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Case study of mode shapes and eigen frequencies for a U shaped plate structure

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Present paper describes determining of mode shapes and Eigen frequencies of a U shaped plate structure without and with damages using the finite element method of SolidWorks software. The first thirty mode shapes and Eigen frequencies obtained by simulations on U shaped plate structure design were determined considering the structure without any damage or with different types of damage. The relative variations of Eigen frequencies obtained by simulation using finite element method (FEM) were calculated and a graphical representation was made considering its mode shapes. Finally, the results for all case studies were evaluated.

Keywords*: Modal analysis, mode shapes, Eigen frequencies, FEM, damage*

1. Theoretical background

Development of modern aeronautical industry, mechanical field and civil industry has generated a new impetus for a more rigorous analysis of issues related to vibrations of plate structures and detection of defects in a timely manner [1].

Recent orientation in development of theory regarding plate structures and detection of defects in these resistance structures is defined by the use of high performance computers, appealing to numerical methods, including finite element method, the results being compared to experimental data and to different theoretical/analytical methods.

A defect is defined as a phenomenon in which structure weakening occurs and it can be considered as a deviation of structure properties, of material or its geometry, which determines unwanted vibrations, displacements and tensions [2]. Numerous algorithms for defect detection have been developed, but many factors remain to be tested until an ideal model is achieved. Due to measuring devices limitations, sensors performance, experimental errors and structures complexity, only several methods of defect detection can be considered efficient.

2. Case studies for determining Eigen frequencies

For plate structures study, following hypotheses will be considered: material used at structure of flat plates is continuous, homogeneous and isotropic; for moderate loads plate structure behaves elastic and Hooke's law can apply. The numerical method chosen for modal analysis is finite element method (MEF) from SolidWorks program. Modeling of analyzed geometrical shape was done in the Geometry module of the same program. To obtain Eigen frequencies, static analysis module for rectangular thin plates subjected to sole weight was used. The results obtained in this module were transferred to modal analysis module, ambient temperature being 25^{0}C. Using modal analysis, we determined first 30 Eigen frequencies, of which the first 20 Eigen frequencies were of interest in present study. Meshing of 3D model was made with tetrahedral finite elements. Material used from software database, figure 1, is Plain Carbon Steel, with mechanical properties shown in table 1.

Table 1. Material characteristics for Plain Carbon Steel

Flow limit	Tensile strength	Density	Elastic modulus	Poisson Coeficient	Thermal extension coefficient
[N/mm^2]	[N/mm^2]	[kg/m^3]	[N/m^2]	[-]	[K^{-1}]
2.20594×10^8	3.99826×10^8	7800	2.1×10^{11}	0.28	0.000013

Used 3D model represents a structure consisting of 3 rectangular plates, arranged in a U-shape having a constant thickness of 10 mm, 15 mm respectively 20 mm, of which 2 equal plates have rectangular surface with the length of 1000 mm and the width of 200 mm and the third plate has a rectangular surface with a length of 500 mm and a width of 200 mm.

After designing plate geometry, creation of frequency type study and defining material, another 4 stages will be completed, namely: applying constraints, meshing, calculation of modal analysis and visualization of results. Finite element discretization was made using "Solid mesh". Eigen frequencies were determined using the Simulation module from SolidWorks software.

The following steps are taken in order to determine frequency: creating geometry of the plates with and without defect in SolidWorks; activation of Simulation mode; creation of a frequency simulation study; from the frequency type study option, Properties is activated, where the number of calculated frequency modes is set, in this case 30 modes; applying restrictions; finite element discretization (mesh) and analysis calculation [1, 2]. 3D model discretization was made with tetrahedral elements having average finite element size of 1 mm.

Figure 1 shows the modes of vibration obtained by finite element simulation for a structure consisting of 3 rectangular plates, arranged in a U-shape with a constant thickness of 10 mm.

