Advances in Computational Design, *Vol. 3, No. 3 (2018) 213-232*
DOI: https://doi.org/10.12989/acd.2018.3.3.213

Free vibration of Levy-type rectangular laminated plates using efficient zig-zag theory

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(Received December 18, 2017, Revised January 15, 2018, Accepted January 17, 2018)

Abstract. First time, an exact solution for free vibration of the Levy-type rectangular laminated plate is developed considering the most efficient Zig-Zag theory (ZIGT) and third order theory (TOT). The plate is subjected to hard simply supported boundary condition (Levy-type) along x axis. Using the equilibrium equations and the plate constitutive relations, a set of 12 m first order differential homogenous equations are obtained, containing displacements and stress resultant as primary variables. The natural frequencies of a single-layer isotropic, multi-layer composites and sandwich plates are tabulated for three values of length-to-thickness ratio (S) and five set of boundary conditions and further assessed by comparing with existing literature and recently developed 3D EKM (extended Kantorovich method) solution. It is found that for the symmetric composite plate, TOT produces better results than ZIGT. For antisymmetric and sandwich plates, ZIGT predicts the frequency for different boundary conditions within 3% error with respect to 3D elasticity solution while TOT gives 10% error. But, ZIGT gives better predictions than the TOT concerning the displacement and stress variables.

Keywords: zig-zag theory; analytical solution; levy-type; free vibration; sandwich plate; composite plate

1. Introduction

In recent years, laminated composite structures are extensively used in some of the weight sensitive and sophisticated engineering applications such as in aerospace, civil, mechanical and naval industries where these structures are subjected to various loadings (static and dynamic loads) and boundary conditions. Unlike the isotropic plate structures, composite laminates experience different couplings among bending, extension and twisting pertaining to its varied stacking order among the layers. Hence, the development of a computationally easy, efficient and reliable dynamic analysis of laminated plates has been the topic of research since last few decades. The two-dimensional (2D) theories are preferred for the design and optimization of laminated structures as it is relatively simple and easy to execute in comparison to 3D solutions with reasonable accuracy. To address the above concern, 2D theories of varying computational efficiency and accuracy are available in abundance for laminated plates which can broadly be

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http://www.techno-press.org/?journal=acd&subpage=7 ISSN: 2383-8477 (Print), 2466-0523 (Online)

$$\begin{aligned}
&K^m_{7,2} = -\omega^2 I_{22} \quad K^m_{7,4} = \omega^2 I_{24} \quad K^m_{7,6} = -\omega^2 I_{26} \quad K^m_{8,1} = -\omega^2 I_{11}, \\
&K^m_{8,3} = \bar{m}\omega^2 I_{13} \quad K^m_{8,5} = -\omega^2 I_{15} \quad K^m_{9,1} = \bar{m}\omega^2 I_{31} \quad K^m_{9,3} = -\bar{m}^2\omega^2 I_{33} - \omega^2 \bar{I}_{33} \\
&K^m_{9,5} = \bar{m}\omega^2 I_{35} \quad K^m_{10,2} = -\omega^2 I_{42} \quad K^m_{10,4} = \omega^2 I_{44} \\
&K^m_{10,6} = -\omega^2 I_{46} \quad K^m_{11,2} = -\omega^2 I_{62} \quad K^m_{11,4} = \omega^2 I_{64} \quad K^m_{11,6} = -\omega^2 I_{66} \\
&K^m_{12,1} = -\omega^2 I_{51} \quad K^m_{12,3} = \bar{m}\omega^2 I_{53} \quad K^m_{12,5} = -\omega^2 I_{55}
\end{aligned} \tag{A.5}$$