

Contents

Front matter	
Title Page	
Certificate	
Declaration by the Candidate	
Copyright Transfer certificate	
Acknowledgements	
Abstract	
Contents	
List of Figures	
List of Tables	
List of Symbols	
Abbreviations	
1. Introduction	(1)
1.1. Overview	(1)
1.2. Laminated composites and Sandwich structures	(1)
1.3. Smart Structures	(6)
1.3.1. Classification of smart structures	(7)
1.3.2. Piezoelectric materials	(8)
1.4. Literature Review	(11)
1.4.1. Introduction	(11)
1.4.2. Elasticity Solutions (3 D)	(13)
1.4.3. Modeling of plates using Plate Theories	(17)
1.4.3.1. Development of the plate theories	(17)
1.4.3.2. Classical Plate theory	(18)
1.4.3.3. First Order Shear Deformation theory	(23)
1.4.3.4. Higher-Order Shear Deformation theories	(25)
1.4.4. Extension of the plate theories for the modeling of multilayered structures	(34)
1.4.4.1. Equivalent Single Layer (ESL) Approach	(35)
1.4.4.2. Layerwise (LW) Approach	(39)
1.4.4.3. Zigzag (ZZ) Approach	(45)
1.4.4.5 Carrera Unified Formulation (CUF)	(53)
1.4.5. Solution Schemes	(56)

1.5. Motivation and Literature Gap	(60)
1.6. Objective and Scopes of the Present Work	(65)
1.7. Organization of the thesis	(66)
2. Mathematical Formulation	(69)
2.1. Introduction	(69)
2.2. Basic Assumptions	(71)
2.3. Stress-Strain Constitutive Relations	(72)
2.4. Strain displacement relationships	(76)
2.5. Plates on elastic foundation	(76)
2.6. Kinematic field	(77)
2.7. Analytical Formulation	(82)
2.7.1. Equations of motion	(83)
2.7.2. Electric Potential	(88)
2.7.3. Solution Scheme	(89)
2.7.3.1. Static Analysis	(90)
2.7.3.2. Free Vibration Analysis	(91)
2.7.3.3. Transient Analysis	(92)
2.8. Finite Element (FE) Formulation	(95)
2.8.1. Discretized Kinematic field	(96)
2.8.2. Discretized Strain displacement relationships	(98)
2.8.3. Discretized Stress-Strain Constitutive relationships	(100)
2.8.4. Discretized governing equations of motion	(101)
2.8.4.1. Static Analysis	(108)
2.8.4.2. Free Vibration Analysis	(109)
2.8.4.3. Transient Analysis	(109)
2.8.4.4. Active Vibration control (AVC) of smart composite plates	(110)
2.9. Material Properties	(115)
2.10. Non-dimensional parameters	(115)
2.11. Summary	(116)
3. Results and Discussions	(119)
3.1. Introduction	(119)
3.2. Static analysis of traditional laminated composites and sandwich plates	(120)
3.2.1. Three-layered laminated composite plate subjected to uniformly	(120)

(0/90/0) distributed pressure	
3.2.2. Three-layered square and rectangular laminated composite plate (0/90/0) subjected to doubly sinusoidal load	(121)
3.2.3. Four-layered laminated composite plate (0/90/90/0) subjected to doubly sinusoidal load	(128)
3.2.4. Three-layered sandwich plate (0/C/0) subjected to sinusoidal load (SSL)	(131)
3.2.5. Three-layered soft-core sandwich plate (0/C/0) subjected to uniform pressure	(136)
3.2.6. Five-layered square and rectangular symmetric sandwich plate (0/90/C/90/0) subjected to SSL	(140)
3.2.7. Five-layered anti-symmetric sandwich plate (0/90/C/0/90) subjected to SSL	(141)
3.3. Static analysis of smart composite plates	(141)
3.3.1. Static analysis of five-layered smart composite plate with PVDF actuator and sensor (PVDF/0/90/0/PVDF) subjected to electromechanical load	(141)
3.3.2. Static analysis of four-layered smart composite plate with PFRC actuator (PFRC/0/90/0) subjected to electromechanical load of sinusoidal variation	(147)
3.3.3. Static analysis of four-layered smart composite plate with PFRC actuator (PFRC/0/90/0) subjected to electromechanical load of uniform variation	(154)
3.3.4. Static analysis of five-layered smart composite plate with PFRC actuator (PFRC/0/90/90/0) subjected to electromechanical load of uniform variation	(159)
3.3.5. Static Responses of smart composite plates with respect to number of layers and different materials	(163)
3.4. Dynamic analysis of traditional laminated composites and sandwich plates	(170)
3.4.1. Free Vibration analysis of traditional laminated composite plates	(171)
3.4.2. Free Vibration analysis of a three-layered (0/C/0) soft-core sandwich plate	(174)
3.4.3. Free Vibration Analysis of five-layered symmetric (0/90/C/90/0) sandwich plate	(175)
3.4.4. Free Vibration Analysis of five-layered anti-symmetric sandwich	(177)

