ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XX, NR. 3, 2013, ISSN 1453 - 7397

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Frequency Changes in Thin Rectangular Plates due to Geometrical Discontinuities. Part I: Finite Element Analysis

This paper series presents an analysis regarding the dynamics of thin rectangular plates, embedded on all edges, in order to highlight the effect of geometrical discontinuities upon the natural frequencies. In this paper the first thirty natural frequencies were obtained for a plate without defect and the same plate with six different types of defect. The defect was placed in the centre of the plate; one dimension (the width) was increased successively. The results in terms of frequencies and mode shapes are finally presented.

Keywords: *defect, finite element analysis, plate, natural frequency, vibration mode shapes*

1. Introduction

Any dynamic response of a structure can be reduced to a set of mode shapes, each with an associated modal frequency and damping. These modal parameters constitute the dynamic properties of the structure and provide for a complete dynamic description of the structure. Most vibration problems are related to the resonance phenomena, where operational forces excite one or more vibration modes that lie within the frequency range of the forces.

Various constructions contain in their structure, plates of various shapes and sizes which means that plates have a great importance in mechanical engineering, and not only. A rectangular plate is a solid with length and width relatively large compared to the thickness. The geometry that characterizes a plate is [1]:

- the shape;
- the size of the area median (median plane);
- thickness.

2. Modal numerical analysis

Modal numerical analysis is a modern tool used in industrial and scientific applications, having a large range of utilities, including:

- checking modal frequencies;
- forming qualitative descriptions of mode shapes;
- verifying and improving analytical models;
- predicting:
  - the response to assumed excitations,
  - the change in dynamic properties due to physical modifications,
  - the necessary modifications required to obtain desired dynamic properties,
  - the combined behavior when two or more structures are coupled together.

This paper presents a comprehensive analysis using the SolidWorks simulation software [2, 3], being considered seven cases of thin plate types, namely:

- plate without defect
- plate with central defect of 5x50 mm;
- plate with central defect of 10x50 mm;
- plate with central defect of 20x50 mm;
- plate with central defect of 30x50 mm;
- plate with central defect of 40x50 mm;
- plate with central defect of 50x50 mm.

The defective plates are presented in figure 1. Defects change the natural frequencies of beams or plates, see [4] and [5], so that we conducted experiments to find out the sensitivity of frequency change due defect for the above presented cases. In this work we determined the natural frequency for a number of 30 vibration modes.

3. The 3D modeling of plates with CAD and simulation with FEA

For modeling the plates in the seven analyzed cases, was considered a thin plate with dimensions of 960x460x2 mm [5]. The material related from SolidWorks software library is the AISI 1045 Steel, cold drawn. This material has these mechanical properties shown in Table 1.

Table 1.

Yield strength	Tensile strength	Mass density	Elastic modulus	Poisson's ratio	Thermal expansion coefficient
[N/mm^2]	[N/mm^2]	[kg/m^3]	[N/mm^2]	[-]	[K^{-1}]
530	625	7,850	205,000	0.29	0.000012

After creating the rectangular plate geometry by extrusion operation and choosing the material, other steps are necessary for a complete simulation:

- the application of restrictions - preprocessor;
- the meshing – preprocessor [6, 7];
- the parameters for modal analysis by preprocessor;
- the calculation of equations by solver;
- the results view by postprocessor.

Plates were fixed by clamping the four contour edges and the mesh was made by the "Solid mesh" pyramid elements (with four characteristic points - Jacobian points), the maximum size of one side being two mm. The undamaged plate with imposed boundary conditions is presented in figure 1, while details of the meshed damaged plats are presented in figure 2. The mesh for all analyzed plates in SolidWorks software, was made using the same type of solid mesh, where the resulting for total number of nodes and elements specific to each type of plate are approximately equal.

Table 2 present the mesh data for each plate analyzed: the number of nodes, the number of elements, the maximum aspect ratio and the necessary time to complete mesh. Figures 3 to 7 show the first 30 vibration modes for the plate without defect; for the defected plates the mode shapes do not change significantly, while the natural frequencies are subjected to important changes.

