FINITE ELEMENT MODAL ANALYSIS OF A HYBRID STIFFENED PLATE

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Abstract: Stiffened plates under longitudinal compression is outlined using several codes. The finite element analysis (FEA) is a powerful technique which is used for the dynamic response of structures. The dynamic behaviour of the hybrid stiffened plate can be investigated further by our modal analyses. The modal analysis helps clarify the causes of resonant vibrations which may occur in application of stiffened plates. The idea of the hybrid plate is to change the Young's modulus of the base plate and the stiffeners, thus assuming that they were made of different materials.

Keywords: stiffened plate, natural frequency, resonance, FEA, hybrid

1. INTRODUCTION

The most common type of analysis is quasistatic analysis, where the load is applied at a slow rate so that the acceleration is negligible. The dynamic analysis is where the effects of acceleration cannot be ignored. Both types provide a relationship between a particular input (e.g. a force applied on a system) to its system response (e.g. a displacement of the system due to its load).

Knowledge of dynamics behavior of stiffened plates is also required for designing structures especially if they are subjected to dynamic effects due to mechanical vibrations from environment. Modal analysis provides another overview of limits of the response of a structure. E.g. for a particular input (load), what are the limits of response of the system (e.g. when and what is the maximum displacement).

Every structure has natural frequencies (the resonant frequencies of structures) at which the structure can naturally vibrate. When the excitation frequency increases and approaches one of natural frequencies, the amplitude of the vibration

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asymptotically increases to infinity in theory, which is something to avoid unless necessary.

Therefore, it is important to know the frequencies at which the structure can behave erratically. There are investigations in different kind of industrial fields e.g. mining excavators (Popescu et al, 2019, Radu et al, 2018).

2. THE STRUCTURE

A stiffened plate loaded by uniaxial compression was optimized (Fig. 1.).

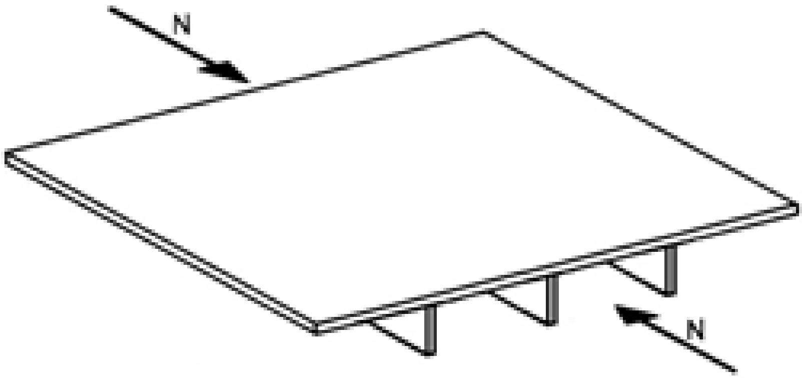


Fig. 1. Longitudinally stiffened plate loaded by uniaxial compression

The design constraints are the follows (Virág, Szirbik, 2019):

- Global buckling of the stiffened plate. The effect of initial imperfections and residual welding stresses is considered by defining buckling curves for a reduced slenderness.
- Single panel buckling. This constraint eliminates the local buckling of the base plate parts between the stiffeners.
- Local and torsional buckling of stiffeners. These instability phenomena depend on the shape of stiffeners. The actual torsional buckling stress can be calculated in the function of the reduced slenderness.
- Distortion constraint. Large deflections due to weld shrinkage should be avoided.

The objective function to be minimized is defined as the material cost.

The given data are width B = 6000 [mm], length L = 4000 [mm], compression force $N = 1.2 \times 10^7$ [N], Young modulus E = 210 [GPa], density $\rho = 7.85 \times 10^{-6}$ [kg/mm^3].

The yield stress is f_y = 235 [MPa]. The optimum results for different fabrication costs calculated by Excel Solver NLP which uses gradient method where the unknowns – the thicknesses of the base plate and the stiffener and the number of the ribs - are limited in size.

