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EFFECT OF STIFFENERS AND THICKNESS OF SHELL ON THE NATURAL FREQUENCIES AND MODE SHAPES OF OBLATE SHELL BY FINITE ELEMENT METHOD

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ABSTRACT

This paper discuss the natural frequencies and modes shapes of oblate shells by finite element method via ANSYS12 package with and without longitudinal and lateral stiffeners. Different types of elements are considered using three dimensional analysis with APDL program to take the variables of shell's thickness, number of stiffeners and size of stiffeners. The obtained results reported the tenth structural natural frequencies and mode shapes which are based upon the behavior of the shell, it can be shown that the natural frequency of the oblate shell increased with increasing the mode number and the amplitude decreasing as increasing the thickness of shell.

KEYWORDS: Vibration , Natural Frequency, Mode Shape, ANSYS, Finite Element Method.

تأثير المصطبات وسمك القشرة على التردد الطبيعي واشكال الانماط للقشور المفلطحة بطريقةِ العناصرِ المحددةِ

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الموجز

تم دراسة الترددات الطبيعية و أشكال الأنماطِ التابعة لها للقشور المفلطحة باستخدام طريقة العناصر المحددة من خلال برنامج ANSYS12 بوجود و بعدم وجود مصطبات طولية وعرضية، حيث استخدمت طريقة العناصر المحدودة الثلاثية الأبعاد لتَمْثيل القشور المفلطحة وتم اعداد برنامج بلغة برنامج الانسز 12 (APDL) لدراسة متغيّراتَ سمك القشور وعدد المصطبات وابعاد المصطبات . بينت النَتائِجُ للتردداتِ الطبيعيةِ العشرةِ وأشكالِ الانماطِ المقابلة لها، بأنّ الترددَ الطبيعيَ للقشرة المفلطحة زادت كلما ازداد عددِ النمطِ وتتناقصِ السعة عند تزايد سمك القشرة.

NOMENCLATURE

$[M]$	mass matrix
$[K_e]$	structure stiffness matrix
$\{\delta_e\}$	nodal deflection vector
$\{F\}$	nodal force vector
$[B]$	strain- displacement matrix
$[D]$	stress- strain matrix
ω	natural frequency

INTRODUCTION

The dynamic characteristics of oblate shell is studied using finite element method via ANSYS12 package. The oblate structure is discretized using 4 node shell63 having three displacements and three rotations as degrees of freedom per node. The eigenvalues and eigenvectors are obtained. The modal analysis is presented as contour plots on the deformed configuration of the oblate shell. The oblate shell has many engineering applications, such as the protective shell used as the housing of the early warning scanner of the airborne warning and control system aircraft (AWACX).

The study of the dynamic analysis of plates and shells have been treated by many investigators using different methods. Extensively in this research we have been restricted to few works, Benzes and Burgin,1965 have been solved the problem of the free vibration of thin isotropic oblate shells using Galerkin's method. Penzs,1969 was extended this work to include thin orthotropic oblate shells. Curved blades can be modeled approximately by fact element (**Zienkiewicz, O.C,1992**). Curved shell elements may provide a more accurate facility for the finite element modeling of curved blades. The basic equations which describe the behavior of a thin elastic shell were originally derived by Loue,1983. Pawsey,1985 explained the basic problems common to most shell elements, and which restrict most elements class of shells, either thin or thick, depending on the parent theory used for developing the element. Recently the concept of quasi comparison function has been introduced for the Reylegh Ritz discretization in self-adjoint eigen-value problem (**Hagedran ,1993**). (**Babich and Khoroshan, 2001**) is studied the stability and natural vibrations of shells with variable geometry and mechanical parameters.

Most of the forgoing published work gave a great deal to the dynamic response to a part of an oblate shell theoretically and/or experimentally. Hence, it becomes essential to study the vibration characteristics of an oblate shell for different thicknesses with and without stiffeners. This study is identified theoretically using finite element method via ANSYS12 package which is studied the modal analysis of oblate shells.

FINITE ELEMENT EQUATION

The element equations of the system can be expressed in general form (**Hani, 2010**):

$$[M]\{\ddot{\delta}_e\} + [K_e]\{\delta_e\} = \{F_{e(t)}\} \tag{1}$$

where :

$$[K_e] = \int_{vol} [B]^t \cdot [D] \cdot [B] \, \mathrm{dvol} \tag{2}$$

the analysis assembles all individual element equations to provide stiffness equations for the entire structure or mathematically

$$[M]\{\ddot{\delta}\} + [K]\{\delta\} = \{F_{(t)}\} \tag{3}$$

$$\text{where:} \quad [K] = \sum_{i=1}^{M} [K_e] \tag{4}$$

$$[M] = \sum_{i=1}^{M}[M_e] \tag{5}$$

EIGENVALUE SOLUTION:

When finite element method is applied for the solution of eigenvalue problems, an algebraic eigenvalue problem is obtained as stated in equation(9). For most engineering problems, [K] and [M] will be symmetric matrices of order n (**Erik,1990**).

$$[M]\{\ddot{\delta}\} + [K]\{\delta\} = 0 \tag{6}$$

Pre-multiplying by $[M]^{-1}$

$$-[I]\omega^2\{\delta\} + [D_o]\{\delta\} = 0 \tag{7}$$

Where:

$$[D_o] = [M]^{-1}[K] \tag{8}$$

$$\lambda = \omega^2$$

$$[[D_o] - \lambda[I]]\{\delta\} = 0 \tag{9}$$

For non trivial

$$|[D_o] - \lambda[I]| = 0 \tag{10}$$

EIGENVECTOR SOLUTION:

Finite element method is applied to find mode shape for a system. It can be express in the following equation:

$$[C] = [[D_o] - \lambda[I]] \tag{11}$$

$$[C]^{-1} = \frac{Adj[C]}{|C|} \tag{12}$$

Pre-multiplying equation (12) by $|C|[C]$:

$$|C| = [C]Adj[C] \tag{13}$$

$$|[D_o] - \lambda[I]| = [[D_o] - \lambda[I]]Adj[[D_o] - \lambda[I]]$$

If λ is one of the eigenvalues then :

$$|[D_o] - \lambda_i[I]| = [[D_o] - \lambda_i[I]]Adj[[D_o] - \lambda[I]] \tag{14}$$

