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N91-10304

# COMPRESSIVE FAILURE OF THICK-SECTION COMPOSITE LAMINATES WITH AND WITHOUT CUTOUTS SUBJECTED TO BIAXIAL LOADING

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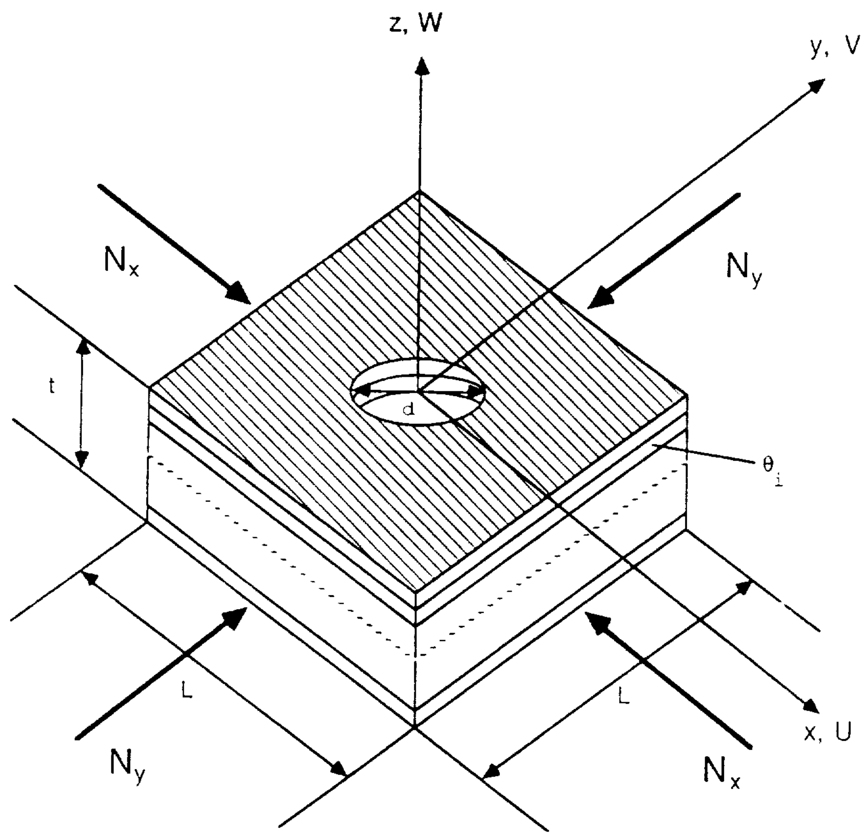
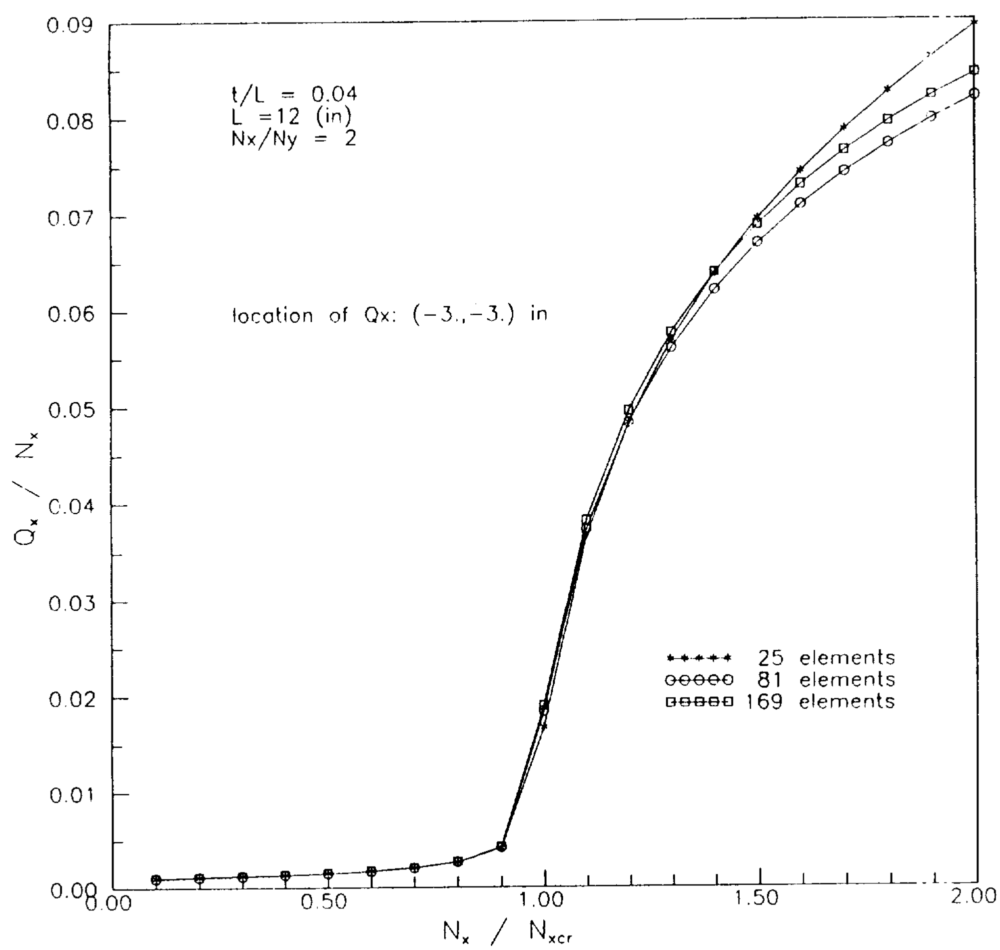
## Coordinates and geometry of a composite laminate with a central circular cutout under compressive loading