(0/90/C/0/90) plate	
3.4.5. Transient analysis of traditional laminated composite plates	(184)
3.4.5.1. Transient analysis of laminated composite plates subjected to sinusoidal loading	(186)
3.4.5.2. Transient analysis of laminated composite plates subjected to pulse loading	(189)
3.4.5.3. Transient analysis of laminated composite plates subjected to triangular loading	(191)
3.4.5.4. Transient analysis of laminated composite plates subjected to exponential loading	(194)
3.4.5.5. Transient analysis of laminated composite plates subjected to ramp loading	(194)
3.4.5.6. Transient analysis of laminated composite plates subjected to staircase loading	(196)
3.4.5.7. Transient analysis of laminated composite plates under blast-loading	(198)
3.4.5.7.1. Air-blast loading	(198)
3.4.5.7.2. Triangular-blast loading	(199)
3.4.5.7.3. Pulse-blast loading	(201)
3.4.5.7.4. Sinusoidal-blast loading	(201)
3.4.5.8. Effect on the forced-vibration response of laminated composite plates due to material and geometrical features of the laminated plate.	(203)
3.5. Dynamic analysis of smart laminated composites plates	(206)
3.5.1. Dynamic response of smart composite plate (PVDF/0/90/0/ PVDF) subjected to mechanical excitations only	(206)
3.5.2. Dynamic response of smart composite plate (PVDF/0/90/0/ PVDF) subjected to electrical load only	(209)
3.5.3. Dynamic analysis of smart composite plate (PFRC/0/90/0) with PFRC actuator at the top	(212)
3.5.3.1. Dynamic response subjected to triangular variation of electromechanical load	(212)
3.5.3.2. Dynamic response subjected to step variation of electromechanical load	(213)
3.5.3.3. Dynamic response subjected to sinusoidal variation of electromechanical load	(216)
3.5.3.4. Dynamic response subjected to ramp variation of	(220)

	electromechanical load	
	3.5.3.5. Dynamic response subjected to staircase variation of electromechanical load	(220)
	3.5.4. Vibration Suppression of laminated composite plates using piezoelectric materials coupled with a control system	(222)
	3.6. Static analysis of laminated composites and sandwich plates on elastic foundation	(229)
	3.7. Free vibration analysis of laminated composite plates on elastic foundation	(234)
	3.8. Forced-vibration analysis of laminated composite plates on elastic foundation	(238)
	3.9. Static analysis of smart laminated composites and sandwich plates on elastic foundation	(243)
	3.10. Dynamic analysis of smart laminated composites and sandwich plates on elastic foundation	(252)
	3.11. Closure	(254)
4.	Conclusions	(263)
	4.1. Concluding Remarks	(263)
	4.2. Contribution of the thesis	(271)
	4.3. Scope for the Future Research	(272)
	References	(275)
	Appendix A	(295)
	Appendix B	(297)
	About the Author	(299)

List of Figures

Figure Number	Caption	Page Number
1.1.	Laminae with different fiber orientations to form a laminate	(4)
1.2.	Sandwich Structure	(6)
1.3.	Smart composite plate with a piezoelectric fiber-reinforced composite (PFRC) layer	(10)
1.4.	Flowchart on the modeling of a plate structure using any Plate theory	(19)
1.5.	3 D displacements (U, V, W) written in terms of the 2 D deformation modes ($u_0, v_0, w_0, \theta_x, \theta_y$) and linear mathematical function of the thickness coordinate	(21)
1.6.	Transverse normal remaining perpendicular to the midplane during the deformation	(22)
1.7.	Rotation of the transverse normal to the mid-plane in FSDT	(25)
1.8.	Expressing a function ' $f(x)$ ' with the Taylor Series expansion centered at $x = 1$	(28)
1.9.	Rotation of the transverse normal in HSDTs	(30)
1.10(a).	Through-thickness variation of Reddy's shear strain function	(32)
1.10(b).	Through-thickness variation of the derivative of Reddy's shear strain function with z	(32)
1.11.	ESL representation of a plate theory	(36)
1.12.	LW representation of a kinematic field	(42)
1.13.	ZZ representation of a kinematic model	(47)
2.1.	Laminated composite plate with a piezoelectric actuator and a piezoelectric sensor	(72)
2.2.	Smart composite plate resting on an elastic foundation	(78)
2.3.	Kinematics of TZZT	(81)
2.4.	Different types of time-dependent electrical and mechanical loads	(94)
2.5.	An eight-noded serendipity element	(95)
2.6.	A smart composite plate coupled with a feedback controller	(111)