The left side of the previous equation becomes zero hence:

$$0 = [[D_o] - \lambda_i[I]]\, Adj[[D_o] - \lambda_i[I]]$$

$$\{\delta\}_i = Adj[[D_o] - \lambda_i[I]]$$

$$0 = [[D_o] - \lambda_i[I]]\{\delta\}_i \tag{15}$$

hence the system equation can be written in the form :

$$[M]\{\ddot{\delta}\} = \{F\} - [K]\{\delta\} = \{F\} - \{F\}^{int} = \{F\}^{residual} \qquad (16)$$

$$\{F\}^{int} = [K]\{\delta\} \qquad (17)$$

$$\{\ddot{\delta}\} = [M]^{-1}\{F\}^{residual} \qquad (18)$$

In practice, the above equation does not usually require solving of the matrix equation , since lumped masses are usually used which forms a diagonal mass matrix (Mario Paz ,1990). The solution to equation(18) is thus trivial, and the matrix equation is the set of independent equations for each degree of freedom i as follows:

$$\delta_i = \frac{f_i^{residual}}{m_i} \qquad (19)$$

MODEL GENERATION BY ANSYS12

The ultimate purpose of a finite element analysis is to re-create mathematically the behavior of an actual engineering system (**Saeed,1999**). In other words, the analysis must be an accurate mathematical model of a physical prototype (**Tim Langlais ,1999**). In the broadest sense, the model comprises all the nodes, elements, material properties, real constants, boundary conditions and the other features that used to represent the physical system. In ANSYS12 terminology, the term model generation usually takes on the narrower meaning of generating the nodes and elements that represent the special volume and connectivity of the actual system. Thus, model generation in this study will mean the process of defining the geometric configuration of the model's nodes and elements. The program offers the following approaches to model generation (**user maual,2009 and training manual,2009**) :(a) Creating a solid model , (b) Using direct generation and (c) Importing a model created in a computer-aided design CAD system. The method used in this research to generate a model is solid model. In solid modeling some one can be described the boundaries of the model, establish controls over the size and desired shape elements automatically, i.e. drawing the three dimensional model and meshing using meshtool. Solid modeling is usually more powerful and versatile than other modeling, and is commonly the preferred method for generation models.

Figure 1 shows the dimensions of the oblate shell. The longitudinal and lateral stiffeners as shown in **Figure 2.**

The one dimension model is done by drawing and dragging to get three dimension model then meshing with element shell63 and the stiffeners is meshed by Beam188 with cross section circular solid (**Marimuthu et al,2007**). **Figure 3** shows the mesh of oblate shell.

Procedure is presented for modeling of oblate shell with stiffeners by ANSYS12 software by using solid-modeling approach method. Hence the program of modeling the vibration characteristics of an oblate shell in APDL (ANSYS Parametric Design Language) is presented in Appendix-A-

RESULTS AND DISCUSSIONS

A structure, such as a dish, may have zones with the variable thickness and construction when it is difficult to use one element type. If a Mindlin facet element is employed for a thin structure shear looking will occur and will lead to inaccurate results. The flat or facet shell element (shell63) is the appropriate and easily employed for curved shells. Free vibration analysis consists of studying the vibration characteristics of the oblate shell, such as natural frequency and mode shapes. The natural frequency and mode shapes of an oblate shell is very important parameter in the design of the large structure such as aircrafts, bridges, ships, vehicles and tall building being constantly acted on by wave and motion, the resulting forces can introduced vibrations at the resonance or repeated many times which may lead to structural failure. A detailed study is made using the formulation presented in this paper on the fundamental natural frequency and mode shape levels of an oblate shell. The free vibration characteristics have been investigated by ANSYS12 software and can be seen in **Figure 4-10.**

The results reported the first ten structural eigenvalue and eigenvectors which are based upon the behavior of oblate shell, numerically values were obtained using the models which was constructed from steel, each one of models was constructed as follows:

Case -1- Oblate without stiffeners.
Case - 2- Oblate with one curved stiffener.
Case - 3- Oblate with two curved stiffeners.
Case - 4- Oblate with three curved stiffeners.
Case - 5- Oblate with four curved stiffeners.
Case - 6- Oblate with one vertical stiffener.
Case - 7- Oblate with two vertical stiffeners .
Case - 8- Oblate with three vertical stiffeners.
Case - 9- Oblate with four vertical stiffeners.
Case- 10- Oblate shell with all curved and vertical stiffeners

Table 1 explained the natural frequencies for oblate Shell with thickness (5mm and 10 mm) for ten modes to the all ten cases above, from that it can be shown that the natural frequencies decreasing with the lateral and longitudinal stiffeners.

Table 2 explained the effect of shell thickness with natural frequency for tenth modes to the all ten cases above, from that it can be deduced that the natural frequencies increasing with the increasing the shell thickness.

Table 3 explained the effect of cross section of stiffener with the natural frequency for tenth modes to the all ten cases above, from that it can be deduced that the natural frequencies are stable within cross section (0.5 – 1.5)mm and other the effect was simply increasing .

Figure 4 shows the mode shapes for the ten cases .It is demonstrated that finite element method can be employed to determine the free vibration frequencies and mode shapes of simplified representation of oblate dish.

Figure 5 shows the variation of amplitude with shell thickness , there is a small decreasing.

Figure 6 shows the variation of natural frequency with stiffener radius, no obvious effect but for case2 decreasing, for case9 increasing.

Figure 7 shows the variation of natural frequency with mode numbers with shell thickness =5mm , there is an obvious increasing in the sixth mode.

Figure 8 shows the variation of natural frequency with mode numbers with shell thickness =10mm, the same as **Figure 7.**

Figure 9 shows variation of natural frequency with case number ,case1 only has the greatest value of natural frequency, then all cases are similar .

Figure 10 shows the variation of natural frequency with shell thickness , there is a small increase.

The dynamic behavior of oblate shells depend upon the coupling and uncoupling of membrane modes and bending modes. Natural frequencies are seen to have two types of behaviors against increasing the shell thickness, one type, which is associated with the membrane modes, remain unaffected by the thickness variations, while the other type, which is associated with the bending modes, tends to increase with the thickness.

Dynamic characteristics of the oblate shell with and without stiffeners is studied through finite element method. The results reported the tenth structural natural frequencies and mode shapes which are based upon the behavior of oblate shell, it can be concluded that the natural frequency of the shell increased with increasing mode number and the amplitude decreases as the thickness of shell increases .

CONCLUSIONS

1- In all cases there are a jump in natural frequency values, and also an obvious change in shape.
2- In all cases the sixth modes are in one color that means the same amplitude changing for all points.
3- The increasing of shell thickness relate to increase the natural frequencies, but the amplitude from (1-5) mm decreased and at thickness 6mm suddenly increased then from (7-10) mm turn to decrease.
4- The mode shapes are the same for most cases in the same number.
5- The effect of stiffener radius is weaken from (0.5-1.5) mm and frequency has small variation increasing and from (1.5-3) mm frequency had small decreased, its effect on mode shapes is none.
6- Always the seventh and tenth mode shapes are symmetric, but eighth and ninth are asymmetric.

