



Dynamic behaviour of floor systems in accommodation areas

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ABSTRACT

Vibration can cause structural damage and negative impacts on human health in accommodation areas. Thus, engineers have to design structures avoiding resonance phenomena which occurs forced frequency equals to natural frequency. Therefore to avoid structural damage and negative impacts on the human health, natural frequencies of structures have to be known by engineers.

Floor system is entire system of components between supporting beams or girders. In shipbuilding industry, accommodation floor systems normally consists at least two different layers which are steel and material based concrete. Developing materials science and industry lead us to have more and better floor options. In order to avoid noise and vibration problems, engineers have better solutions. In contrast these floor types have complex structures. Therefore measuring and analysing the dynamic behaviour of floor structures are essential matters for engineers.

In this study, dynamic behaviour of typical design solutions as applied in accommodation areas was evaluated. Local vibration analyses were performed for selected configurations. Using finite element method the different layers of floor systems were modelled as composite elements and volume elements. The effect of added masses was analysed. The main focus of this study is local vibration analysis of floor systems in accommodation areas. Finite element method is based on modal analysis for local vibration analyses.

All materials and parameters were selected according to floor applications in accommodation areas. These data can be used for any further calculations. For the effect of added masses, input values were selected according to previous local vibration analyses. Definition of typical dimensions and configurations were considered according to a real ship's accommodation floor design plans. Plate, stiffener and panel vibrations were calculated with special focus on varying floor systems. All floor systems which have different layers are modelled using ANSYS structural model elements. Finite element analyses conducted include modal analyses and harmonic analyses using ANSYS Mechanical APDL software package

The thesis was developed as application of finite element method. The accuracy of results was confirmed by analytical formulae. More complex floor systems and the actual parts of accommodation areas analyses can be future studies.

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III. List of Abbreviations

APDL	ANSYS Parametric Design Language
DOF	Degree of freedom
FEA	Finite element analysis
HP-profile	Holland profile; this profile type is typical profile used for ship constructions as stiffeners; it is similar to the L-profile, however it has bulb-shaped flange, instead of a flat plate flange
L-profile	L-shaped profile has straight web and straight flange structure
POST26	Enters the time-history results postprocessor
AF	Amplification factor

IV. Nomenclature

E	Young's modulus
A	Cross sectional area
Hz	Hertz; unit of frequency in international units system SI
f	Natural frequency of the structure
d	Densities of materials
I	Moment of inertia of the area
K	Global stiffness matrix
M	Mass matrix including the structural mass and the added mass matrix
r	Bulb radius
ROTX, ROTY, ROTZ	Rotational degrees of freedom around longitudinal, vertical and horizontal axes, respectively
s	Chord length
t	Plate thickness
UX, UY, UZ	Displacement degree of freedom in longitudinal, vertical and horizontal directions respectively
u, \dot{u}, \ddot{u}	Time dependent displacement vectors with first and second derivative
ν	Poisson's ratio
t_{FL}	Thickness of flange

Declaration of Authorship

I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Where I have consulted the published work of others, this is always clearly attributed.

Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

I have acknowledged all main sources of help.

Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma.

I cede copyright of the thesis in favour of the University of Rostock.

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1. INTRODUCTION

Vibration and noise can cause bad effects on human beings and more importantly vibration can cause resonance phenomena that cause structural damage. As an engineering task we have to perform enough analyses in order to prevent structural damage and fulfill the defined comfort criteria at the preliminary design stage or during the structural design phase.

With regard to effect of vibration on human beings, existing standards are aimed to ensure comfort and well-being. When we consider the accommodation area, our main task is to provide safe and comfortable cruising for crew and passengers.

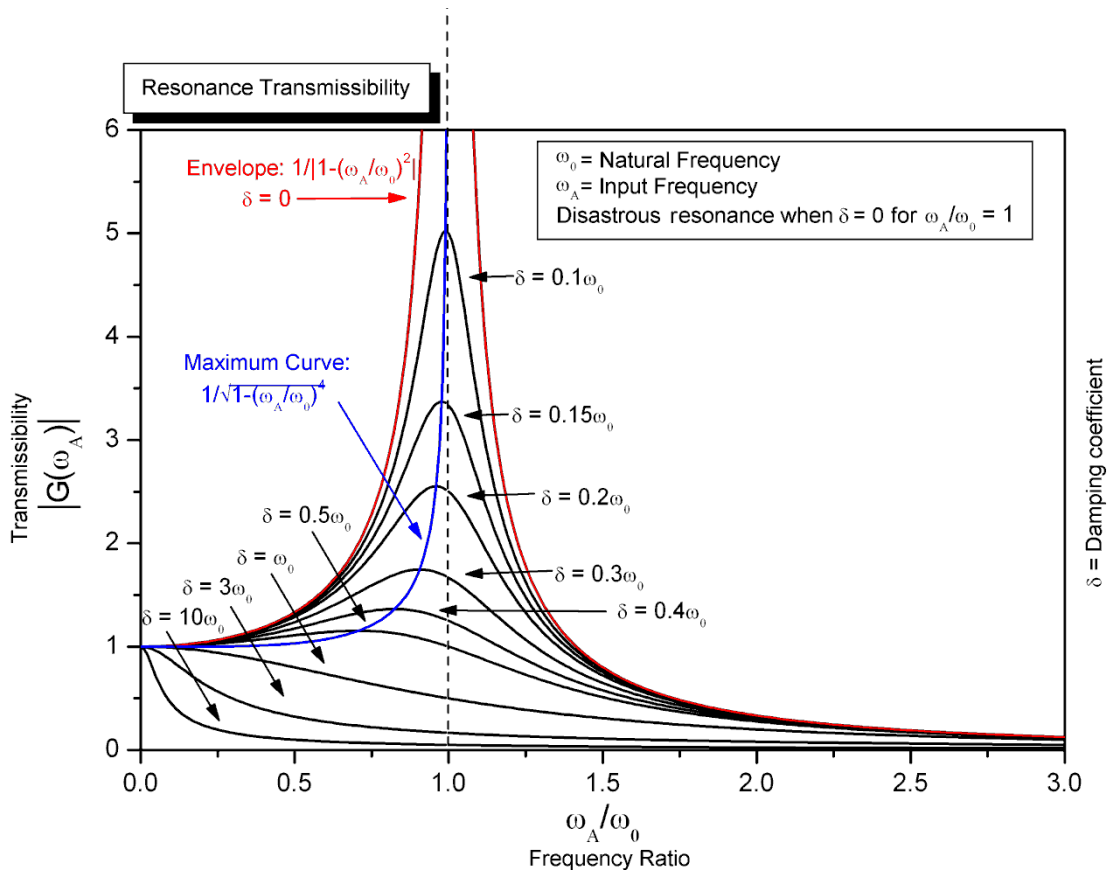


Figure 1.1: Resonance and natural frequency relation [1]

Basically there are two vibration analyses in calculating ship's vibration. These are global vibration analysis and local vibration analysis. Global vibration analysis is done for ship's entire hull. Local vibration analysis is done for specific area or part of ship structure. In our case we will use local vibration analysis for calculation of floor systems in accommodation areas.

Local vibration analysis will be our analysis way in order to calculate accommodation deck. Local ship structures have comparatively high natural frequencies; therefore, we need high detailed FE models for their calculation. “The aim of local vibration investigations is usually to limit vibration magnification relative to the global level. Thus, for example, vibration amplitudes at the centre of a deck grillage of an accommodation deck should not be much larger than at stiffly supported edges. This can be achieved only if freedom from resonance exists for all structural components of the deck.” The aim of this analysis is to avoid resonance situation in vibration modes.

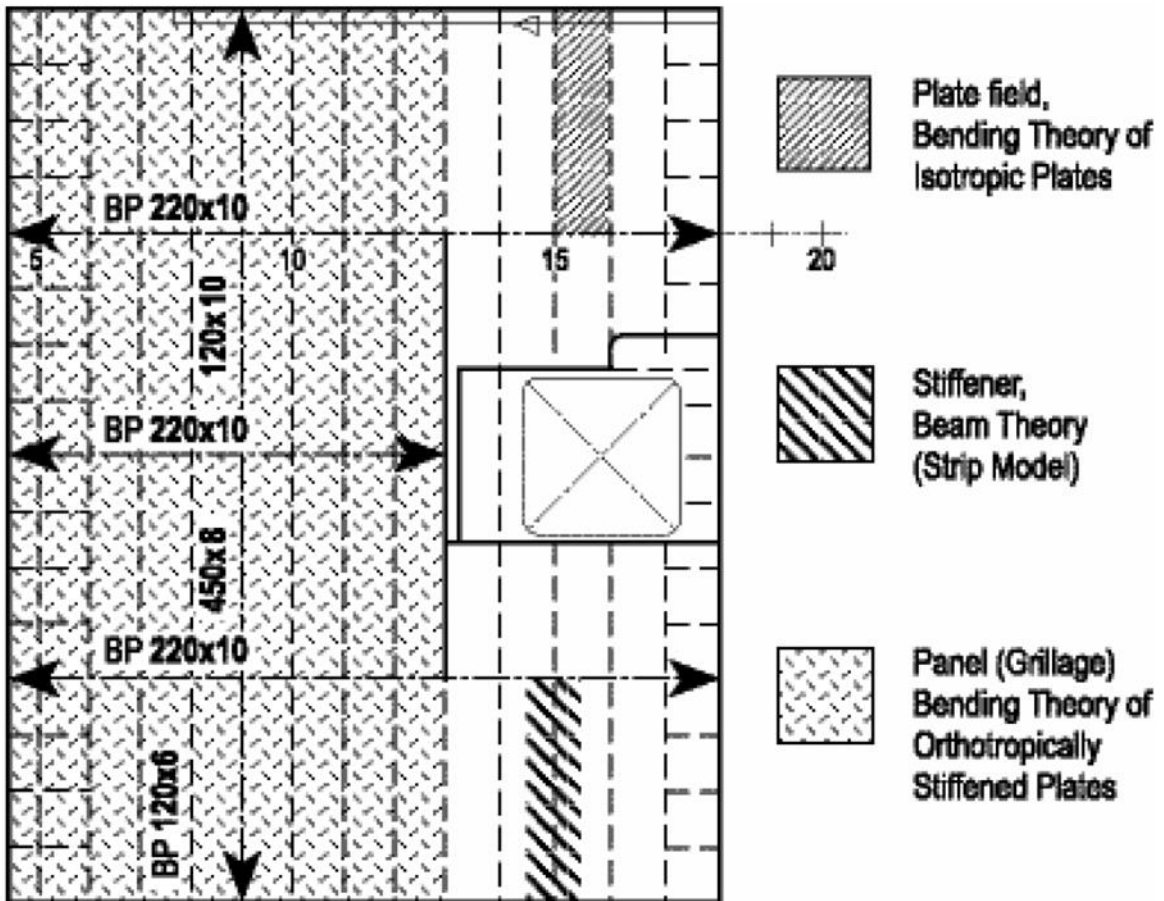


Figure 1.2: Structural components in local vibration analyses [1]

Calculation approach of steel structure in floor systems is simply,

Structural Element

Vibration Criteria

Decks in Superstructure

Plate, Stiffened plate, Panel

Typical characteristic frequencies for ship vibration are represented below (figure 1.3), frequency range is found between 10 to 50 Hz.

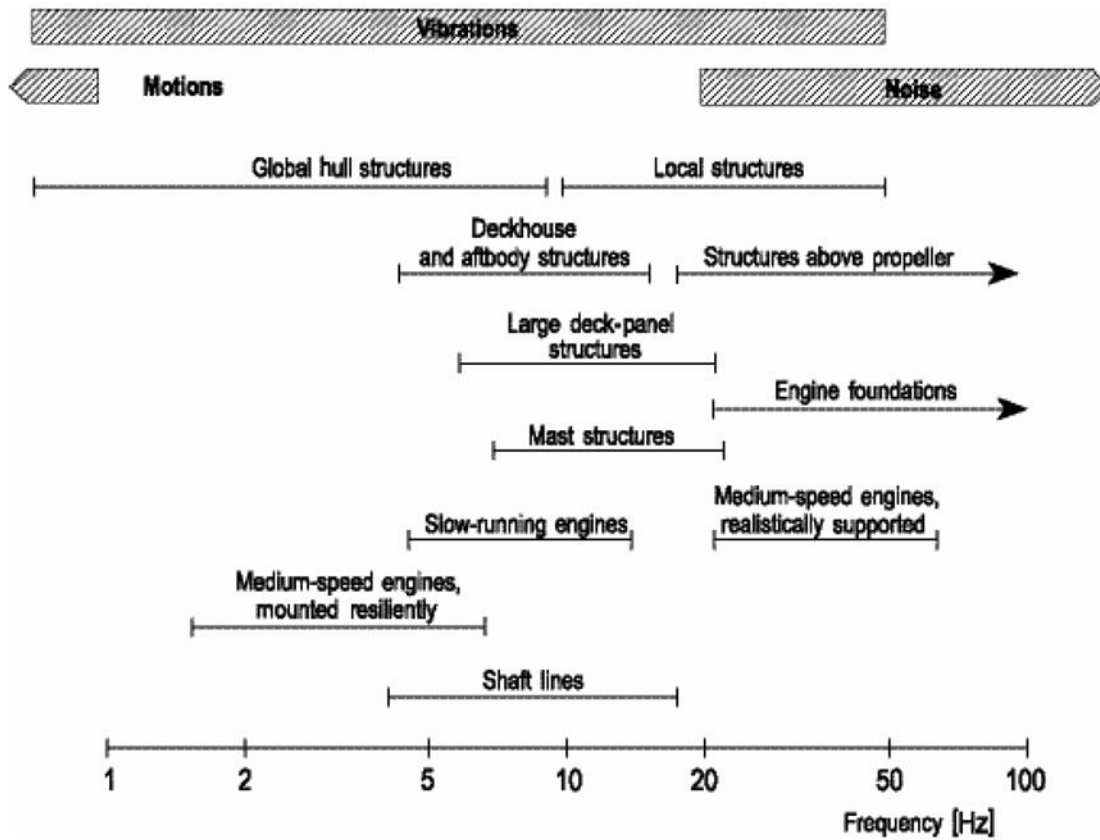


Figure 1.3: Natural frequency ranges in shipbuilding applications [1]

The first mode shape represents the lowest characteristic frequency, therefore first mode shapes are analysed. Further vibration modes are the subject of noise problems.

2. DYNAMIC BEHAVIOUR OF STEEL STRUCTURES

2.1. Analytical Methods

Engineering calculations must be verifiable therefore our numerical results which are coming from FEM analyses verified by using analytical methods.

2.1.1. Plate Vibration

Plate structures are basic part of deck structure. In order to verify numerical methods (FEM, GL LocVibs) plate vibrations are calculated by using analytical formulae. For the two and more layered structures, rules of mixtures composite materials are used.

Equation for the simply supported rectangular plate calculation of natural frequency:

$$f = \frac{\alpha}{L^2} \sqrt{\frac{Et^3}{12 \cdot \mu(1-\nu^2)}} \quad (2.1)$$

$$\alpha = 1.57 \cdot (1 + \lambda^2) \quad (2.2)$$

2.1.2. Stiffener Vibration

Equation for the simply supported beam calculation of natural frequency:

$$f = \frac{2}{\pi} \sqrt{\frac{3EI}{0.49\mu l^4}} \quad (2.3)$$

2.2. Numerical Methods

In this section, the general theory of the modal analysis for structures is described. Modal analysis is used in order to determine the natural frequencies and the mode shapes of structures.

2.2.1. Finite Element Method

Nowadays the finite element method (FEM) is an essential and powerful tool for solving structural problems not only in the field of shipbuilding but also in the design of most industrial products and even in non-structural fields [2]. Finite element method is a numerical technique for finding approximate solutions. It cuts structures into several elements that called finite elements. ANSYS 14.5 is used as finite element software.

2.2.2. Modal Analysis

Modal analysis is the study of measuring and analysing dynamic response of structure under vibrational excitation. The modal analysis in structural mechanics is used to determine the natural frequencies and mode shapes of structure during free vibration excitation.

General equation of motion:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F(t)\} \quad (2.4)$$

External load factor is not considered for modal analyses. Assuming free vibrations and ignoring the impact of damping, the equation 2.1 reduces to:

$$[M]\{\ddot{u}\} + [K]\{u\} = \{0\} \quad (2.5)$$

To represent the free vibration solutions of structure, assuming harmonic motion,

$$([K] - \omega^2[M])\{u\} = \{0\} \quad (2.6)$$

Corresponding vectors are $\{u\}_i$ the eigenvectors. The eigenvectors represent the mode shapes of structure when vibration occurs.

The Block Lanczos eigenvalue solver uses the Lanczos algorithm where the Lanczos recursion is performed with a block of vectors. This method is as accurate as the subspace method, but faster. The Block Lanczos method uses the sparse matrix solver, overriding any solver specified via the EQSLV command. [5]

2.2.3. Harmonic Analysis

When a structure is sustained to cyclic loading, the resulting response will be cyclic response as well. ANSYS provides the user with the capability to predict sustained dynamic behaviour of structures.

There are three harmonic response analysis methods: full, reduced, and mode superposition. Mode superposition method will be our method in ANSYS Mechanical APDL. The full method is the easiest way for harmonic analysis. Before we study the details of full method and mode superposition method, advantages and disadvantages of these two methods are given below.