3.1(a).	Convergence of the analytical solution	(122)
3.1(b).	Convergence of the FE solution	(122)
3.2.	Convergence of the FE results for 0/90/0 plate subjected to SSL	(127)
3.3.	Through-thickness variations of in plane displacement (U_1) for a 0/90/0 plate subjected to SSL	(128)
3.4(a).	Through-thickness variations of in plane normal stress ($\bar{\sigma}_{11}$) for a 0/90/0 plate subjected to SSL	(129)
3.4(b).	Through-thickness variations of in plane normal stress ($\bar{\sigma}_{22}$) for a 0/90/0 plate subjected to SSL	(129)
3.5.	Through-thickness variations of in plane shear stress ($\bar{\tau}_{12}$) for a 0/90/0 plate subjected to SSL	(130)
3.6(a).	Through-thickness variations of in plane shear stress ($\bar{\tau}_{13}$) for a 0/90/0 plate subjected to SSL	(132)
3.6(b).	Through-thickness variations of in plane shear stress ($\bar{\tau}_{23}$) for a 0/90/0 plate subjected to SSL	(132)
3.7.	Convergence of the FE results of 0/C/0 sandwich plate subjected to SSL	(139)
3.8.	Non-dimensional transverse displacement of a five-layered smart laminated plate (PVDF/0/90/0/PVDF) subjected to sinusoidal electromechanical load	(147)
3.9(a).	The variation of inplane displacement (\bar{U}) of a smart composite plate (PVDF/0/90/0/PVDF) for various electrical loadings	(148)
3.9(b).	Static deflection control of a PVDF/0/90/0/PVDF plate	(148)
3.10.	Through-thickness variations of in plane displacement (\bar{U}_1) for various magnitudes of electromechanical loads	(159)
3.11(a).	Through-thickness variation of in plane normal stress ($\bar{\sigma}_{11}$) for various magnitudes of electromechanical loads	(161)
3.11(b).	Through-thickness variation of in plane normal stress ($\bar{\sigma}_{22}$) for various magnitudes of electromechanical loads	(161)
3.12(a).	Through-thickness variations of transverse shear stress ($\bar{\tau}_{13}$) for various magnitudes of electromechanical loads	(162)
3.12(b).	Through-thickness variations of in plane normal stress ($\bar{\tau}_{23}$) for various magnitudes of electromechanical loads	(162)
3.13.	Convergence of the present analytical solution	(163)
3.14(a).	Actuation in the transverse displacement (\bar{U}_3) of five-layered (PFRC/0/90/90/0) smart composite plate for various magnitudes of	(169)

electromechanical loads

- 3.14(b). Actuation in the in-plane normal stress ($\bar{\sigma}_{11}$) of the smart composite plate for various magnitudes of electromechanical loads (169)
- 3.15. Static responses of smart composite plate with respect to number of layers subjected to electromechanical load (170)
- 3.16. Static responses of smart composite plates ($S=10$) with respect to the piezoelectric coefficient ' e_{31} ' (172)
- 3.17. Static responses of smart composite plate (PFRC/0/90/0) with different types of composite materials (172)
- 3.18(a). Static-deflection control for a thick ($S=10$) smart composite plate (PFRC/0/90/0) (173)
- 3.18(b). Static-deflection control for a thin ($S=100$) smart composite plate (PFRC/0/90/0) (173)
- 3.19(a). Variation of the normalized natural frequency of a 0/90/0 laminated plate with modular ratio (MR) and span-thickness ratio (l/h) (179)
- 3.19(b). Variation of the normalized natural frequency of a 0/90/0 laminated plate with modular ratio (MR) and aspect ratio (l/b) (179)
- 3.20. Higher order modes of vibration of a 0/90/0 laminated plate with span-thickness ratio, $S = 10$ and modular ratio, $E_{11}/E_{22} = 40$ (180)
- 3.21(a). Variation of the normalized natural frequency with the number of layers of a laminated composite plate (181)
- 3.21(b). Normalized natural frequencies of various laminated composite plates (181)
- 3.22. Variation of the fundamental natural frequencies of a 0/C/0 sandwich plate with thickness of the core (t_c) and span-thickness ratio (182)
- 3.23. Variation in the fundamental frequencies of a 0/90/C/90/0 sandwich plate with span-thickness ratio and core density (ρ) (183)
- 3.24(a). Forced-Vibration response of laminated composite plate with equal transverse shear modulus (190)
- 3.24(b). Forced-Vibration response of laminated composite plate unequal transverse shear modulus (190)
- 3.25. Effect of the shear deformation on the dynamic responses of the laminated composite plate (191)
- 3.26. Dynamic response of the laminated composite plate subjected to sinusoidal load of different frequencies less than the natural frequency of the plate (192)
- 3.27. Occurrence of the beating phenomenon when the frequencies of the harmonic excitation approach the natural frequency of the plate (192)