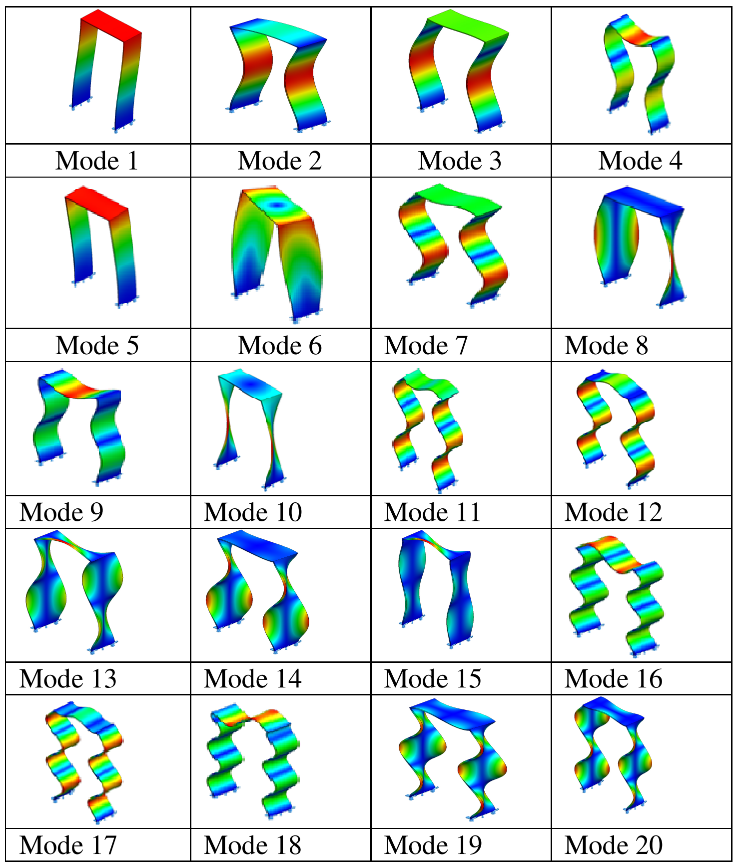


Figure 1. Vibration modes of plates with no defect (1000x500x200x10)

Following numerical simulation, first 30 frequencies were obtained for plate structures with no defect studied. Also, first 30 Eigen frequencies were obtained for the plate structure having the thickness of 10 mm with a single defect, with 2 defects, respectively 3 defects of punctured type considered in different positions. The results obtained are presented in table 2.

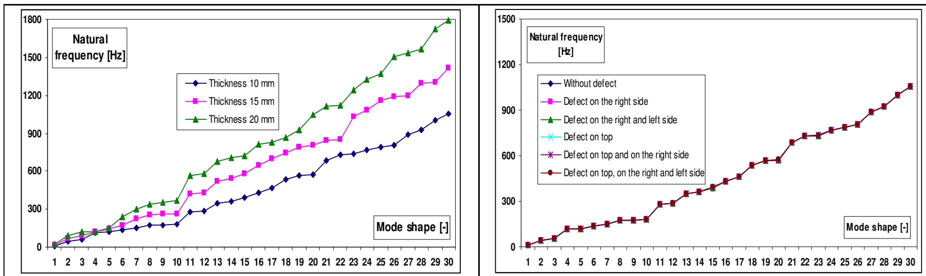
Table 2. Values for displacement [mm] for various applied loads

No	No defect			With defect for 1000x500x200x10				
	1000x500 x200x10	1000x500 x200x15	1000x500 x200x20	right	left-right	up	up-right	up-left-right
1	9.9942	15.102	20.391	9.9954	9.9966	9.9994	10.001	10.002
2	43.382	65.456	88.045	43.407	43.433	43.382	43.408	43.434
3	58.402	88.158	118.65	58.435	58.468	58.415	58.448	58.481
4	115.7	117.85	119.3	115.7	115.71	115.78	115.78	115.79
5	117.02	141.5	146.92	116.96	116.89	117.1	117.03	116.97
6	135.71	174.85	237.3	135.67	135.62	135.72	135.67	135.63
7	148.21	223.43	300.04	148.21	148.21	148.23	148.23	148.23
8	174.28	259.32	342.44	174.39	174.51	174.28	174.39	174.51
9	175.69	266.21	350.93	175.69	175.7	175.93	175.94	175.94
10	181.75	266.28	365.37	181.86	181.96	181.75	181.86	181.96
11	279.48	420.72	564.38	279.59	279.72	279.5	279.61	279.74
12	286.52	431.24	578.2	286.65	286.77	286.6	286.73	286.85
13	348.31	517.62	675.08	348.28	348.24	348.58	348.54	348.51
14	362.38	538.57	707.22	362.32	362.26	362.37	362.32	362.26
15	390.11	578.62	725.28	390.09	390.07	390.83	390.8	390.79
16	428.89	644.21	809.92	428.9	428.92	428.88	428.89	428.91
17	464.37	696.95	829.89	464.37	464.36	464.42	464.41	464.41
18	538.44	748.6	866.26	538.45	538.45	538.43	538.43	538.44
19	566.17	792.92	928.76	566.46	566.85	566.16	566.45	566.85
20	571.35	803.03	1046.6	571.75	572.05	571.38	571.78	572.08