“The *full method* is the easiest of the three methods. It uses the *full* system matrices to calculate the harmonic response (no matrix reduction). The matrices may be symmetric or unsymmetric. The advantages of the full method are:

- It is easy to use, because you don't have to worry about choosing master degrees of freedom or mode shapes.
- It uses full matrices, so no mass matrix approximation is involved.
- It allows unsymmetric matrices, which are typical of such applications as acoustics and bearing problems.
- It calculates all displacements and stresses in a single pass.
- It accepts *all* types of loads: nodal forces, imposed (non-zero) displacements, and element loads (pressures and temperatures).
- It allows effective use of solid-model loads.

A disadvantage of the full method is that no prestressed option is available. Another disadvantage is that this method usually is more expensive than either of the other methods when you use the frontal solver. However, when you use the JCG solver or the ICCG solver, the full method can be very efficient.”[3]

“Its advantages are:

- It is faster and less expensive than either the reduced or the full method for many problems.
- Element loads applied in the preceding modal analysis can be applied in the harmonic response analysis via the LVSCALE command.
- It allows solutions to be clustered about the structure's natural frequencies. This results in a smoother, more accurate tracing of the response curve.
- Pre stressing effects can be included.
- It accepts modal damping (damping ratio as a function of frequency).

Disadvantages of the mode superposition method are:

- Imposed (non-zero) displacements cannot be applied.
- When you are using Power Dynamics for the modal analysis, initial conditions cannot have previously-applied loads.”[3]

3. CHARACTERISTICS

3.1. Geometry of Study

The dimensions of all floor systems which include different layers, Holland profiles and T girders are based on real ship's accommodation structure plans. However in order to make models and analyses some generalizations are made.

All models boundary conditions are defined on edge of models as simply supported. Simply supported conditions are respectively; $UX = 0$, $UY = 0$ and $UZ = 0$. In symmetry boundary conditions additionally rotational boundary conditions are applied according to coordinate system of models. These rotational boundary conditions can be applied on same location together or separately. The rotational boundary conditions are respectively; $ROTX = 0$, $ROTY = 0$ and $ROT = 0$. In the describing stage of all models, SI unit system is used in ANSYS Mechanical APDL.

3.1.1. Plates

Plate dimensions are chosen according to similar plates structures that used in accommodation areas in ships. For all plate calculations, same length and same breadth are used with different thicknesses. Length is chosen as 2000 mm and breadth is chosen 600 mm.

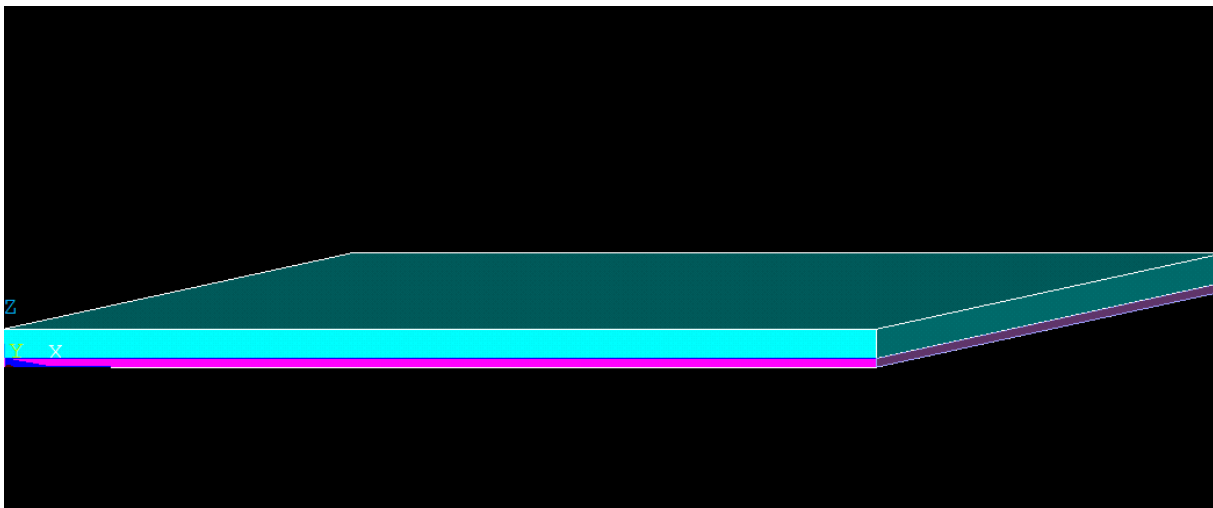


Figure 3.1: Model view of steel-concrete plate

Lowest layer always modelled as using steel plate properties, as seen in figure 3.1, pink coloured layer represents steel deck plate.

3.1.2. Stiffened Plates

Stiffened plates structures include plate and beam structure. Same length and same breadth values are chosen for plate structure. In accommodation area plan, usually HP 120x6 is used as beam structure for many area parts. Thus HP 120x6 is chosen as beam structure.

In addition to have correct natural frequency and mode shapes, side edges of stiffened plate where locates equally distanced from stiffeners mid part of plate area symmetry boundary conditions are applied according to adjacent structure. Front and back edges are simply supported.

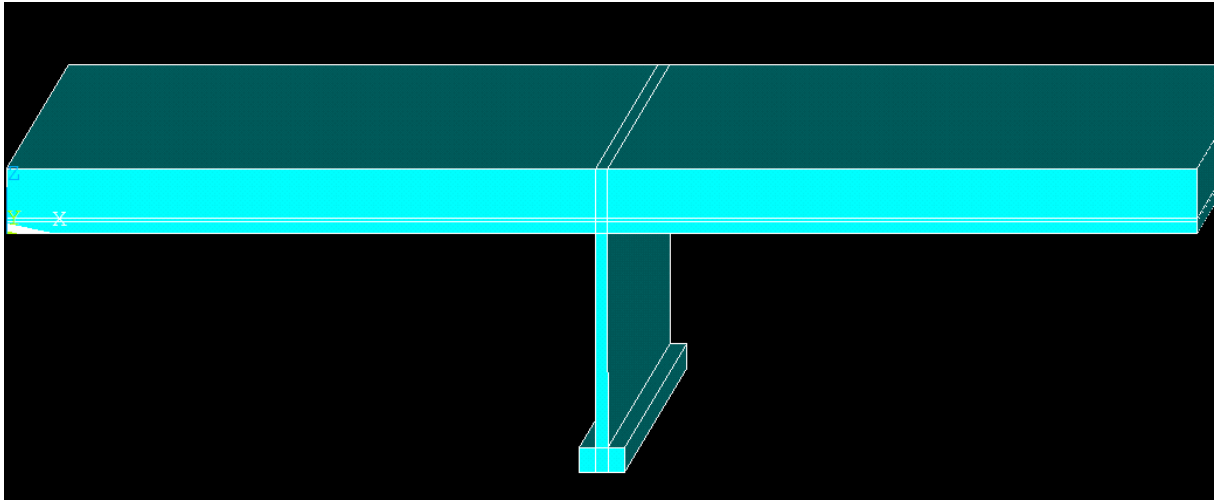


Figure 3.2: Model view of steel – visco elastic – concrete stiffened plate

Also for the replacement of HP 120x6 to L-Profile, we need to calculate the flange thickness of L-Profile, therefore information of HP 120x6 is shown below tables.

Table 3.1: Information of HP 120x6 [10]

Designation		Dimensions			Bulb Radius
Section	Mass per meter	Width b (mm)	Thickness t (mm)	Bulb Height c (mm)	r1 (mm)
120x6	7,60	120,00	6,00	17,00	5,00

Table 3.2: Information of HP 120x6 [10]

Cross Section	Distance of the Axis	Characteristic Values for the Bending Axis x-x	
A (mm ²)	dx (mm)	I _x (cm ⁴)	W _x (cm ⁴)
930,00	72,00	133,00	18,40

After several calculation steps flange thickness of L-Profile is found as,

$$t_{FL} = 12.353 \text{ mm}$$

3.1.3. Panels

Geometry of panels is shown below figure 3.3. Transversally the distance between each two stiffeners is 600 mm and the distance between each two girders is 1800 mm, so two stiffeners structures are located between each two girders. Longitudinally, girders are located every 2000 mm. The stiffeners are chosen as HP 120x6 and necessary mathematical transformations for replacement to L profile is written previous page. Additionally, T girders consists web and flange structures in order of; T girders are described as T 450x8x100x10.

For panel calculation, steel and steel – concrete floor systems calculated.

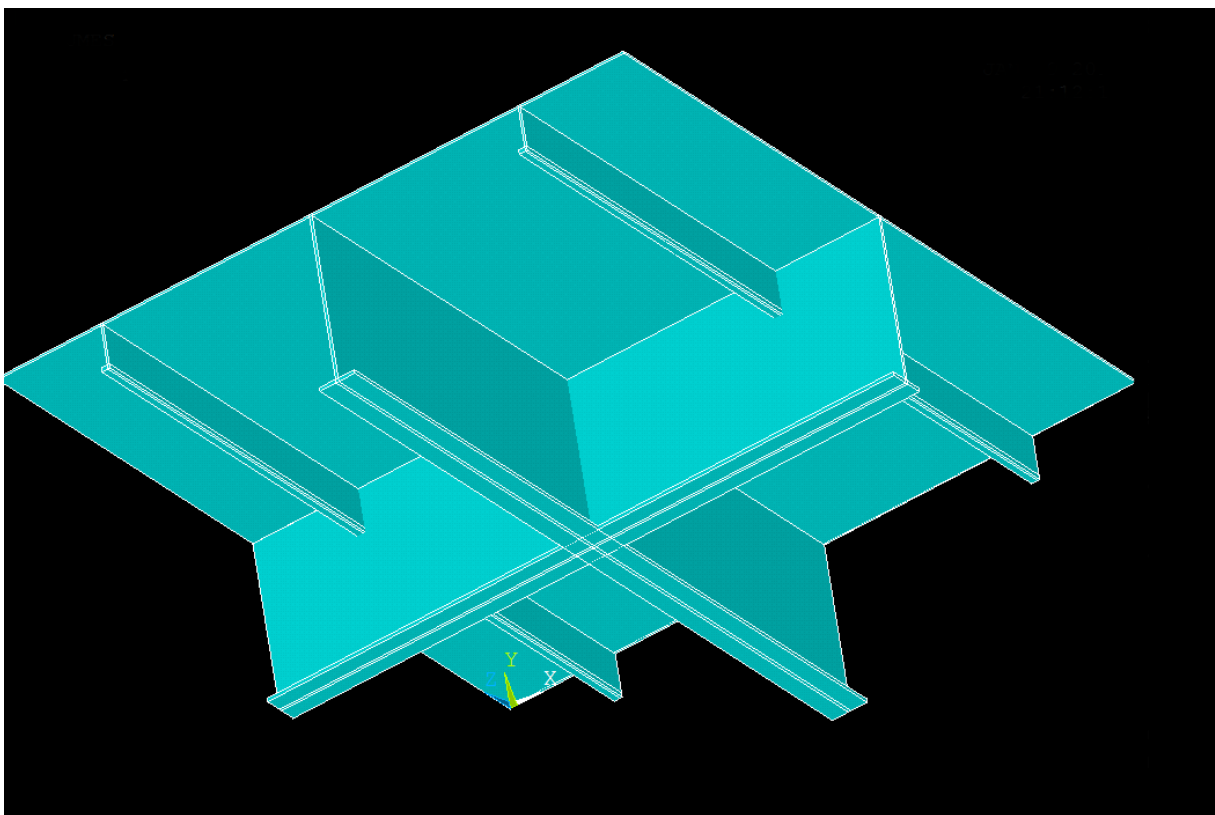


Figure 3.3: Model view of steel panel

3.2. Surface Loads

Regarding the surface loads, all values are taken under the guidance of company and from previous weight estimations for accommodation areas.

Surface loads are applied due to effect of furniture and other materials on deck. The surface loads are chosen as respectively $0 \frac{kg}{m^2}$, $40 \frac{kg}{m^2}$ and $80 \frac{kg}{m^2}$.

4. PARAMETERS OF STUDY

Before modelling all models in FEM software, the most important part of this study undoubtedly is to find material properties. For modal analyses, there are three properties have to be defined by user. Respectively they are Young's modules, Poisson's ratios and densities. All these information is found in Prof. Dr.-Ing. habil. Günther Schlottmann's "Dynamisches Verhalten von Flächentragwerken in Schiffsaufbauten" named study [4].

The material properties of analyses are given as follows,

4.1. Young's Modules

Young's modulus is the ratio of stress along an axis to the strain along the axis. Also it is known as elastic modulus or tensile modulus. It measures stiffness of an elastic material and gives a quantity to characterize materials. Young's modules of materials are listed below.

Young's module for steel,

$$E_s = 2.1 \cdot 10^{11} \frac{N}{m^2}$$

Young's module for concrete,

$$E_c = 2.8 \cdot 10^{10} \frac{N}{m^2}$$

Young's module for mineral wool,

$$E_m = 0.15 \cdot 10^6 \frac{N}{m^2}$$

Young's module for viscoelastic material,

$$E_v = 5.5 \cdot 10^6 \frac{N}{m^2}$$

4.2. Poisson's Ratios

Poisson's ratio is measure of the change of material dimensions. For example, if one material is compressed in one direction, the material tends to expand in the other two directions. This enlargement is perpendicular to compression direction. Poisson's ratios of materials are listed below.

Poisson ratio for steel,

$$v_s = 0.3$$

Poisson ratio for concrete,

$$v_c = 0.16$$

Poisson ratio for mineral wool,

$$v_m = 0.1$$

Poisson ratio for viscoelastic material,

$$v_v = 0.495$$

4.3. Densities

In this part, densities are listed below but these density values including Young's modules values and Poisson's ratios values are special for material names. If need to describe briefly, Tefrotex 60 is based on concrete material; Rockwool Marine Slab 140 is based on mineral wool material and lastly Tefrotex Viscoelastic is based on viscoelastic material.

Density value for steel,

$$\rho_s = 7800 \frac{kg}{m^3}$$

Density value for concrete,

$$\rho_c = 1800 \frac{kg}{m^3}$$

Density value for mineral wool,

$$\rho_m = 140 \frac{kg}{m^3}$$

Density value for viscoelastic material,

$$\rho_v = 1400 \frac{kg}{m^3}$$

5. ELEMENT TYPES

5.1. Shell Elements

Shell elements are suitable for analysing thin and moderately-thick shell structures.

5.1.1. Shell 181

SHELL181 is four-node element with six degrees of freedom at each node. Six degrees of freedom cover translations in x, y and z directions, and rotations about the x, y and z axes.

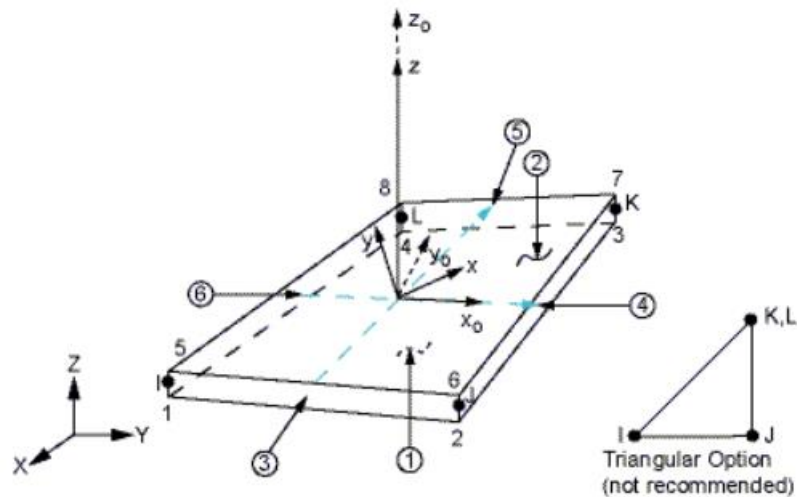


Figure 5.1: Shell181 Geometry [5]

5.1.2. Shell 281

SHELL281 is eight-node element with six degrees of freedom at each node. The six degrees of freedom include translations in x, y and z directions, and rotations about the x, y and z axes.

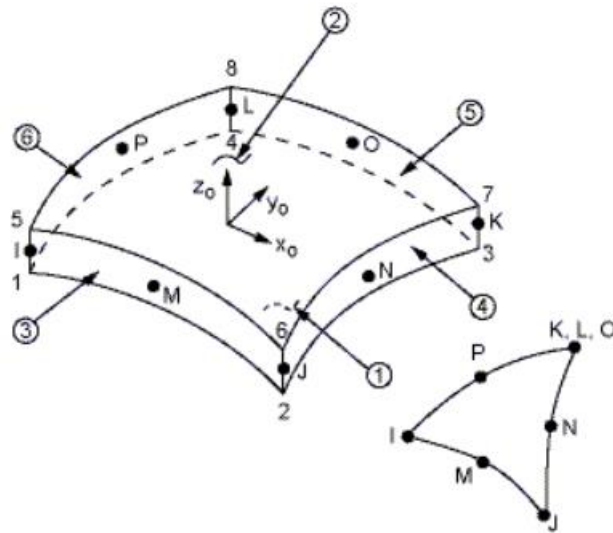


Figure 5.2: Shell281 Geometry [5]

5.2. Beam Elements

Beam elements are suitable for analysing thin to moderately thick beam structures.

5.2.1. Beam 188

BEAM188 element is a linear two-node beam element in 3-D with six degrees of freedom at each node. The six degrees of freedom include translations in x, y, and z directions, and rotations about the x, y, and z directions. Theory of BEAM188 element is based on Timoshenko beam theory.