The result for material cost is shown in Table 1.

Table 1. **Optimum result**

t_f [mm]	t_s [mm]	φ	K/k_m [kg]
5	10	29	2172

3. MODAL ANALYSIS RESULTS OF HYBRID STIFFENED PLATES

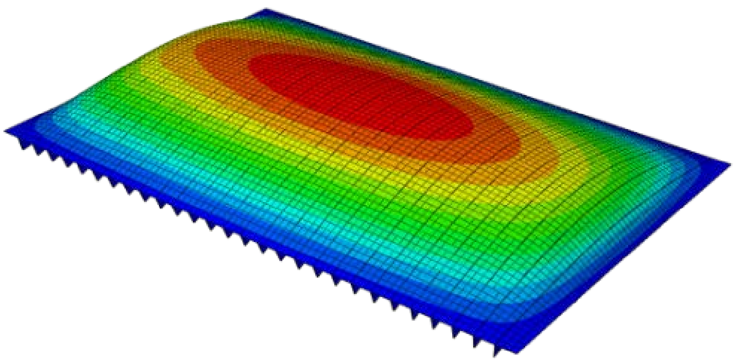
The idea of the hybrid plate is to change the Young's modulus of the base plate and the stiffeners. The geometric dimensions of the selected stiffened plate are given in Table 1.

Below are finite element representations of the rectangular steel stiffened plate which is simply supported on four edges. The stiffened plate possessing various number and thickness stiffeners has been analysed to determine its natural frequencies and mode shapes that the plates oscillate within at natural frequencies. The free vibrations occur at these discrete frequencies, depending only on the geometry and material but in the absence of applied loads (Mukherjee, Mukhopadhyay, 1986).

The main concept is the subdivision of the model of structure into non-overlapping components of simple shaped geometry called finite elements with well-defined stress displacement relationships. According to the finite element method (FEM), the plates with stiffeners are divided into finite elements for the dynamic finite element analysis (FEA). More detailed descriptions of finite element procedures can be found in Bathe's book (Bathe, 1996).

To investigate the natural frequencies, a linear perturbation analysis for a thin shell structure is performed in the commercial software Abaqus. In each FE model a conventional shell model, a 4-node shell element (S4R) is employed. The FE model of the optimized design (for details see in Table 1.) contains 8150 linear shell elements such that the approximate global size is 70 mm. Each FE model is modificated by changing material properties, Firstly, Young's modulus of the stiffeners is changed and the base plate remains original in its material (210 GPa) then vice versa.

Different mode shapes at different frequencies are depicted in the Figure 2.