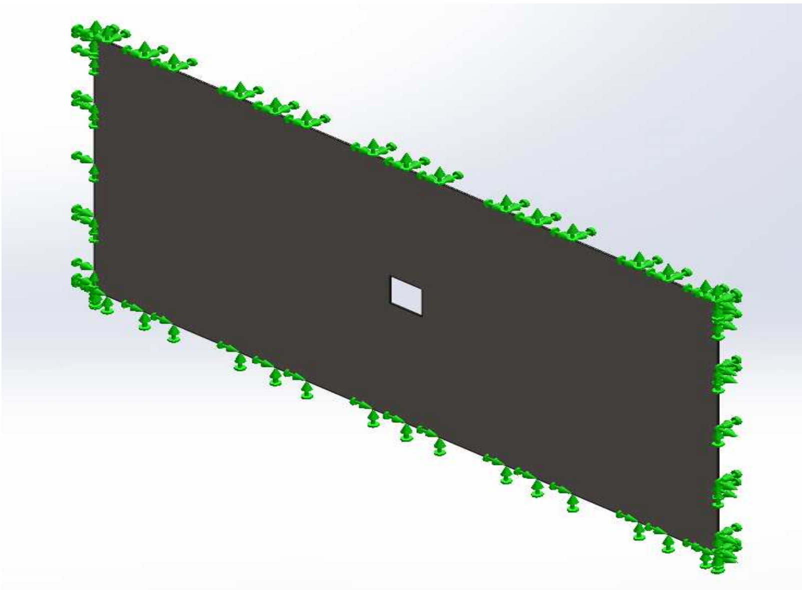
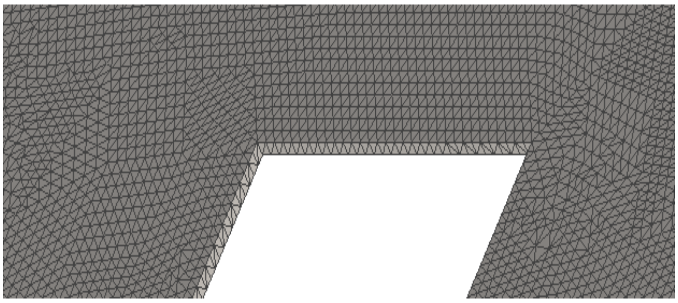
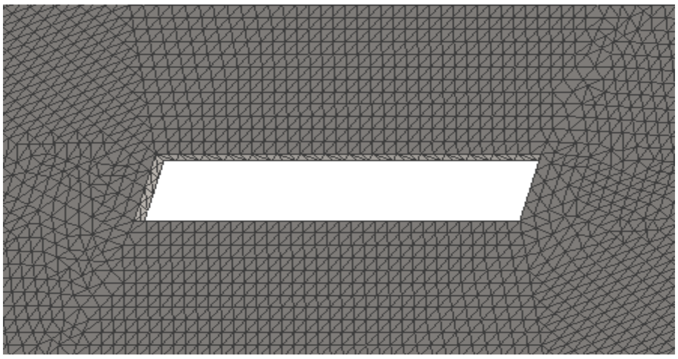


Figure 1. Plate with imposed constraints.



a) Meshed plate with central defect of 50x50 mm.



b) Meshed plate with central defect of 5x50 mm.

Figure 2. The mesh for analyzed plates.

Table 2.

Plate type	Total Nodes	Total Elements	Maximum Aspect Ratio	Time to complete mesh [min:s]
Without defect	2489930	1476647	3.9894	04:42
Central defect 5x50	2477378	1437411	4.0159	04:35
Central defect 10x50	2517888	1467061	4.0003	04:38
Central defect 20x50	2510268	1460333	3.9208	05:25
Central defect 30x50	2763438	1648846	5.1802	05:25
Central defect 40x50	2693349	1593738	5.4731	05:35
Central defect 50x50	2662646	1568556	7.0379	04:12

4. Simulations and results

After the numerical simulation with FEA, for the natural frequencies of the first 30 vibration modes, we obtained results that are presented in Table 3. The modes being arranged in ascendant order of the healthy plate frequencies; the changes are concordance with our expectations [5].