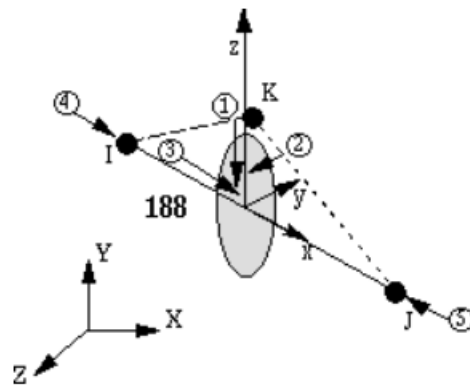


Figure 5.3: Beam188 Geometry [5]

5.2.2. Beam 189

BEAM189 element is a quadratic three-node beam element in 3-D with six degrees of freedom at each node. The six degrees of freedom include translations in x, y, and z directions, and rotations about the x, y, and z directions. Theory of BEAM188 element is based on Timoshenko beam theory.

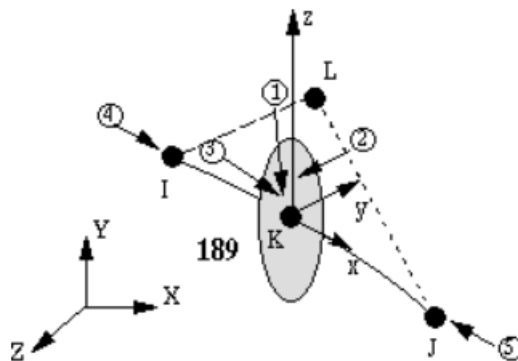


Figure 5.4: Beam189 Geometry [5]

5.3. Volume Elements

5.3.1. Solid 186

SOLID186 element is a higher order twenty-node solid element in 3-D. This element shows quadratic displacement behaviour. SOLID186 is defined by twenty-nodes having three degrees of freedom at each node: translations in the x, y, and z directions.

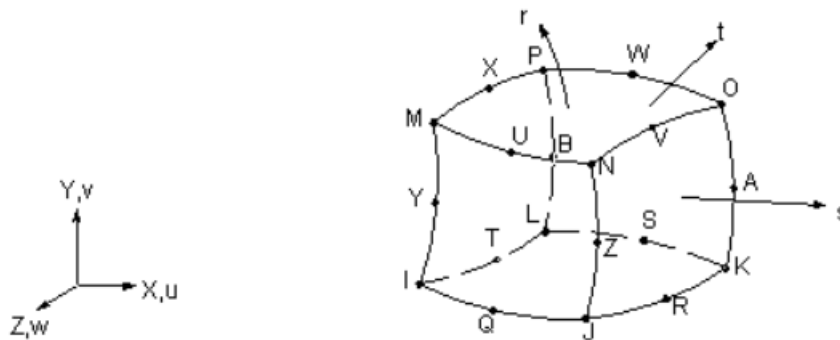


Figure 5.5: Solid186 Geometry [5]

Regarding the reason of working with solid elements is the thickness of mineral wool material. Length/thickness and width/thickness ratios are so small that means thickness is higher than it should be. Besides the theory of shell elements explain that shell elements appropriate for 2D structures.

5.4. Surface Effect Elements

5.4.1. Surface 154

SURF154 used for surface load effect applications. The element is applicable to three-dimensional structural analyses. It is used onto an area face of Solid186 element. For shell element applications densities are recalculated according to various surface loads.[8]

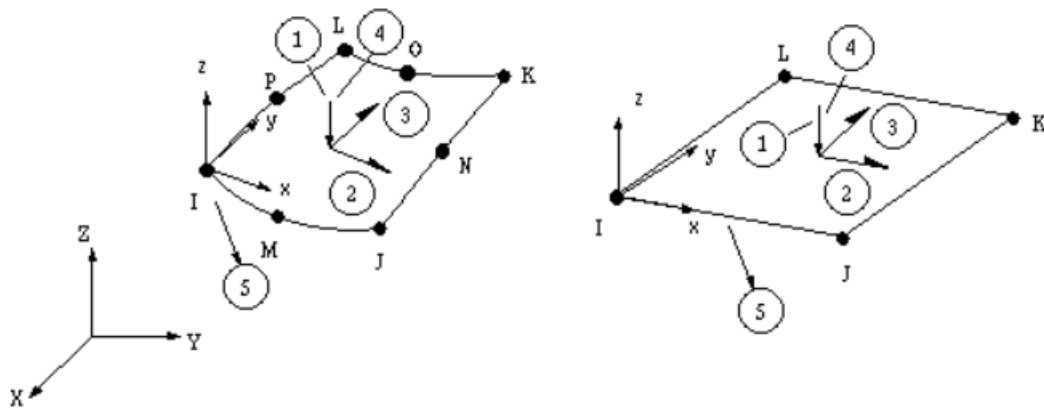


Figure 5.6: Surface154 Geometry [5]

6. MODEL DESCRIPTION

6.1. Meshing

Mesh size basically effects two important factor in ANSYS; workload on ANSYS and to have close solution to the real one. In order to compare our results and check the mesh size effect on models, three different mesh size options are chosen for shell elements which are 0.1, 0.05 and 0.02. For the solid models, volume sweep mesh command is used with different options.

Effect of variable mesh sizes and convergence study is represented further chapters.

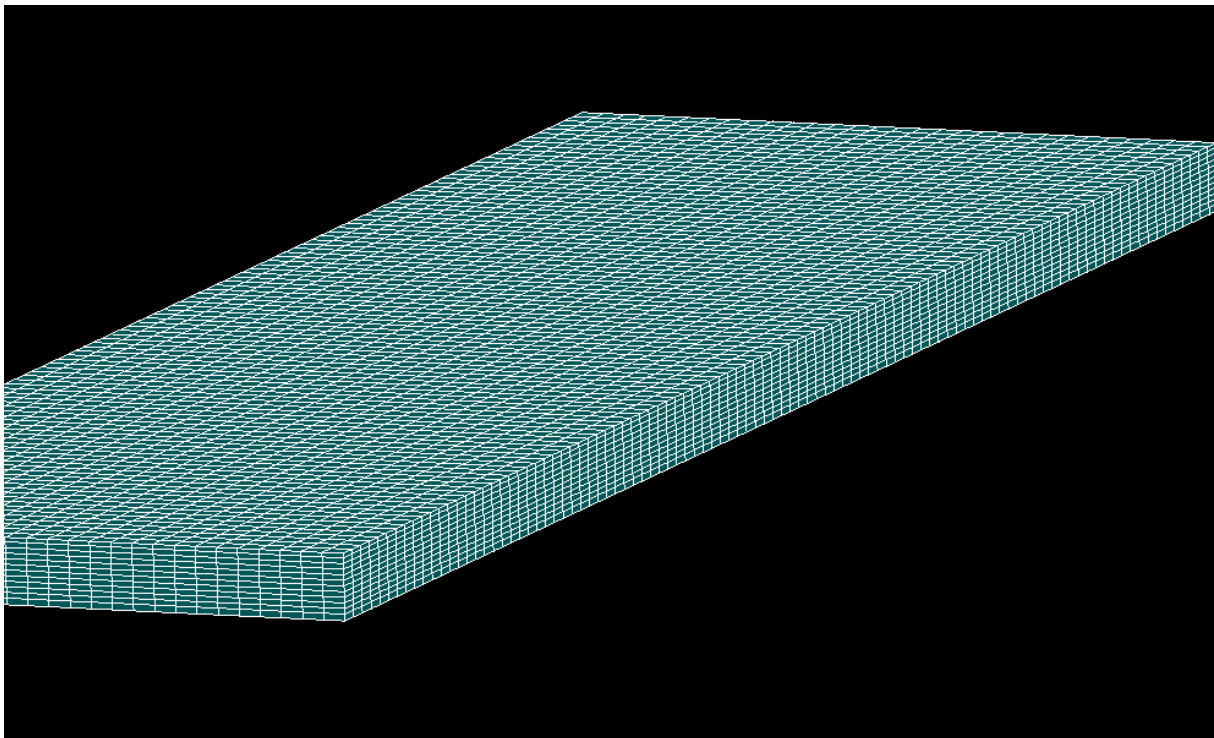


Figure 6.1: Solid model mesh sample of steel-mineral wool-steel plate

6.2. Describing FEM Model

6.3. Neutral Axis

To determine neutral axis location where the boundary conditions applied has crucial importance for modal analyses. The slightest change of the neutral axis location changes boundary conditions applying place and effects greatly natural frequency value. In this

section, neutral axis location calculation formulae and theory of rules of mixture of composites are shown. All neutral axis locations are calculated by using below equations.

Neutral axis location is determined relative to the bottom surface of structure but it is not mandatory. Neutral axis location can be relative to any location.

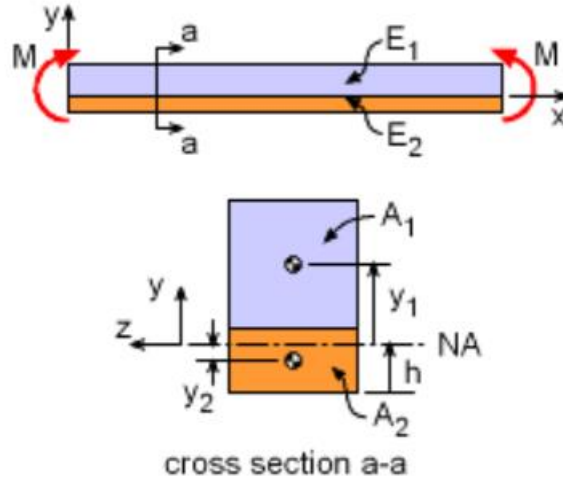


Figure 6.2: Neutral Axis Location [6]

$$0 = \int_{A_1} -E_1 \frac{y_1}{\rho} dA + 0 = \int_{A_2} -E_2 \frac{y_2}{\rho} dA \quad (6.1)$$

Centroid of each material area is known in this study, thus the equation is rewritten as,

$$0 = E_1(y_1 A_1) + E_2(y_2 A_2) \quad (6.2)$$

Neutral axis calculation tables are shown below tables. For all analyses steel deck plate thickness is taken as 6 mm and for steel – mineral wool – steel layered floor system upper steel plate thickness is 4 mm for each condition.

Calculation results for the 10 mm thickness tefrotex 60 (concrete) materials,

Table 6.1: Neutral axis calculation for steel – concrete layered floor system

Steel+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,1E+11	n=	7,50E+00	
Etefrotex	28000000000			
Dimensions	(m)			(m)
L	2		na from bottom	0,004454545
B	0,6			
tsteel	0,006		For Shell Elements SECOFFSET Value	
ttefrotex	0,01		User Input Location	0,003545455

For 15 mm thickness tefrotex 60 (concrete) material,

Table 6.2: Neutral axis calculation for steel – concrete layered floor system

Steel+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,1E+11	n=	7,50E+00	
Etefrotex	28000000000			
Dimensions	(m)			(m)
L	2		na from bottom	0,005625000
B	0,6			
tsteel	0,006		For Shell Elements SECOFFSET Value	
ttefrotex	0,015		User Input Location	0,004875

For 20 mm thickness tefrotex 60 (concrete) material,

Table 6.3: Neutral axis calculation for steel – concrete layered floor system

Steel+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,1E+11	n=	7,50E+00	
Etefrotex	28000000000			
Dimensions	(m)			(m)
L	2		na from bottom	0,007000000
B	0,6			
tsteel	0,006		For Shell Elements SECOFFSET Value	
ttefrotex	0,02		User Input Location	0,006

If neutral axis location is somewhere above upper plane of steel deck, neutral axis is chosen as upper plane of steel deck because our floor system is floating floor system which theoretically connection is made only steel part with adjacent structures. For steel – mineral wool – steel floor systems, all neutral axis values are calculated naturally above steel deck plate, therefore all analyses are made according to steel upper deck plane which is 6 mm from bottom.

For 40 mm thickness rock wool (mineral wool) material,

Table 6.4: Neutral axis calculation for steel – mineral wool – steel layered floor system

Steel+Mineralwool+Steel	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n=	1,40E+06	
Erockwool	1,50E+05			
Dimensions	(m)			(m)
L	2		na from bottom	0,021000
B	0,6			
t steel	0,004			
t rockwool	0,04			
t steel	0,006			

For 50 mm thickness rock wool (mineral wool) material,

Table 6.5: Neutral axis calculation for steel – mineral wool – steel layered floor system

Steel+Mineralwool+Steel	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n=	1,40E+06	
Erockwool	1,50E+05			
Dimensions	(m)			(m)
L	2		na from bottom	0,025000
B	0,6			
t steel	0,004			
t rockwool	0,05			
t steel	0,006			

For 60 mm thickness rock wool (mineral wool) material,

Table 6.6: Neutral axis calculation for steel – mineral wool – steel layered floor system

Steel+Mineralwool+Steel	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n=	1,40E+06	
Erockwool	1,50E+05			
Dimensions	(m)			(m)
L	2		na from bottom	0,029000
B	0,6			
t steel	0,004			
t rockwool	0,06			
t steel	0,006			

For 15 mm thickness tefrotex 60 (concrete) material,

Table 6.7: Neutral axis calculation for steel – visco elastic – concrete layered floor system

Steel+Viscoelastic+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n1=	2,62E-05	
Evisco	5,50E+06	n2=	1,33E-01	
Etefrotex	2,80E+10			
Dimensions	(m)			(m)
L	2		na from bottom	0,006000004
B	0,6			
t steel	0,006			
t visco elastic	0,0015			
t tefrotex	0,015			

For 20 mm thickness tefrotex 60 (concrete) material,

Table 6.8: Neutral axis calculation for steel – visco elastic – concrete layered floor system

Steel+Viscoelastic+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n1=	2,62E-05	
Evisco	5,50E+06	n2=	1,33E-01	
Etefrotex	2,80E+10			
Dimensions	(m)			(m)
L	2		na from bottom	0,007461535
B	0,6			
t steel	0,006			
t visco elastic	0,0015			
t tefrotex	0,02			

For 25 mm thickness tefrotex 60 (concrete) material,

Table 6.9: Neutral axis calculation for steel – visco elastic – concrete layered floor system

Steel+Viscoelastic+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n1=	2,62E-05	
Evisco	5,50E+06	n2=	1,33E-01	
Etefrotex	2,80E+10			
Dimensions	(m)			(m)
L	2		na from bottom	0,009071419
B	0,6			
t steel	0,006			
t visco elastic	0,0015			
t tefrotex	0,025			

For 40 mm thickness rock wool material,

Table 6.10: Neutral axis calculation for steel – mineral wool – concrete layered floor system

Steel+Mineralwool+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n1=	7,14E-07	
Erockwool	1,50E+05	n2=	1,33E-01	
Etefrotex	2,80E+10			
Dimensions	(m)			(m)
L	2		na from bottom	0,00755008
B	0,6			
t steel	0,006			
t rockwool	0,04			
t tefrotex	0,005			

For 50 mm thickness rock wool material,

Table 6.11: Neutral axis calculation for steel – mineral wool – concrete layered floor system

Steel+Mineralwool+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n1=	7,14E-07	
Erockwool	1,50E+05	n2=	1,33E-01	
Etefrotex	2,80E+10			
Dimensions	(m)			(m)
L	2		na from bottom	0,00855012
B	0,6			
t steel	0,006			
t rockwool	0,05			
t tefrotex	0,005			

For 60 mm thickness rock wool material,

Table 6.12: Neutral axis calculation for steel – mineral wool – concrete layered floor system

Steel+Mineralwool+Concrete	(N/m ²)	new length value for other layers according to steel		
Esteel	2,10E+11	n1=	7,14E-07	
Erockwool	1,50E+05	n2=	1,33E-01	
Etefrotex	2,80E+10			
Dimensions	(m)			(m)
L	2		na from bottom	0,00955017
B	0,6			
t steel	0,006			
t rockwool	0,06			
t tefrotex	0,005			

6.4. Convergence

In this section, the importance of choosing correct mesh size is explained only for our analyses because different mesh sizes can be possible for other type of analyses. Before meshing the model, ANSYS Mechanical APDL, help menu gives the accurate length/width ratios in the cause of accurate mesh size.[9]

Table 6.13: Error ratios of choosing different mesh sizes

mesh sizes	steel plate natural frequency numerical results	steel plate natural frequency analytical results	error
0,33	60,58	44,78	26,08%
0,1	46,15	44,78	2,97%
0,05	45,13	44,78	0,78%
0,02	44,84	44,78	0,13%
0,01	44,79	44,78	0,02%