3.28	Dynamic response of the laminated plate under resonance condition	(193)
3.29.	Dynamic responses of the laminated plate under pulse excitation for 0.006 sec	(193)
3.30.	Dynamic responses of the laminated plate under triangular excitation for 0.006 sec	(194)
3.31(a).	Variations of the exponential blast load with various decay parameters	(195)
3.31(b).	Dynamic responses of the laminated plate under various exponential blast loads	(195)
3.32(a).	Dynamic response of the laminated plate under ramp loading	(197)
3.32(b).	Dynamic responses of the laminated plate under ramp loading acting for 0.006 sec	(197)
3.32(c).	Dynamic response of laminated plate under ramp-constant load	(197)
3.33.	Dynamic responses of the laminated plate under staircase load variation	(198)
3.34.	Variation of the dynamic response of the laminated plate with aspect ratios (l/b) subjected to air-blast loading	(200)
3.35(a).	Variation of the air-blast loading with various values of the positive phase duration of pulse (t_p)	(202)
3.35(b).	Dynamic response of the laminated plate with various values of the positive phase duration of pulse in the air-blast load	(202)
3.36(a).	Effect of the shock pulse length factor (r) on the variation of the triangular blast load	(204)
3.36(b).	Effect of the shock pulse length factor on the dynamic responses of the laminated plate subjected to triangular blast load	(204)
3.37(a).	Effect of the shock pulse length factor (r) on the variation of the pulse blast load	(205)
3.37(b).	Dynamic response of the laminated composite plate subjected to pulse blast load	(205)
3.38(a).	Variation of the sinusoidal blast load with various values of the shock pulse length factor (r)	(207)
3.38(b).	Dynamic response of the laminated composite plate subjected to sinusoidal blast load	(207)
3.39(a).	Effect of the modular-ratio (MR) on the dynamic response of the laminated composite plate ($S=5$)	(208)
3.39(b).	Effect of the span-thickness ratio ($S = a/h$) on the dynamic response of the laminated composite plate	(208)

3.40.	Dynamic responses of PVDF/0/90/0/PVDF plate with very small thickness of the PVDF layers under suddenly applied sinusoidal mechanical excitation	(209)
3.41.	Dynamic responses of PVDF/0/90/0/PVDF plate under harmonic electrical and electromechanical excitations	(211)
3.42(a).	Dynamic response of smart plate (PFRC/0/90/0) under triangular load with different span-thickness ratios	(214)
3.42(b).	Dynamic response under different magnitudes of electrical loading	(214)
3.43(a).	Dynamic response of smart plate (PFRC/0/90/0) under triangular load with aspect-ratio	(215)
3.43(b).	Suppression of the dynamic response by triangular electrical loads	(215)
3.44(a).	Dynamic response of smart plate (PFRC/0/90/0) under pulse loading acting for 0.03 second	(217)
3.44(b).	Suppression of the dynamic response by pulse electrical loads	(217)
3.45(a).	Dynamic response of smart plate (PFRC/0/90/0) under pulse loading acting for the entire duration of the plate vibration	(218)
3.45(b).	Dynamic response under different magnitudes of pulse load	(218)
3.46.	Dynamic responses of PFRC/0/90/0 plate with various thickness of the PFRC layer	(219)
3.47(a).	Dynamic response of smart plate (PFRC/0/90/0) under sinusoidal load	(221)
3.47(b).	Suppression of the dynamic response by sinusoidal electrical loads	(221)
3.48(a).	Effect of span-thickness ratio on the magnitude of electric loads	(222)
3.48(b).	Dynamic response of smart plate (PFRC/0/90/0) under resonance condition	(222)
3.49(a).	Dynamic response of smart plate (PFRC/0/90/0) under ramp loading	(224)
3.49(b).	Suppression the dynamic response under the ramp loading	(224)
3.50(a).	Dynamic response of smart plate (PFRC/0/90/0) under ramp loading acting for 0.01 second	(225)
3.50(b).	Suppression of the dynamic response by electrical loads	(225)
3.51(a).	Dynamic response of smart plate (PFRC/0/90/0) under ramp-constant electro-mechanical loading	(226)
3.51(b).	Suppression of the dynamic response by electrical loads	(226)
3.52.	Dynamic response of smart plate (PFRC/0/90/0) under staircase loading	(227)

