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REALIZATION OF GEOMETRIC NONLINEARITIES IN THE DETERMINATION OF EIGEN FREQUENCIES AND SHAPES BY FINITE ELEMENT METHOD

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Abstract: *The presented paper describes the process of determination of eigen shapes and eigen frequencies of the structure with non-linear joint. The presented method uses three different configurations of applied boundary conditions for describing the non-linear behaviour of the structure using linear tools of FE software.*

Keywords: ***FEM, non-linear joint, eigen frequency, eigen shape.***

1. Introduction

The subject is the test lifting platform used in theatre applications. The device consists of fixed horizontal frame, two vertical pillars and two tables. The lifting of the tables is realized by two devices – so called spiralift and erective chain. The longitudinal and lateral guiding of the tables is ensured by U-profiles fixed with pillars and by combined bearings connected with tables.

The aim of the work is to determine the modal properties – eigen shapes and eigen frequencies of the introduced platform. Since the connection of both tables and guiding profiles does not transfer the tension forces in longitudinal direction the joint has to be considered as non-linear. With respect to this fact the appropriate solution has to be proposed. Its description is described in following articles. The modal analysis is performed by the computational modelling method in the software ANSYS – Mechanical APDL v12.0 (Ferfecki et al., 2007).The device is depicted in Fig. 1.

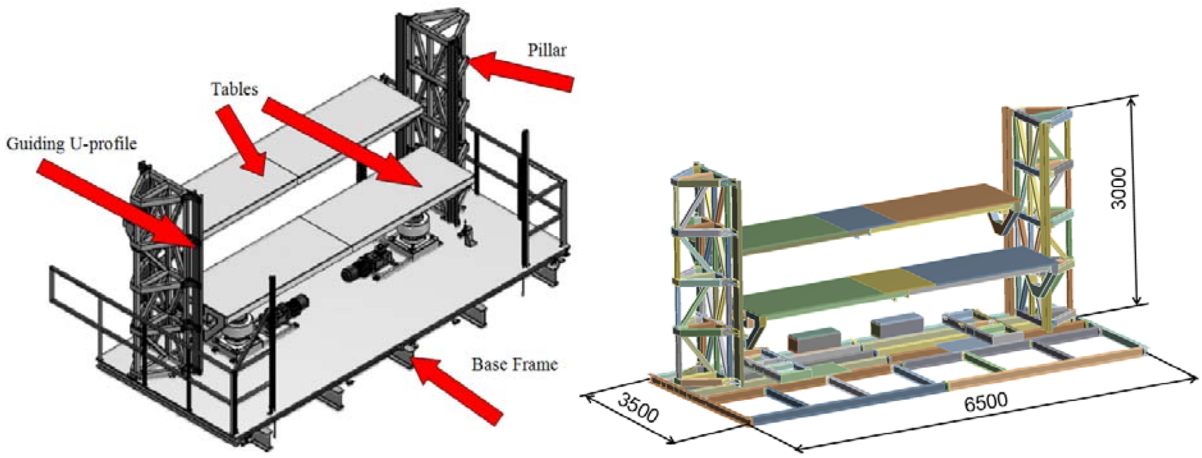

Fig. 1: Geometry of Lifting Platform.

2. Computation

Before the model properties were identified the mechanism was simplified in order to reduce the hardware and time demands (Poruba et al., 2010). The stiffness of lifting devices was determined via

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FEM (Finite Element Method) and consequently compared with stiffness of other components (tables, pillars). Since the stiffness of both lifting devices is of higher order, their modelling can be realized by appropriate boundary condition – by removing of degrees of freedom in vertical direction in the location of connection of lifting devices and tables – see Fig. 2. The base frame firmly coupled with the ground was substituted by appropriate boundary condition as well. Its influence on the modal properties can be neglected. Regarding to this fact all degrees of freedom of the pillars were removed in the location of their connection with the base frame – see Fig. 3.

The beam elements BEAM188 (pillars) (Saeed et al., 2009) and shell elements (tables, reinforcements) were used in the finite element model. The device was loaded by the MASS21 element located in the middle of both tables – symmetrical loading of 1000 kg was assumed. The model contained 12726 finite elements and 33662 nodes.

The two types of materials were assumed in the model – construction steel E = 210000 MPa, μ = 0.3, ρ = 7850 kg.m^{-3} and wood E = 10000 MPa, μ = 0.2, ρ = 600 kg.m^{-3} which is located in the form of wooden board on the top sides of both tables.

