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Dynamic stability of Woven Fiber Laminated Composite Curved Plates in Adverse Hygrothermal Environment

M.K.RATH

Abstract

Structural components subjected to in plane periodic loads may undergo instability due to certain combinations of natural frequency and in plane load parameters which is called parametric resonance. Composite structural components are often subjected to various environmental loads during their service life. The presence of temperature and moisture concentration may significantly reduce the stiffness and strength of the structures and may affect some design parameter such as vibration and instability characteristics of the structures. Therefore the parametric resonance behaviour of laminated composite curved panels subjected to adverse hygrothermal environment are studied in the present investigation

Keywords: Dynamic Stability; Excitationfrequency; Excitationfrequency;Hygrothermalenvironment; Dynamic load factor; Instability regions, Parametric resonance

Author correspondence:

M.K.RATH
Department of Civil Engineering
Centurion University of Technology Bhubaneswar

1. Introduction

Composite materials are being increasingly used in aerospace, civil, naval and other high-performance engineering applications due to their light weight, high specific strength, stiffness, excellent thermal characteristics, ease in fabrication and other significant attributes. Structures used in the above fields are more often exposed to high temperature as well as moisture. The varying environmental conditions due to moisture absorption and temperature seem to have an adverse effect on the stiffness and strength of the structural composites. This wide range of practical applications demands a fundamental understanding of their vibrations, static and dynamic stability characteristics under hygrothermal conditions.

Studies on vibration and buckling of composite panels subjected to hygrothermal loads are available in literature and reviewed by [1] through 1991. The effects of hygrothermal conditions on the free vibration of laminated panels was considered earlier by [2] using the Ritz method based on the classical laminated plate theory. [3] and [4] presented the effects of moisture and temperature on the linear free vibration of laminated composite plates using first order and higher order shear deformation theories respectively. The vibration response of flat and curved panels subjected to thermal and mechanical loads are presented by Librescu and Lin [5],[6] investigated the effect of moisture and temperature on the dynamic behaviour of composite laminated plates and shells with or without delaminations. The dynamic analysis of laminated cross-ply composite non-circular thick cylindrical shells subjected to thermal/mechanical load is carried out based on higher-order theory was studied by [7], [8] Investigated the large deformation behaviour of anti-symmetric angle-ply curved panels under non-uniform temperature loading. A geometrically nonlinear analysis of linear viscoelastic laminated composite systems subjected to mechanical and hygrothermal load was presented by Marques and [9] considering three-dimensional degenerated shell element. The nonlinear free vibration behaviour of laminated composite shells subjected to hygrothermal environment was investigated by [10]. The geometrically non-linear vibrations of linear elastic composite laminated shallow shells under the simultaneous action of thermal fields and mechanical excitations are analysed by [11]. The vibration characteristics of pre- and post-buckled hygro-thermo-elastic laminated composite doubly curved shells was investigated by Kundu and [12], [13] studied the nonlinear free vibration behaviour of single/doubly curved shell panel was addressed within the post-buckled state where thermal post-buckling of shell panel was accounted for a uniform temperature field.

The finite element method was applied to study the problem of moisture and temperature effects on the stability of a general orthotropic cylindricalcompositeshell panels subjected to axial or in-plane shear loading by [14]. The effect of hygrothermal conditions on the post buckling of shear deformable laminated cylindrical shells subjected to combined loading of axial compression and external pressure was investigated using micro-to-macro mechanical analytical model by [15]. The hygrothermoelastic buckling behaviour of laminated composite shells were numerically simulated using geometrically nonlinear finite element method was studied by [16]. The effect of random system properties on the post buckling load of geometrically nonlinear laminated composite cylindrical shell panel subjected to hygro-thermo-mechanical loading is investigated by [17]

2. Research Method

2.1 Mathematical Formulation

The mathematical formulation for parametric instability behavior of laminated composite plates subjected to moisture and temperature are presented. Consider a laminated plate of uniform thickness ‘t’ consisting of a number of thin laminae, each of which may be arbitrarily oriented at an angle ‘θ’ with reference to the X-axis of the co-ordinate system as shown in Figures 1 and 2.

