Abstract

Laminated composite structures are extensively used in aerospace vehicles, marine applications, automotive and various other industries for their high specific strength, design flexibility and requiring low maintenance. These structures with embedded or surface bonded piezoelectric layers often called as smart or intelligent or hybrid structures offer additional advantage of sensing and control apart from their primary structural responsibility. The smart structures are extensively used in structural health monitoring, shape and vibration control applications, but the presence of geometric and material inhomogeneity across the layers introduce complex electromechanical couplings inducing sharp stress variations near the non-simply supported edges. So, the analysis of such structures with high accuracy demand special tools with greater computational efficiency. Three dimensional (3D) analytical solutions are the most efficient tools for analysis of smart or hybrid laminated structures which can compute the global as well as local responses more accurately. In this thesis, three dimensional extended Kantorovich method (3D EKM) is used to obtain the static and free vibration elasticity/piezoelasticity solution of hybrid rectangular laminated plates and results from two dimensional (2D) zig-zag and third order theory are assessed with respect to the 3D solutions.

The generalized coupled three-dimensional piezoelasticity solution for multi-layered composite plates integrated with piezoelectric layers subjected to Levy-type boundary conditions is presented using the mixed-field multi-term extended Kantorovich method (EKM) and Fourier series expansion. A mixed formulation approach in which displacement as well as stresses are taken as state variables in the solution domain is followed. The initial functions are not required to satisfy the essential or natural boundary conditions and the solution converges very fast. The convergence and accuracy of this method is established by comparing the results with the 3D exact solution, wherever available, and with the 3D finite element (FE) solution for the rest for both pressure and potential loading cases. The anomalies and pitfalls of the FE solution in predicting stress responses at or near to the edges are pointed out. The effect of adhesive layer between the face and elastic substrate is also investigated and found that it eases out the sharp stress variations at the layer interface. The method is further extended to the free vibration analysis of finite dimensional elastic laminated plates. Results are presented for various laminate lay-ups and boundary conditions and are extensively validated by comparing with the results of other theories and 3D FE results. Benchmark natural frequencies and mode shapes are presented for laminated composite and sandwich plates. It is found that single term solution is sufficient enough for obtaining accurate natural frequencies, but stresses near the clamped edge are accurately predicted by multi-term (n=2) solution. The effect of span-to-thickness ratio and in-plane modulus ratio on the natural frequency is also studied. The effect of adhesive modulus, density and layer thickness on the free vibration behaviour of elastic laminated plates is also investigated. The 3D EKM has also been extended to investigate the free vibration behaviour of Levy-type hybrid laminated composite and sandwich plates integrated with piezoelectric actuators and sensors. The accuracy and efficacy of this method is verified thoroughly by comparing it with the existing results in the literature and FE solutions. The numerical results are presented for bimorph, hybrid composites and sandwich plates. Effect of piezo-layer thickness, electric circuit conditions and plate aspect ratios on the natural frequency are also investigated. Effect of adhesive layer on the free vibration characteristics of a bimorph plate is also investigated.

Apart from the above 3D analysis, analytical solutions for the free vibration of Levy-type rectangular elastic laminated plates based on efficient layerwise 2D zig-zag theory and the third order theory (TOT) are also presented. The 2D results are assessed in comparison with the 3D elasticity solution to estimate its accuracy. Further, the analysis is extended for the piezoelasticity static and free vibration solution of hybrid rectangular plates. The improved zig-zag theory (IZIGT) and its smeared counterpart, the improved third order theory (ITOT) are developed to obtain the results and are assessed for the accuracy with respect to the 3D piezoelasticity solution of 3D EKM.