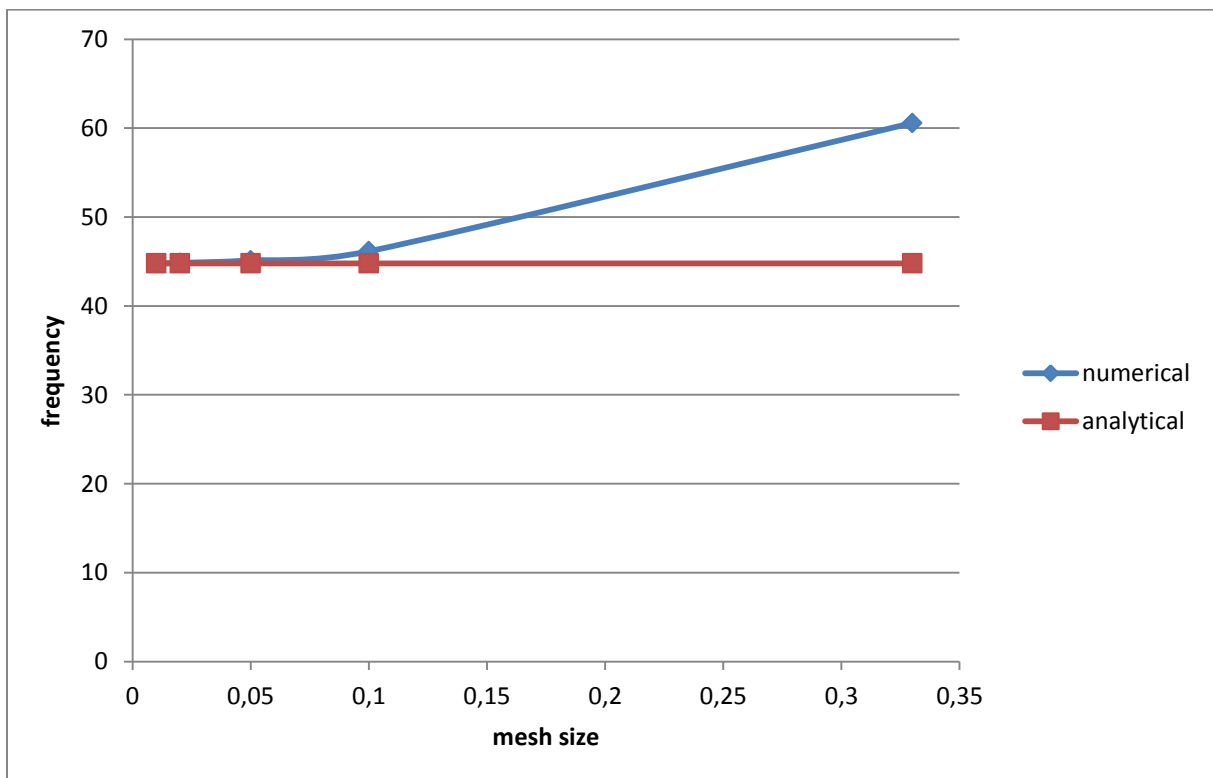


Figure 6.3: Frequency & mesh size relation

To exemplify mesh size convergence some figures are shown below;

Using shell elements models, two sample convergence of mesh size results are shown below,

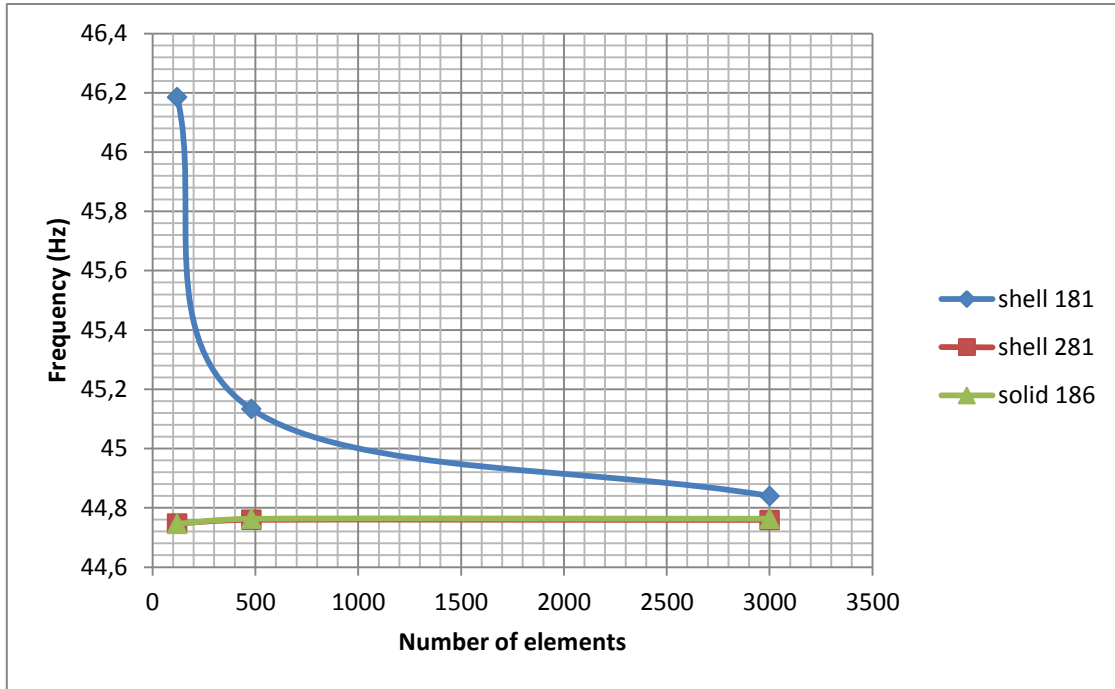


Figure 6.4: Effect of mesh size of 6mm steel plates

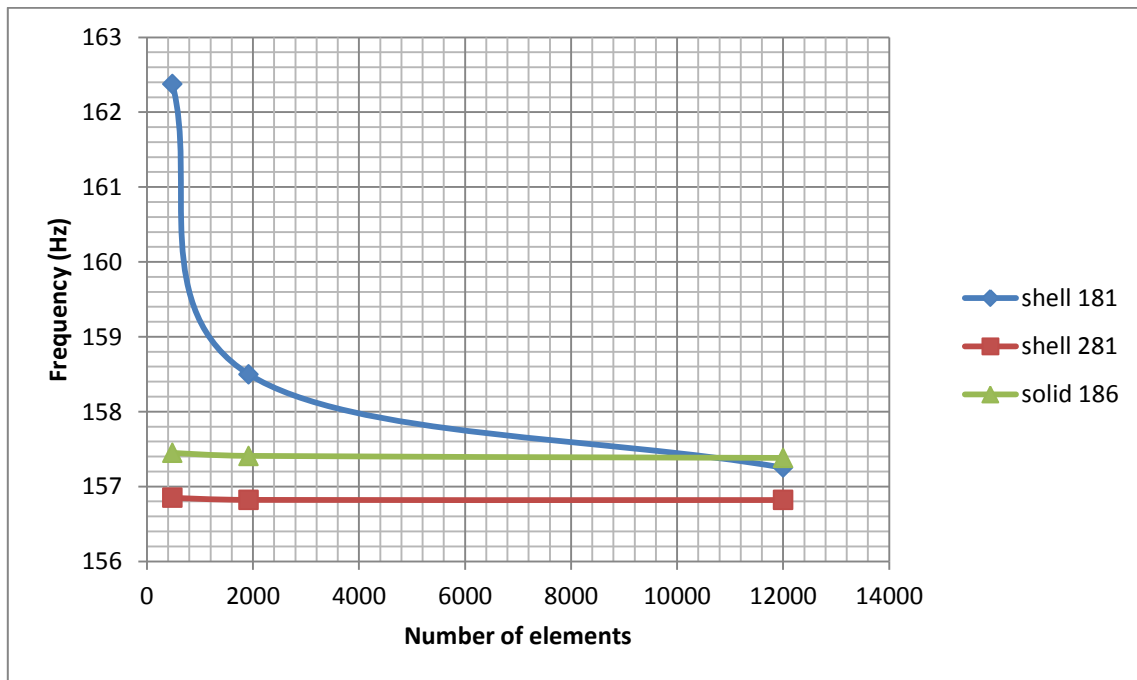


Figure 6.5: Effect of mesh size of 6mm steel + 20 mm tefrotex plates

As seen in above figures, reducing mesh size increases number of elements and accuracy of results. However, small values for mesh size also increase work load on ANSYS Mechanical APDL. Therefore, users have to find necessary and optimum mesh size before starting modal analyses.

7. RESULTS FOR PLATES

7.1. Steel

7.1.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of steel plates as shown below,

$$f_{n,ANSYS} = 44,7592 \text{ Hz}$$

$$f_{n,Analytical} = 44,78 \text{ Hz}$$

$$f_{GLLocVibs} = 44,64 \text{ Hz}$$

These are first mode shape results.

As clearly seen above results, analytical and numerical results converge and confirm each other. Consequently, we can say that our numerical analysis in ANSYS Mechanical APDL is right also this study is done for other floor systems and structure components. To creating model in GLLocVibs in order to have two numerical results GL's software user's guide is used to create same conditions with ANSYS model. [16]

First couple of mode shapes are shown below,

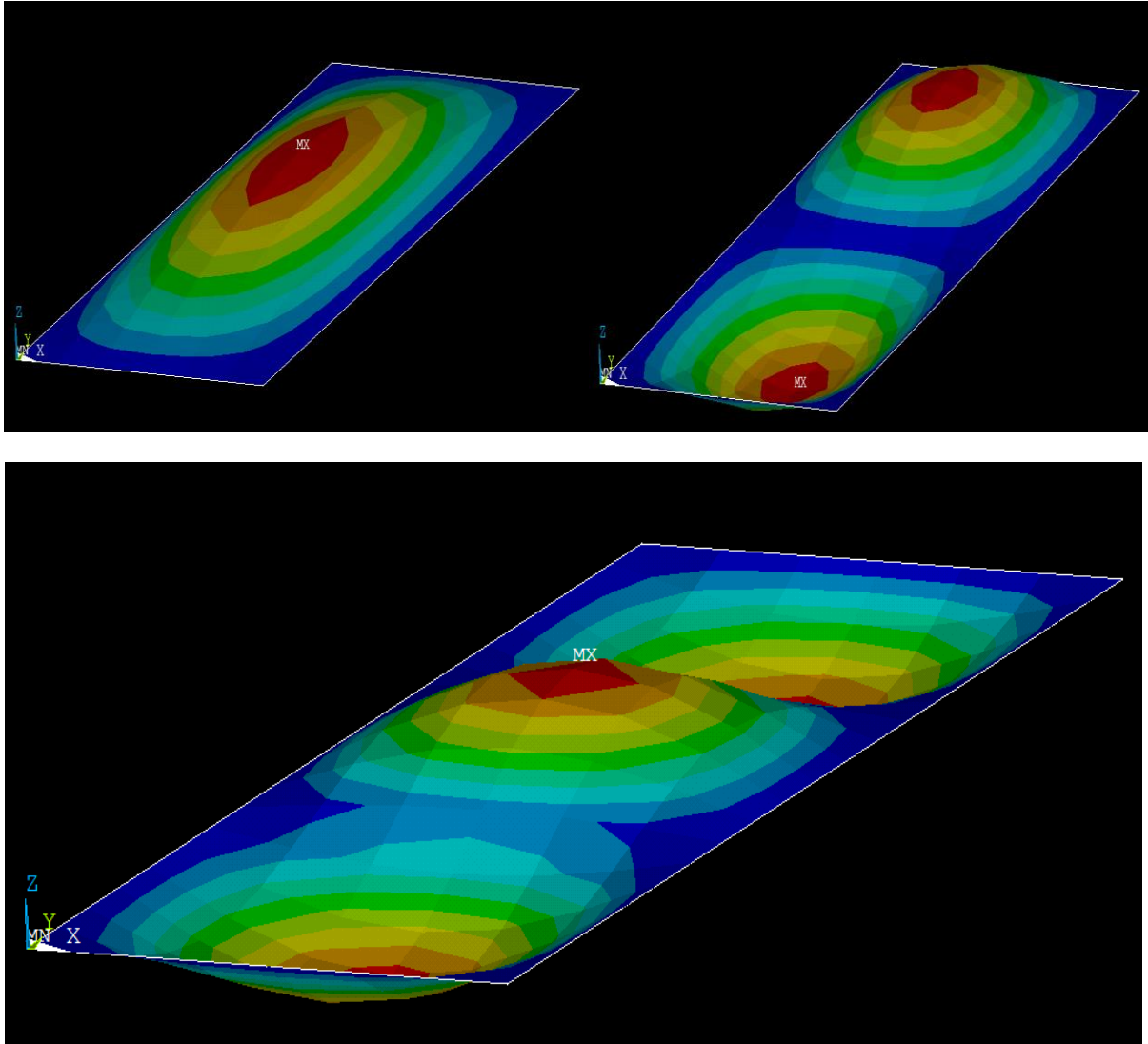


Figure 7.1: First three mode shapes of plates

7.1.2. Influence of Surface Loads

In the graph, results and convergence of two different shell and solid elements are plotted.

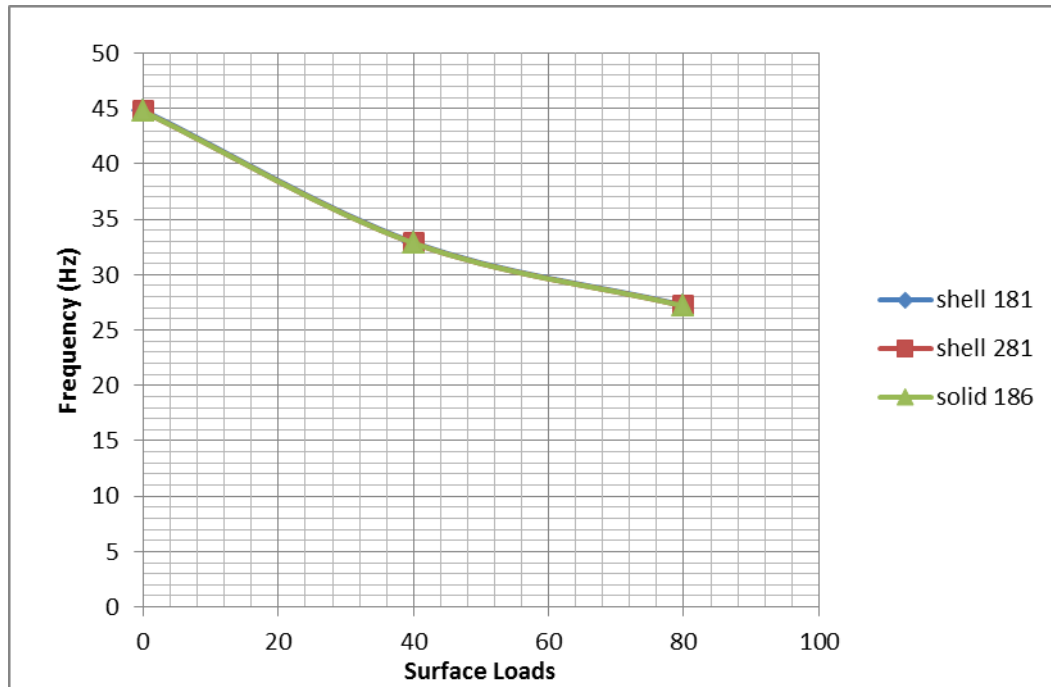


Figure 7.2: Influence of surface loads of steel plate

As it clearly seen in Figure 7.2, when surface loads increase, frequencies decrease.

7.1.3. Influence of Thickness

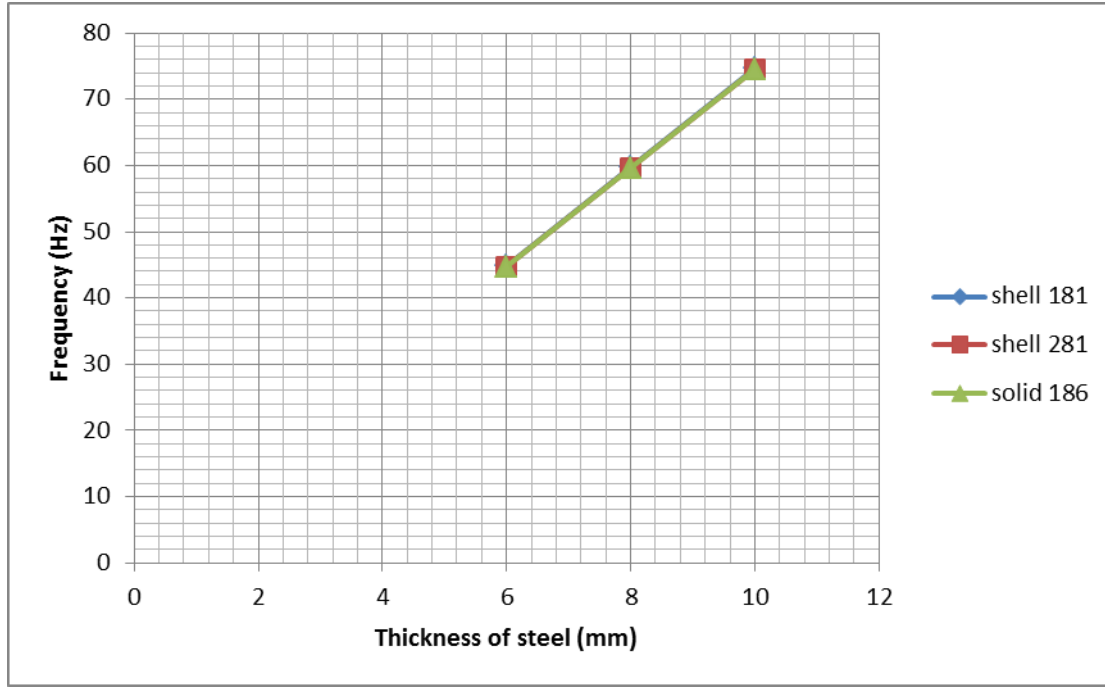


Figure 7.3: Influence of thickness of steel plate

Increasing thickness of steel plate increases also frequencies linearly. When the analytical formula is checked this result is expected.

7.2. Steel - Concrete

7.2.1. Natural Frequency Results

In this section, theoretical background of analytical natural frequency calculation for two and more layered floor systems is explained. To get these analytical results, rules of mixtures of composites are applied in formulae. Also same theory is available in Mechanical APDL Theory Reference for shell elements.

