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Free Vibration Response of Laminated Composite Box Beams

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Abstract: **- Laminated composites are made of layers of fibers in matrix material. They are very thin and light weight which makes them efficient in various applications. However, this thin configuration itself makes them prone to vibration damage. In this paper, an attempt has been made to study vibration response of laminated composite box beams. The variation of orthotropic stiffness parameter with natural frequency for different length to width ratios is studied. Analysis is based on finite element principles implemented via ANSYS 15.**

Index Terms— Laminated composites, Box section, Free vibration, Orthotropic Stiffness, Natural frequency

1. INTRODUCTION

Laminated composites consist of layers of fibers in a matrix material. The individual fibers are of high modulus and high strength. The matrix may be polymeric, metallic or ceramic. They are very strong and efficient in various applications while being light. Some of their properties are high strength to weight ratio, stiffness to weight ratios, long fatigue life and corrosion resistance. Besides this their major advantage is that they can be used as per requirement to achieve maximum efficiency which makes them more reliable. The application includes automobiles, civil, mechanical and athletic industries.

Laminated composite box beams are thin and hence vulnerable to damage when subjected to vibrations. The vibrations are part of many structural applications like ship hull decks and even helicopter blades. To overcome such a major challenge, a design parameter had been proposed, called the orthotropic stiffness parameter [1]. The orthotropic stiffness parameter was found to influence the free vibration characteristics of laminated composite box beams. As the orthotropic stiffness parameter reduced, the natural frequency of the box beams where also found to reduce, for a constant value of extension stiffness A12. However, the application of this design parameter, to other geometry needs to be established as well. Hence an attempt is made to understand the free vibration response of laminated composite box beams of different length to width ratios.

II. METHODOLOGY

A. General

Finite Element Software ANSYS 15 is used to study the vibration behavior of laminated composite box beams. ANSYS carries out advanced engineering analyses quickly by variety of contact algorithms. The properties of laminated composite box beams, number of layers, thickness, type of layup configuration and fiber orientations are to be defined for exact modelling of the same in ANSYS 15. Various elements used in finite element analysis are available in ANSYS 15. However, the resemblance of laminated composites to shell element makes it better to resort to the same. Hence, element used is Shell 281. It has 8 nodes, with 6 degrees of freedom at each node.

B. Orthotropic Stiffness Parameter

Laminated composites are famous for their high strength to weight ratios and stiffness to weight ratios. Stiffness is a governing factor in structural response towards vibrations. For laminated composites, what influences the stiffness is namely the layup configuration. Lay up configuration means the manner in which each layer is tailored. Layers can be symmetric.

An attempt has been clearly made to study the influence of orthotropic stiffness parameter on natural frequencies in case of same layup configurations in web and flange for different length to width ratios. The layups were selected based on arbitrary trials, such that their values of extension stiffness A12 was constant. The orthotropic stiffness parameter was calculated as given below:

Orthotropic Stiffness Parameter, ω

$$=0.5\{(A_{11}/A_{66})_{web} + (A_{11}/A_{66})_{flange}\}$$

C. Finite Element Modelling

Graphite Epoxy laminated composite box section is modelled as shown in Figure 1. The material properties are as in Table 1.

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TABLE 1 MATERIAL PROPERTIES

Material properties	
Longitudinal modulus of elasticity, E_1(N/mm^2)	145000
Transverse modulus of elasticity, E_2(N/mm^2)	16500
Longitudinal Poisson's ratio,υ_1	0.314
Transverse Poisson's ratio, υ_2	0.0357
Shear Modulus, G (N/mm^2)	4480
Density, ρ (Kg/m^3)	1520

