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Buckling Analysis of Hybrid versus FR Laminate Composite Box Beams

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Abstract— The buckling analysis of thin-walled laminated composite box beams subjected to flexural loading conditions has been studied in this research. Considered box beams are made up of 8 layers of glass fiber reinforced polymer (GFRP) laminate and fiber metal laminate (FML) with different lay ups. The comparative study of buckling behaviour for box sections made with GFRP laminate and FML have been done. Top flange buckling of laminated composite box beams are emphasized in this study. Numerical models were analysed using ANSYS 18.1. Numerical models were prepared with simply supported boundry conditions. The parametric studies are carried out by changing fiber orientation, breadth to depth ratio and length to breadth ratio.

Index Terms— ANSYS, Box beams, Flexural loading, FML, GFRP laminate, Laminated composites, Top flange buckling.

1 Introduction

Composite materials have been in occurrence for centuries, the inclusion of composite technology in to the civil engineering world is over five decades old. Many industries started using composites because of their high strength to weight ratio and resistance to corrosion and weather. Laminated composites are widely used in thin walled structures due to their high specific strength and stiffness.

Composite material such as GFRP is the latest technology which is adequately addresses many structural problems such as premature deterioration of concrete and structural deficiencies**.** FRP's are mainly used in the aerospace, automotive, marine, and construction industries. Specifying the fiber orientation in reinforcing can increase the strength and resistance to deformation of the polymer. FRP is used to strengthen the structural members even after they have been severely damaged due to loading.

Fiber metal laminates are one of the modern hybrid composite materials. FML have excellent mechanical properties such as impact and fatigue resistance, so it is widely used in aerospace industry. FML consists of bonded thin metal sheets and fibers embedded in adhesives. ARALLL, GLARE, CARALL are commercially available most well known fiber metal laminates. GLARE type is widely used in aerospace structures.

Laminated composite box beam sections are mainly preferred in light weight bridges due to their high inherent torsional stiffness and high specific strength. Replacing of composite box beams instead of steel box beams further it reduces self weight of structure.Thin walled structures are more susceptive to buckling. Thus an accurate buckling analysis of the laminated composite structure is a predominant part of the structural design.

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[1] The paper presented some studies on buckling analysis of thin walled laminated box beams. The studies are carried out by number of layers, lay-up sequence and fiber angles for symmetric and anti symmetric lay-ups. [2] Carried out a parametric study on buckling analysis of simply supported laminated composite stiffened panels subjected to in plane shear loading. Data base were prepared for different plate and stiffner combinations. An accurate knowledge of critical buckling load and mode shapes essential for light weight thin walled structures and reliable structural design. [3] The paper studied the buckling and post buckling behaviour of FML column was investigated experimentally and numerically and compares the results. Specimen 3/2 type Z shape FML column subjected to axial compression tested in laboratory and modelled in finite element method and based on Koiters theory examined analytically. Manufacturing process of FML was discussed. [4] Conducted the buckling and postbuckling behaviour of short columns made of FML and GFRP laminate channel section subjected to uniform loading. The comparative study of buckling load, post buckling behaviour, failure loads of columns was developed. The advantages and disadvantages of the type materials used for columns are discussed.

In the literature review has proven that studies involvingbuckling analysis of laminated composite box beam is very limited. There are no papers investigated the way of numerical modelling of buckling analysis of thin walled box beams made of FML. The present study investigates about buckling analysis of symmetrically laminated thin walled composite box beams under flexural loading. The comparative study of buckling behaviour for box beams are made of GFRP laminate and FML with different lay ups. Studies carried out by changing fiber orientation, B/D ratio and L/B ratio.

2 Buckling Behaviour

Thin walled structures are more vulnerable to instability and buckling failure due to their slenderness and mechanical behaviour. The increase in usage of laminated composites in the application of aerospace and civil infrastructure has generatead a special intrest in the analysis of elastic stability of laminated composite structures subjected to in plane loading. In thin-walled laminated composite box beam subjected to compressive force which leads to the top flange buckling of box beams. Local flange buckling is focused in this study. Generally in thin-walled box beams have two types of buckling are possible such as web and flange buckling. Flange buckling is superior buckling mode when web is having better resistance against bending compression and shear. Flange buckling is caused by both primary and secondary stresses. Primary stresses are due to bending and secondary stresses are caused by shear lag, distortion and torsion. The compression flnge of a box beam can be buckled when the bending stress in the flange exceeds the critical stress. One of the major failure mechanisms in thin walled laminated structure is buckling. Thus an accurate knowledge of buckling analysis of the laminated composite structure is an important part of structural design.