Table 3.

Mode m - n	Calculated frequency values for the seven plate types grouped into m-n						
	Without defect	With central defect					
		5x50	10x50	20x50	30x50	40x50	50x50
1-1	56.494	56.422	56.427	56.416	56.387	56.343	56.281
1-2	71.611	71.596	71.596	71.589	71.582	71.575	71.567
1-3	98.771	98.203	98.181	98.151	98.139	98.137	98.139
1-4	137.96	137.9	137.89	137.84	137.78	137.71	137.62
2-1	147.91	147.88	147.88	147.82	147.73	147.59	147.4
2-2	162.85	162.78	162.74	162.63	162.52	162.42	162.32
2-3	188.53	187.15	187.11	187.11	187.2	187.34	187.5
1-5	188.64	188.5	188.49	188.44	188.36	188.23	188.03
2-4	225.46	225.31	225.2	224.94	224.67	224.42	224.17
1-6	250.42	250.26	250.19	250	249.76	249.47	249.16
2-5	273.81	273.77	273.77	273.72	273.62	273.47	273.22
3-1	285.31	284.95	284.85	284.56	284.24	283.89	283.51
3-2	300.32	300.24	300.25	300.22	300.2	300.18	300.16
1-7	323	319.97	320.01	320.3	320.78	321.31	321.81
3-3	325.76	325.56	325.47	325.24	325.02	324.85	324.76
2-6	333.5	333.3	333.15	332.79	332.43	332.1	331.79
3-4	361.82	361.63	361.6	361.5	361.39	361.3	361.19
2-7	404.36	404.31	404.31	404.24	404.12	403.92	403.25
1-8	406.41	405.99	405.8	405.28	404.64	403.95	403.57
3-5	408.94	407.89	407.96	408.11	408.34	408.61	408.9
3-6	467.16	466.75	466.66	466.41	466.15	465.45	463.53
4-1	468.32	468.17	468.05	467.56	466.72	465.92	465.7
4-2	483.4	483.3	483.3	483.2	483.06	482.9	482.66
2-8	486.28	486.05	485.85	485.42	485.05	484.75	484.54
1-9	500.39	496.14	496.27	496.9	497.74	498.65	499.49
4-3	508.81	508.65	508.55	508.11	507.39	506.37	505
3-7	537.36	536.64	536.52	535.96	535.38	534.94	534.77
4-4	544.68	544.47	544.35	544.04	543.72	543.42	543.09
2-9	578.99	578.91	578.9	578.81	578.63	578.29	577.69
4-5	591.27	591.11	591.04	590.65	590.01	589.13	587.97