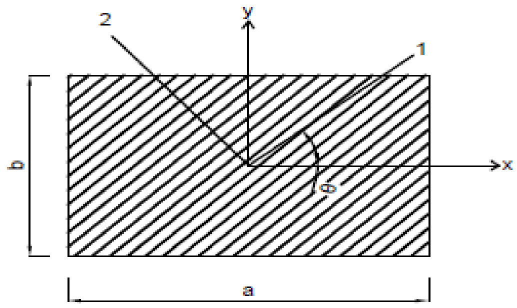

Fig. 1 Arbitrarily oriented laminated plate

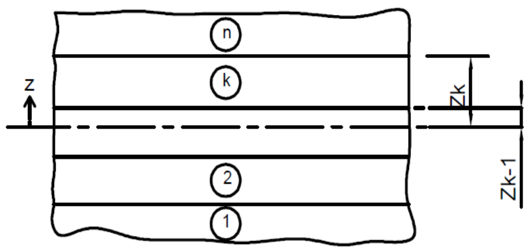

Fig. 2 Geometry of an n- layered laminate

2.2Governing Equations

The governing differential equations for vibration of a shear deformable laminated composite plates and shells in general are specified here but the scope of the analysis is for composite plates. The behavior of laminated composite plates in hygrothermal environment derived on the basis of first order shear deformation theory (FSDT) subjected to in-plane loads are;

$$\frac{\partial N_x}{\partial x}+\frac{\partial N_{xy}}{\partial y}-\frac{1}{2}\left(\frac{1}{R_y}-\frac{1}{R_x}\right)\frac{\partial M_{xy}}{\partial y}+\frac{Q_x}{R_x}+\frac{Q_y}{R_{xy}}=P_1\frac{\partial^2 u}{\partial t^2}+P_2\frac{\partial^2\theta_x}{\partial t^2}$$

$$\frac{\partial N_{xy}}{\partial x}+\frac{\partial N_{y}}{\partial y}+\frac{1}{2}\left(\frac{1}{R_{y}}-\frac{1}{R_{x}}\right)\frac{\partial M_{xy}}{\partial x}+\frac{Q_{y}}{R_{y}}+\frac{Q_{x}}{R_{xy}}=P_{1}\frac{\partial^{2} v}{\partial t^{2}}+P_{2}\frac{\partial^{2}\theta_{y}}{\partial t^{2}} \quad (1)$$

$$\frac{\partial Q_{x}}{\partial x}+\frac{\partial Q_{y}}{\partial y}-\frac{N_{x}}{R_{x}}-\frac{N_{y}}{R_{y}}-2\frac{N_{xy}}{R_{xy}}+N_{x}^{a}\frac{\partial^{2} w}{\partial x^{2}}+N_{y}^{a}\frac{\partial^{2} w}{\partial y^{2}}+N^{a}{}_{xy}\frac{\partial^{2} w}{\partial x\partial y}=P_{1}\frac{\partial^{2} w}{\partial t^{2}}$$

$$\frac{\partial M_{x}}{\partial x}+\frac{\partial M_{xy}}{\partial y}-Q_{x}=P_{3}\frac{\partial^{2}\theta_{x}}{\partial t^{2}}+P_{2}\frac{\partial^{2} u}{\partial t^{2}}$$

$$\frac{\partial M_{xy}}{\partial x}+\frac{\partial M_{y}}{\partial y}-Q_{y}=P_{3}\frac{\partial^{2}\theta_{y}}{\partial t^{2}}+P_{2}\frac{\partial^{2} v}{\partial t^{2}}$$

Where N_x, $N_y$and N_{xy} are the in-plane stress resultants, M_x, M_y and M_{xy} are moment resultants and Q_x, Q_y= transverse shear stress resultants. R_x, R_y and R_{xy} identify the radii of curvatures in the x and y direction and radius of twist.

$$(P_{1},P_{2},P_{3})=\sum_{k=1}^{n}\int_{z_{k-1}}^{z_{k}}(\rho)_{k}(1,z,z^{2})dz \quad (2)$$

Where n= number of layers of laminated composite twisted curved panel, $(\rho)_k$= mass density of k_{th}layer from mid-plane.