3 Numerical Studies

3.1 Object of Analysis

Fiber metal laminate and GFRP laminates are used for laminated composite box beams. FML is made of 8 layers of laminate composed of aluminium alloy 2024 T3 and R-glass fiber reinforced epoxy resin and second 8 layers of GFRP laminate. All elements are symmetric laminate. The material properties of FML used for modelling is specified in Table 1. Considered box beams length is varies from 1500 to 4000 mm, breadth and depth is varies from 150 to 400 mm.

In FML type, the laminates are composed in 4 layers of metal and 2 double layers of FRP. The thickness of each aluminium layer and one FRP layer is 0.25 mm. FML and GFRP thickness is equal to 2 mm (thicknees of flange=thickness of web=2 mm). Depending on fibers alignment 3 various lay-up configurations of FML have been considered.

- A/0/0/A/A/0/0/A
- A/90/90/A/A/90/90/A
- A/45/-45/A/A/45/-45/A

Where A denotes the aluminium layer and specific numbers on composite plies denotes the fiber alignment. In case of GFRP laminate 3 various lay-ups have been considered.

- (0/0/0/0)s
- (90/90/90/90)s
- (45/-45/45/-45)s

In all these cases, top flange buckling is considered and the fiber orientations 0^0, ± 45^0 and 90^0 are considered to cover extreme cases of orthotropy.

3.2 Numerical Model

Numerical analysis was conducted using ANSYS 18.1 software (APDL). Top flange buckling of box sections takes place at mid span due to compression loading. Loading configuration of box beam is mid point load of 1 kN. Shell 181 a four node multi layered laminated shell element was used to model the various elements of box beams. Shell 181 is four node element with six degrees of freedom at each node is suitable for for thin to moderate thick shell structures. A 3D finite element model of laminated composite box beam is developed in ANSYS is shown in Fig. 1.

The numerical models were prepared with simply supported boundary conditions. The material properties for FRP layers are linearly elastic orthotropic and the bilinear elastic model with kinematic hardening for aluminium layers. Top flange buckling of box sections takes place at mid span due to compression loading. Eigen buckling analysis has been performed to determine the buckling load with corresponding buckling mode in ANSYS 18.1 by changing fiber orientation, length to breadth and breadth to depth ratio (Mode=1). Buckling load factor is multiplied by intensity of loading to get the buckling load.

TABLE 1
SELECTED MECHANICAL PROPERTIES FOR LAYERS OF FML

Parameters	R-Glass epoxy resin	Aluminium 2024 T3
Young modulus	$E_1 = 46.6$ GPa	$E = 72$ GPa
	$E_2 = 14.9$ GPa	
Poisson ratio	$\mu_{12} = 0.27$	$\mu = 0.3$
Modulus of rigidity	$G_{12} = 5.2$ GPa	-
Yield strength	-	$R_e = 359$ MPa
Tangent modulus	-	$E_t = 600$ MPa

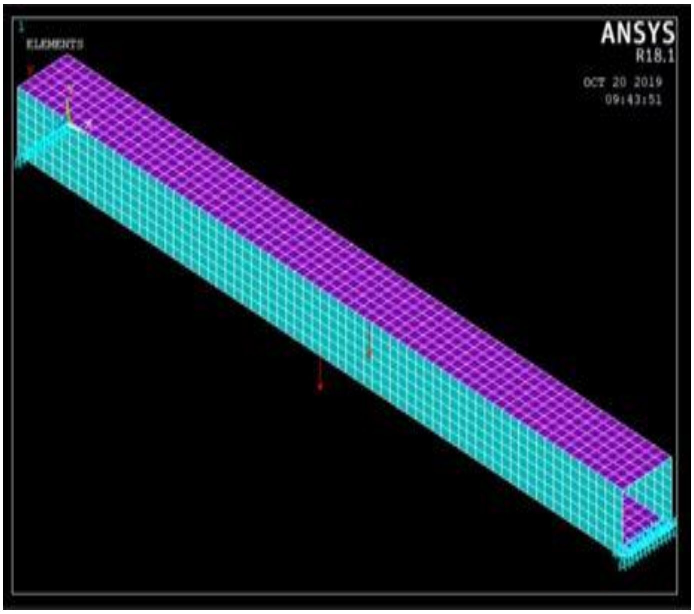

Fig. 1. 3D finite element model of laminated composite box beam

4 Parametric Studies

4.1 Effect of Fiber Orientation

Numerical studies are carried out for FML with different fiber orientations (A/0/0/A)s, (A/90/90/A)s, (A/45/-45/A)s and for GFRP laminate lay-ups are (0/0/0/0/)s, (90/90/90/90), (45/-45/45/-45)s. Thickness of web and flange is equal to 2 mm. Many models have been generated and Eigen buckling analysis is performed using ANSYS software. Table 2 – 5 shows how the fiber orientation influences the buckling of laminated composite box beam models.

