crack propagation. By comparing the image of stresses in second variant to stresses in first variant, two additional dowels reduce the maximum stress in the joint from 32 MPa to 6 MPa. Significant reduction of stress in the joint with two additional dowels can be explained by the fact that two additional dowels on positions 64 and 320 stabilise them by receiving the degrees of freedom

Variant 5

The fifth variant is the improvement of first variant. Added 3 extra dowels at positions 128, 192, 256. The additional dowels are designed to reduce strain in the middle of specimen. The maximum stress in this variant occurs near drilling for eccentric joint, stresses is 6.3 MPa. Thus, they are at the same level as in the first variant. Increased number of fasteners causes stress distribution across a larger number of connectors, reducing the area of stress greater than 1 MPa. Aded 3 additional dowels at positions 128, 192, 256 improved the performance of joint due to the displacement, is the maximum displacement of 1.3 mm. Dowels are not able to provide rigidity, such as eccentric connects and causes light concentration of displacements in the center of specimen. However, the use of a larger number of pins resulted in a more uniform nature of the displacements the entire plane, comparing to the variants 1 and 2.

Variant 6

Version 6 is a simplified variant of the fifth variant. Removed three dowels of positions 64, 192, 320. Dowels at positions 64 and 320 may stabilise the eccentric connector. The maximum stress in this variant occurs near drilling for dowels in positions 192 and 256 - is 6.4 MPa. Thus it can be concluded that the dowels can stabilise the joint. They can cause local exceeded the allowable stresses. However, they will not cause destruction of joints, due to their local character. The maximum displacement is at the level of 1.64 mm. No eccentric joint in the middle results slight concentration of displacements in the middle of specimen. Dowels are not able to provide rigidity such as eccentric connector. The use of larger number of dowels results in a more homogeneous character of displacements than under variant 1 and 2. Comparing to variant 5 and 6, the presence of even one pin at position 192 in the variant 5, positively influenced the movement, reducing it from 1.64 mm to 1.30 mm.

Variant 3

Variant 3 presents the theoretical joint structure, consisting only of a single eccentric in position 192 and two dowels in the extreme positions. This variant is the reference for the evaluation of rigidity and strength of the rest of specimens. The use of a eccentric connector results in a very large area of stress above 1 MPa. There is a risk that the norm load of 1500 N/m^2 exceeds the allowable stress in specimen. Due to the small number of joints, the maximum displacement is 2.96 mm. This value is large.

Variant 4

Variant 4 presents joint designed for increased rigidity. This option has the three eccentric connectors with two dowels. The maximum stress in this variant occurs near drilling for eccentric connector - is 7.24 MPa. Increased number of fasteners causes stress distribution across a larger number of connectors, reducing the area of stress greater than 1 MPa. In terms of stress distribution, the variant shows relatively evenly distributed stress. The use of more of the eccentric caused more uniform nature of the displacements, as compared to other options. The maximum displacement was 1.09 mm. It is the smallest value among all variants. This option will be able to transfer heaviest loads compare to other.

Rotational stiffness

Based on numerical simulations, rotational stiffness of joints was calculated. The chart below provides a summary of the six variants of specimens. Rotational stiffness is the relationship between an applied force and the displacement that the force produces. Rotational stiffness was calculated by the following formula (1):

$$k = \frac{\Delta M}{\Delta \gamma} \tag{1}$$

Where:

k – rotational stiffness [Nm/rad],
M - moment of increment [Nm],
γ - rotation angle caused by the moment of increment [rad],

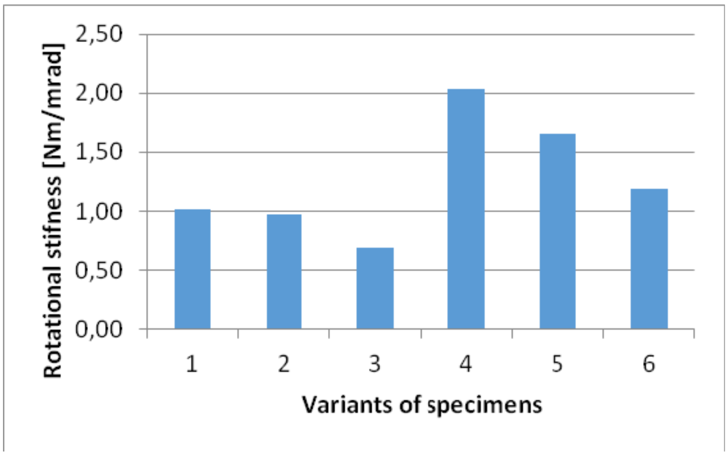

Fig. 6 Rotational stiffness for six variants of analysed specimens

To calculate the theoretical force causing the displacement of 50 [mrad] to analysed connection was performed an additional simulation with half the established power (Tab.3.). Performed simulations are linear, so there is no need for them to getting greater loads to achieve maximum force at given assumptions. The values from two simulations will be the basis for the calculation of the theoretical maximum force. Assumed maximum angle connector terminal capacity as a criterion. Maximum angle of rotation of the connectors was founded on the basis of literature. Was 50 [mrad] (Branowski and Pohl 2004)

Tab. 3. Calculation of theoretical force that cause rotation of 50 mrad rotation of joint

Variant	Theoretical force required for 50 mrad rotation of joint [N/m^2]	Force calculated on joint [N]
1.	5726	351
2.	5561	341
3.	3636	223
4.	8130	499
5.	8165	501
6.	6518	400

CONCLUSION

- Research confirms the possibility of using CAD package and FEM analysis for rapid prototyping of design variants of semi-rigid furniture joints with dowel and eccentric connector.
- Numerical simulations shows difference between design variants. Stress distribution and displacements may be point to choose proper design variant.
- Numerical simulation shows that variant 4 with three eccentric connectors and two dowels have the best rotational stiffness and have no displacements concentrations.

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Streszczenie: *Możliwość wykorzystania oprogramowania CAD i analiz numerycznych (FEM) do szybkiego prototypowania półsztywnych węzłów konstrukcyjnych mebli z łącznikiem mimośrodowym i kołkami.* Badania dotyczyły sprawdzenia możliwości wykorzystania oprogramowania CAD i FEM do modelowania i analizy konstrukcyjnej połączenia meblowego skonstruowanego w wyniku wykorzystania łącznika mimośrodowego i kołków. Dzięki oprogramowaniu FEM możliwe jest wyselekcjonowanie wariantu, który ma najbardziej korzystny rozkład naprężeń i możliwie małe przemieszczenia. Analiza numeryczna potwierdziła możliwość analizy konstrukcyjnej i umożliwiła wybranie najkorzystniejszego wariantu konstrukcyjnego.

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