Rule of Mixtures is a method of approach to approximate estimation of composite material properties, based on an assumption that a composite property is the volume weighed average of the phases (matrix and dispersed phase) properties. [7]

$$d_c = d_m * V_m + d_f * V_f \quad (7.1)$$

Where, d_c, d_m, d_f – densities of the composite, matrix and dispersed phase respectively; V_m, V_f – volume fraction of the matrix and dispersed phase respectively.

$$E_c = E_m * V_m + E_f * V_f \quad (7.2)$$

Where, E_f is modulus of elasticity of fiber material; E_m is modulus of elasticity of matrix material.

$$\mu_c = \mu_m * V_m + \mu_f * V_f \quad (7.3)$$

Where, μ_m is Poisson's ratio of matrix material; μ_f is Poisson's ratio of fiber material.

Natural frequency values and mode shapes for 6 mm thickness of steel deck plate - 20 mm thickness of concrete layer as shown below,

$$f_{n,ANSYS} = 157,382 \text{ Hz}$$

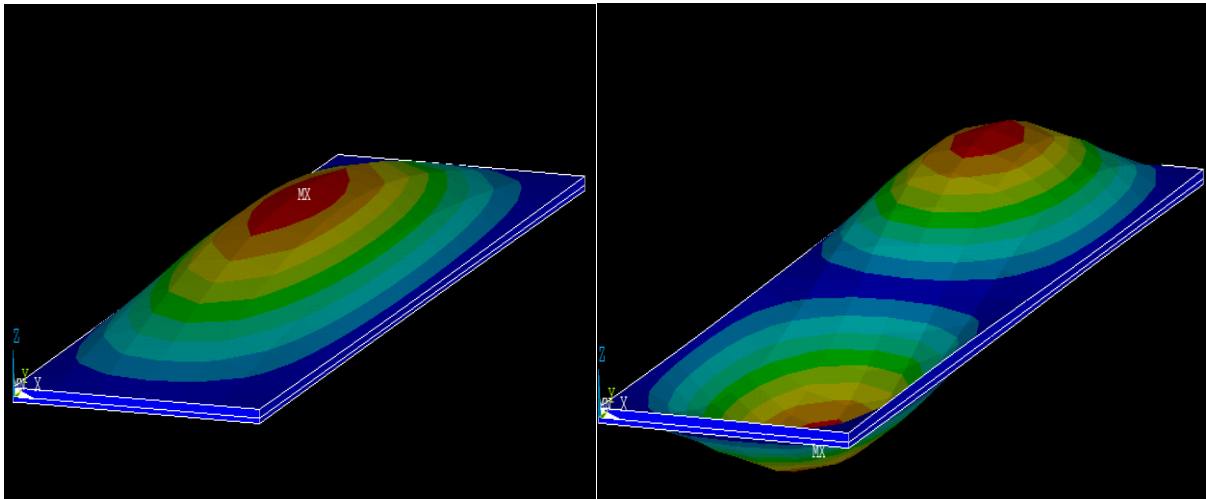


Figure 7.4: First two mode shapes of steel – concrete plates

In the next parts of plate results mode shape views of plate structures are exactly same therefore, they are not shown below results.

7.2.2. Influence of Surface Loads

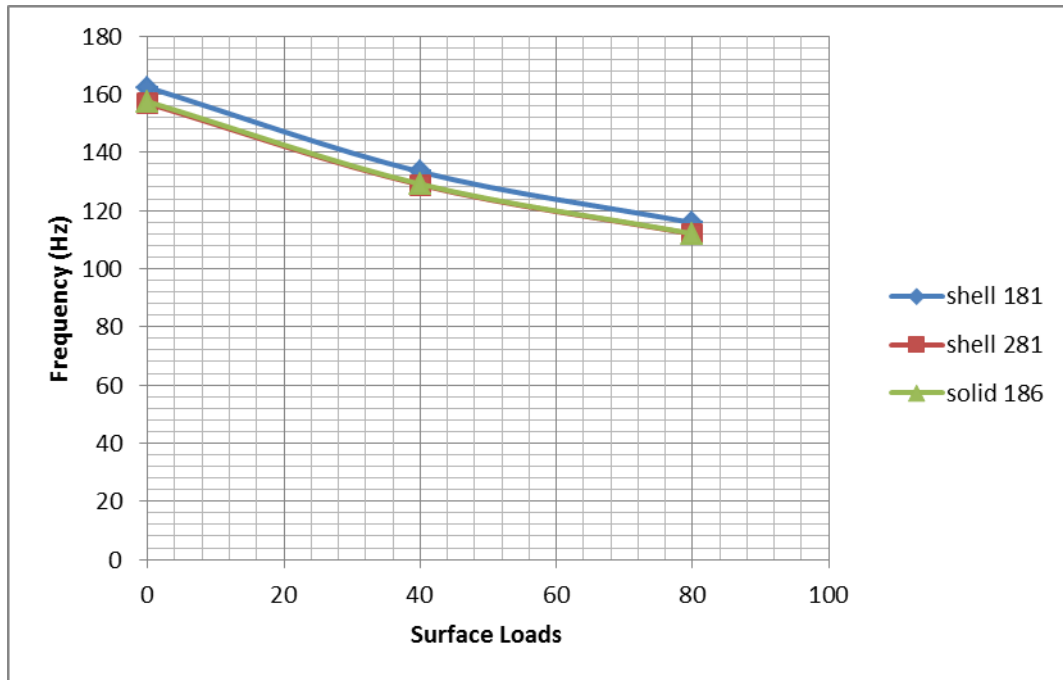


Figure 7.5: Influence of surface loads of steel–concrete plate

With this model, first time additional layer part is applied on steel deck plate, behaviour of plate vibration is similar to steel plate vibration. However there are so small differences between results because of different node numbers of elements.

7.2.3. Influence of Thickness

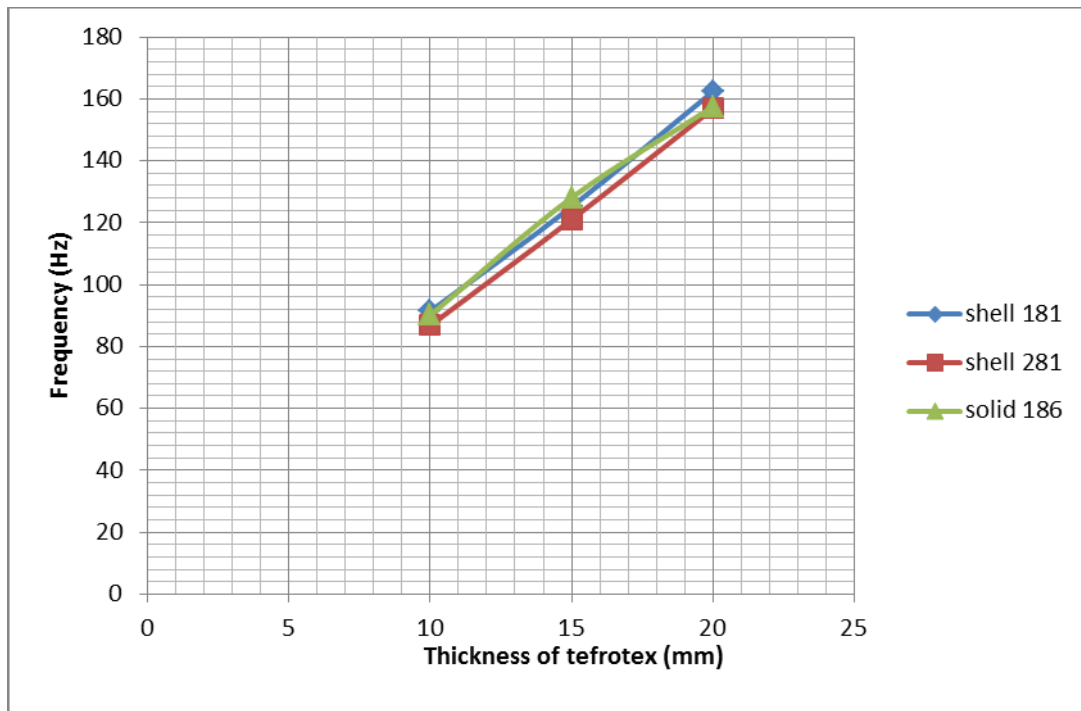


Figure 7.6: Influence of thickness of steel-concrete plate

Increasing thickness of concrete layer also increase natural frequency. Mathematically all these results show increasing mass increase stiffness matrix more than mass matrix therefore frequency value increases that is the right side of the equation in modal analysis.

7.3. Steel – Mineral Wool – Steel

7.3.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of steel deck plate - 50 mm thickness of mineral wool layer – 4 mm thickness of steel plate layer as shown below,

$$f_{n,ANSYS} = 40,3682 \text{ Hz}$$

7.3.2. Influence of Surface Loads

For 50 mm mineral wool

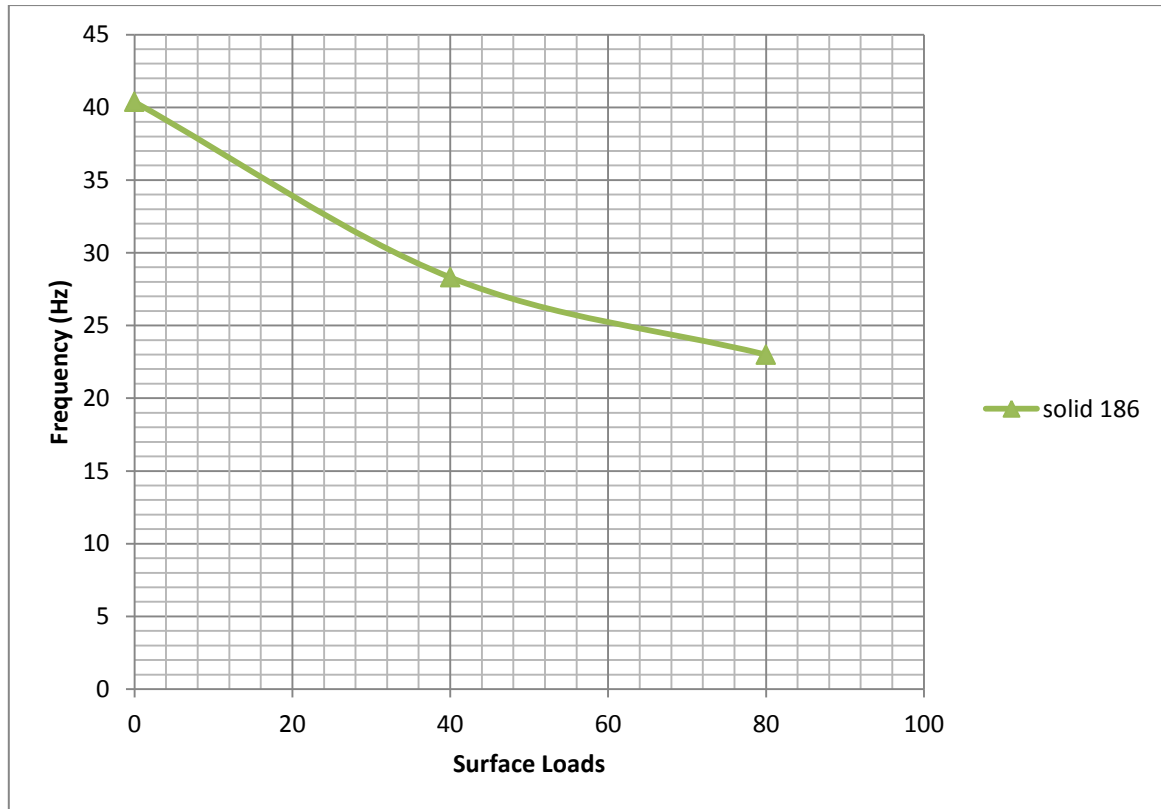


Figure 7.7: Influence of surface loads of steel–concrete plate

7.3.3. Influence of Thickness

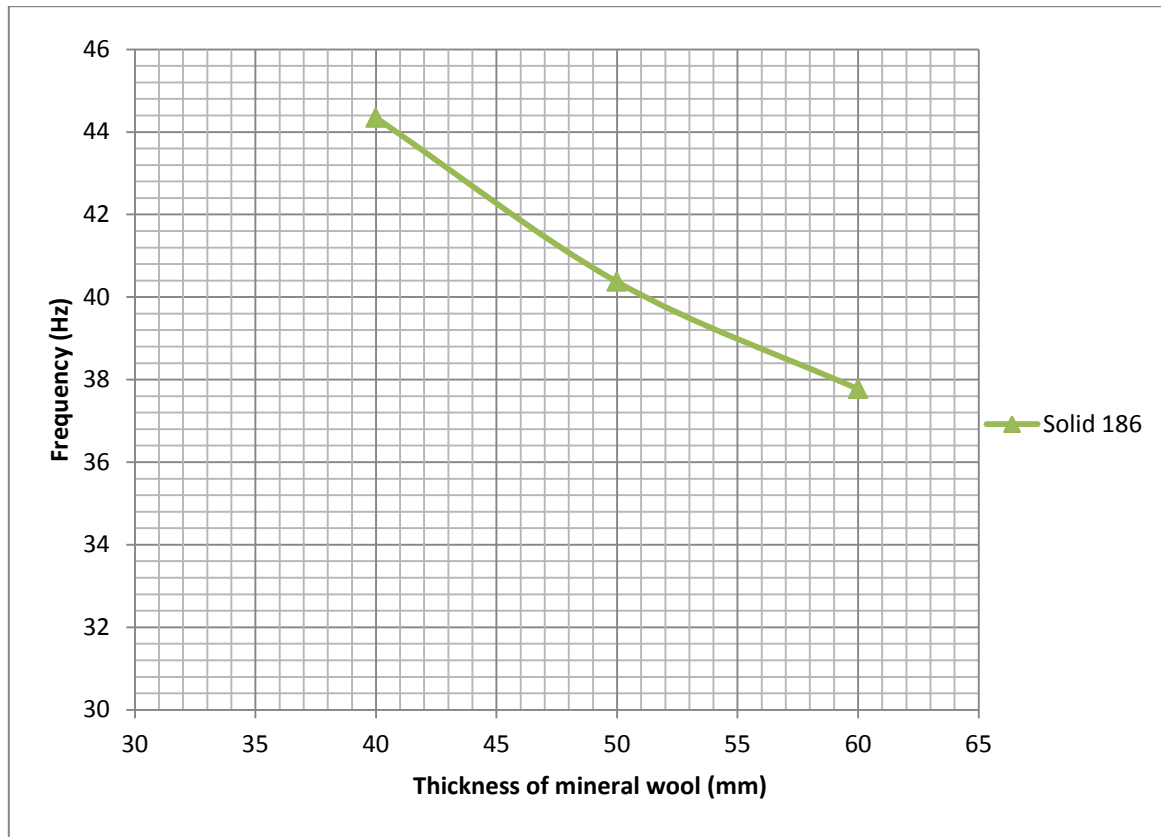


Figure 7.8: Influence of thickness of steel-mineral wool-steel plate

Unlike other materials, using mineral wool between two steel plates effects natural frequency in opposite way. Increasing thickness of wool material decreases the natural frequency value.