- 3.53. Uncontrolled and Controlled Forced-Vibration responses of smart composite plate (PVDF/090/0/PVDF) subjected to sinusoidal excitation in the time-domain and uniformly distributed in the spatial-domain (230)
- 3.54. Free vibration responses of smart composite plate (PVDF/0/90/0/PVDF) coupled with a negative feedback controller (230)
- 3.55. Uncontrolled and Controlled dynamic responses of the smart composite plate subjected to pulse variation of the mechanical load acting for 0.0015 sec (231)
- 3.56. Uncontrolled and Controlled dynamic responses of the smart composite plate subjected to sinusoidal variation of the mechanical load acting for 0.0015 sec (231)
- 3.57. Uncontrolled and Controlled dynamic responses of the smart composite plate subjected to triangular variation of the mechanical load acting for 0.0015 sec (232)
- 3.58. Variation of the in-plane stress ($\bar{\sigma}_{11}$) along the length of the plate (235)
- 3.59. Variation of the in-plane stress ($\bar{\sigma}_{22}$) along the width of the plate (235)
- 3.60. Variation of the in-plane stress ($\bar{\tau}_{12}$) along the length of the plate (236)
- 3.61. Variation of transverse displacement (\bar{U}_3) of a laminated composite plate with Winkler stiffness and shear stiffness of the foundation (237)
- 3.62. Variation of the normalized natural frequency of a laminated composite plate on elastic foundation with modulus ratio (MR) and Winkler stiffness ($\bar{K}_w = \bar{K}_1$) (240)
- 3.63. Variation of the normalized natural frequency of a laminated composite plate on elastic foundation with modulus ratio (MR) and shear stiffness ($\bar{K}_s = \bar{K}_2$) (240)
- 3.64. Variation of the normalized natural frequency of a laminated composite plate on elastic foundation with modulus ratio (MR) and span-thickness ratio ($\bar{K}_w = 100$; $\bar{K}_s = 10$) (241)
- 3.65. Forced and free vibration response of a laminated composite plate resting on elastic foundation under pulse loading acting for 0.006 second (242)
- 3.66. Forced and free vibration response of a laminated composite plate resting on elastic foundation under triangular loading acting for 0.006 second (242)
- 3.67(a). Variation of the sinusoidal excitation with time (244)
- 3.67(b). Forced and free vibration response of a laminated composite plate resting on elastic foundation under sinusoidal loading acting for 0.006 second (244)
- 3.68(a). Sinusoidal excitation at a frequency equal to the natural frequency of the plate (245)
- 3.68(b). Vibration response under the sinusoidal excitation without considering (245)

	the foundation stiffness	
3.68(c).	Vibration response of the plate under the sinusoidal excitation by considering the foundation stiffness	(245)
3.69(a).	3 D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering Winkler stiffness under pulse loading	(256)
3.69(b).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering shear stiffness under pulse loading	(246)
3.70(a).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering Winkler stiffness under ramp loading	(247)
3.70(b).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering shear stiffness under ramp loading	(247)
3.71(a).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering Winkler stiffness under ramp loading acting for 0.006 sec	(248)
3.71(b).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering shear stiffness under ramp loading acting for 0.006 sec	(248)
3.72(a).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering Winkler stiffness under ramp-constant load	(249)
3.72(b).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering shear stiffness under ramp-constant load	(249)
3.73(a).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering Winkler stiffness under exponential blast load	(250)
3.73(b).	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation by considering shear stiffness under exponential blast load	(250)
3.74.	3D graphical representation of forced-vibration response of laminated composite plate on elastic foundation subjected to exponential-blast load with various decay constants	(251)
3.75.	Variation of the in-plane normal stress ($\bar{\sigma}_{11}$) at the top surface of a smart composite plate (PVDF/0/90/0/PVDF) resting on elastic foundation subjected to combined electromechanical load	(256)
3.76.	Displacement-time response of a smart composite plate (PVDF/0/90/0/PVDF) on elastic foundation subjected to sinusoidal	(258)

electrical excitation ($S=50$)