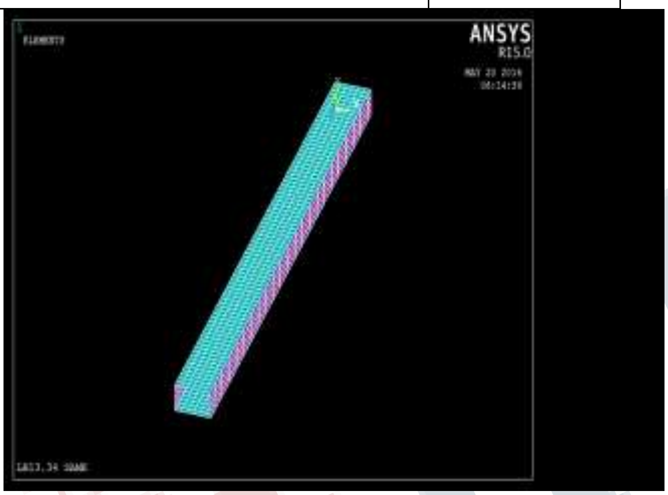

Fig 1 Laminated Composite Box Beam: ANSYS 15

The symmetric layup configuration is used. Angle combinations are 0·, 15·, 30·, 45·, 60·, 75· and 90·. Same layup is provided in both web and flange of laminated composite box beams. 26 layup configurations were considered for five constant values of extension stiffness

The list of layup used and their orthotropic stiffness are enlisted in Table 2. The modelled beams have their length to width ratios ranging from 13.33 to 40. The model geometry with respective L/B ratios is mentioned in Table 3

D. Free Vibration Analysis

The frequency at which a system oscillates without any driving force is called natural frequency. Natural frequencies are found by Modal Analysis in ANSYS 15. The lowest natural frequency is used for comparison from the analysis results.

III. RESULTS

Table 4 shows the results of modal analysis performed on laminated composite box beam sections for models with L/B ratios ranging from 13.334 to 40, for constant extension stiffness A12 = 16092.8931. For constant extension stiffness of 16092.8931, the lowest registered natural frequency varies from 13.169 Hz to 1.477 Hz for L/B ratios from 13.334 to 40.

For constant extension stiffness of 27337.94, the lowest registered natural frequency varies from 12.652 Hz to 1.421 Hz for L/B ratios from 13.334 to 40. Similar behavior is seen other layups of constant extension stiffness of 32960.46, 44205.5 and 49828.027 for all L/B ratios. In all cases, the natural frequency reduces by an average of 53%.

TABLE 2 LAY UP CONFIGURATION

Sl no	Lay up	A_{12}
1	$[90/75/90]_S$	16092.8931
2	$[15/90/90]_S$	16092.8931
3	$[0/75/90]_S$	16092.8931
4	$[0/15/90]_S$	16092.8931
5	$[75/0/0]_S$	16092.8931
6	$[75/75/75]_S$	27337.9377
7	$[90/60/90]_S$	27337.9377
8	$[60/90/0]_S$	27337.9377
9	$[0/30/90]_S$	27337.9377
10	$[60/0/0]_S$	27337.9377
11	$[60/90/75]_S$	32960.4601
12	$[45/90/90]_S$	32960.4601
13	$[90/60/15]_S$	32960.4601
14	$[0/60/75]_S$	32960.4601
15	$[0/45/90]_S$	32960.4601
16	$[0/75/30]_S$	32960.4601
17	$[60/60/90]_S$	44205.5047
18	$[75/75/45]_S$	44205.5047
19	$[90/60/30]_S$	44205.5047
20	$[60/60/0]_S$	44205.5047
21	$[30/60/0]_S$	44205.5047

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22	[75/60/60]$_S$	49828.0271
23	[90/60/45]$_S$	49828.0271
24	[75/60/30]$_S$	49828.0271
25	[75/30/30]$_S$	49828.0271
26	[60/30/15]$_S$	49828.0271

TABLE 3 SECTION PROPERTIES

Section properties	L/B ratios
4,000 X 300 X 200 mm	13.334
6,000 X 300 X 200 mm	20
8,000 X 300 X 200 mm	26.667
10,000 X 300 X 200 mm	33.334
12,000 X 300 X 200 mm	40