From table 2 it can be observed that the Eigen frequencies increase with the thickness of the plates that form the structure. For the same type of structure, Eigen frequencies increase depending on the number of defects, but also depending on the position of the defect on the analyzed plate structure.

We analyze graphical representation of frequencies on studied plate structures without defect, respectively the Eigen frequencies for plate structure having the thickness of 10 mm, with a single defect, with 2 defects, respectively 3 defects in different positions of the structures depending on their Eigen modes.

From graphical representation shown in Figure 2 a) and b), it is observed that Eigen frequencies for all simulated cases increase almost linearly, depending on their Eigen modes. It can also be stated that Eigen frequencies for the defect-free U-plate structure are very close to the Eigen frequencies for the analyzed structure with 1, 2 or 3 defects.



a) No defect | b) With defect

Figure 2. Eigen frequencies depending on vibration modes of plates

3. Case studies for determining relative variation of Eigen frequencies

We calculated the relative variation ε, of Eigen frequencies for different thicknesses of plates forming the structure, respectively for the plate structure having 1, 2 and 3 defects, with the relation:

$$\varepsilon = \frac{|f_1 - f_2|}{f_1} \cdot 100 \ [\%] \tag{1}$$

where:

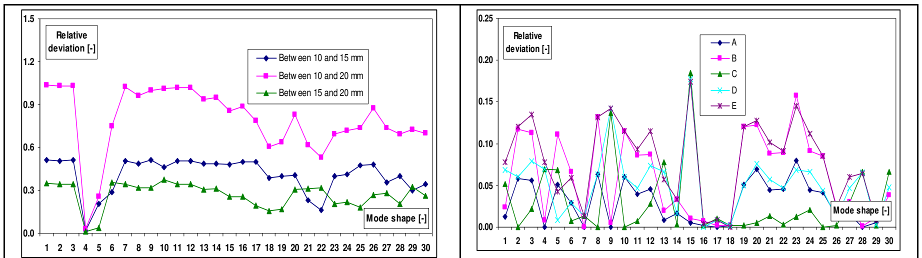
f_1 -Eigen frequency value for the plate structure having a thickness of 10 mm without defect;

f_2 -Eigen frequency value for the plate structure having the thickness of 15 mm and 20 mm, without defect, respectively for the plate structure with different defects.

The results obtained by calculation are used to make a graphical representation, as shown in figure 3, from which it can be observed that relative deviations of the frequencies for the defect-free structure are significant. For structure having defects it is noticed that there are no significant errors of Eigen frequencies, compared to the cases analyzed, regardless of the number of defects.

It can be seen from figure 3 a) that relative variation of Eigen frequencies remains approximately constant regarding its shape, in all 3 cases for the defect-free U-shaped plate structure.

From the graphical representation of relative variation of Eigen frequencies according to their Eigen modes with defect shown in figure 3 b), it can be noticed that the relative variation of Eigen frequencies does not maintain its shape for the first Eigen modes. For small defects it is more adequate to study the relative variation of Eigen frequencies according to their Eigen modes.



a) No defect	b) With defect

Figure 3. Relative variation of Eigen frequencies depending on **v**ibration modes of plates

4. Conclusion

From a summary analysis we concluded that the defects produce frequency changes. These changes depend on the location of the defect and the number of defects, and for small defects it is advisable to study the relative variation of the Eigen frequencies according to their Eigen modes.

References

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