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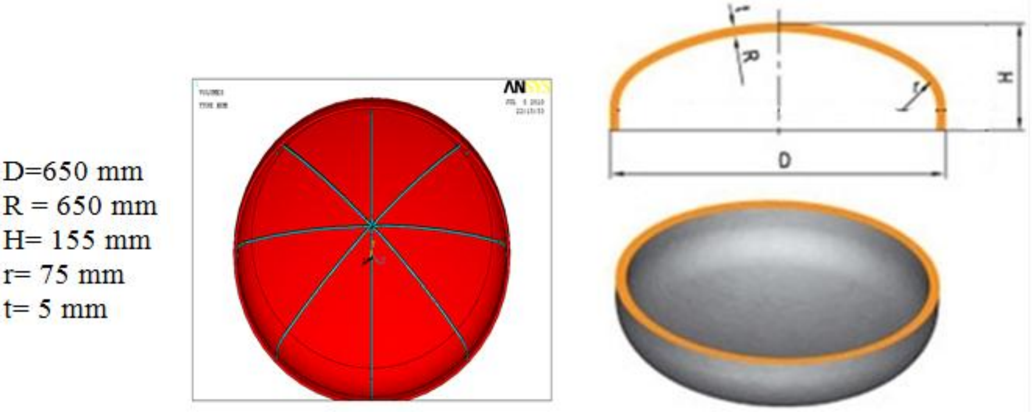


Figure 1 The dimension of oblate shell

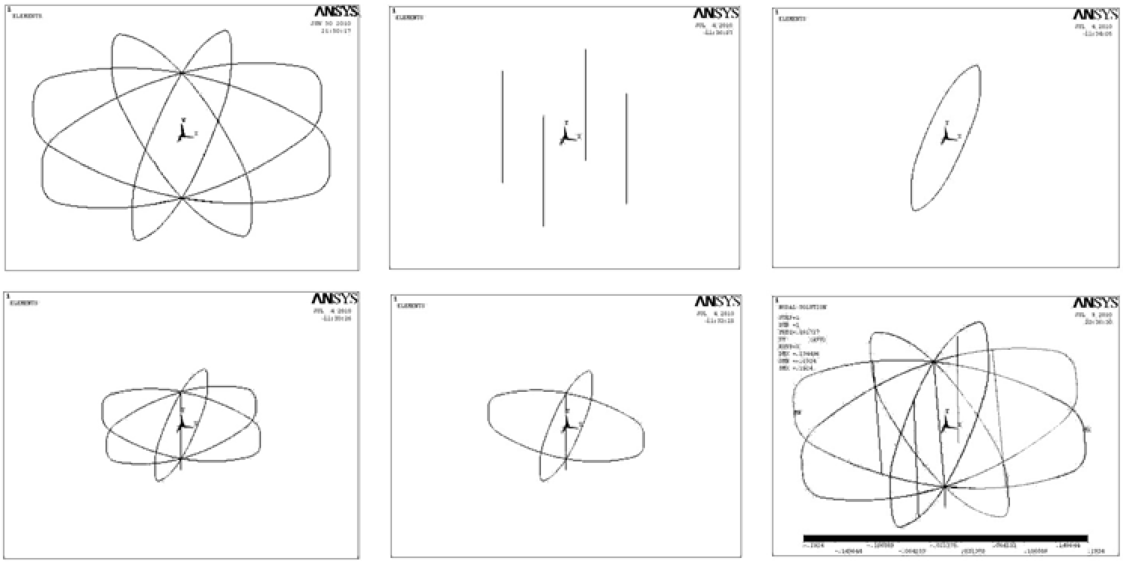


Figure 2 Longitudinal and lateral stiffeners.

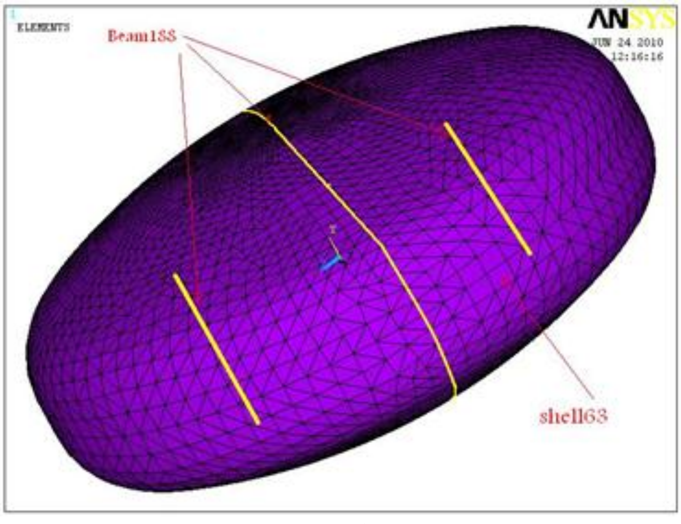


Figure 3 Mesh of Oblate Shell.

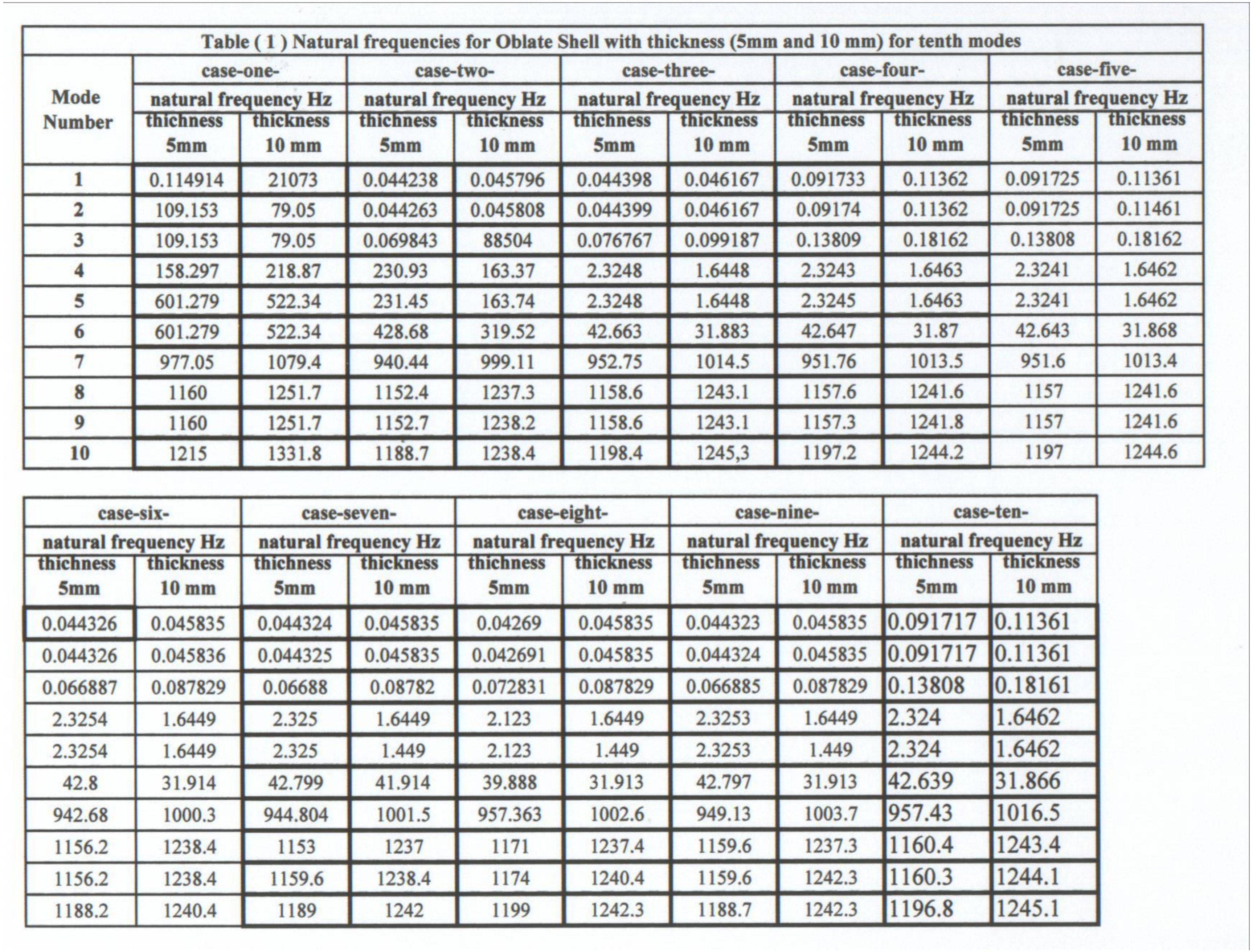


Table (1) Natural frequencies for Oblate Shell with thickness (5mm and 10 mm) for tenth modes