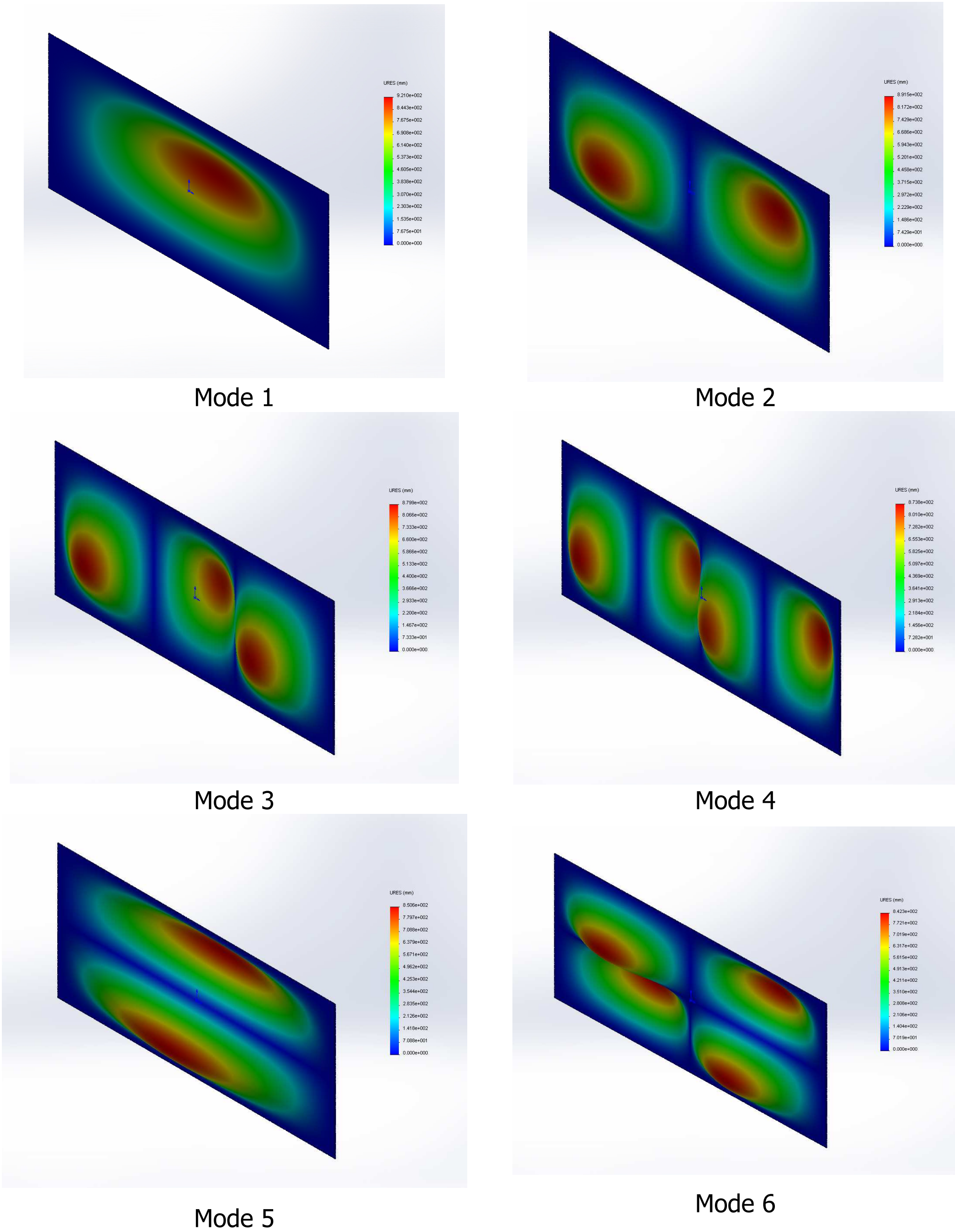


Figure 3. First six vibration modes of plate without defect.