TABLE 4: VARIATION OF NATURAL FREQUENCY FOR DIFFERENT L/B RATIOS

A_{12}=16092.89

Sl No	Lay-up	ω	L/B ratios				
			13.334	20	26.667	33.334	40
1	[90/75/90]$_S$	2.30	13.2	5.9	3.3	2.1	1.5
2	[15/90/90]$_S$	7.45	20.3	9.2	5.2	3.3	2.3
3	[0/75/90]$_S$	8.24	24.3	11	6.3	4.0	2.8
4	[0/15/90]$_S$	13.4	28.4	13	7.4	4.7	3.3
5	[75/0/0]$_S$	14.2	31.1	14	8.2	5.3	3.7

A_{12}=27337.94

Sl No	Lay-up	ω	L/B ratios				
			13.334	20	26.667	33.334	40
1	[75/75/75]$_S$	1.313	12.65	5.6	3.2	2.04	1.42
2	[90/60/90]$_S$	1.477	13.44	13.5	3.38	2.16	1.5
3	[60/90/0]$_S$	4.832	24.89	24.9	6.33	4.06	2.82
4	[0/30/90]$_S$	6.509	26.32	26.3	6.73	4.32	3.00
5	[60/0//0]$_S$	8.186	31.57	31.6	8.2	5.26	3.66

A_{12}=32960.46

Sl No	Lay-up	ω	L/B ratios	14	8.2	5.3	3.7
			13.334	20	26.667	33.334	40
1	[60/90/75]$_S$	1.219	13.36	5.96	3.36	2.15	1.49
2	[45/90/90]$_S$	1.723	14.27	6.37	3.58	2.29	1.59
3	[90/60/15]$_S$	3.605	21.31	9.56	5.39	3.45	2.40
4	[0/60/75]$_S$	3.974	24.56	11.11	6.28	4.03	2.81
5	[0/45/90]$_S$	4.478	25.35	11.42	6.45	4.13	2.87
6	[0/75/30]$_S$	5.351	26.93	12.16	6.87	4.41	3.06

A_{12}=44205.5

Sl No	Lay-up	ω	L/B ratios				
			13.334	20	26.667	33.334	40
1	[60/60/90]$_S$	1.01	13.2	5.89	3.32	2.12	1.476
2	[75/75/45]$_S$	1.28	14.7	6.58	3.69	2.37	1.651
3	[90/60/30]$_S$	2.02	16.8	7.52	4.28	2.72	1.887
4	[60/60/0]$_S$	3.03	24.3	10.9	6.2	3.97	2.764
5	[30/60/0]$_S$	4.05	26.7	12.1	6.81	4.36	3.036

A_{12}=49828.027

Sl No	Lay-up	ω	L/B ratios				
			13.334	20	26.667	33.334	40
1	[75/60/60]s	0.893	12.91	5.76	3.24	2.07	1.44
2	[90/60/45]s	1.221	14.17	6.32	3.56	2.28	1.58
3	[75/60/30]s	1.789	17.27	7.72	4.35	2.78	1.94
4	[75/30/30]s	2.686	18.05	8.07	4.55	2.92	2.026
5	[60/30/15]s	3.342	22.11	9.92	5.59	3.58	2.5
6	[0/45/30]$_S$	3.911	25.98	11.7	6.59	4.23	2.94

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The variations of orthotropic stiffness parameter with natural frequency for different L/B ratios are more evident from figures given below, fig 2, 3, 4, 5 and 6

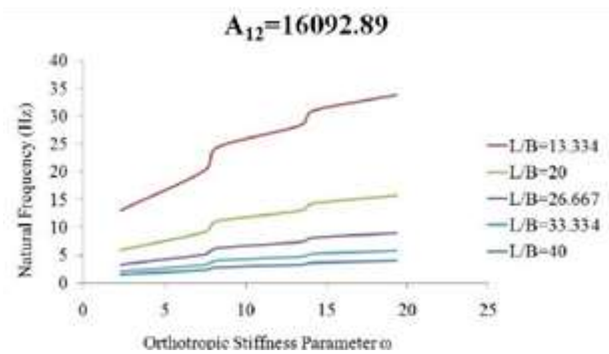

Fig 2 Variation of orthotropic stiffness parameter and natural frequency for A12=16092.89