Mode Number	case-one-		case-two-		case-three-		case-four-		case-five-	
	natural frequency Hz		natural frequency Hz		natural frequency Hz		natural frequency Hz		natural frequency Hz	
	thichness 5mm	thickness 10 mm	thichness 5mm	thickness 10 mm	thichness 5mm	thickness 10 mm	thichness 5mm	thickness 10 mm	thichness 5mm	thickness 10 mm
1	0.114914	21073	0.044238	0.045796	0.044398	0.046167	0.091733	0.11362	0.091725	0.11361
2	109.153	79.05	0.044263	0.045808	0.044399	0.046167	0.09174	0.11362	0.091725	0.11461
3	109.153	79.05	0.069843	88504	0.076767	0.099187	0.13809	0.18162	0.13808	0.18162
4	158.297	218.87	230.93	163.37	2.3248	1.6448	2.3243	1.6463	2.3241	1.6462
5	601.279	522.34	231.45	163.74	2.3248	1.6448	2.3245	1.6463	2.3241	1.6462
6	601.279	522.34	428.68	319.52	42.663	31.883	42.647	31.87	42.643	31.868
7	977.05	1079.4	940.44	999.11	952.75	1014.5	951.76	1013.5	951.6	1013.4
8	1160	1251.7	1152.4	1237.3	1158.6	1243.1	1157.6	1241.6	1157	1241.6
9	1160	1251.7	1152.7	1238.2	1158.6	1243.1	1157.3	1241.8	1157	1241.6
10	1215	1331.8	1188.7	1238.4	1198.4	1245,3	1197.2	1244.2	1197	1244.6

case-six-		case-seven-		case-eight-		case-nine-		case-ten-	
natural frequency Hz		natural frequency Hz		natural frequency Hz		natural frequency Hz		natural frequency Hz	
thichness 5mm	thickness 10 mm	thichness 5mm	thickness 10 mm	thichness 5mm	thickness 10 mm	thichness 5mm	thickness 10 mm	thichness 5mm	thickness 10 mm
0.044326	0.045835	0.044324	0.045835	0.04269	0.045835	0.044323	0.045835	0.091717	0.11361
0.044326	0.045836	0.044325	0.045835	0.042691	0.045835	0.044324	0.045835	0.091717	0.11361
0.066887	0.087829	0.06688	0.08782	0.072831	0.087829	0.066885	0.087829	0.13808	0.18161
2.3254	1.6449	2.325	1.6449	2.123	1.6449	2.3253	1.6449	2.324	1.6462
2.3254	1.6449	2.325	1.449	2.123	1.449	2.3253	1.449	2.324	1.6462
42.8	31.914	42.799	41.914	39.888	31.913	42.797	31.913	42.639	31.866
942.68	1000.3	944.804	1001.5	957.363	1002.6	949.13	1003.7	957.43	1016.5
1156.2	1238.4	1153	1237	1171	1237.4	1159.6	1237.3	1160.4	1243.4
1156.2	1238.4	1159.6	1238.4	1174	1240.4	1159.6	1242.3	1160.3	1244.1
1188.2	1240.4	1189	1242	1199	1242.3	1188.7	1242.3	1196.8	1245.1

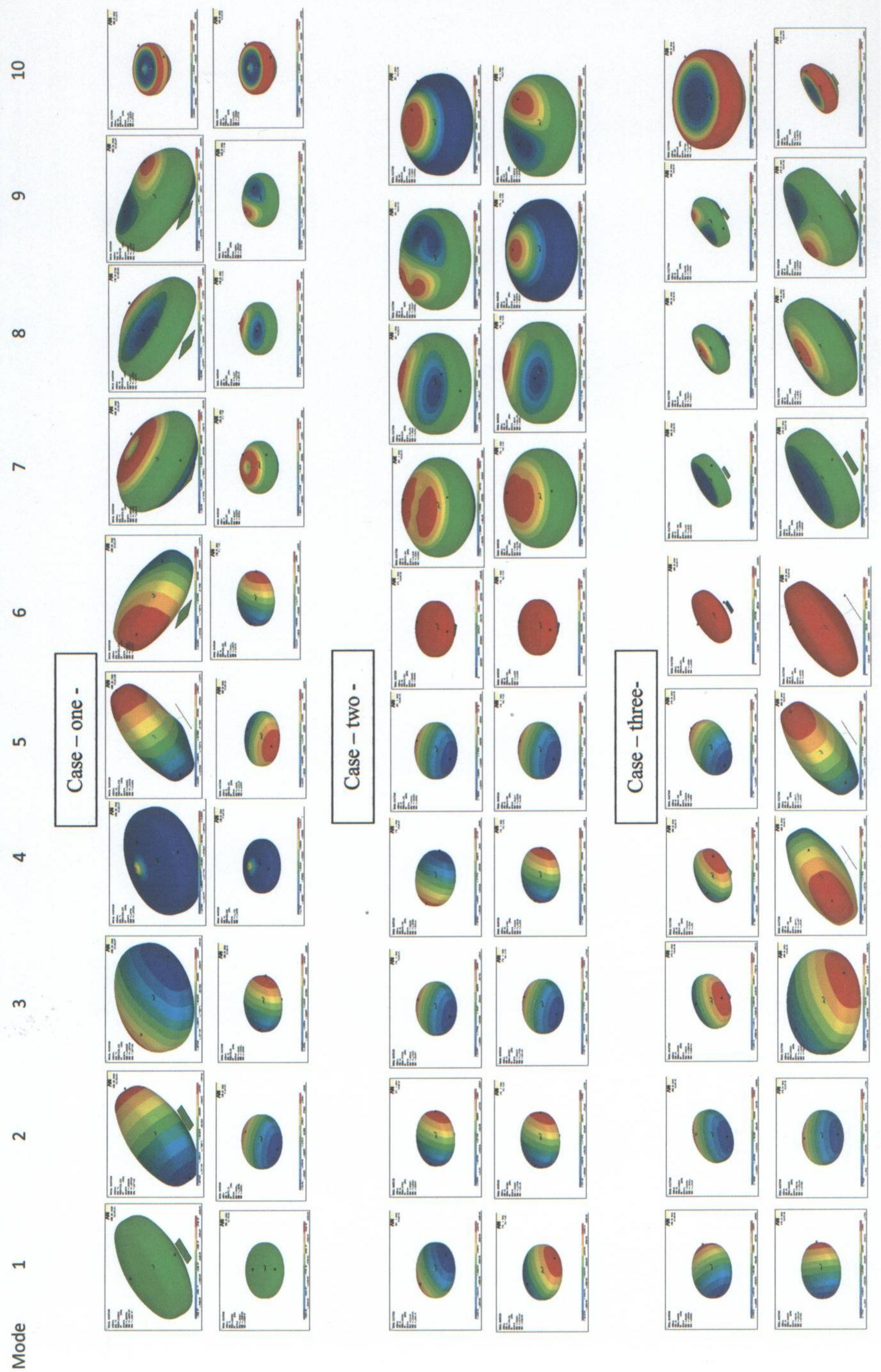
Table(3) effect of cross sectionof stiffener radius with the natural frequency