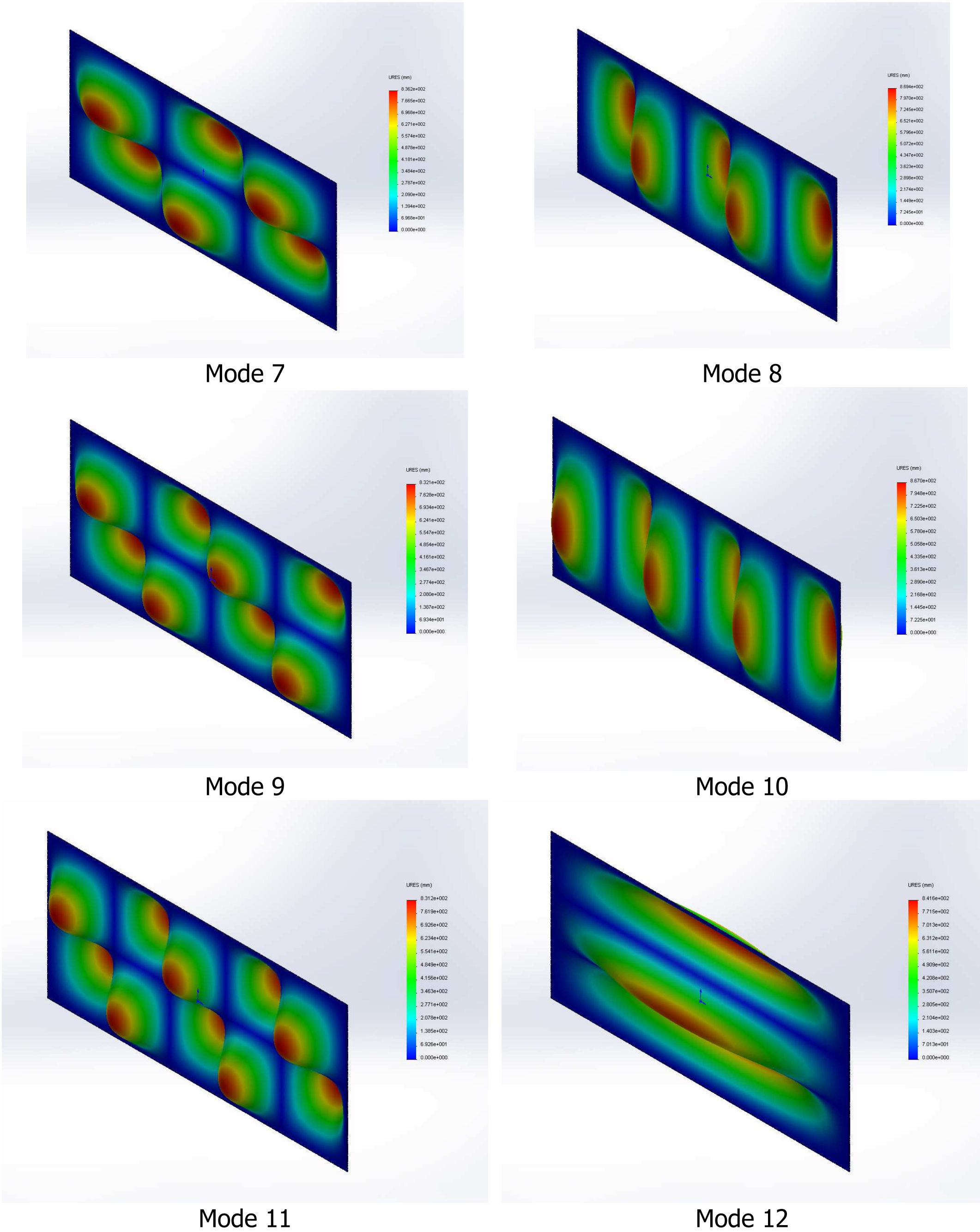
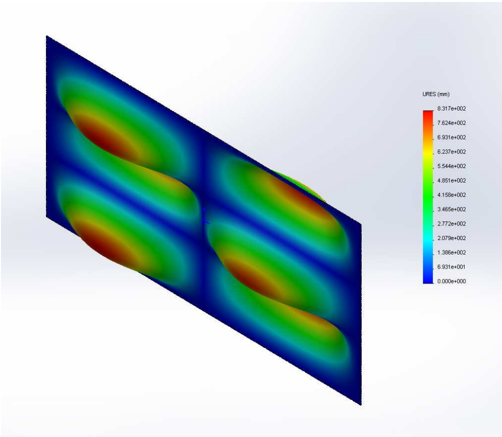


Figure 4. Vibration modes seven to twelve of the plate without defect.



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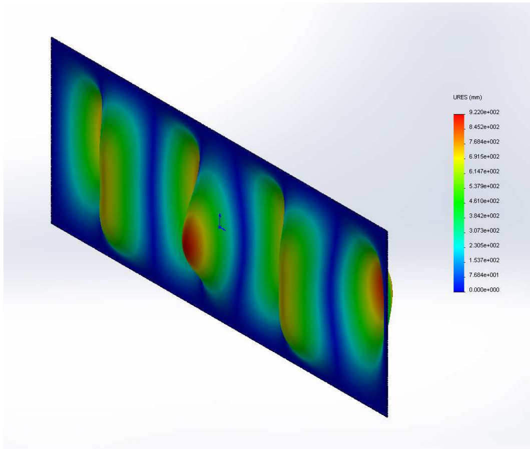