- 3.77. Displacement-time response of a smart composite plate (PFRC/0/90/0) on elastic foundation subjected to pulse electromechanical excitation ($S=100$) (259)
- 3.78. 3D graphical representation of forced vibration of a smart composite plate (PFRC/0/90/0) without considering foundation stiffness for various magnitudes of pulse electrical excitation ($S=100$) (259)
- 3.79. 3D graphical representation of forced vibration of a smart composite plate (PFRC/0/90/0) by considering Winkler foundation stiffness for various magnitudes of pulse electrical excitation ($S=100$) (260)
- 3.80. 3D graphical representation of forced vibration of a smart composite plate (PFRC/0/90/0) by considering both Winkler and shear foundation stiffness for various magnitudes of pulse electrical excitation ($S=100$) (260)
- 3.81. Displacement-time response of a smart composite plate (PFRC/0/90/0) on elastic foundation subjected to sinusoidal excitation of frequency equal to natural frequency of the smart composite plate ($S=100$) (261)

List of Tables

Table Number	Caption	Page Number
1.1.	Various shear strain functions used in the kinematic models	(32)
2.1.	Material properties of the composite and core layers	(115)
2.2.	Material properties of the piezoelectric layer	(115)
3.1.	Non-dimensional deflection (\bar{U}_3) of a three-layered (0/90/0) plate subjected to uniformly distributed load	(121)
3.2.	Non-dimensional deflection and stresses of three-layered (0/90/0) laminated composite plate subjected to doubly sinusoidal mechanical load	(125)
3.3.	Non-dimensional deflection and stresses of simply supported rectangular ($b = 3a$) laminated composite plate (0/90/0) subjected to SSL	(133)
3.4.	Non-dimensional deflection and in-plane stresses of four-layered (0/90/90/0) plate subjected to SSL	(134)
3.5.	Non-dimensional transverse shear stresses of four-layered (0/90/90/0) plate subjected to SSL	(135)
3.6.	Non-dimensional deflection and in-plane stresses of sandwich plate (0/C/0) subjected to SSL	(137)
3.7.	Non-dimensional transverse shear stresses of sandwich plate (0/C/0) subjected to SSL	(138)
3.8.	Non-dimensional deflection and stresses of sandwich plate (0/C/0) subjected to uniform pressure ($S = 10$)	(143)
3.9.	Non-dimensional deflection and stresses of five layered symmetric sandwich (0/90/C/90/0) plate subjected to SSL	(145)
3.10.	Non-dimensional deflection and stresses of five-layered anti-symmetric sandwich plate (0/90/C/0/90) under SSL	(146)
3.11.	Normalized static transverse deflection and inplane normal stress of PVDF/0/90/0/PVDF plate structure subjected to sinusoidal electromechanical load	(146)
3.12.	Non dimensional in-plane and transverse displacement of smart composite plate (PFRC/0/90/0) with PFRC actuator at the top of the plate subjected to mechanical and electrical loading	(155)

- 3.13. Non dimensional in-plane stresses of smart composite plate (PFRC/0/90/0) with PFRC actuator at the top of the plate subjected to mechanical and electrical loading (156)
- 3.14. Non dimensional in-plane and transverse shear stresses of smart composite plate (PFRC/0/90/0) with PFRC actuator at the top of the plate subjected to mechanical and electrical loading (157)
- 3.15. Non dimensional transverse deflection of PFRC/0/90/0 plate with uniformly distributed electromechanical load (165)
- 3.16. Non dimensional in-plane and transverse displacement of smart composite plate (PFRC/0/90/90/0) with PFRC actuator at the top of the plate subjected to mechanical and electrical loading (166)
- 3.17. Non dimensional in-plane stresses of smart composite plate (PFRC/0/90/90/0) with PFRC actuator at the top of the plate subjected to mechanical and electrical loading (167)
- 3.18. Non dimensional in-plane and transverse shear stresses of smart composite plate (PFRC/0/90/90/0) with PFRC actuator at the top of the plate subjected to mechanical and electrical loading (168)
- 3.19. Non dimensional fundamental frequencies of a symmetric laminated composite plate (0/90/90/0) with variation in the modular ratio (176)
- 3.20. Non dimensional fundamental modes of vibration of a symmetric laminated composite plate (0/90/90/0) with variation in the span-thickness ratio (178)
- 3.21. Non-dimensional fundamental frequencies of a sandwich plate (0/C/0) ($[Q]_{(face-sheets)} = R[Q]_{(core)}$) (182)
- 3.22. Non dimensional fundamental frequencies of a 0/90/C/90/0 sandwich plate with variation in the span-thickness ratio (183)
- 3.23. Non dimensional fundamental frequencies of an anti-symmetric sandwich plate (0/90/C/0/90) with variation in the thickness of the core to the face sheets (t_c/t_f) (185)
- 3.24. Non dimensional fundamental frequencies of an anti-symmetric laminated sandwich plate (0/90/C/0/90) with variation in the span thickness ratio (187)
- 3.25. Non dimensional higher-order modes of vibration of a five-layered simply supported anti-symmetric laminated sandwich plate (0/90/C/0/90) with variation in the span-thickness ratio (188)
- 3.26. Non dimensional fundamental frequencies of an anti-symmetric laminated sandwich plate (0/90/C/0/90) with variation in the aspect ratio (188)
- 3.27. Convergence and validation of the transient deflection of symmetric laminated composites plates (189)
- 3.28. Validation of the Forced vibration response of smart composite plate (211)