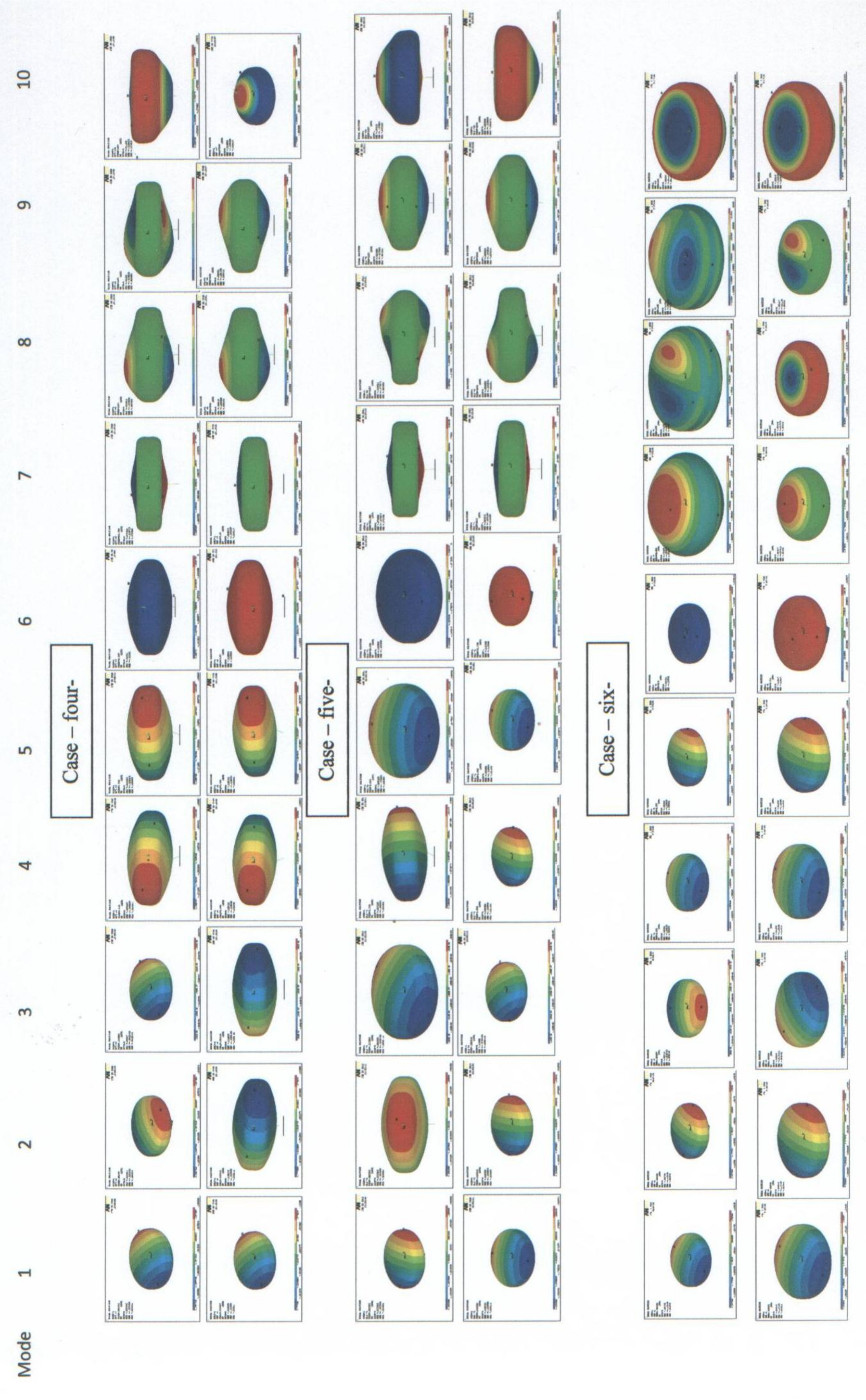
cross section beam raduis mm	case-two-	case-three	case-four-	case-five-	case-six-	case-seven-	case-eight-	case-nine-	case-ten-
	Frequency Hz	Frequency Hz	Frequency Hz	Frequency Hz	Frequency Hz	Frequency Hz	Frequency Hz	Frequency Hz	Frequency Hz
0.5	1188.7	1198.4	1197.2	1197	1188.2	1189	1199	1189	1197
1	1192	1201	1199	1192	1192.72	1192	1192	1192	1197
1.5	1195	1202	1199	1197	1195.52	1194	1194	1194	1195
2	1196	1202	1198	1197	1197.42	1200	1200	1200	1194
2.5	1197	1201	1196	1197	1198.2	1207.6	1207.6	1208	1196
3	1196	1171	1193	1197	1198.2	1212.3	1211.9	1211	1196