7.4. Steel – Mineral Wool – Concrete

7.4.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of steel deck plate - 50 mm thickness of mineral wool layer – 5 mm thickness of concrete layer as shown below,

$$f_{n,ANSYS} = 56,4271 \text{ Hz}$$

7.4.2. Influence of Surface Loads

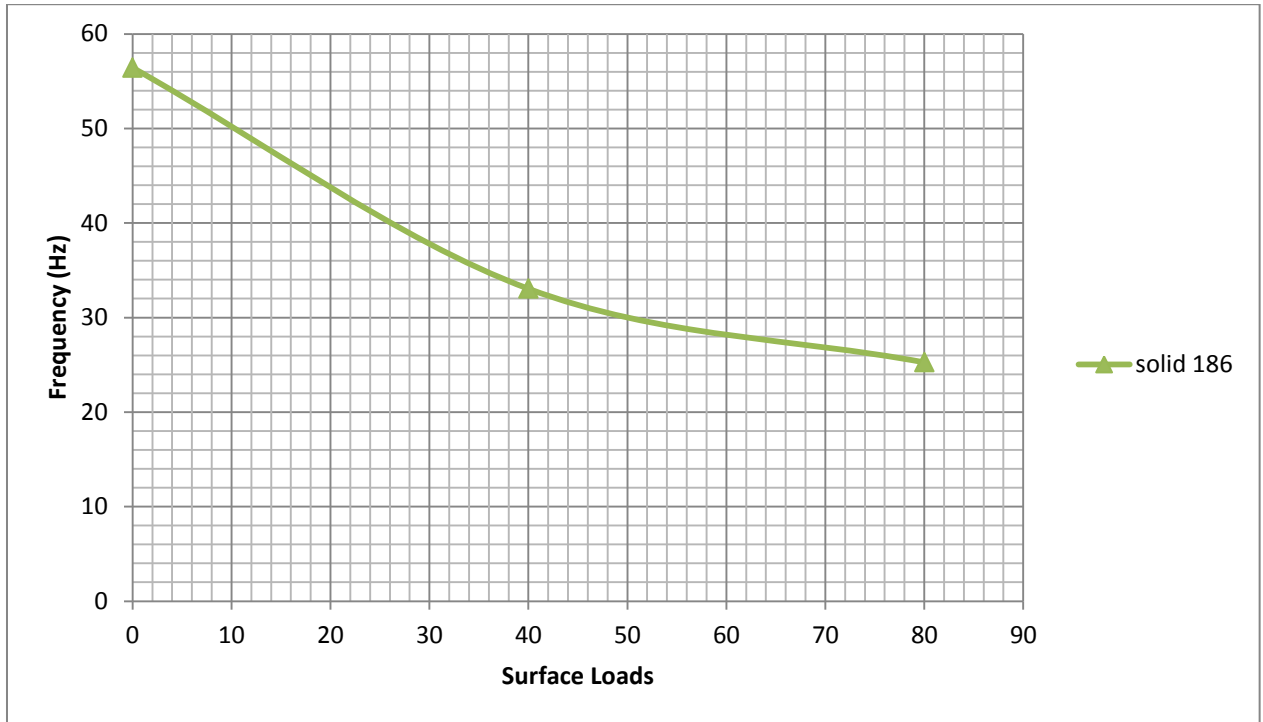


Figure 7.9: Influence of surface loads of steel–mineral wool–concrete plate

7.4.3. Influence of Thickness

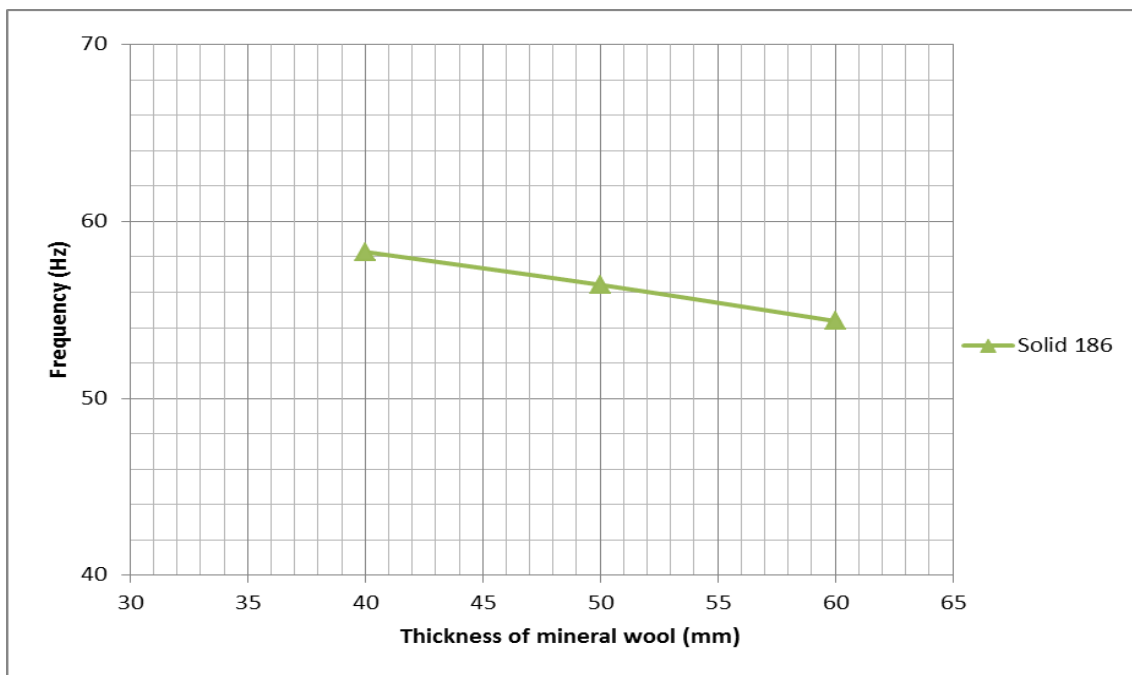


Figure 7.10: Influence of thickness of steel–mineral wool–steel plate

7.5. Steel – Viscoelastic Material – Concrete

7.5.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of steel deck plate – 1.5 mm thickness of visco elastic layer – 20 mm thickness of concrete layer as shown below,

$$f_{n,ANSYS} = 98,5214 \text{ Hz}$$

7.5.2. Influence of Surface Loads

For 20 mm concrete,

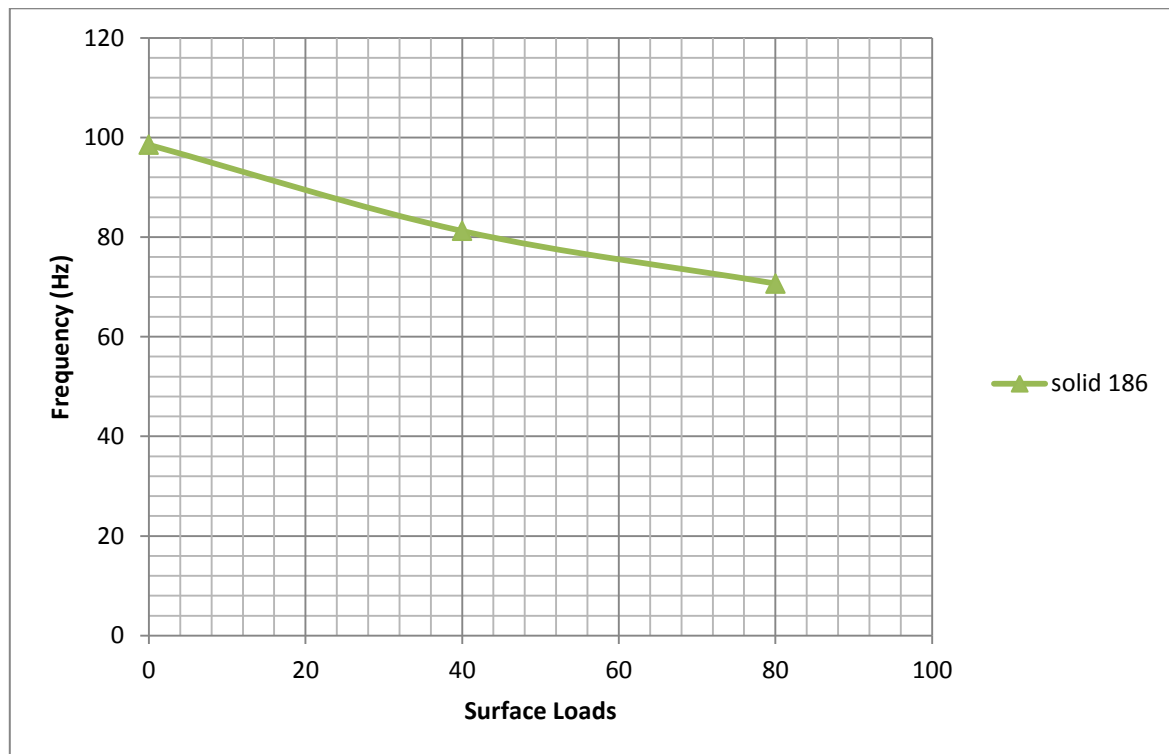


Figure 7.11: Influence of surface loads of steel – viscoelastic – concrete plate

After all these influence of surface loads data, it can be said that surface loads only increase mass matrix, therefore natural frequencies decreases when surface loads increase.

7.5.3. *Influence of Thickness*



Figure 7.12: Influence of thickness of steel - viscoelastic - concrete plate

8. RESULTS FOR STIFFENED PLATES

8.1. Steel

8.1.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of stiffened steel deck plate;

$$f_{n,ANSYS} = 60,6491 \text{ Hz}$$

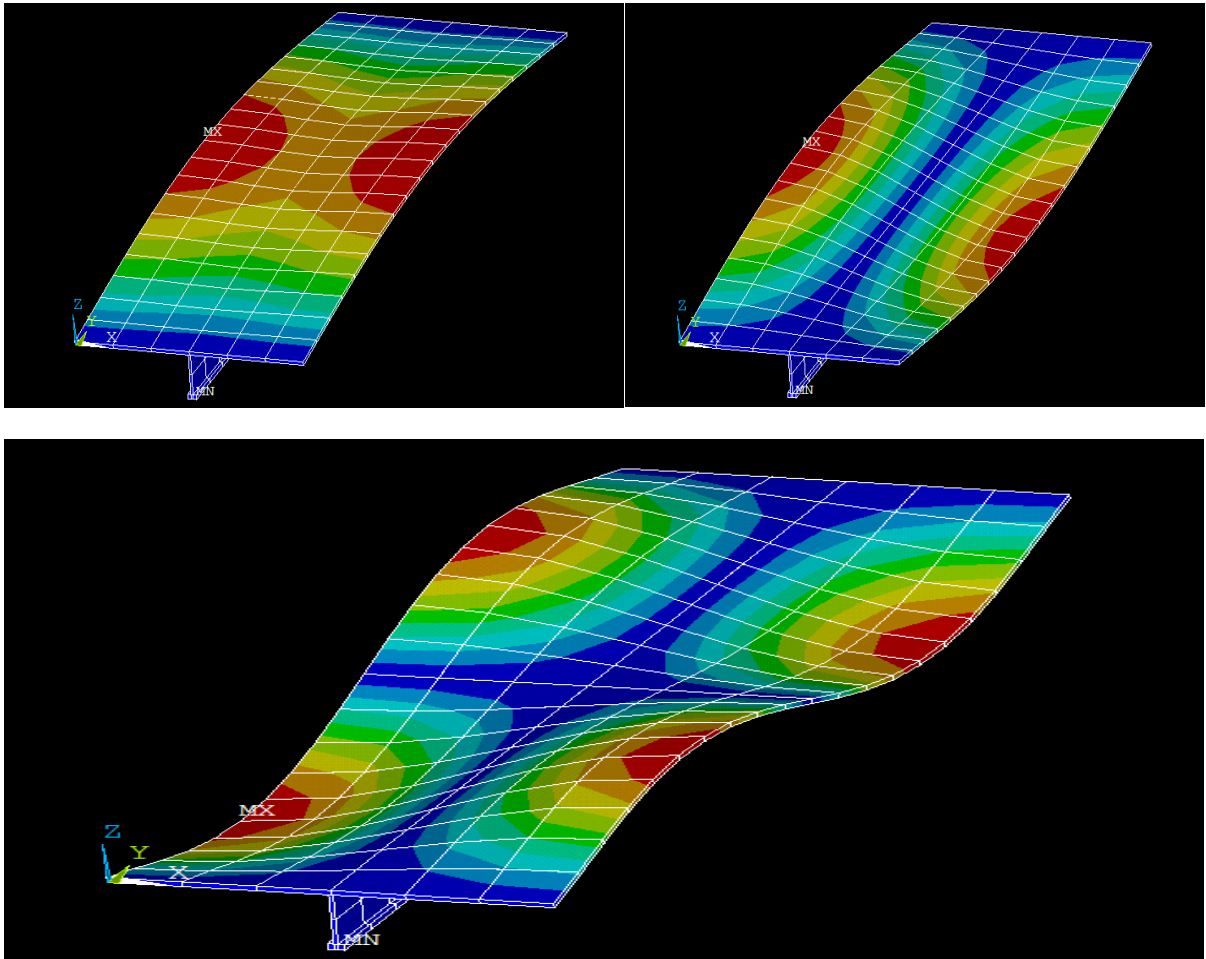


Figure 8.1: First three mode shapes of stiffened steel plate

First eigenvector represents stiffener vibration; second one represents plate vibration therefore second eigenfrequency values are plate eigenfrequency values. Results of under the title of

natural frequency are calculated without any surface loads or it can be said under the effect of 0 kg/m^2 load.

8.1.2. Influence of Surface Loads

Effect of 40 kg/m^2 surface load on stiffener is given below and for plate value there is less than %0.5 differences between two results. This situation is valid for all other analyses.

$$f_{n,ANSYS} = 45,6018 \text{ Hz}$$

This frequency value is similar also for 8 mm and 10 mm thicknesses of steel plates under the same surface load.

Effect of 80 kg/m^2 surface load on stiffener is,

$$f_{n,ANSYS} = 38,0598 \text{ Hz}$$

8.2. Steel - Concrete

8.2.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of stiffened steel deck – 10 mm thickness of concrete layered plate;

$$f_{n,ANSYS} = 61,3164 \text{ Hz}$$

For different thicknesses of concrete layer stiffener eigenfrequency results are so close to each other as it is mentioned above chapter. To see differences, results for 15 mm concrete layer and 20 mm concrete layer are written respectively;

$$f_{n,15mm \text{ concrete}} = 60,0189 \text{ Hz}$$

$$f_{n,15mm \text{ concrete}} = 58,7705 \text{ Hz}$$

8.2.2. Influence of Surface Loads

Effect of 40 kg/m^2 surface load on steel - concrete stiffened plate is,

$$f_{n,ANSYS} = 49,5268 \text{ Hz}$$

This frequency value is similar also for 8 mm and 10 mm thicknesses of steel plates under the same surface load.

Effect of 80 kg/m² surface load on stiffener is,

$$f_{n,ANSYS} = 42,126 \text{ Hz}$$

8.3. Steel – Mineral Wool – Steel

Steel plates with using mineral wools restrict our modelling elements numbers. In every model that includes mineral wool material, solid elements are used to model in ANSYS Mechanical APDL.

8.3.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of stiffened steel deck – 50 mm thickness of mineral wool – 4 mm thickness of steel layered plate;

Steel – mineral wool – steel floor system result,

$$f_{n,ANSYS} = 55,3104 \text{ Hz}$$

8.3.2. Influence of Surface Loads

Effect of 40 kg/m² surface load for same steel – mineral wool – steel layered plate;

$$f_{n,ANSYS} = 46,6958 \text{ Hz}$$

Effect of 80 kg/m² surface load,

$$f_{n,ANSYS} = 41,6203 \text{ Hz}$$

Results which are given above according to 50 mm thickness of mineral wool layer calculations, thicknesses of steel plates are fixed.

8.4. Steel – Mineral Wool – Concrete

8.4.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of stiffened steel deck – 50 mm thickness of mineral wool – 5 mm thickness of concrete layered plate;

Steel – mineral wool – concrete floor system result,

$$f_{n,ANSYS} = 58,9023 \text{ Hz}$$

8.4.2. Influence of Surface Loads

Effect of 40 kg/m² surface load,

$$f_{n,ANSYS} = 49,1821 \text{ Hz}$$

Effect of 80 kg/m² surface load,

$$f_{n,ANSYS} = 43,1734 \text{ Hz}$$

Results which are given above according to 50 mm thickness of mineral wool layer calculations. Steel deck plate and concrete upper plate thicknesses are fixed.

8.5. Steel – Viscoelastic Material – Concrete

8.5.1. Natural Frequency Results

Natural frequency values and mode shapes for 6 mm thickness of stiffened steel deck – 1.5 mm thickness of viscoelastic – 20 mm thickness of concrete layered plate;

For 20 mm concrete,

$$f_{n,ANSYS} = 55,5495 \text{ Hz}$$

Steel deck plate and viscoelastic layered thicknesses are fixed. Regarding the models, models are created by only using solid 186 and surface 154 elements. Models are shown below.

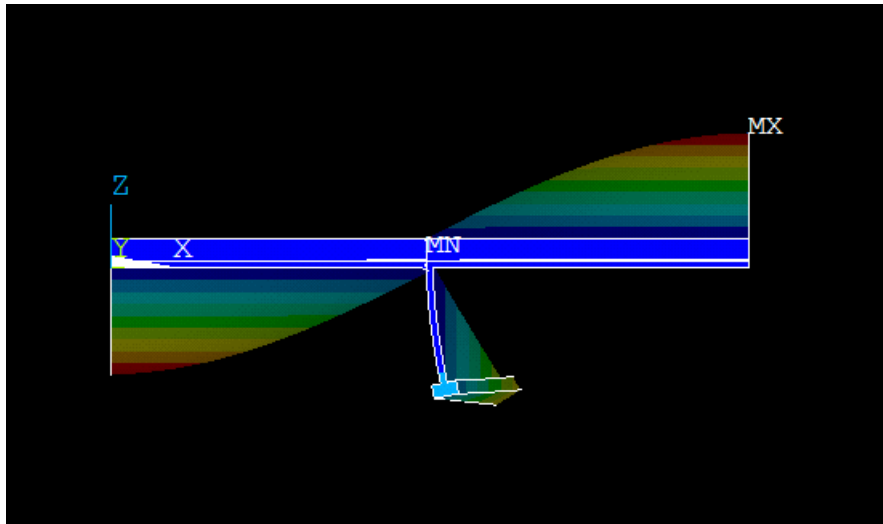


Figure 8.2: Front side view of second mode shape of steel – viscoelastic – concrete stiffened plate

