Optimal Stiffener Configuration for Maximizing Nonlinear Frequencies of Rhombic Laminated Composite Hyperbolic Paraboloids

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Laminated composite hyperbolic paraboloids are widely utilized in civil, marine and aerospace structures for their aesthetic appeal, high specific stiffness, and lower susceptibility to decay from weathering. Civil engineering panels experience dynamic excitations due to wind, snow, and seismic actions. Moderately thin panels undergo large amplitudes of vibration, for which a geometrically nonlinear approach is essential. The performance of such panels can be improved by stiffeners, as shown by several research studies. However, stiffened panels are costlier to fabricate and heavier than unstiffened ones. Since dynamic performance is compromised for heavier panels, stiffeners should be applied optimally. The additional cost of stiffeners should also be justified by maximizing frequencies significantly. This study proposes guidelines to optimize stiffeners for laminated composite rhombic hyperbolic paraboloids (Figure 1) using a C^0 continuous geometrically nonlinear finite element code, eight noded elements and first order shear deformation theory. The optimal stiffeners aim for maximizing nonlinear fundamental frequencies within a given weight ratio of stiffened to unstiffened panels.

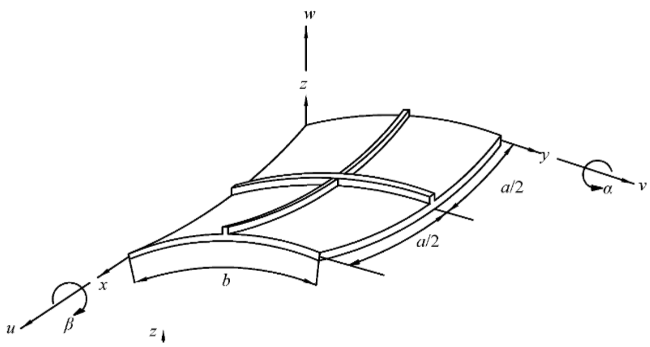

Figure 1. Laminated composite hyperbolic paraboloid with stiffeners.

The governing equation of free vibration is given below. The derivation was reported in [1].

$$[M_{sh}]\{\ddot{\delta}_k\}_g + [K_s]\{\delta_k\}_g = 0 \quad (1)$$

$\{\ddot{\delta}_k\}_g$, $\{\delta_k\}_g$ are acceleration and displacement vectors, respectively. mass and stiffness matrices are $[M_{sh}] = \int_A [T]^T[N_i]^T[m][N_i][T]dA$, and $[K_s] = \int_A [T]^T[\overline{B}\,]^T[E]\left([B_L] + \frac{1}{2}[B_{NL}]\right)[T]\ dA$

[1] M. Trivedi, K. Bakshi, *Thin-Walled Structures*, 2026, 114600. https://doi.org/10.1016/j.tws.2026.114600