$N(t)$

2.3 Dynamic stability studies

The equation of motion for vibration of a laminated composite panel in hygrothermal environment, subjected to generalized in-plane load. $N(t)$ May be expressed in the matrix form as:

$$[M]\{\ddot{q}\}+[[K_{e}]-N(t)[K_{g}]]\{q\}=0 \quad (3)$$

'q' is the vector of degrees of freedoms (u, v, w, θ_x, θ_y). The in-plane load 'N (t)' may be harmonic and can be expressed in the form:

$$N(t)=N_{s}+N_{t}Cos\Omega t \quad (4)$$

Where N_s the static portion of load N (t), N_t the amplitude of the dynamic portion of N (t) and Ω is the frequency of the excitation. The stress distribution in the panel may be periodic. Considering the static and dynamic component of load as a function of the critical load,

$$N_{s}=\alpha N_{cr}\ ,\ \ N_{t}=\beta N_{cr} \quad (5)$$

Where α and β are the static and dynamic load factors respectively. Using Eq. (5), the equation of motion for panel in hygrothermal environment under periodic loads in matrix form may be obtained as:

$$[M]\{\ddot{q}\}+[[K_{e}]-\alpha N_{cr}[K_{g}]-\beta N_{cr}[K_{g}]Cos\Omega t]\{q\}=0 \quad (6)$$

The above Eq. (6) represents a system of differential equations with periodic coefficients of the Mathieu-Hill type. The development of regions of instability arises from Floquet's theory which establishes the existence of periodic solutions of periods T and 2T. The boundaries of the primary instability regions with period 2T, where T=2 π/Ω are of practical importance and the solution can be achieved in the form of the trigonometric series:

$$q(t) = \sum_{k=1,3,5,..}^{\infty}[\{a_k\}Sin(k\Omega t/2) + \{b_k\}Cos(k\Omega t/2)] \quad (7)$$

Putting this in Eq. (6) and if only first term of the series is considered, equating coefficients of Sin Ωt/2 and Cos Ωt/2, the equation (6) reduces to

$$[[K_e] - \alpha P_{cr}[K_g] \pm \frac{1}{2}\beta P_{cr}[K_g] - \frac{\Omega^2}{4}[M]]\{q\} = 0 \quad (8)$$

Eq. (8) represents an eigenvalue problem for known values ofα, β and P_{cr} . The two conditions under the plus and minus sign correspond to two boundaries (upper and lower) of the dynamic instability region. The above eigenvalue solution give of Ω, which give the boundary frequencies of the instability regions for the given values of αandβ. In this analysis, the computed static buckling load of the panel is considered as the reference load. Before solving the above equations, the stiffness matrix [K] is modified through imposition of boundary conditions.

3. Results and Analysis

To validate the formulation, the frequencies of vibration of composite plates are computed and compared with previously published results from literature.

Table 1 Comparison of non-dimensional free vibration frequencies for SSSS (0/90/90/0) Plates at 325K temperature a/b=1, a/t=100, At T = 300*K*, E_1= 130Gpa , E_2= 9.5Gpa, G_{12}=6Gpa , G_{13}=G_{12}, G_{23}=0.5G_{12}, ν_{12}=0.3, α_1=-0.3 X 10^{-6}/^{O}K, α_2 =28.1 X 10^{-6}/^{O}K

Non dimensional frequency, $\lambda = \omega_n a^2 \sqrt{\rho / E_2} t^2$

Non- dimensional frequencies at 325K Temperature			
Mode number	Shen, Zheng and Huang [15]	Sairam&Sinha [14]	Present FEM
1	7.702	8.088	8.079
2	17.658	19.196	19.100
3	38.312	39.324	39.335
4	44.038	45.431	45.350

The structural instability may lead to large deflection or large amplitude vibrations of structural elements leading to local or global failures. So the analysis is focused on the determination of the primary instability region of laminated composite plates under hygrothermal loads. The width of primary instability region frequencies is the separation of the boundaries of the primary instability region for the given plate. This can be used as an instability measure to study the influence of the other parameters. This is the most dangerous zone and has the greatest practical importance. The primary instability region that occurs in the vicinity of 2ω (α= β=0) and the upper and lower excitation frequencies of the plates decrease with the increase of the static load parameter. The woven fiber composite plates subjected to hygrothermal conditions are considered here to study the effect of different parameters on the excitation frequency of specimens. The effect of increase in number of layers with thickness of the composite plates on the non-dimensional excitation frequency is illustrated in figure 3 and figure 4 for composites at temperatures 300K and 400K respectively. As observed, the onset of instability of laminated composite plates occurs later with narrow instability regions with increase in number of layers due to higher stiffness for both cases. Comparing the figure 3 and Figure 4, it is observed that for same number of layers, the onset of instability occurs earlier with increase of temperature from 300K to 400K.Woven fiber laminated plates is more stable with increase in number of layers under periodic loads due to bending stretching coupling. However, the effect of number of layers is more significant for the composite plates at 400K than that for 300K.