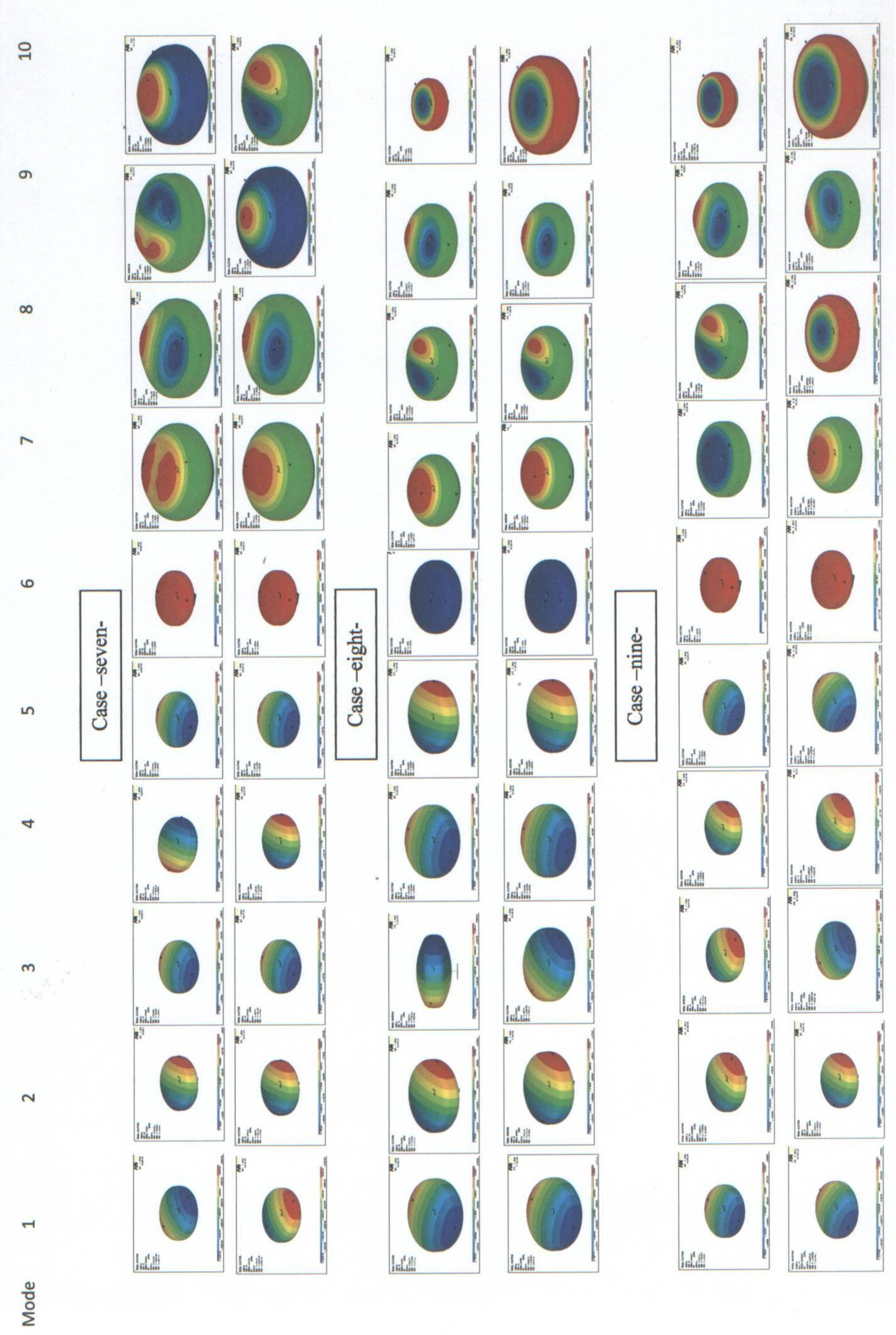
Table(2) effect of shell thickness with natural frequency

Thickness of shell mm	Natural frequency , Hz								
	case-one	case-two-	case-three-	case-four-	case-five-	case-six-	case-seven-	case-eight-	case-nine-	case-ten-
3	1175	1162	1171	1169.9	1169.6	1162	1162	1162	1162	1169
4	1195	1177	1186	1185.2	1185	1177	1177	1177	1177	1185
5	1215	1189	1198.4	1197.2	1197	1188.2	1189	1199	1189	1197
6	1235	1199	1208	1207.3	1207.2	1199	1199	1198	1199	1207
7	1257	1208	1218	1216.5	1216.4	1208.3	1208	1208	1208	1216
8	1280	1218	1227	1225.5	12254	1217.3	1218	1217	1218	1225
9	1305	1227	1236	1234.6	1234.5	1227.3	1227	1242	1227	1234
10	1331.8	1238.4	1245.3	1244.2	1244.6	1240.4	1242	1257	1242.3	1245.1

Fig.( ) Mode shapes for the cases studies




Mode
1
2
3
4
5
6
7
8
9
10
Case – four-
Case – five-
Case – six-


Mode
1
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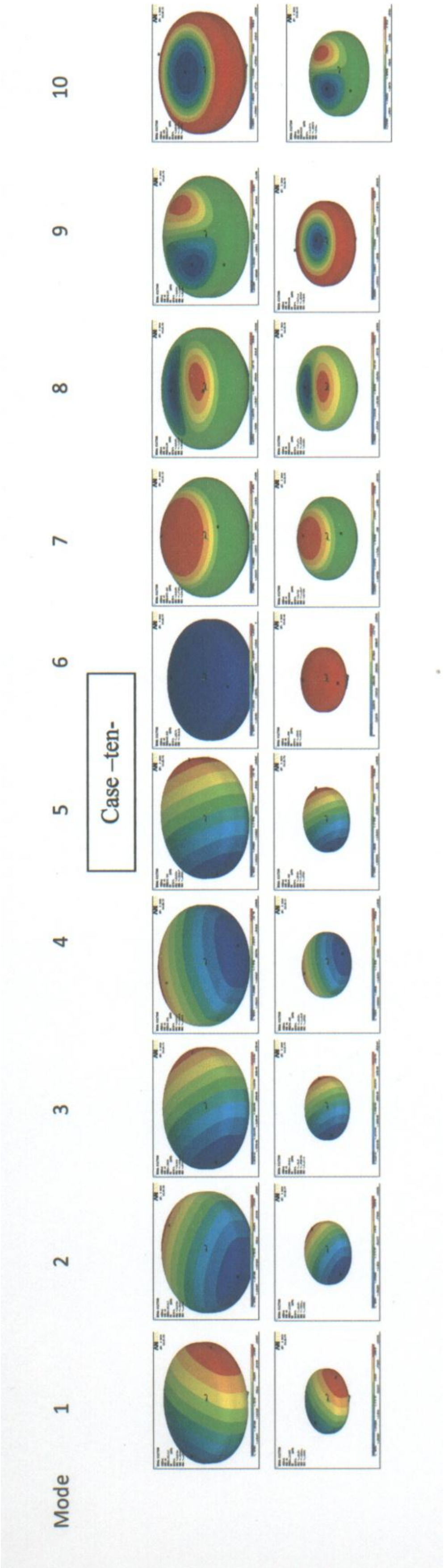
Case -seven-
Case -eight-
Case -nine-