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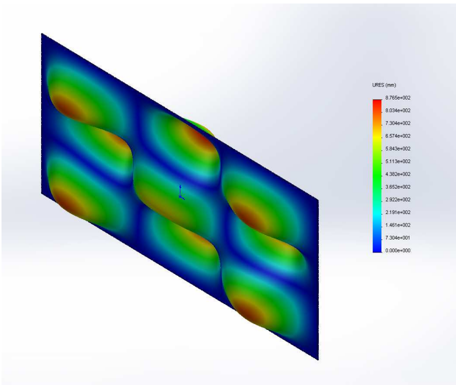

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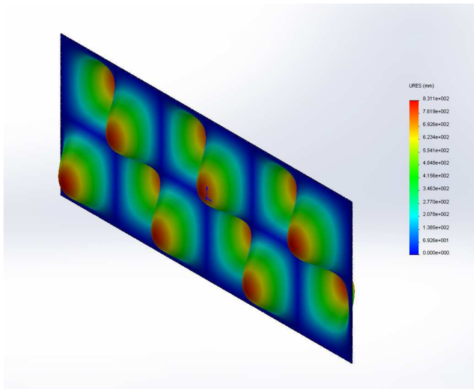

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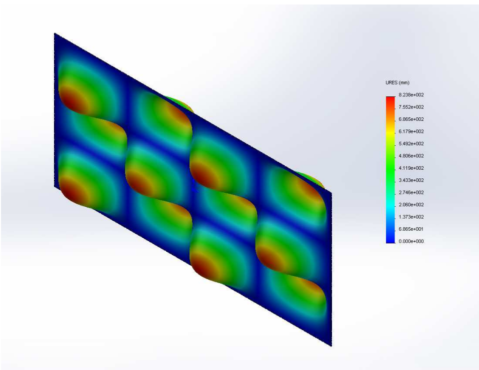

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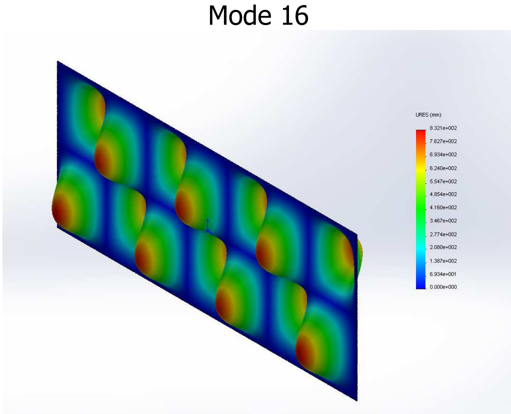
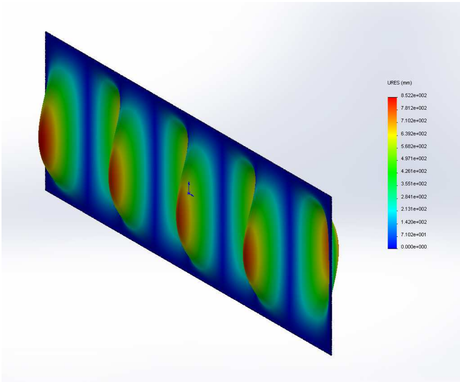


Mode 18

Figure 5. Vibration modes thirteen to eighteen of the plate without defect.



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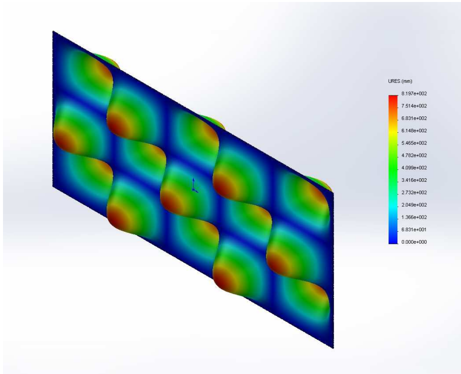