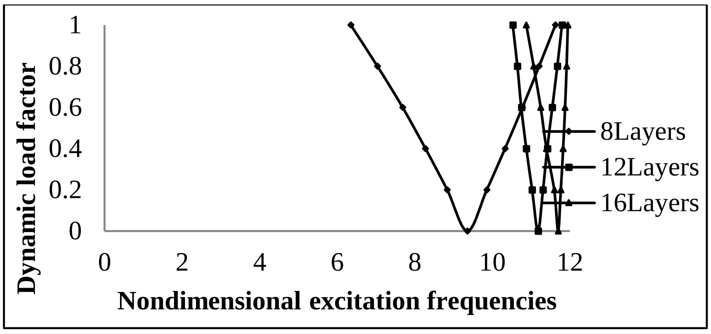

Fig 3 Variation of instability regions with temperature at 300K for simply supported (s-s-s-s) of a/b=1, α= 0.2, woven fiber Laminated composite plates.

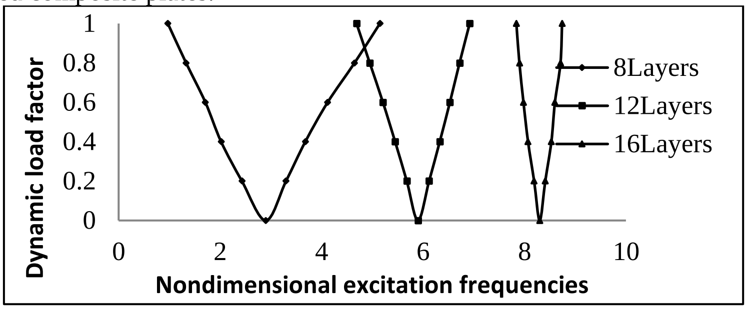

Fig 4 Variation of instability regions with temperature at 400K for simply supported (s-s-s-s) of a/b=1, α= 0.2, woven fiber Laminated composite plates

3.1 Effect of static load factor on instability regions of uniformly loaded symmetric curved panels

The effect of static component of load for α= 0.0, 0.2, 0.4, 0.6 and 0.8 on the instability region of laminated composite panel subjected to elevated temperature 325K is shown in fig.2. Due to increase of static component, the instability regions tend to shift to lower frequencies and become wider. With increase in static load factor from 0 to 0.8, the excitation frequency is reducing by 2.3%. All further studies are made with a static load factor of 0.2 (unless otherwise mentioned)

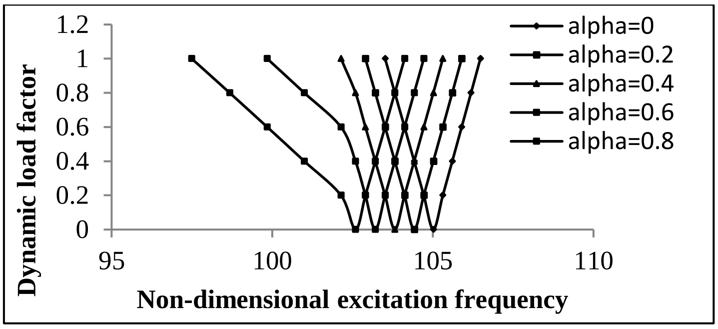

Fig 5: Variations of instability region with static load factor of composite symmetric laminated shell subjected to elevated temperature (Temp=325K, a/b=1, Ry/b=Rx/b=5, b/t=100)

The variation of excitation frequency with dynamic load factor of composite laminated simply-supported anti-symmetric angle-ply square shells subjected to uniform distribution of temperature from 300K, 325K, 350K, 375K & 400K is shown in fig.5. As shown, the onset of instability occurs earlier with wider DIR for anti-symmetric angle-ply laminated composite shells subjected to elevated temperature compared to composite shells with normal temperature. With increase in temperature from 300K to 350K, the excitation frequency is reducing by 65.2%.

