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# Nonlinear Response of Laminated Panels Under Blast Load

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**Abstract**

Nonlinear response of laminated composite plates and cylindrical panels subjected to a parabolically distributed blast load is studied here using a shear deformable finite element method. The nonlinear finite element equations of motion are solved in the time domain by an energy and momentum conserving time integration technique. The state-of-stress inside the laminated panels is calculated at each time-step to predict the occurrence of damage using Tsai-Wu quadratic failure criterion. The effects of span-to-thickness ratio, radius-to-span ratio and peak pressure on the nonlinear dynamic response of laminated composite plates and curved panels are investigated.

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*Keywords:* Blast load; finite element method; nonlinear dynamic response; composite; curved panels

## 1. Introduction

Laminated composites are widely used in transportation and defence industry because of their high strength-to-weight ratio and higher energy absorption capability. The dynamic response and safety of thin-walled structural components of aircrafts, vehicle bodies and sheltering structures under extreme loading conditions, for example, the nearby blast / explosion is a primary concern. The pressure wave generated by such blast / shock load is available in the literature (Kinney and Graham [1]).

Linear and nonlinear dynamic response of laminated plate have been investigated thoroughly using analytical methods on the basis of various plate theories. The dynamics and damage of such composite panels under exponential blast load has also received a considerable attention of the researchers. Dobyns [2] analyzed the linear transient response of orthotropic plates under various time dependent loads, e.g., sinusoidal load, step load,

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triangular load and exponential blast load using the Navier's method. Lam and Chun [3] studied the linear dynamic behavior of laminated angle-ply plates under explosive blast load based on semi-analytical approach.

Upadhyay *et al*. [4] examined the nonlinear dynamic response of laminated plates under blast load using Chebyshev series and studied the effect of load intensity, duration of the load and aspect ratio on the non-dimensional centre deflection of laminated plates. Basturk *et al*. [5] investigated the nonlinear dynamic response of basalt laminated plates under different time dependent loads, such as sine load, step load, triangular load and exponential air blast load using the Galerkin method. However, all these analytical solutions are limited to simply supported immovable boundary conditions and transverse air blast load with uniformly distributed structural load variation.

Turkmen [6-7] studied the linear dynamic behavior (displacement and strain time history) of a laminated cylindrical shell under blast load by employing the Galerkin method based on classical plate theory. Furthermore, author modeled and analyzed the laminated cylindrical panel using 8-noded shell element through ANSYS and compared with the theoretical results. In addition, Turkmen [7] conducted experimental investigation on two types of clamped laminated panels to obtain strain time history and compared the experimental results with analytical and numerical results. It is observed from the literature review that very few literature is available on the transient response of laminated panels under exponential blast load with the effect of distance on the magnitude and load distribution.

Reddy and Reddy [8] carried out damage analysis of laminated composite plates under uniformly distributed, concentrated and in-plane tensile load using a 9-node Lagarangian element based on the first-order shear deformation theory and various failure criteria like maximum stress, maximum strain, Tsai-Hill, Hoffman and Tsai-Wu. Bakshi and Chakravorty [9] employed the finite element method to investigate the first-ply failure of composite cylindrical panels based on Sanders shallow shell theory and Tsai-Wu failure criterion. The dynamic failure analysis of laminated plates and panels under blast load is scarce in the literature.

In the present paper, nonlinear dynamic response of laminated composite plates and curved panels under parabolically distributed exponential blast load is investigated using a shear deformable finite element approach. For realistic loading conditions on plates / panels, blast load is assumed to be parabolic in nature. The occurrence of damage is examined here using the two-dimensional Tsai-Wu quadratic failure criterion. A detailed parametric study is carried out on the nonlinear vibration behavior of the laminated plates and cylindrical panels.

## 2. Finite Element Formulation

A sixteen-noded degenerated isoparametric finite element (schematically shown in Figure 1) having five degrees of freedom per node ($u_1$, $u_2$, $u_3$, $\alpha$ and $\beta$) is employed here to model the laminated composite plates and curved panels under parabolically distributed exponential blast load. The global coordinates ($x_i$, $i$ = 1,3) and displacement fields ($u_i$, $i$ = 1,3) are taken as Bathe [10]:

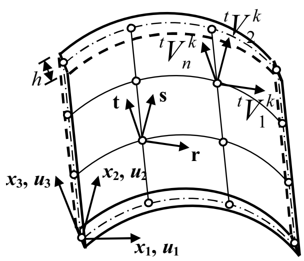


Figure 1. The geometry of 16 node degenerated shell element

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