TABLE 2
Buckling Load Factor of Box Beam Section having B=250, D=200, L=2500

Fiber orientation (degree)	Buckling load factor
(0/0/0/0)s	2.3821
(90/90/90/90)s	2.2601
(45/-45/45/-45)s	2.5827
(A/0/0/A)s	6.0217
(A/90/90/A)s	5.7988
(A/45/-45/A)s	5.7989

TABLE 3
Buckling Load Factor of Box Beam Section having B=350, D=250, L=3500

Fiber orientation (degree)	Buckling load factor
(0/0/0/0)s	1.5624
(90/90/90/90)s	1.4172
(45/-45/45/-45)s	1.6164
(A/0/0/A)s	3.7651
(A/90/90/A)s	3.6307
(A/45/-45/A)s	3.6299

TABLE 4
Buckling Load Factor of Box Beam Section having B=300, D=200, L=2000

Fiber orientation (degree)	Buckling load factor
(0/0/0/0)s	2.5035
(90/90/90/90)s	2.5262
(45/-45/45/-45)s	2.7784
(A/0/0/A)s	6.4069
(A/90/90/A)s	6.3923
(A/45/-45/A)s	6.4655

TABLE 5
Buckling Load Factor of Box Beam Section having B=350, D=400, L=3500

Fiber orientation (degree)	Buckling load factor
(0/0/0/0)s	1.8326
(90/90/90/90)s	2.3454
(45/-45/45/-45)s	2.7226
(A/0/0/A)s	5.3323
(A/90/90/A)s	5.5855
(A/45/-45/A)s	5.6307

From this study it is found that buckling load factor is found to be maximum when fiber orientation is (A/0/0/A)s for FML. Some cases (A/45/-45/A)s has highest buckling load when L/D ratio ≤ 10 and B/D ratio ≥ 0.75. In case of GFRP, buckling load is maximum when fiber orientation is (45/-45/45/-45)s.

4.2 Effect of Length to Breadth Ratio

Numerical studies are carried out by keeping B/D ratio, tf=tw was constant values and by changing L/B ratio buckling load factor of models are calculated. Thickness of flange and webs are 2 mm. Fiber orientations for FML and GFRP 0^0, 90^0, ± 45^0 are considered. Fig. 2 – 4 graphically represented the effect of L/B ratio in buckling load factor of these models.

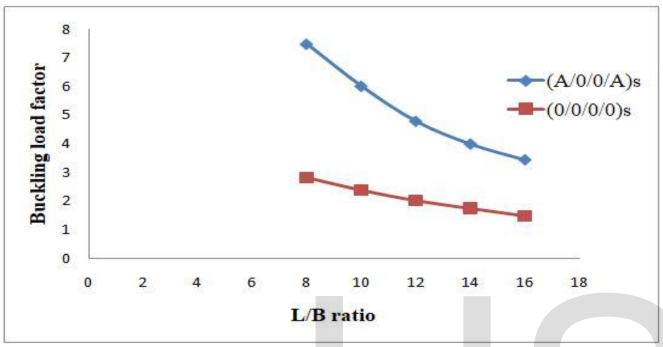

Fig. 2. Buckling load factor by changing L/B ratio for box beam having B=250, D=200 and fiber orientation (0/0/0/0)s, (A/0/0/A)s.

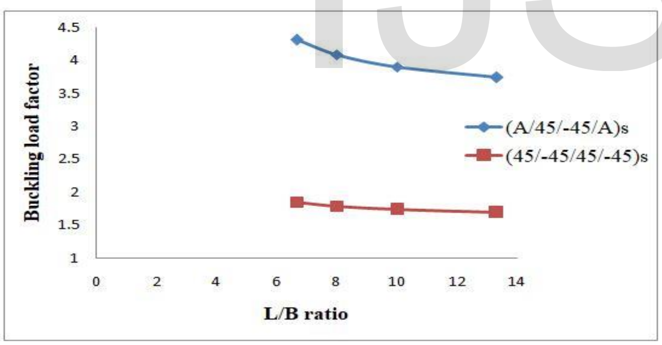

Fig. 3. Buckling load factor by changing L/B ratio for box beam having B/D=1.5,L=3000 mm and fiber orientation (45/-45/45/-45)s,(A/45/-45/A)s

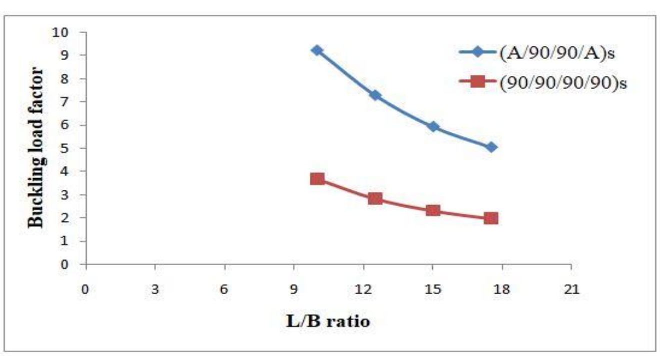

Fig. 4. Buckling load factor by changing L/B ratio for box beam having B=200, D=200 mm and fiber orientation (90/90/90/90)s and (A/90/90/A)s

From this study it can be observed that the buckling load factor decreases with increase in L/B ratio for FML and GFRP laminates.