(PVDF/0/90/0/PVDF)

- 3.29. Convergence and validation of transverse deflection of laminated composite plate (0/90/90/0) resting on elastic foundation subjected to SSL (233)
- 3.30. Transverse deflection of laminated composite plate (0/90/0) resting on elastic foundation subjected to UDL (236)
- 3.31. Static response of soft-core sandwich plate subjected to uniform pressure resting on elastic foundation (237)
- 3.32. Natural frequencies of a three-layered (0/90/0) laminated composite plate resting on elastic foundation (239)
- 3.33. Normalized Transverse deflection of smart composite plate (PVDF (actuator)/0/90/0/PVDF (sensor)) resting on elastic foundation subjected to electromechanical load of sinusoidal variation (255)
- 3.34. Normalized Transverse deflection of smart composite plate (PFRC (actuator)/0/90/0) resting on elastic foundation subjected to electromechanical load of sinusoidal variation (257)
- 3.35. Transient deflection of smart composite plate on elastic foundation subjected to electrical load of sinusoidal variation (258)

List of Symbols

x_1, x_2, x_3	Cartesian coordinate system
U_1, U_2, U_3	3D displacements in the global x_1, x_2 and x_3 - direction
u_1, u_2, u_3	Mid-plane displacement components in the x_1, x_2 and x_3 -direction
β_1, β_2	Rotation of the transverse normal to the mid-plane about x_2 and x_1 -direction
$\alpha_{1u}^i, \alpha_{1l}^j, \alpha_{2u}^i, \alpha_{2l}^j$	Auxiliary variables defined at the interfaces of the multi-layered plate structures in the x_1 and x_2 -direction
$\{\sigma\}$	Stress vector in the global coordinate system
$\{\varepsilon\}$	Strain vector in the global coordinate system
$[\bar{Q}]$	Transformed reduced stiffness matrix
$\{\bar{\sigma}\}$	Stress vector in the material coordinate axis
$\{\bar{\varepsilon}\}$	Strain vector in the material coordinate axis
$[Q]$	Reduced stiffness matrix
E_{11}, E_{22}	Young's Modulus in the longitudinal and transverse direction to the fiber direction
G_{12}	In-plane shear modulus
G_{13}, G_{23}	Transverse shear modulus
$\{\bar{E}\}$	Electric field vector in the material coordinate axis
$[\epsilon]$	Electric permittivity matrix in the material coordinate axis
$\{\bar{D}\}$	Electric displacement vector in the material coordinate axis
$\{E\}$	Electric field vector in the global coordinate axis
$[\bar{\epsilon}]$	Electric permittivity matrix in the global coordinate axis
$\{D\}$	Electric displacement vector in the global coordinate axis
k_w	Winkler stiffness of the foundation
k_s	Shear stiffness of the foundation

