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Technical Note

Validity of simplified analysis for the stability of laminated composite stiffened panels subjected to in-plane shear

Upendra K. Mallela† and Akhil Upadhyay‡

Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, India

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1. Introduction

Stiffened panel is an appropriate structural form to utilize the advantages of laminated composites efficiently. The mounting use of laminated composite stiffened panels in various structural applications demands better understanding of the buckling behaviour. To understand the buckling behaviour of laminated composite stiffened panels, researchers are using numerical approaches like finite strip method (Loughlan 1994) and finite element analysis (FEA) (Mallela and Upadhyay 2006). These numerical methods are computationally expensive from design point of view. Especially in optimum design applications, the analysis have to be repeated a number of times. No design aids are available and intuitions will not work, so, automation is needed. Due to computational efficiency of smeared stiffener approach (SSA), Upadhyay and Kalyanaraman (2000) could develop GA based optimization procedure for composite stiffened panels. Stroud *et al.* (1984) reported deviation in results between SSA and FEA for shear loaded panels. However, the trends of error and the parameters affecting the error in the simplified analysis are not available and there is a need to assess its accuracy so that it can be used in optimum procedures with confidence.

2. Studies on stiffened panels

This study is carried out to identify the range of application of simplified analysis for predicting the shear-buckling load and to find the parameters influencing the error. Expressions for the smeared orthotropic stiffness are available in literature. The FE modeling approach (using ANSYS) is validated for a blade-stiffened panel (a/b = 1) with the results reported by Stroud *et al.* (1984) and good match was observed. Numerical studies on simply supported laminated composite blade stiffened panels with a/b ratio 5 (having dimensions 3810 mm × 762 mm) are carried out for different orthotropy ratios (ranging from 13 to 165) by changing the number of stiffeners and depth of the stiffeners in a given width of the panel. The panels are made of graphite-epoxy having E_1 = 131 kN/

† Research Scholar
‡ Associate Professor, Corresponding author, E-mail: akhilfce@iitr.ernet.in

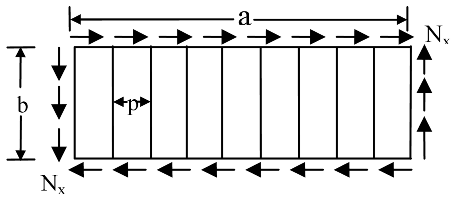


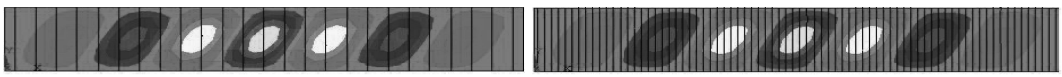
Fig. 1 Shear loaded stiffened panel

mm^2, E_2 = 13 kN/mm^2, G_{12} = 6.41 kN/mm^2, ν_{12} = 0.38. The laminate configuration for the plate is (45@h/-45@h/-45@h/45@h/0@h/90@9h)$_s$ and the stiffener is (45@h/-45@h/-45@h/45@h/0@2h)$_s$ where h is 0.1397 mm. Numbers of iterations were made on trial and error basis for fixing the depth of the stiffener to maintain the same orthotropy ratio even when the pitch of the stiffeners is changed and the same is used in the FE modeling. Buckling loads of 80 stiffened panels (Mallela and Upadhyay 2006) analyzed using FEA, are compared with the buckling loads obtained by the SSA.

2.1 Behaviour of laminated composite stiffened panels

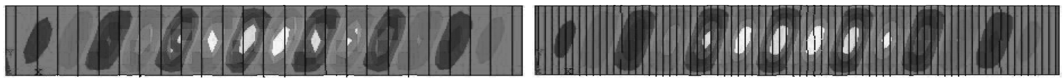
Figs. 2 and 3 show the contour plots of the buckled mode shapes for different D_1/D_2 ratios and pitch lengths. For a given D_1/D_2 ratio, corresponding to considerable change in pitch length, the variation in the half sine wave length is less.

Table 1 shows that for a given D_1/D_2 ratio, reduction in pitch length improves local buckling as well as interaction between local and global buckling and hence the buckling load improves. However, from Figs. 2 and 3 it can be seen that the half sine wave length associated mostly with global buckling modes does not alter much. Hence, reduction in pitch of stiffeners does enhance the buckling load but corresponding change in length of half sine waves is insignificant, indicating that half sine wave length is mainly a function of D_1/D_2 ratio. From the contour plots it can also be observed that for a given pitch length, as D_1/D_2 ratio increases, the number of half sine waves also increases. Smeared stiffener solution gives reasonable results for global buckling modes not affected by local buckling and subsequent interaction between local and global buckling. Local buckling can be controlled by providing more number of stiffeners for a given D_1/D_2 ratio.



(a) Pitch length = 152.4 (b) Pitch length = 50.13

Fig. 2 Contour plots of buckled mode shapes for D_1/D_2 = 13



(a) Pitch length = 152.4 (b) Pitch length = 50.13

Fig. 3 Contour plots of buckled mode shapes for D_1/D_2 = 100

2.2 Factors affecting the error

Fig. 4 shows the effect of orthotropy ratio and pitch length on percentage error. For a particular pitch length, as D_1/D_2 increases the percentage error increases. Further, for a given skin, at lower $D_1/$

D_2 the error remains unchanged even when the pitch length of the stiffeners is reduced, but as D_1/D_2 increases the error increases significantly, when the pitch length of the stiffeners is increased. Hence smeared stiffener solution is deviating more from the FEA results when the pitch length is more.