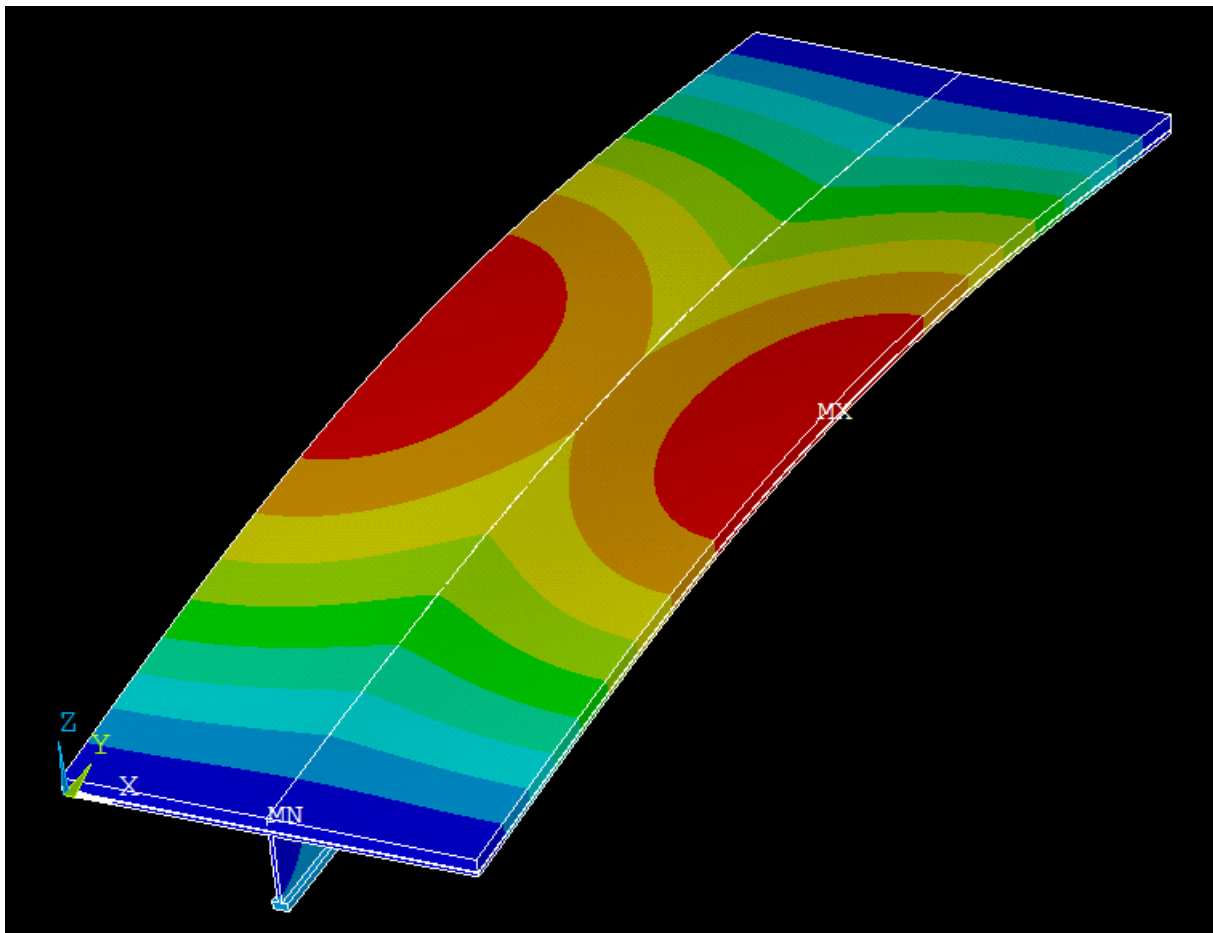


Figure 8.3: First mode shape (stiffener vibration) of steel – viscoelastic – steel stiffened plate

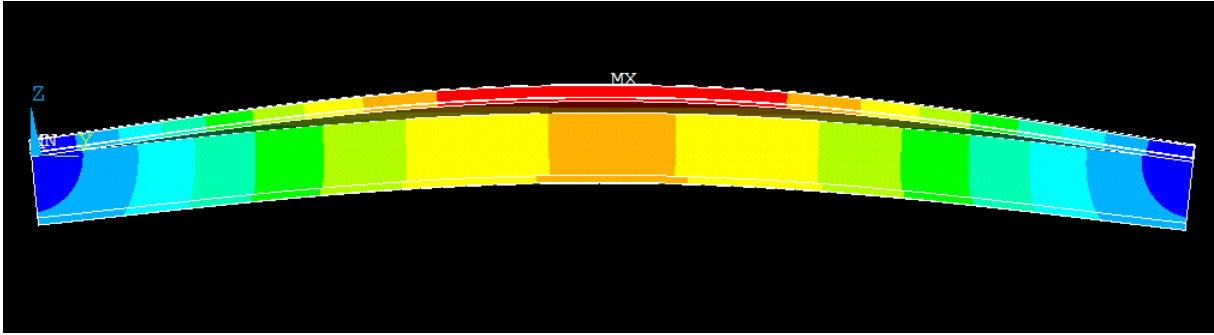


Figure 8.4: Side view of steel – viscoelastic – steel stiffened plate

All these figures represents also other stiffened plates except results, these are valid only for view of mode shapes.

8.5.2. Influence of Surface Loads

Effect of 40 kg/m^2 surface load on steel – viscoelastic – concrete stiffened plate equals,

$$f_{n,ANSYS} = 46,4655 \text{ Hz}$$

Effect of 80 kg/m^2 surface load,

$$f_{n,ANSYS} = 40,7693 \text{ Hz}$$

Results for stiffened plates, graphs are not included even analyses are made for three different thicknesses values and surface loads. Because all graphs curves are similar graphs of previous chapter which is results for plates.

9. RESULTS FOR PANELS

Panel modal analyses are done for the most common applications which are steel and steel - concrete floor systems in ship accommodation areas. Symmetry boundary conditions are applied on lines as boundary conditions.

9.1. Steel

9.1.1. *Natural Frequency Results*

As expected dynamic behaviour of panel structure, adding girders and stiffeners increase the characteristic frequencies. The reason behind this phenomenon is; rise in stiffness matrix is so higher than rise in mass matrix. For comparison plate with stiffened and without stiffened results are shown.

$f_{n,Analytical} = 8,26 \text{ Hz}$ only for $2 \times 1.8 \times 0.006$ steel plate vibration without any stiffener structure and our panel vibration is 6 times bigger than same dimensioned plate.

$$f_{n,ANSYS} = 51,3098 \text{ Hz}$$

Several views of first mode shape of steel panel are shown (see Figure 9.1, 9.2 and 9.3).

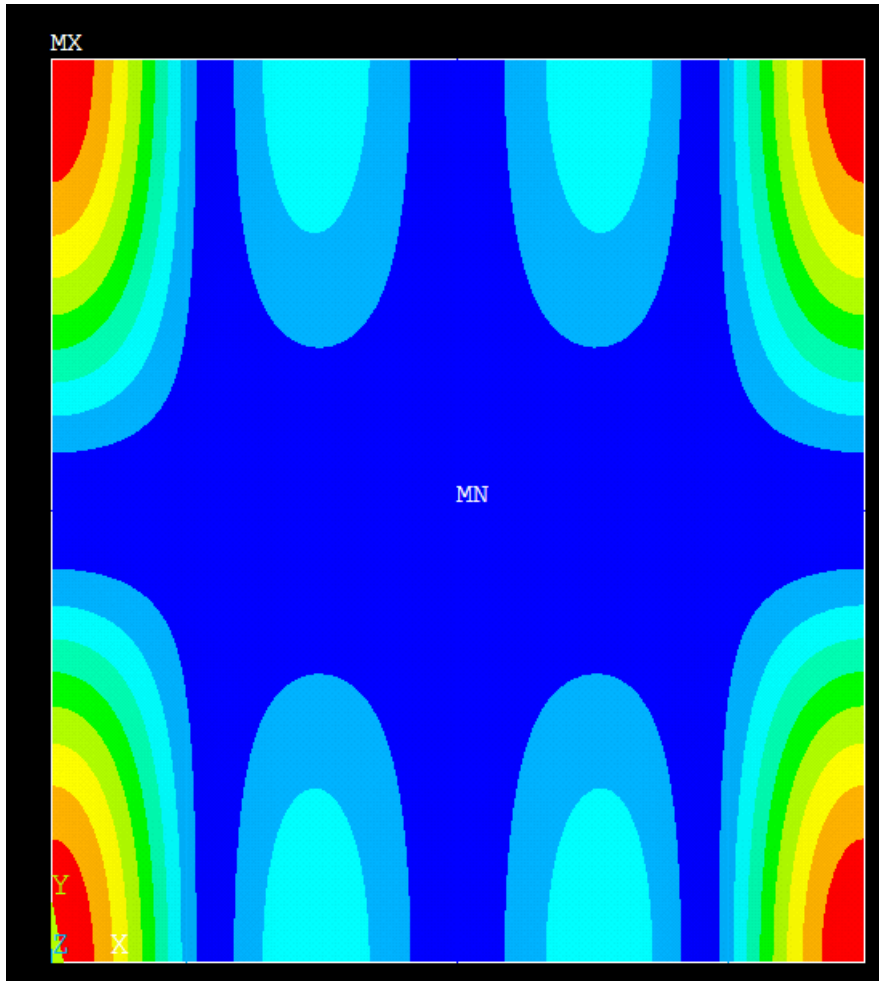


Figure 9.1: First mode shape of steel panel

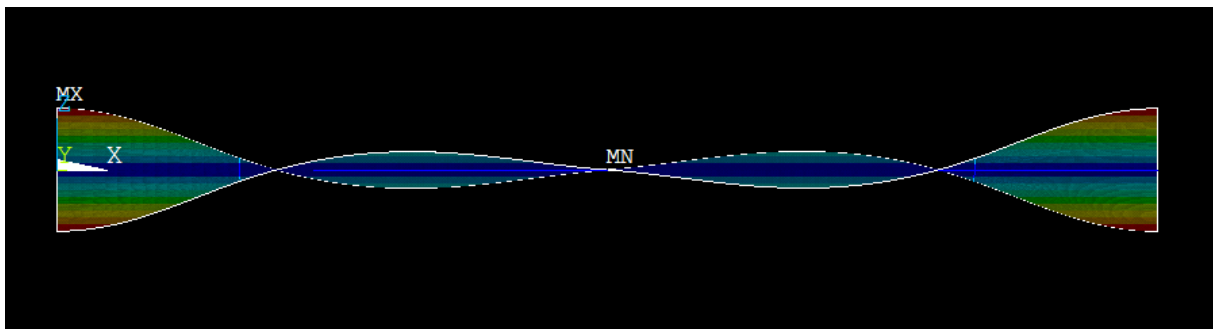


Figure 9.2: Front side view of vibrated steel panel

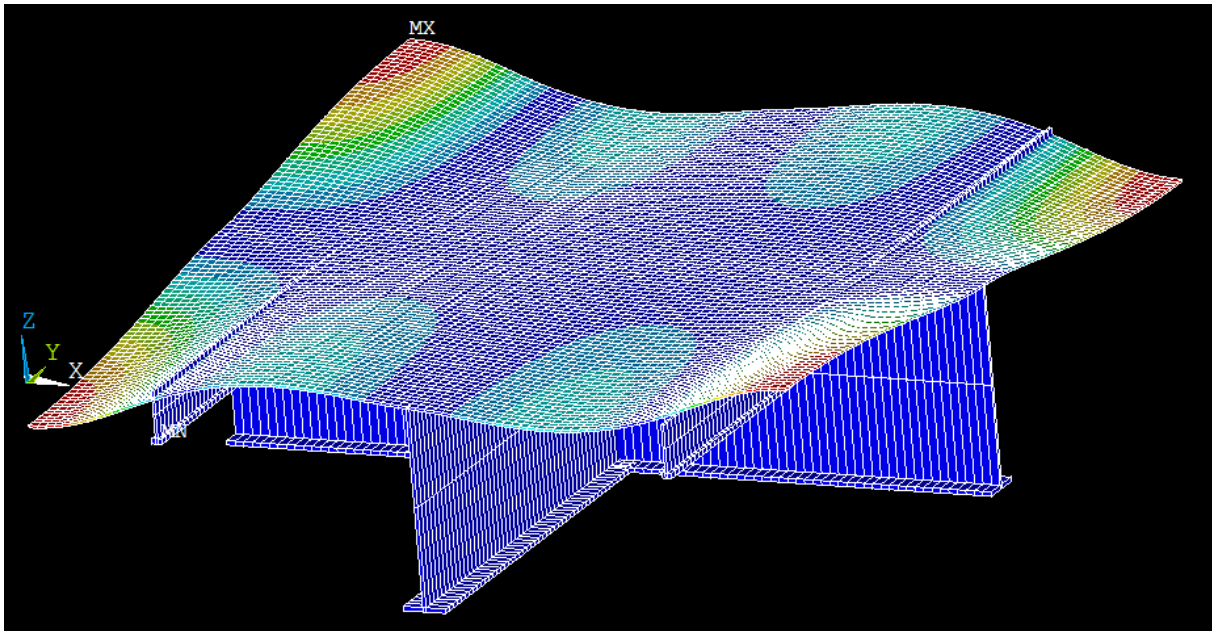


Figure 9.3: Perspective view of steel panel

If we double the panel dimensions under the same symmetry boundary conditions respectively; 3.6 m width and 4 m length. Briefly we have four steel panels which are connected to each other and created big panel. Our result is exactly same value with previous (smaller) panel model.

$$f_{n,ANSYS} = 51,3098 \text{ Hz}$$

Characteristic frequency result for two times bigger panel structure.

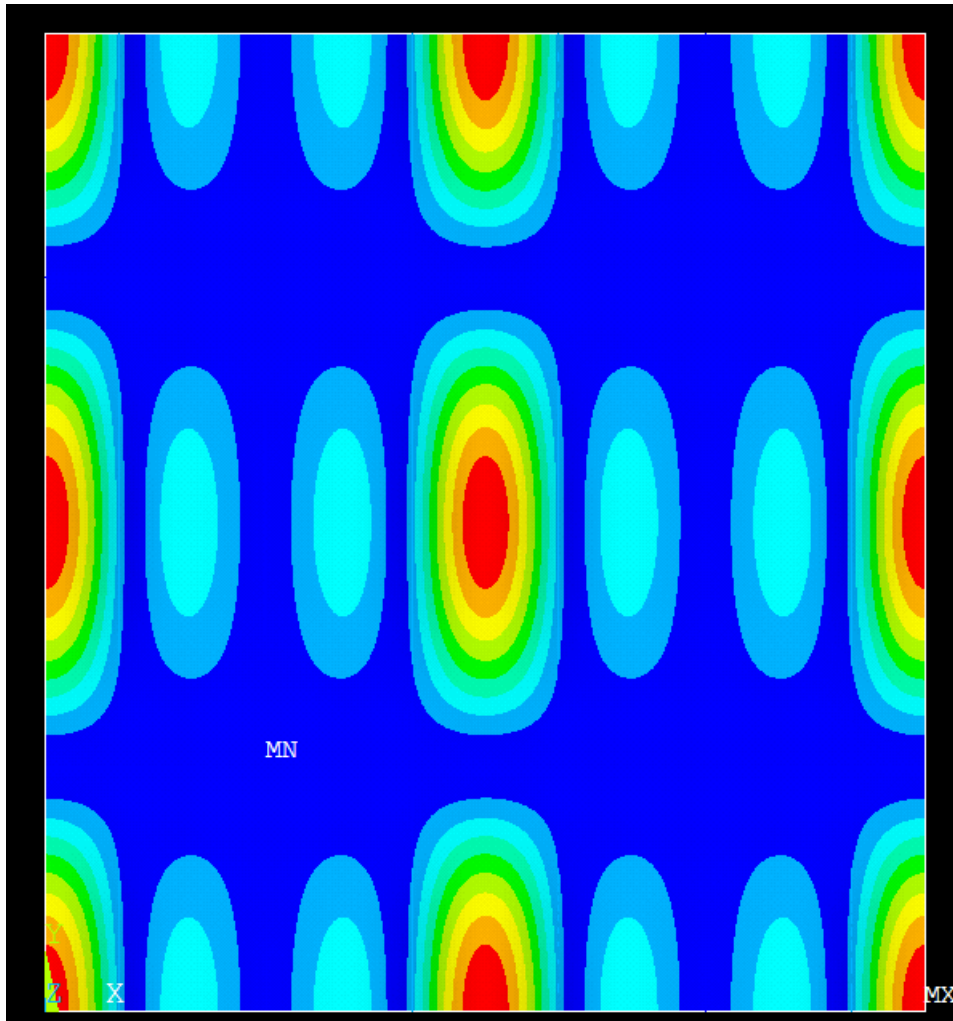


Figure 9.4: First mode shape of bigger steel panel

9.2. Steel - Concrete

9.2.1. Natural Frequency Results

Additionally the one of most common applications in accommodation area is steel – concrete layered floor system; therefore, to see its panel vibration result is important.