p_1, p_2, q_1, q_2	Mathematical functions of the thickness coordinate
U	Strain energy of the smart laminated composite plate
U_F	Strain energy of the elastic foundation
W	Work potential of the applied loads
K	Kinetic energy of the smart laminated composite plate
N_{11}, N_{12}, N_{22}	In-plane stress resultants
M_{11}, M_{12}, M_{22}	Moment stress resultants
N_{11}^*, N_{12}^*	Higher-Order In-plane stress resultants
M_{22}^*, M_{12}^*	Higher-Order moment stress resultants
Q_1, Q_2	Transverse shear stress resultants
T_1^*, T_2^*	Higher-Order transverse shear stress resultants
h	Overall thickness of the laminated composite plate
t_p	Thickness of the piezoelectric actuator and sensor
q	Mechanical pressure
$\bar{I}_0, \bar{I}_1, \bar{I}_2, \bar{I}_3,$ $\bar{I}_4, \bar{I}_5, \bar{I}_6, \bar{I}_7, \bar{I}_8$	Inertia components
$[A], [B], [C], [D],$ $[G], [H], [I], [L],$ $[M], [P]$ $[AA], [EE], [FF];$ $[SS], [TT], [UU]$	Rigidity submatrices relating the stress-resultants and derivatives of the primary variables
$\{A\}, \{C\}, \{E\}, \{G\},$ $\{L\}, \{N\}, \{P\}$	Forces generated due to piezoelectric coefficients
V	Electric voltage
NL	Number of layers in the smart laminated plate
Φ	Electric potential
$[\bar{K}]$	Stiffness matrix of the smart composite plate
$\{\Delta\}$	Displacement vector
$\{\bar{F}_M\}$	Mechanical force vector
$\{\bar{F}_E\}$	Electrical force vector

ω	Natural frequency of the plate
$[\bar{M}]$	Mass matrix
$[\bar{N}_i]$	Shape function matrix
ξ, η	Natural coordinate system used in finite element
$\{d^e\}$	Nodal coordinates
$\rho^{(s)}, \rho^{(k)}, \rho^{(a)}$	Density of piezoelectric sensor, laminated composite plate and actuator, respectively
$[H]$	Matrix relating the strains and derivatives of the primary variables
$[B]$	Matrix relating the derivatives of the primary variables and the nodal coordinates
$\{V(t)^e\}$	Elemental electric force vector
$\{d^e\}$	Elemental velocity force vector
P_e	Penalty function
$[K^{(s)}]$	Elemental stiffness matrix of sensor
$[K]$	Elemental stiffness matrix of laminated plate
$[K^{(a)}]$	Elemental stiffness matrix of actuator
$[K_{ds}]$	Piezoelectric coupling matrix of the sensor
$[K_{da}]$	Piezoelectric coupling matrix of the actuator
$[K_{pe}]$	Elemental penalty stiffness matrix
$[K^{(F)}]$	Elemental stiffness matrix of the foundation
$\{F_M\}$	Elemental force vector
$[M]$	Elemental mass matrix
L	Lagrangian
$\{\bar{F}_M\}$	Global mechanical force vector
$[\bar{M}]$	Global mass matrix
$[\bar{K}^{(s)}]$	Global stiffness matrix of the sensor
$[\bar{K}]$	Global stiffness matrix of the laminated composite plate

$[\bar{\mathbf{K}}^{(a)}]$	Global stiffness matrix of the actuator
$[\bar{\mathbf{K}}^{(F)}]$	Global stiffness matrix of the foundation
$[\bar{\mathbf{K}}^{(pe)}]$	Global stiffness matrix containing the penalty terms
G_c	Constant gain of the amplifier
G	Gain of the amplifier
$[C_R]$	Rayleigh damping matrix
$[C_{cnt}]$	Active damping matrix

Abbreviations

3 D	Three Dimensional
2 D	Two Dimensional
CLPT	Classical Laminated Plate Theory
CPT	Classical Plate Theory
FSDT	First Order Shear Deformation Theory
HSDT	Higher-Order Shear Deformation Theory
FRP	Fiber Reinforced Polymers
FGM	Functionally Graded Material
PZT	Lead Zirconate Titanate
PVDF	Polyvinylidene Fluoride
PFRC	Piezoelectric Fiber-Reinforced Composites
ESL	Equivalent Single Layer
LW	Layerwise
ZZ	Zigzag
PHSDT	Polynomial Higher-Order Shear Deformation Theory
NPHSDT	Non-Polynomial Higher-Order Shear Deformation Theory
ODE	Ordinary Differential Equation
PDE	Partial Differential Equation
FEM	Finite Element Method
SBFEM	Scaled Boundary Finite Element Method
IGA	Isogeometric Analysis
XFEM	Extended Finite Element Method
FDM	Finite Difference Method
DSC	Discrete Singular Convolution
DQM	Differential Quadrature Method

CUF	Carrera Unified Formulation
EE	Equilibrium Equations
EKM	Extended Kantorovich method
SCF	Shear-Correction Factor
RHZZT	Refined Higher-Order Zigzag Theory
RFSDT	Refined First Order Shear Deformation Theory
FN	Fundamental Nucleus
BEM	Boundary Element Method
TZZT	Trigonometric Zigzag Theory
AVC	Active Vibration Control
UDL	Uniformly Distributed Load
SSL	Sinusoidal Load
MM	Material Model
ND	Non-Dimensional Parameter