From the Table 1 it is observed that for a given D_1/D_2, with the increase in $(EA)_s/(EA)_p$ by increasing the number of stiffeners, the percentage error between the two approaches reduces in global buckling zone. For different D_1/D_2 ratios, the error is un-conservative when global buckling takes place and the error is conservative but sometimes un-conservative, when local buckling takes place as predicted by SSA. It can also be seen that for the same pitch length and the same skin configuration, with the increase in the depth of the stiffener, the un-conservative percentage error increases in the global buckling zone and the conservative error increases in the local buckling zone. This may be because smeared stiffener solution does not take into account the rotational restraint provided by the stiffeners with the increase in the depth of the stiffener. Near transition zone (i.e., when the mode of buckling changes from local to global) as per SSA, un-conservative errors in all the cases is maximum. Therefore, in global buckling zone it is better to remain away from transition zone to minimize the error. Further, at locations away from the transition zone, mode of buckling predicted by both the methods is the same in most of the cases.

For a given D_1/D_2, $(EA)_s/(EA)_p$ may be varied by changing the spacing or depth of stiffener. If we prefer to decrease the spacing to increase $(EA)_s/(EA)_p$ the error reduces. Hence, from the above discussion it can be observed that as the number of stiffeners in one-half sine wave is increased, the error between the two approaches reduces.

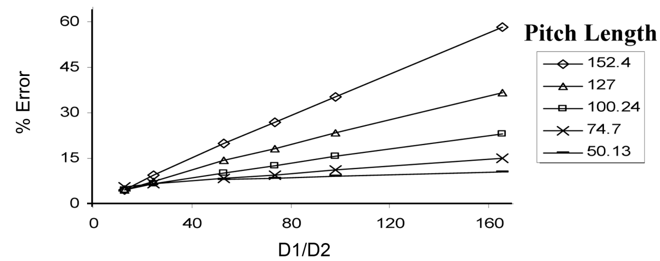


Fig. 4 Effect of orthotropy ratio and pitch length on percentage error

Table 1 Comparison of buckling load by the two approaches

D_1/D_2	Stiffener depth (mm)	Pitch length (mm)	$\frac{(EA)_s}{(EA)_p}$	$N_{xy,\,crit}$ (N/mm) FEA[a] (a)	SSA[b] (b)	% Error $\left(\frac{b-a}{a}\right)\times 100$	Buckling mode FEA[a]	SSA[b]
13	29.49	423.33	0.0599	63.68	79.91	25.49	G[c]	L[d]
	28.44	381.00	0.0642	68.12	92.62	35.96	G[c]	G[c]
	26.70	317.50	0.0724	76.99	92.85	20.60	G[c]	G[c]
	24.73	254.00	0.0838	83.59	93.17	11.46	G[c]	G[c]
	22.39	190.50	0.1011	88.12	93.66	6.28	G[c]	G[c]
	20.74	152.40	0.1171	89.87	94.09	4.70	G[c]	G[c]
	19.48	127.00	0.1320	90.53	94.51	4.39	G[c]	G[c]
	17.96	100.26	0.1541	90.85	95.10	4.68	G[c]	G[c]
	16.24	74.70	0.1871	90.83	95.98	5.67	G[c]	G[c]
	14.19	50.13	0.2435	90.51	97.44	7.65	G[c]	G[c]

Table 1 Continued

D_1/D_2	Stiffener depth (mm)	Pitch length (mm)	$\frac{(EA)_s}{(EA)_p}$	$N_{xy,\,crit}$ (N/mm) FEA[a] (a)	SSA[b] (b)	% Error $\left(\frac{b-a}{a}\right) \times 100$	Buckling mode FEA[a]	SSA[b]
53	50.73	423.33	0.1031	99.01	79.91	-19.29	L[d]	L[d]
	49.00	381.00	0.1107	103.43	98.65	-4.62	G[c]	L[d]
	46.16	317.50	0.1251	115.40	142.06	23.09	G[c]	L[d]
	42.92	254.00	0.1454	143.15	221.96	55.06	G[c]	L[d]
	39.10	190.50	0.1766	194.22	258.98	33.34	G[c]	G[c]
	36.40	152.40	0.2055	217.96	261.24	19.85	G[c]	G[c]
	34.34	127.00	0.2327	230.57	263.24	14.17	G[c]	G[c]
	31.87	100.26	0.2735	241.53	266.16	10.20	G[c]	G[c]
	29.08	74.70	0.3350	249.34	270.39	8.44	G[c]	G[c]
	25.76	50.13	0.4421	256.87	277.21	7.92	G[c]	G[c]
100	63.06	423.33	0.1282	118.65	79.91	-32.65	L[d]	L[d]
	60.95	381.00	0.1376	125.19	98.65	-21.20	L[d]	L[d]
	57.47	317.50	0.1558	139.33	142.06	1.96	L[d]	L[d]
	53.52	254.00	0.1813	167.88	221.96	32.22	G[c]	L[d]
	48.87	190.50	0.2207	243.51	394.60	62.05	G[c]	L[d]
	45.58	152.40	0.2573	302.91	409.41	35.16	G[c]	G[c]
	43.08	127.00	0.2919	334.37	413.17	23.57	G[c]	G[c]
	40.08	100.26	0.3440	361.76	418.61	15.72	G[c]	G[c]
	36.69	74.70	0.4226	382.96	426.32	11.32	G[c]	G[c]
	32.65	50.13	0.5605	402.34	438.48	8.98	G[c]	G[c]

[a]Finite element analysis; [b]Smeared stiffener approach; [c]Global buckling; [d]Local buckling.

3. Conclusions

Number of stiffeners is an important parameter, which affects the accuracy of SSA for the determination of the buckling load of the stiffened panels subjected to in-plane shear. Maximum error occurs near the transition zone. In global buckling zone increase in $(EA)_s/(EA)_p$ by reducing spacing of stiffener decreases the deviation in results between SSA and FEA considerably at higher orthotopy ratios.

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