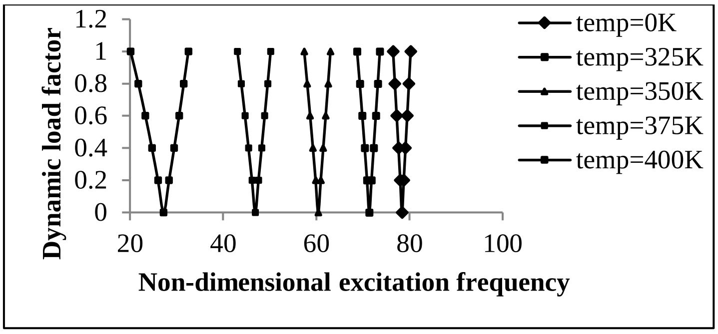

Fig 6: Variations of instability region with temperature of composite laminated anti-symmetric angle-ply (45/-45/45/-45) curved panel (a/b=1, b/t=100, Ry/b=5)

The variation of excitation frequency with dynamic load factor of composite laminated simply-supported anti-symmetric angle-ply shell subjected to uniform distribution of moisture concentration from 0%, 0.1%, 0.25% & 0.5% is shown in fig.7. It is revealed that the onset of instability occurs earlier with wider DIR for anti-symmetric angle-ply laminated composite shells subjected to elevated moisture condition compared to composite shells with normal moisture concentration. When moisture concentration is increased from 0% to 0.25% then excitation frequency reduces for about 49.3%.

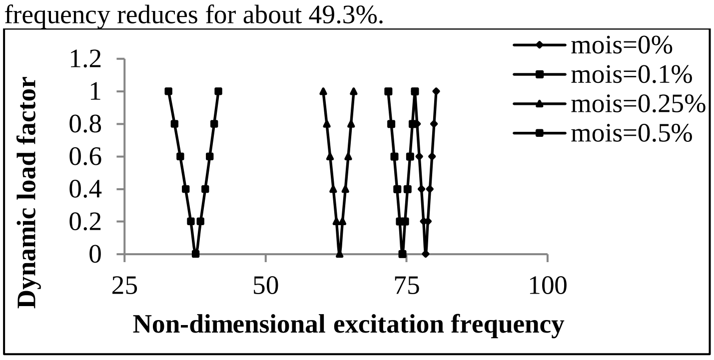

Fig 7: Variations of instability region with moisture of composite laminated anti-symmetric angle-ply (45/-45/45/-45) shell (Ry/b=5, a/b=1, b/t=100)

3.2 Effect of shallowness ratio

The variation of excitation frequency with dynamic load factor of composite laminated simply supported symmetric cross-ply and for anti-symmetric angle-ply shells subjected to uniform distribution of temperature are shown in figures 8& 9. The effect of shallowness ratio on instability regions is studied for $R_x/a = R_y/b = 3, 5, 10$ keeping other geometries and material properties constant. As seen from the fig., the instability excitation frequency is higher for decrease of shallowness by decreasing R_x and R_y. The onset of instability occurs earlier with increase of shallowness ratio but with wide instability region. The excitation frequency is reduced but the instability region is wider in cross-ply symmetric laminate rather than anti-symmetric angle-ply laminate in elevated temperature.

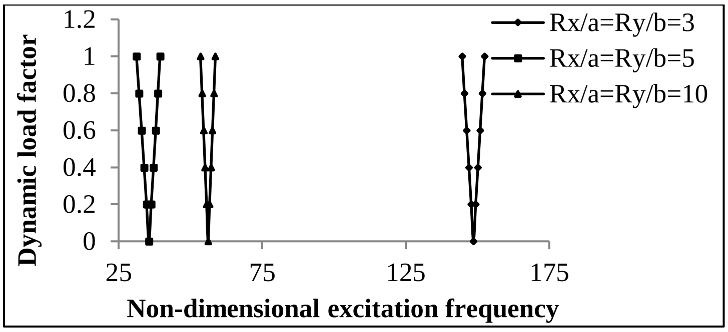

Fig.8: Effect of R_y/b on instability region of (0/90/90/0) laminate for elevated temperature (a/b=1, b/t=100, Temp=325K, $R_y=R_x$ = 1.5, 2.5, 5)

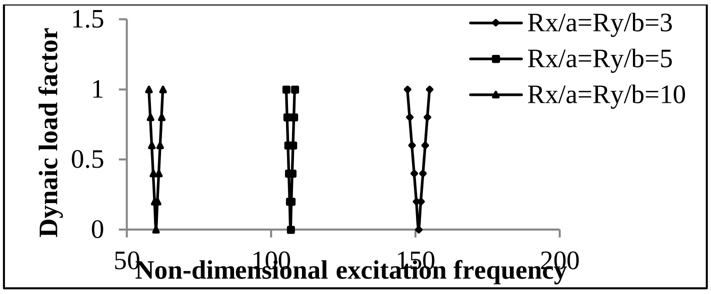

Fig 9: Effect of R_y/b on instability region of (0/90/90/0) laminate for elevated moisture (a/b=1, b/t=100, Mois=0.001, $R_y=R_x$ = 1.5, 2.5, 5)

4. Conclusions

A general formulation for vibration, buckling and parametric resonance characteristics of laminated composite curved panels subjected to hygrothermal loads is presented.