4.3 Effect of Breadth to Depth Ratio

Numerical studies are carried out by keeping L/B ratio, tf=tw was constant values and by changing B/D ratio buckling load factor of models are calculated. Thickness of flange and webs are 2 mm. Fiber orientations for FML and GFRP 0^0, 90^0, ± 45^0 are considered. Fig. 5 – 7 graphically represented the effect of B/D ratio in buckling load factor of these models.

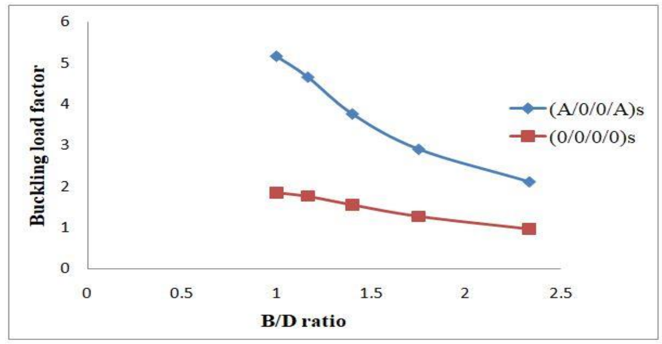

Fig. 5. Buckling load factor by changing B/D ratio for box beam having B=350, L=3500 mm and fiber orientation (0/0/0/0)s, (A/0/0/A)s

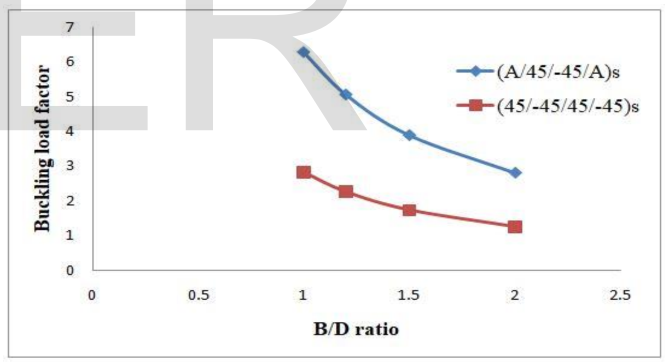

Fig. 6. Buckling load factor by changing B/D ratio for box beam having B=300, L=3000 mm and fiber orientation (45/-45/45/-45)s, (A/45/-45/A)s

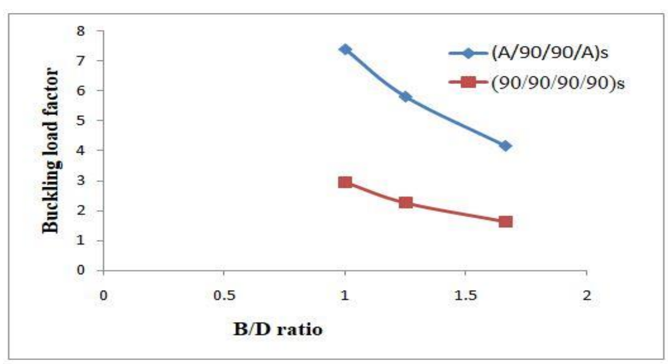

Fig. 7. Buckling load factor by changing B/D ratio for box beam having B=250, L=2500 mm and fiber orientation (90/90/90/90)s and (A/90/90/A)s

From this study it can be observed that the buckling load factor decreases with increase in B/D ratio for FML and GFRP laminates.

4 Conclusion

Buckling strength of laminated composite box sections have analysed by ANSYS 18. Top flange buckling of thin walled box sections are observed under static loading. Buckling load is an important parameter in the analysis of thin walled laminated composite box beams as they are very slender sections. Based on the parametric study the following conclusions are obtained:

- In case of fiber orientation, FML lay up (A/0/0/A)s has highest buckling strength. Some cases (A/45/-45/A)s has maximum buckling strength. When L/D ratio ≤ 10 and B/D ratio ≥ 0.75. GFRP lay-up (45/-45/45/-45)s has highest buckling strength.
- The buckling loads of fiber metal laminates are 2 times higher than for GFRP laminated box sections.
- When we consider the L/B ratio in a box section, buckling strength decreases with increase in L/B ratio for both FML and GFRP laminate.
- When we consider the B/D ratio in a box section, buckling strength decreases with increase in B/D ratio for both FML and GFRP laminate.

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