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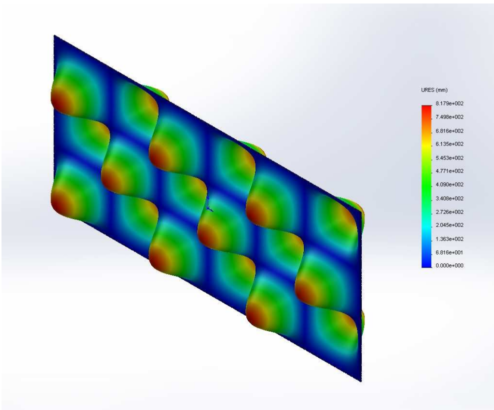

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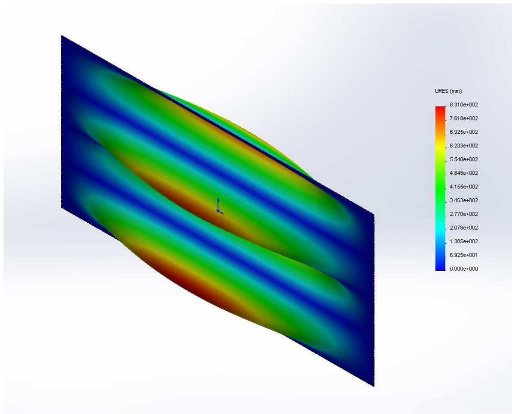

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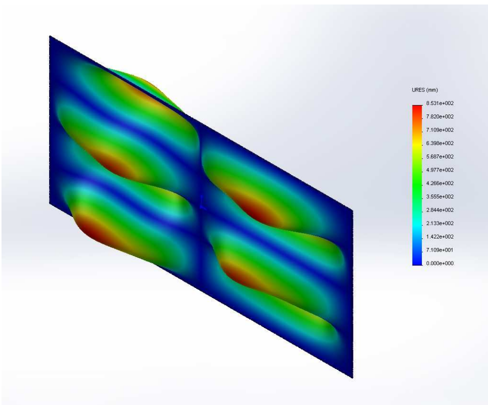

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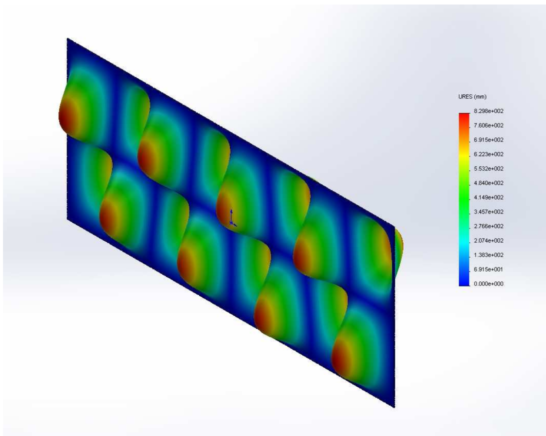
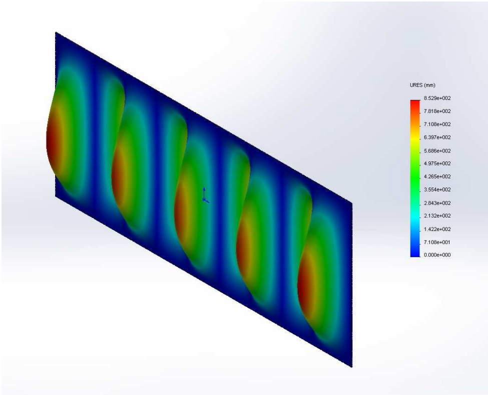


Mode 24

Figure 6. Vibration modes nineteen to twenty-four of the plate without defect.