Case –ten-

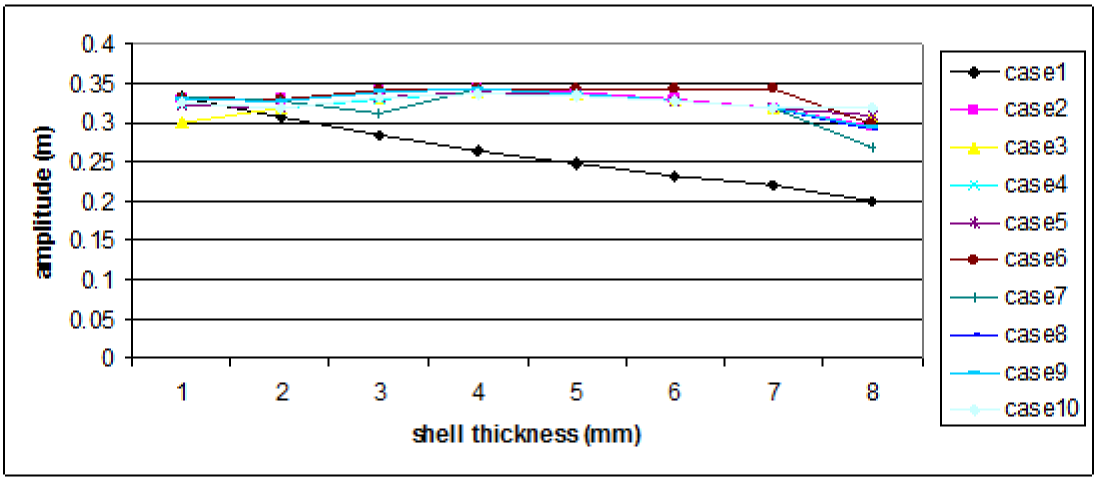


Figure 5 variation of amplitude with shell thickness

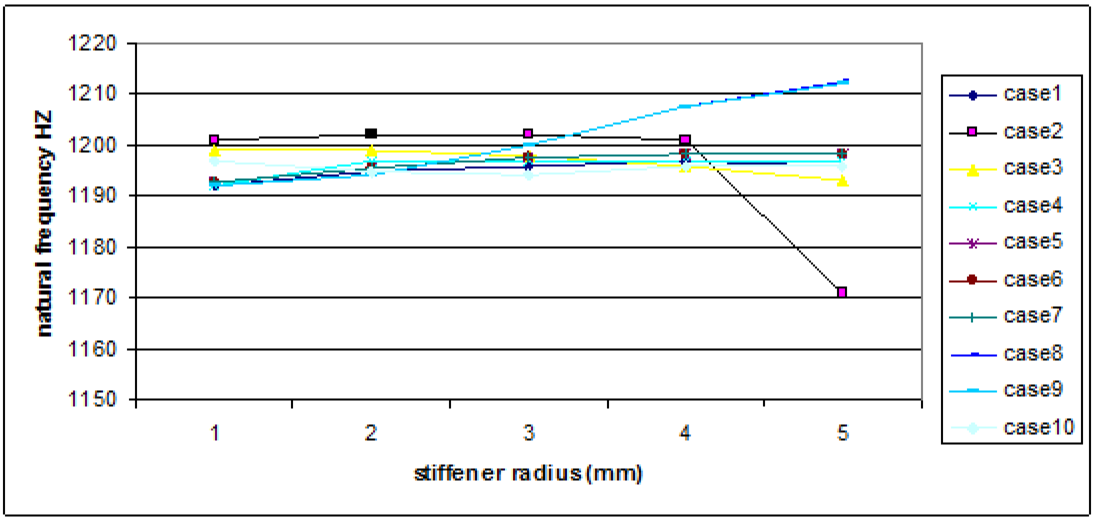


Figure 6 variation of natural frequency stiffener radius

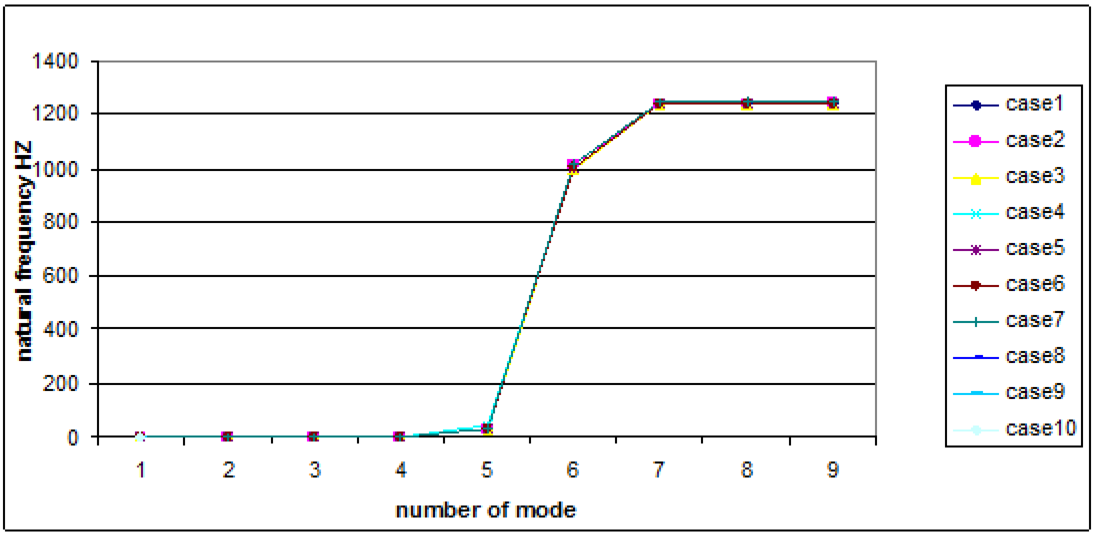


Figure 7 variation of natural frequency with mode numbers with shell thickness =5mm

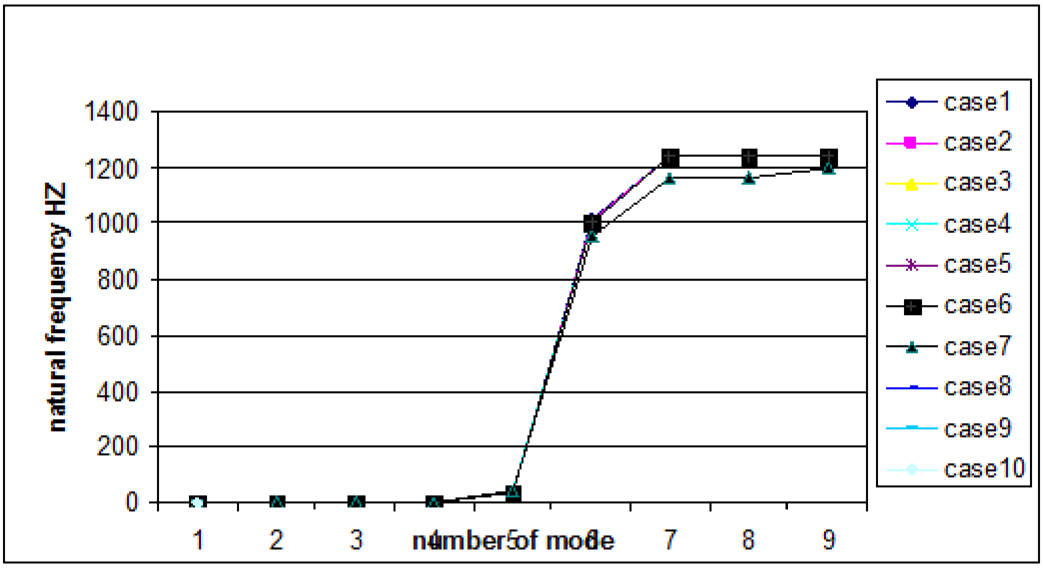


Figure 8 variation of natural frequency with mode numbers with shell thickness =10mm.