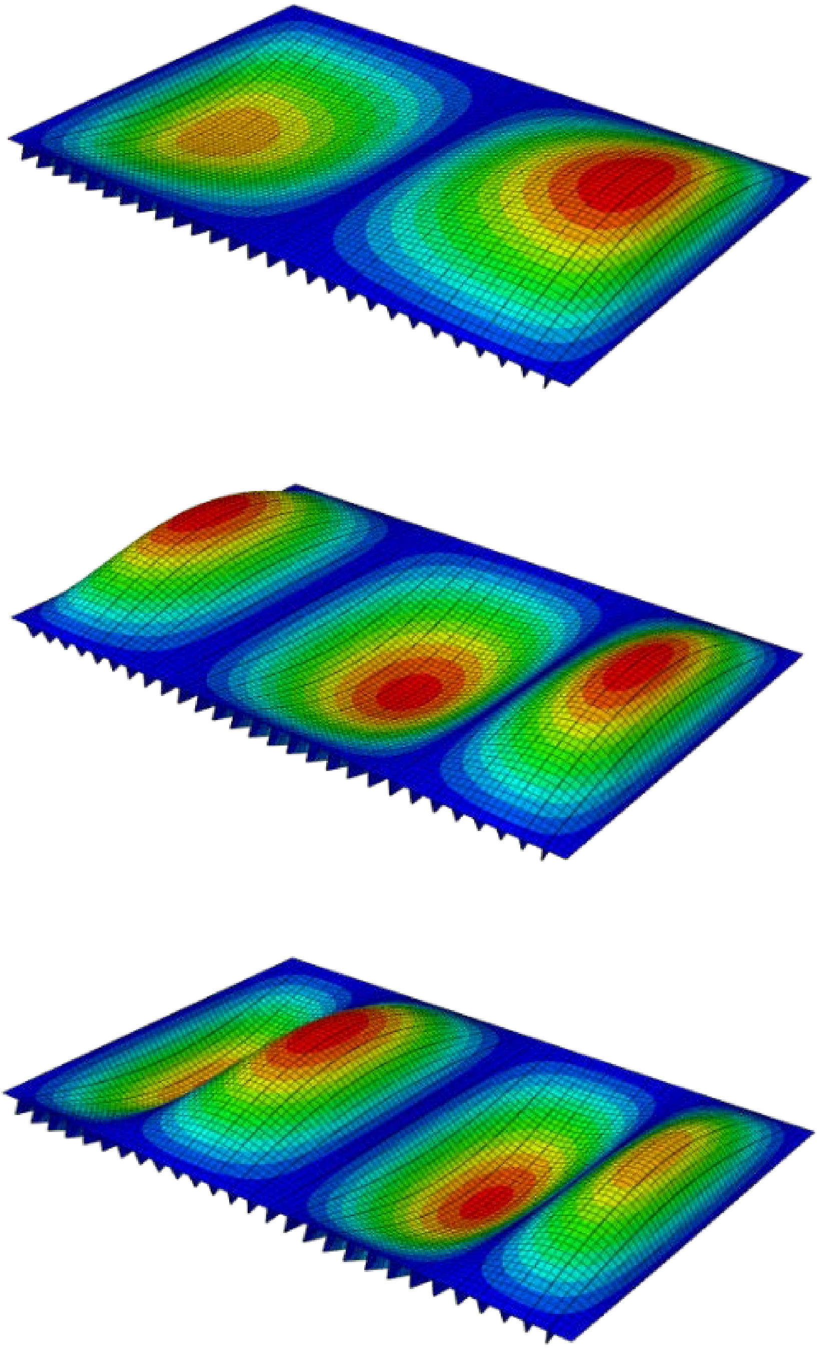


Fig. 2. The first four modes of vibrations of rectangular plate

The first eight natural frequencies in both cases are listed in the Table 2. and 3.

Table 2. **Comparison of natural frequencies (rad/s) for a base plate E = 210 [GPa]**

Mode No	**Stiffener Young modulus [GPa]**		
	210	**200**	**190**
1.	142.57	140.35	138.04
2.	147.14	144.80	142.37
3.	159.08	156.33	153.47
4.	168.85	165.72	162.47
5.	177.06	173.65	170.11
6.	184.65	181.08	177.39
7.	192.89	189.27	185.53
8.	202.60	199.01	195.32

Table 3. **Comparison of natural frequencies (rad/s) for stiffeners E = 210 [GPa]**

Mode No	**Base plate Young modulus [GPa]**		
	210	**200**	**190**
1.	142.57	141.32	140.00
2.	147.14	145.89	144.58
3.	159.08	157.95	156.75
4.	168.85	167.88	166.84
5.	177.06	176.17	175.22
6.	184.65	183.75	182.80
7.	192.89	191.86	190.78
8.	202.60	201.30	199.97

4. CONCLUSIONS

This paper is devoted to an investigation of hybrid stiffened plates. The two components of the structure (the base plate and the stiffeners) can be made of different materials, which are simple modeled as different Young's moduli. The results show higher differences when we change the modulus of the stiffeners. Therefore, it is important that the structure is properly designed and made from proper material. The dynamic behaviour of the stiffened plates can be further investigated by mode superposition analysis with knowledge of natural frequencies and modes. The finite element analysis is a powerful technique which is enabled to obtain the forced response of the plates.

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