Natural frequency result of steel – concrete panel and mode shape views:

$$f_{n,ANSYS} = 109,382 \text{ Hz}$$

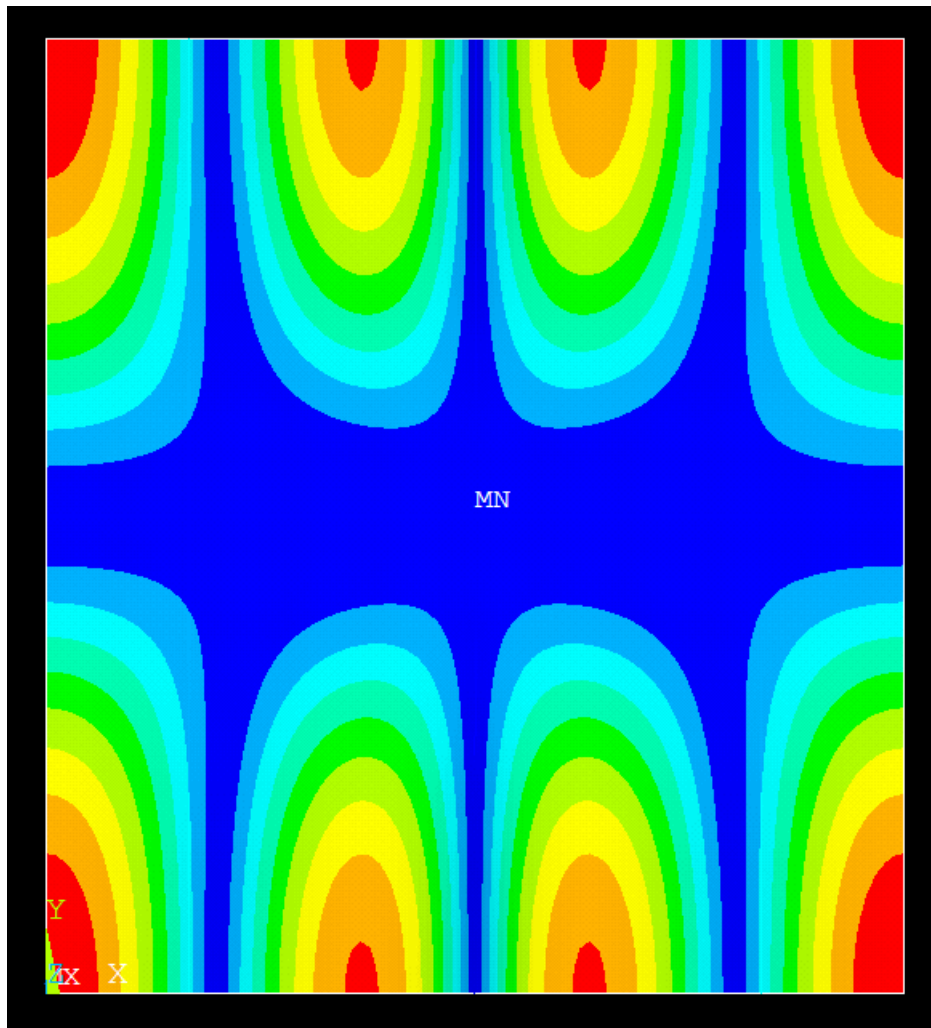


Figure 9.5: First mode shape of steel - concrete panel

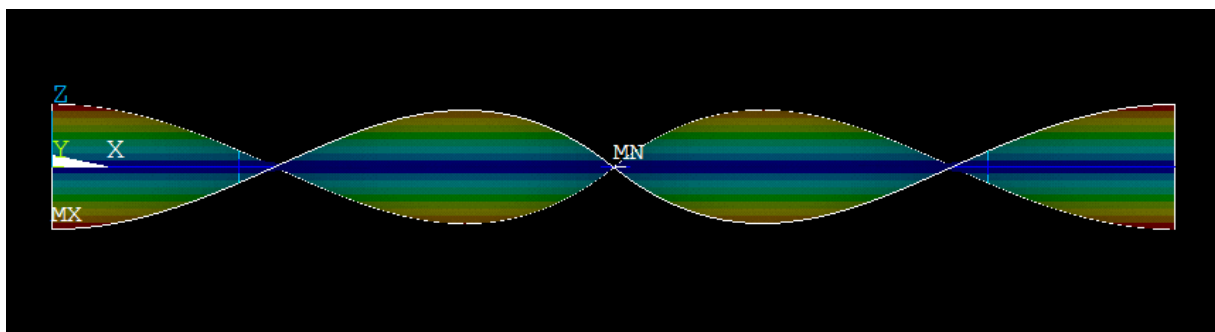


Figure 9.6: Front side view of vibrated steel - concrete panel

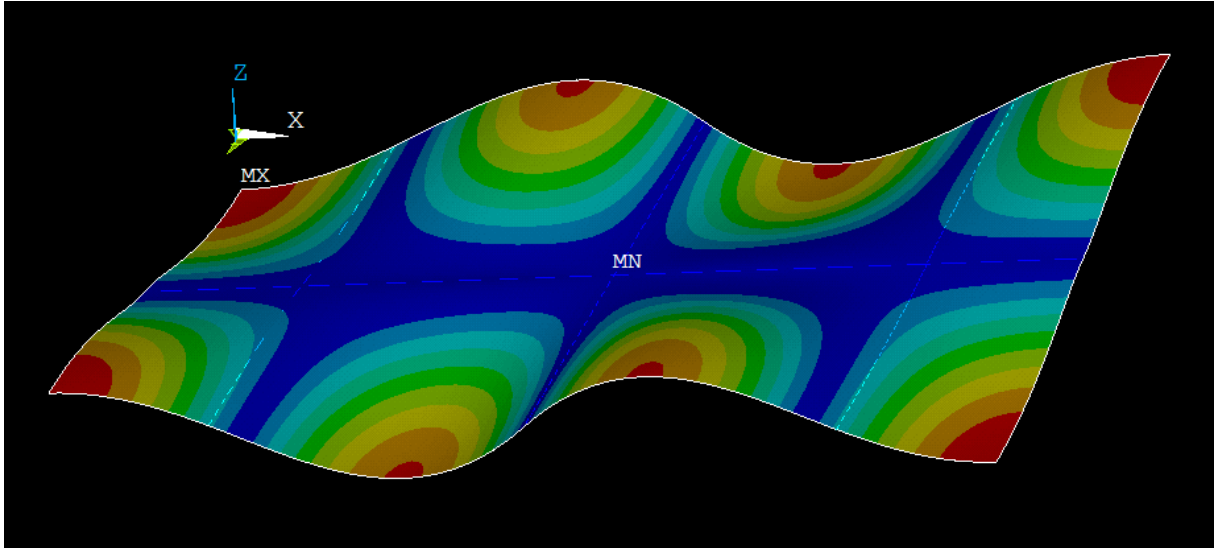


Figure 9.7: Perspective view of only plate part of steel – concrete panel

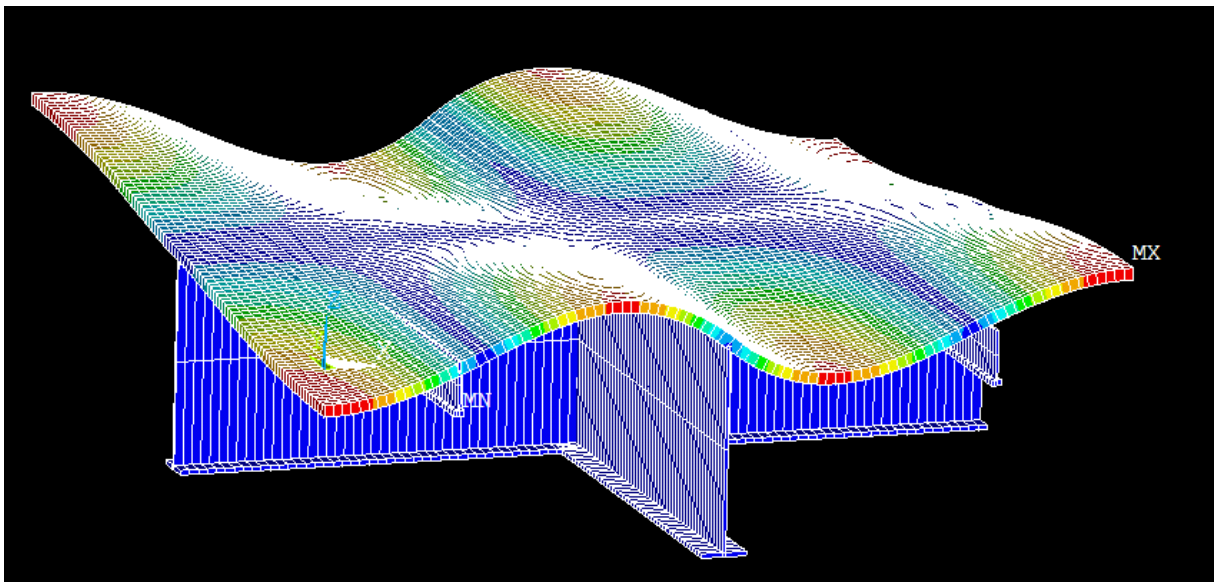


Figure 9.8: Perspective view of steel - concrete panel

10. HARMONIC ANALYSES

Harmonic analyses are done for steel and steel – concrete panels also by using ANSYS Mechanical APDL. Midpoints of panel where two T girders cross each other and corner point of panel are interested in this study.

10.1. Steel Panel Harmonic Analysis

In order to get these frequency & amplitude graphs, full mode option of harmonic analysis is applied after the obtaining modal analysis and then for the review of results POST26 set up is used.

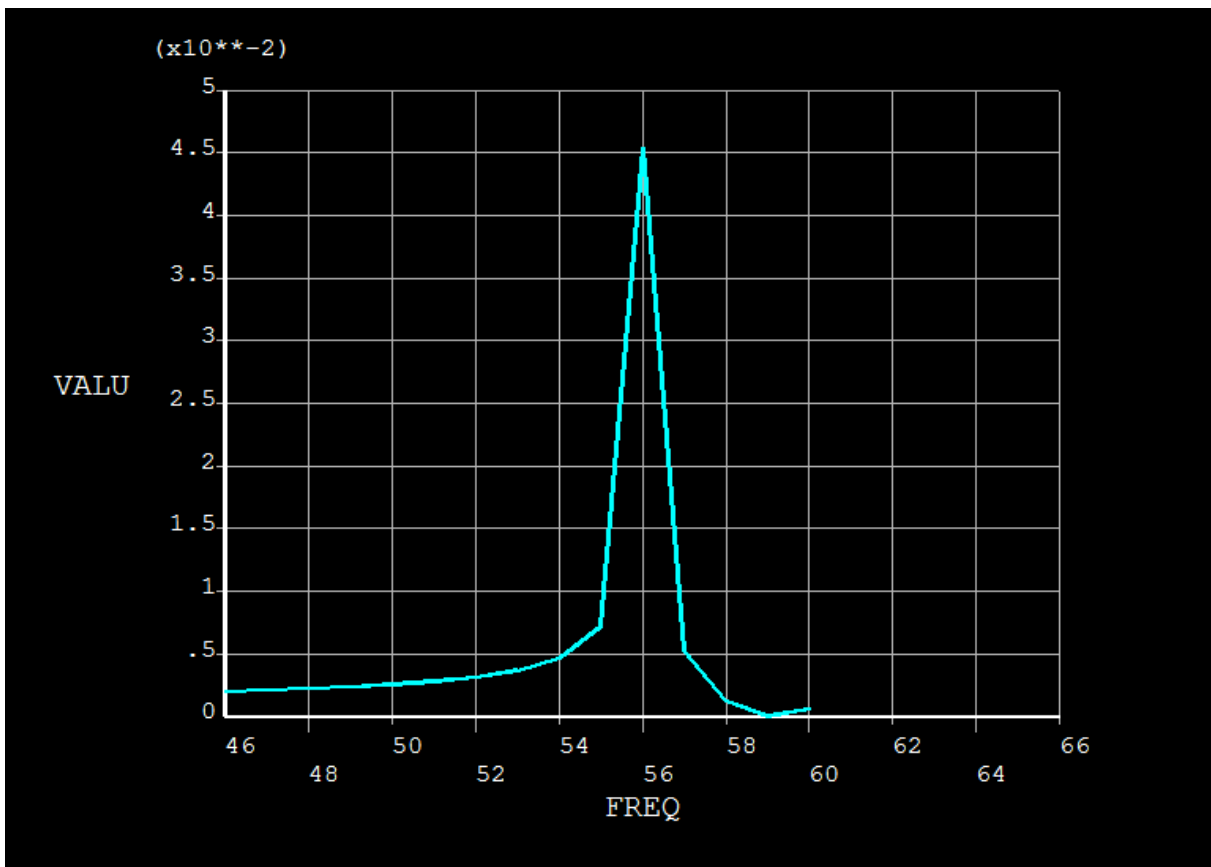


Figure 10.1: Frequency & amplitude graph of steel panel

Frequency range is set according to first mode shape of panel results. Steel panel frequency range is set between 45 Hz to 60 Hz with 15 sub steps option. Steel – Concrete panel frequency range is set between 105 Hz to 140 Hz with 25 sub steps option. Actually for steel – concrete panel result is high and out of range of vibration range in shipbuilding applications.

However in order to understand, clarify situation and check the amplification factor, it is done.

10.2. Steel – Concrete Panel Harmonic Analysis

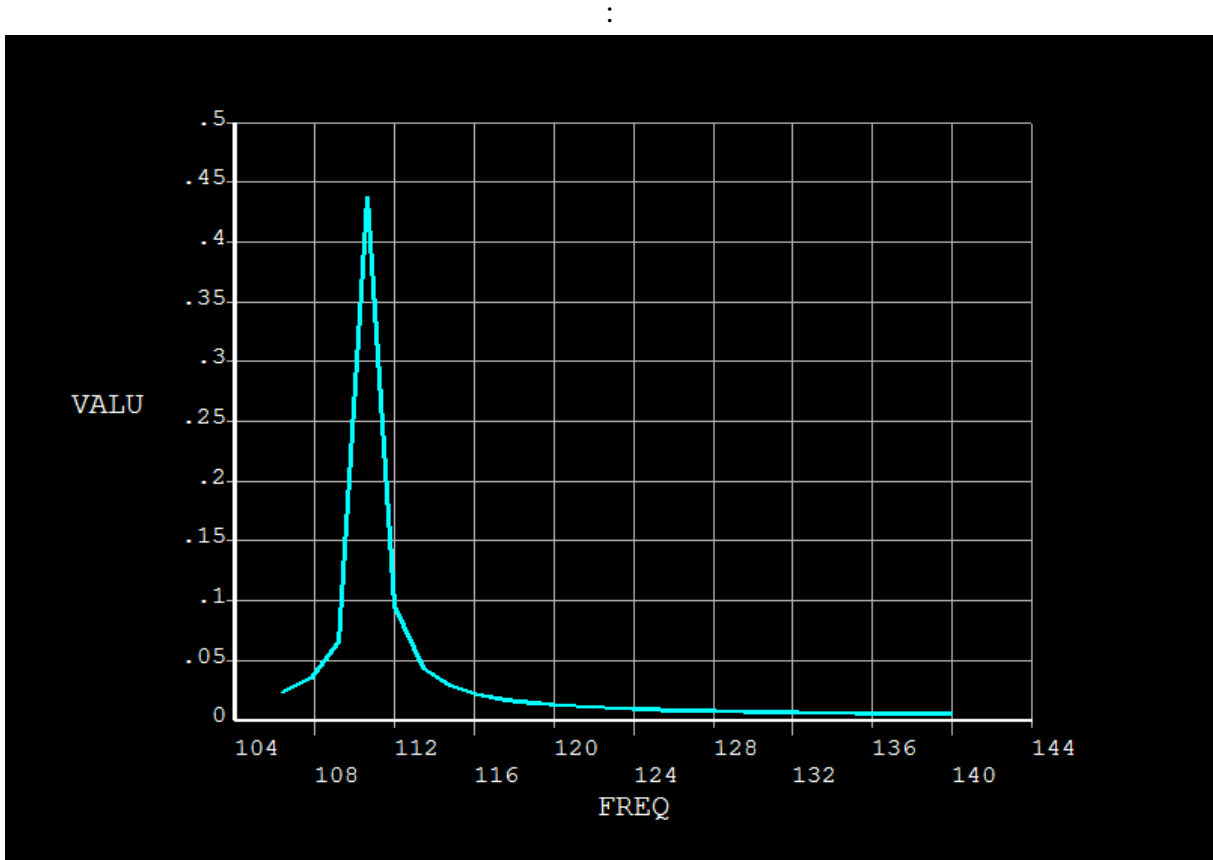


Figure 10.2: Frequency & amplitude graph of steel – concrete panel

Amplification factors are interested part of this study, when we look at the amplitude - frequency graphs of steel panel harmonic analysis and steel – concrete panel harmonic analysis; we can get amplification factors for the corner of panel. Displacement value $UZ = 0.001$ m is applied on mid-point of panels for both situation.

For steel panel, our peak frequency value is 56 Hz and amplitude value is 4.5×10^{-2} m and applied UZ is 0.001 m. So amplification factor is found for the corner of panel is amplitude divided by UZ . AF is for steel,

$$\text{steel}_{AF} = 45$$

For steel – concrete panel, our peak frequency value is somewhere around 111 Hz and amplitude value is 0.44 m and applied UZ is 0.001 m. For the corner of panel is amplitude divided by UZ gives amplification factor. AF is for steel

$$\text{steel-concrete}_{AF} = 450$$

As it can be seen, amplification factors are high especially for the steel – concrete panel. Because no damping applied therefore the amplitude can be infinite at resonance frequency moreover chosen point for amplification factor is weakest (farthest point from T girders and stiffeners).

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11. CONCLUSION

In this study, dynamic behaviour of floor systems in accommodation areas is investigated and compared the results that are coming from variable parameters. For this reason typical floor systems are defined and modelled for numerical analyses. Dimensions and material properties of floor systems are generalized and described. Shell, beam, solid and surface elements are used in order to find natural frequencies and mode shapes of vibrated structures.

Analysing the floor systems, different frequency results are found for each floor system, but with varying thicknesses, surface loads. Relations between those differences are given under the same type of floor structure part for same floor system. With regarding using mineral wool is the only material effects in opposite way natural frequencies unlike others. Different approximations of the natural frequencies of more complex floor structures, by using analytical formulae or numerical methods, give different values. These difference increases when the complexity of structure increases. Influence of thicknesses and influence of surface loads for each type of floor system are shown. For two types of panels, harmonic analyses are done and amplification factors are found.

For further work, more complex floor systems and the actual parts of accommodation areas analyses can be future studies. Also these studies must be supported by experimental results.

Lastly, it is suggested to have more realistic models and more analyses for local structures in order to develop statements about the effect of thicknesses and surface loads. In order to develop a method for floor systems in accommodation areas, after supporting results with experimental ones, it is possible to do approximation methods for natural frequencies of floor structures.

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