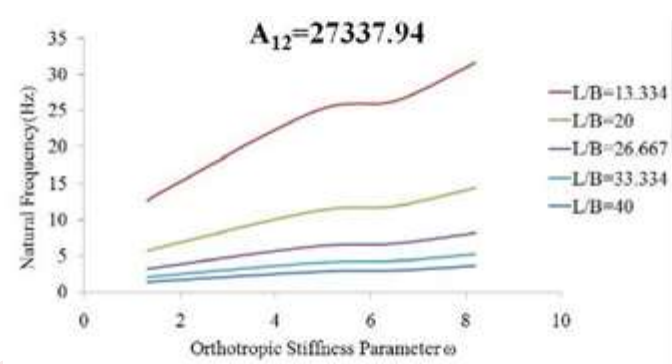

Fig 3 Variation of orthotropic stiffness parameter and natural frequency for A12=27337.94

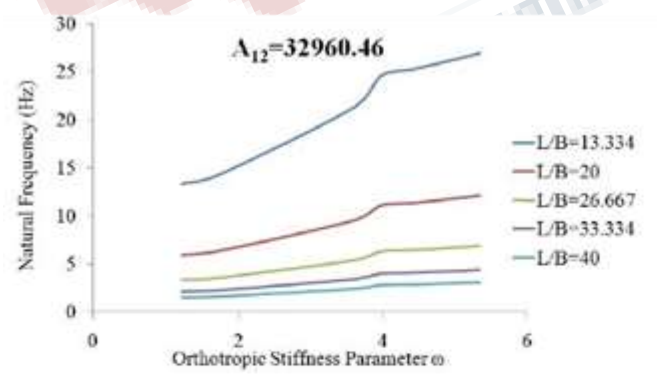

Fig 4 Variation of orthotropic stiffness parameter and natural frequency for A12=32960.96

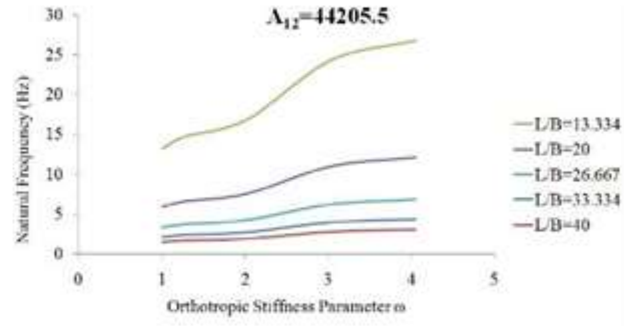

Fig 5 Variation of orthotropic stiffness parameter and natural frequency for A12=44205.5

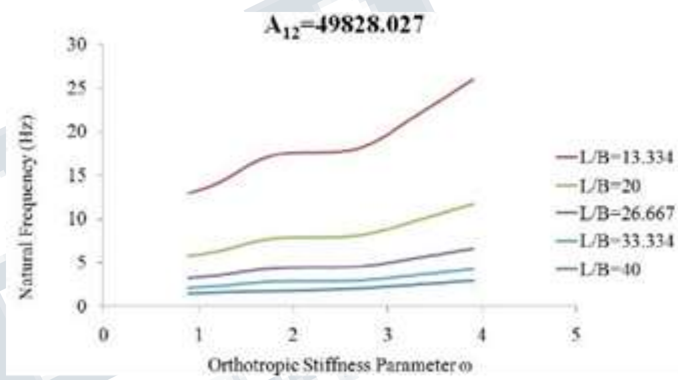

Fig 6 Variation of orthotropic stiffness parameter and natural frequency for A12=49828.027

IV. CONCLUSION

The relevance of orthotropic stiffness parameter as design criteria for laminated composite box sections for reducing free vibration response has been established. As orthotropic stiffness parameter reduces natural frequency reduces, for a constant value of extension stiffness A12. This relation is well evident from the above study for sections having same layup configurations in web and flange. Thus selecting a layup configuration with low orthotropic stiffness helps to reduce natural frequency of the system there by reducing damages due to vibration problems.

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