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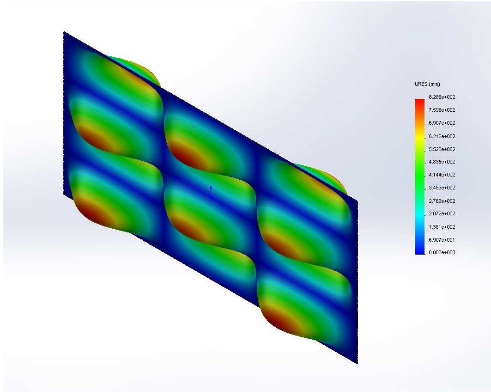

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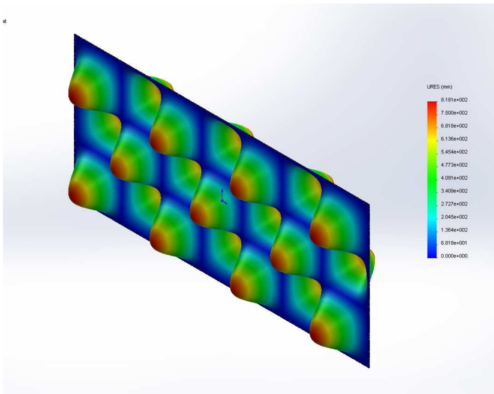

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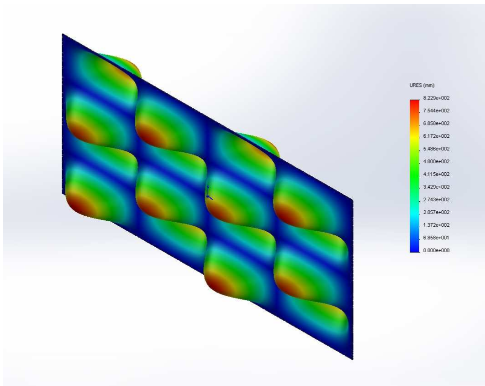

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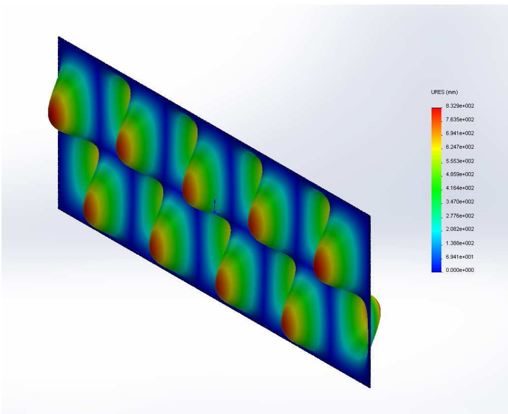

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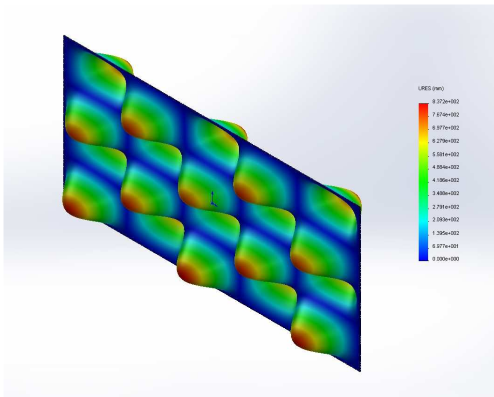

Mode 30

Figure 7. Vibration modes twenty-five to thirty of the plate without defect.

5. Conclusion

The paper, part of a series of two papers focused on highlighting the effect of defects on the dynamic behavior of plates, presents a finite element study on plates in absence and presence of damage. A large number of vibration modes were and damage scenarios were considered. From a summary analysis we concluded that damages produce frequency changes; these changes are dependent on the damage dimension and location. As further work we focus on finding a relation between the frequency changes and damage's characteristics, in terms of dimensions, location and loss of mass.

Acknowledgments

This work was supported in part by the Managing Authority for Sectorial Operational Program for Human Resources Development (MASOPHRD), within the Romanian Ministry of Labor, Family and Equal Opportunities by co-financing the project "Doctoral Scholarships investing in research-development-innovation for the future (DocInvest)" POSDRU/107/1.5/S/76813.

The authors also gratefully acknowledge the support of the Research Institute for Construction Equipment and Technology-ICECON S.A. București, for realization of the experimental stand and virtual instrumentation procedures.

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