- The excitation frequencies of laminated composite panels decrease with increase of temperature due to reduction of stiffness for all laminates.
- The excitation frequencies of laminated composite panels also decrease substantially with increase of moisture concentration for all laminates.
- Due to static component of load, the onset of instability shifts to lower frequencies with wide instability regions of the laminated composite panels.

From the present studies, it is concluded that the instability behaviour of laminate composite plates and shells is greatly influenced by the geometry, lamination parameter and adverse hygrothermal conditions. So the designer has to be cautious while dealing with structures subjected to hygrothermal loading. This can be utilized to the advantage of tailoring during design of laminated composite structures in adverse hygrothermal environment.

References

[1] T R Tauchart. "Thermally induced flexure, buckling, and vibration of plates" Appl. Mech. Rev.(1991);44, Issue 8, 347 (14 pages)

[2] JM Whitney, JE Ashton. "Effect of environment on the elastic response of layered composite plates.AIAA J (1971); 9: 1708-13.

[3] KS Sai Ram, PK Sinha. "Hygrothermal effects on the free vibration of laminated composite plates. J Sound Vib (1992);158(1):133-48

[4] B P Patel, M Ganapathi, DP Makhecha. "Hygrothermal effects on the structural behaviour of thick composite laminates using higher order theory". Journal of Composite Structure (2002);56:25–34.

[5] L Librescu , W Lin. "Vibration of geometrically imperfect panels subjected to thermal and mechanical loads". J Spacecraft Rockets (1996):33(2):285-91.

[6] P.K. Parhi , S.K. Bhattacharyya, PK Sinha, "Hygrothermal effects on the dynamic behaviour of multiple delaminated composite plates and shells" J Sound Vib (2001);248(2):195-214

[7] M. Ganapathi, B.P. Patel, D.S.Pawargi ,"Dynamic analysis of laminated cross-ply composite non-circular thick cylindrical shells using higher-order theory". International Journal of Solids and Structures 39(2002):5945-5962

[8] NN Huang, TR Tauchert. "Large deformations of laminated cylindrical and doubly curved panels under thermal loading".ComputStruct (1991); 41(2):303-12.

[9] SPC Marques, GJ. Creus, "Geometrically nonlinear finite element analysis of viscoelastic composite materials under mechanical and hygrothermal loads". Comput Struct(1994);53(2):449-56.

[10] N.V. Swamy Naidu, P.K. Sinha , "Nonlinear free vibration of laminated Composite Shells in Hygrothermal condition", Journal of Composite Structures, 77, (2006): 475-483

[11] P. Ribeiro, E.Jansen, "Non-linear vibrations of laminated cylindrical shallow shells under thermomechanical loading" . Journal of Sound and Vibration 315(2008):626-640

[12] C. K. Kundu& Jae-Hung Han, "Vibration characteristics and snapping behaviour of Hygro-thermo-elastic composite doubly curved shells". Composite Structures91 (2009):306-317

[13] S.K. Panda & B.N. Singh,"Large amplitude free vibration analysis of thermally post-buckled composite doubly curved panel using non-linear FEM". Finite Elements in Analysis and Design 47(2011):378-386

[14] SY Lee, WJ. Yen, "Hygrothermal effects on the stability of cylindrical composite shell panel",ComputStruct 33(2):(1989); 551-559.

[15] ShenHui-Shen, "The effects of hygrothermal conditions on the postbuckling of shear deformable laminated cylindrical shells", International Journal of Solids and Structures 38(2001):6357-6380

[16] C. K. Kundu& Jae-Hung Han, "Nonlinear buckling analysis of hygrothermoelastic composite shell panels using finite element method". Composites: part B40 (2009):313-328.

[17] AchheLal, B.N Singh, Sushil Kale, "Stochastic post buckling analysis of laminated composite cylindrical shell panel subjected to hygrothermomechanical loading". Composite Structures93 (2011):1187-1200