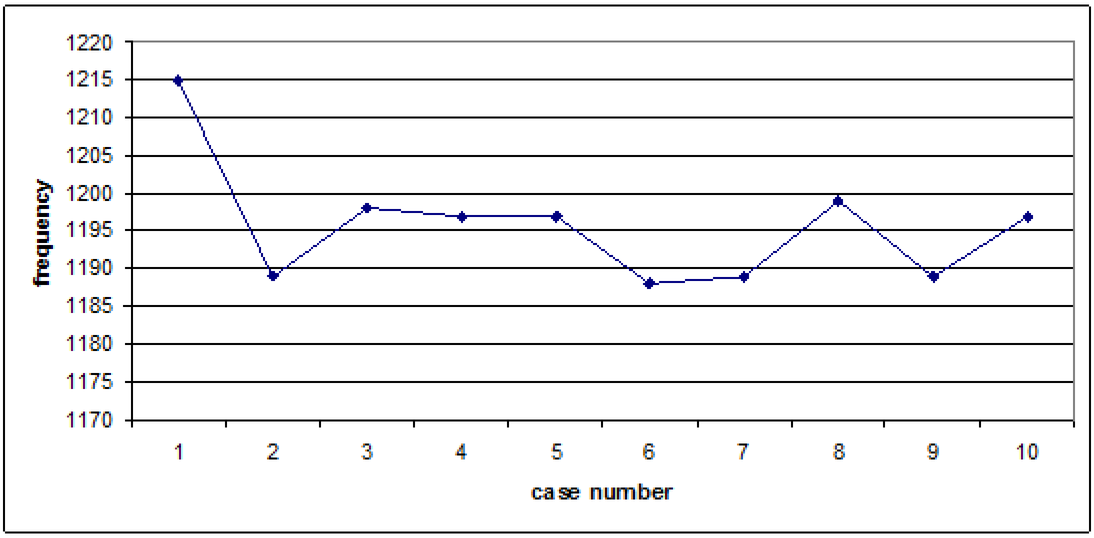


Figure 9 variation of natural frequency with case number

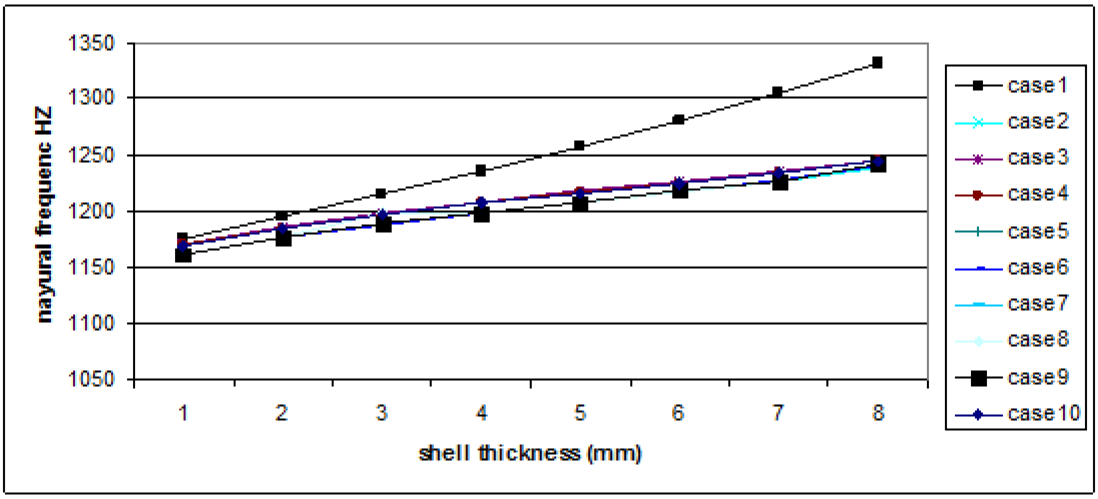


Figure 10 variation of natural frequency with shell thickness.

APPENDIX-A-

In the present study the following program is done to analysis the vibration characteristics of oblate shell by finite element method by ANSYS12 package.

```
/prep7
k,1,0,-495/1000 :  k,2,0,155/1000 : k,3,650/1000,-495/1000
k,4,325/1000,0  : k,5,250/1000,0 : k,6,325/1000,75/1000
k,7,0,80/1000 :  k,8,575/1000,-495/1000 : larc,7,8,1,575/1000
larc,6,5,4,75/1000 : lcsl,1,2:  ldele,3,6,1,0: k,10,253/1000,96
k,11,328/1000,21/1000 : k,15,288.075/1000,87.2929/1000
larc,15,11,9,75/1000 : larc,2,15,1,650/1000:  ldiv,2,,,4
k,500,328/1000 : l,11,500:  lcomb,3,4: lcomb,3,5 : lcomb,3,1:lcomb,1,6
arotate,2,,,,,,1,2,45:  arotate,1,,,,,,1,2,45:  arotate,3,,,,,,1,2,45: arotate,5,,,,,,1,2,45
arotate,8,,,,,,1,2,45 : arotate,10,,,,,,1,2,45 : arotate,13,,,,,,1,2,45
arotate,15,,,,,,1,2,45 : arotate,20,,,,,,1,2,45:  arotate,18,,,,,,1,2,45
arotate,23,,,,,,1,2,45 : arotate,26,,,,,,1,2,45: arotate,28,,,,,,1,2,45
arotate,31,,,,,,1,2,45 : arotate,33,,,,,,1,2,45: arotate,36,,,,,,1,2,45
arsymm,y,1,,,,0 : arsymm,y,2,,,,0: arsymm,y,3,,,,0 : arsymm,y,4,,,,0
arsymm,y,5,,,,0 : arsymm,y,6,,,,0: arsymm,y,7,,,,0
arsymm,y,8,,,,0 :arsymm,y,9,,,,0 : arsymm,y,10,,,,0
arsymm,y,11,,,,0 : arsymm,y,12,,,,0: arsymm,y,13,,,,0
arsymm,y,14,,,,0 : arsymm,y,15,,,,0: arsymm,y,16,,,,0
et,1,shell63 : keyopt,1,7,0 : mp,ex,1,208e9 :mp,nuxy,.3
mp,dens,1,7850 : r,1,5/1000: esize,,20: amesh,all
nummerg,all : !\\\\ ribs : et,4,beam188: keyopt,4,1,0: sectype,1,beam,csolid
secdata,3/1000,8,2 : mp,ex,4,208e9: mp,dens,4,7850
mp,nuxy,4,.3 : type,4: mat,4: real,4:
!\\\\\\\\\: !first stiffener:e,1,773 : *do,i,773,790 : e,i,i+1: *enddo …..
\\\\\\second stiffener: e,1,42:  *do,i,42,59:  e,i,i+1:  *enddo…….
\\\\\third stiffener:  e,1,3 : *do,i,3,20:  e,i,i+1:  *enddo: ………..
!\\\\\fourth stiffener: et,6,beam188: keyopt,6,1,0:  sectype,1,beam,csolid
secdata,.5/1000,8,2:  mp,ex,6,208e9:  mp,dens,6,7850: mp,nuxy,6,.3
type,6 : mat,6: real,6: e,1,4843: *do,i,4843,4860: e,i,i+1: *enddo
\\\\base: nummerg,all: wplane,1,0,0,0,0,0,10/1000,10/1000,0,0
wpoffst,0,0,-207/1000:  blc5,0,0,140/1000,140/1000
type,1: mat,1: real,1: amesh,33:
!\\\\\\\\: !column:  et,5,beam188:  keyopt,5,1,0:  sectype,2,beam,ctube
secdata,34/1000,40/1000,8: mp,ex,5,208e9: mp,dens,5,7850
allsel,all: nummerg,all: asel,s,,,33:  : nsla,s,1: d,all,all: allsel,all
finish
/solu : antype,modal
modopt,lanb,10
EQSLV,SPAR
MXPAND,10, , ,0
Solve finish
```