The important chapter is the realization of non-linear joint between the tables and guiding U-profiles. Placing of the table in guiding profile is obvious from Fig. 1 and Fig. 4. The tables are on both sides provided by two rollers (see Fig. 4) guided in U-profile so the longitudinal and lateral guidance is ensured. Regarding to the shape of the cross-section area of U-profile, the possible lateral vibration is hindered in both directions. In case of longitudinal vibration only the compression force is transferred because the contact between the roller and guiding profile occurs only at one its side. This fact has to be considered in the FE model.

The transfer of the forces between roller and guiding profile was realized by coupling of degrees of freedom belonging to both parts. The rise of compression force in lateral direction is ensured in all cases (at one or other parallel side of U-profile). As already mentioned above, the force transfer in longitudinal direction can occur only if the transferred force has compression character. In the case when coupling is applied at both sides of the tables (at one side the transfer of tension force occurs) the calculated eigen frequencies and eigen shapes do not need to correspond with those of real structure. The further calculations were carried out in following steps:

– Coupling in longitudinal direction was applied at both sides of both tables. The eigen frequencies and corresponding eigen shapes were calculated – see Tab. 1, column “Coupling everywhere”,
– Coupling in longitudinal direction was applied only at one side of table. In case of the other table the coupling was applied at the opposite side. The eigen frequencies and corresponding eigen shapes were calculated – see Tab. 1, column “Coupling opposite”,
– Coupling in longitudinal direction was applied only at one side of table. In case of the other table the coupling was applied at the same side as at neighbouring table. The eigen frequencies and corresponding eigen shapes were calculated – see Tab. 1, column “Coupling same”.

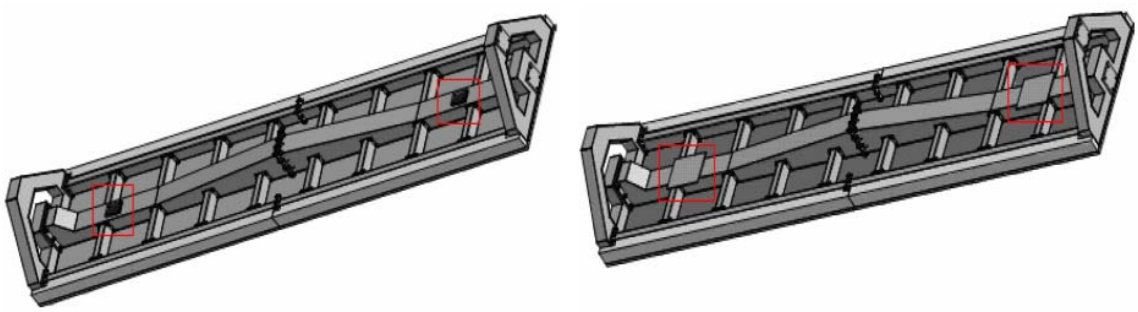

Fig. 2: Location of Boundary Condition Substituting Erective Chain and Spiralift.

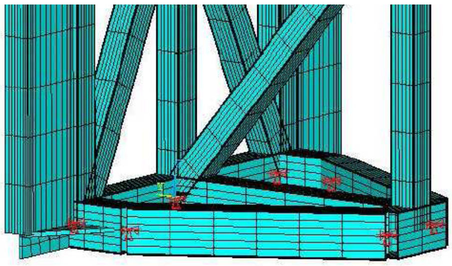

Fig. 3: Location of Boundary Condition Substituting Influence of Base Frame.

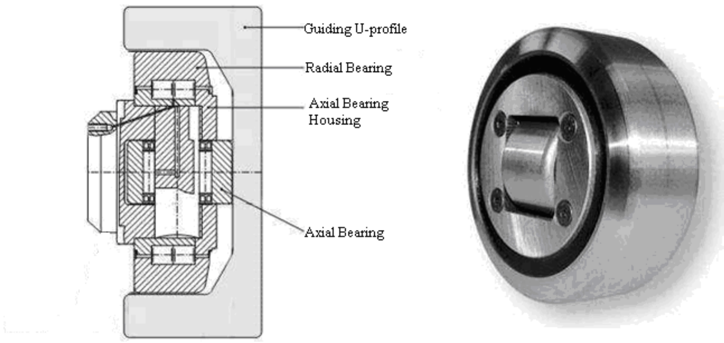

Fig. 4: Scheme of Roller Used for Table Guiding.

3. Results

The realization of described steps produces the eigen frequencies and eigen shapes of investigated structure – both real and unreal ones for all possible configurations of applied coupling in longitudinal direction. The results are summarized in Tab. 1. Only such results can be considered as real where the tension force in longitudinal direction between roller and guiding U-profile is not transferred. This fact was found out on the base of visualization of particular eigen shapes. The example is depicted in Fig. 5 which presents the first eigen shape for the coupling configuration "Coupling everywhere". The mutual position of tables and pillars requires the presence of tension forces, hence the eigen shape is considered as unreal. The first real eigen shape was then evaluated from the column "Coupling opposite" with frequency $6.5\ Hz$. The eigen shapes and eigen frequencies for all described configurations of boundary conditions could be divided into two groups – real and unreal. The calculated real values of eigen shapes and eigen frequencies were consequently sorted in increasing order (marked in Tab. 1 by number of eigen frequency in brackets) and could be used for the description of dynamical behaviour of lifting platform.

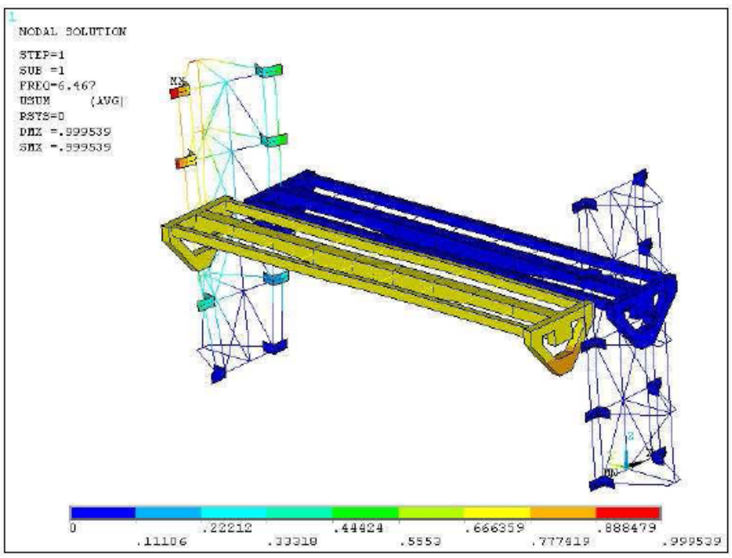

Fig. 5: Visualization of First Eigen shape.

4. Conclusion

The article describes the determination of eigen shapes and eigen frequencies of the lifting platform containing the non-linear joint between table and guiding U-profile. The non-linear joint transfers only the compression forces in longitudinal direction. This fact was respected in the FE analysis by appropriate setting of boundary conditions so that both real and unreal vibration shape was captured. From the obtained results those eigen shapes and eigen frequencies were identified as real which transferred only compression forces between tables and guiding U-profiles.

Tab. 1: Calculated Eigen shapes and Eigen Frequencies with Marked Real Values of Eigen frequencies.

Eigen shape Nr.	Coupling everywhere		Coupling opposite		Coupling same	
	Frequency [Hz]	Description	Frequency [Hz]	Description	Frequency [Hz]	Description
1.	7.232	In-phase pillar torsion	**6.467 (1)**	Pillar torsion (left side)	5.407	Pillar torsion (right side)
2.	**7.684 (2)**	In-phase table torsion	**6.495 (1)**	Pillar torsion (left side)	**7.684 (2)**	In-phase table torsion
3.	**8.842 (3)**	Anti-phase table torsion	**7.685 (2)**	In-phase table torsion	**8.840 (3)**	Anti-phase table torsion
4.	**10.715 (5)**	Table bending (err. Chain)	**8.842 (3)**	Anti-phase table torsion	**8.969 (4)**	Pillar bending (right side)
5.	11.732	In-phase pillar bending	**10.713 (5)**	Table bending (err. chain)	**10.715 (5)**	Table bending (err. chain)
6.	**12.349 (6)**	Table bending (spiralift)	**12.348 (6)**	Table bending (spiralift)	**12.348 (6)**	Table bending (spiralift)
7.	**26.72 (7)**	Pillar bending (right side)	22.001	Pillar torsion (right side)	17.389	Pillar torsion (left side)
8.	28.538	Pillar bending (left side)	22.245	Pillar torsion (left side)	25.169	Pillar torsion (right side)
9.	34.381	Anti-phase pillar torsion	27.216	Pillar bending&torsion (r.s.)	**26.720 (7)**	Pillar bending&torsion (r.s.)
10.	34.787	Anti-phase pillar torsion	29.240	Pillar bending (left side)	29.552	Pillar bending&torsion (l.s.)
11.	39.064	Anti-phase pillar torsion	**35.804 (8)**	Pillar torsion (right side)	**35.730 (8)**	Pillar torsion (right side)
12.	43.665	Anti-phase pillar bending	36.379	Pillar torsion (left side)	**36.320 (9)**	Pillar bending (right side

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