The composites studied are fiber-composite laminate plates made of carbon fibers and a thermoplastic-matrix material. The elastic properties of the lamina are: $E_{11} = 15.6 \times 10^6$ (psi), $E_{22} = 0.9 \times 10^6$ (psi), $\nu_{12} = 0.313$, $G_{12} = G_{13} = 0.77 \times 10^6$ (psi), and $G_{23} = 0.31 \times 10^6$ (psi). The plates have a square geometry with a length of 12 (in), a cutout diameter of 2 (in) and a constant lamina thickness of 0.005 (in). A $[0/90/\pm45]_{ns}$ layup is considered. Biaxial loading is applied in the form of uniform displacements along the edges of the laminates.



**Solution convergence for transverse shear $Q_x$ at (-3.,-3.) (in) in a clamped $[0/90/\pm45]_{12s}$ plate without cutout under biaxial compression ($N_x/N_y$ = 2, t/L = 0.04)**

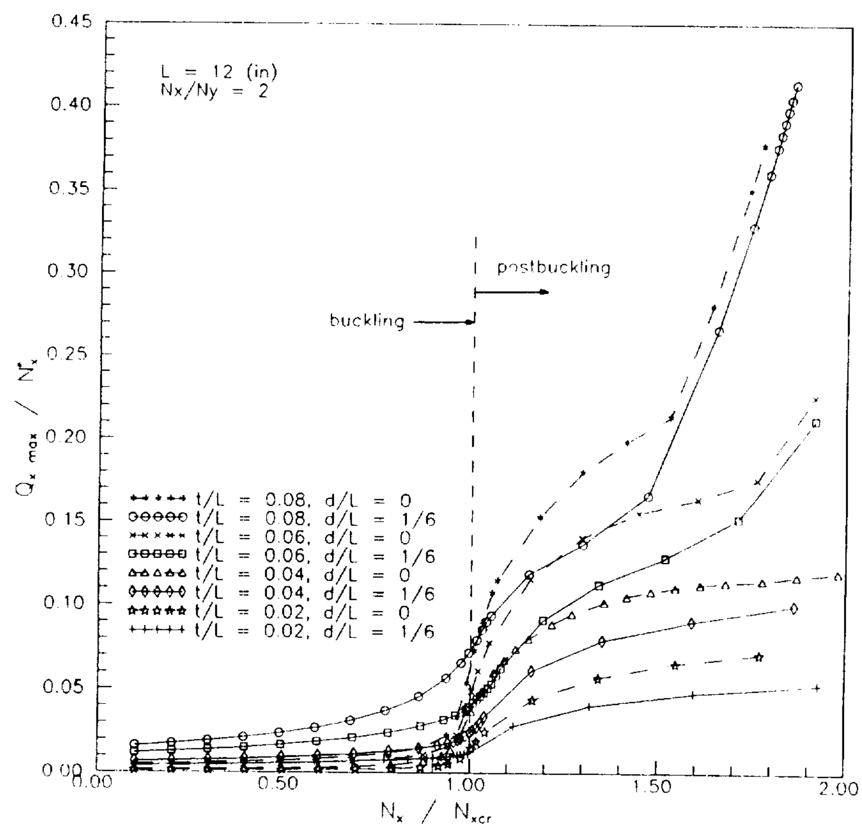
The transverse shear force $Q_x$ is the resultant of $\tau_{xz}$ integrated over the laminate thickness. $Q_x$ is interpolated at (-3.,-3.) (in) from the values at the four Gaussian points of the element containing this location (using a bilinear interpolation). Three finite-element meshes are considered.



**Effects of cutout and laminate thickness on maximum shear $Q_x$ in buckling and postbuckling response of a clamped $[0/90/\pm45]_{ns}$ plate under biaxial compression**

Without cutout, $|Q_{x\,max}|$ is located at (±3.3,0.) for t/L = 0.02 and t/L = 0.04, and also for t/L = 0.06 and t/L = 0.08 before activation of higher (i.e., second and third lowest) modes takes place for these two thickness/length ratios (beyond $N_x = 1.7\ N_{xcr}$ and $N_x = 1.5\ N_{xcr}$, respectively). After activation of higher modes, the location is at (±6.,±4.7) for t/L = 0.06 and t/L =0.08.

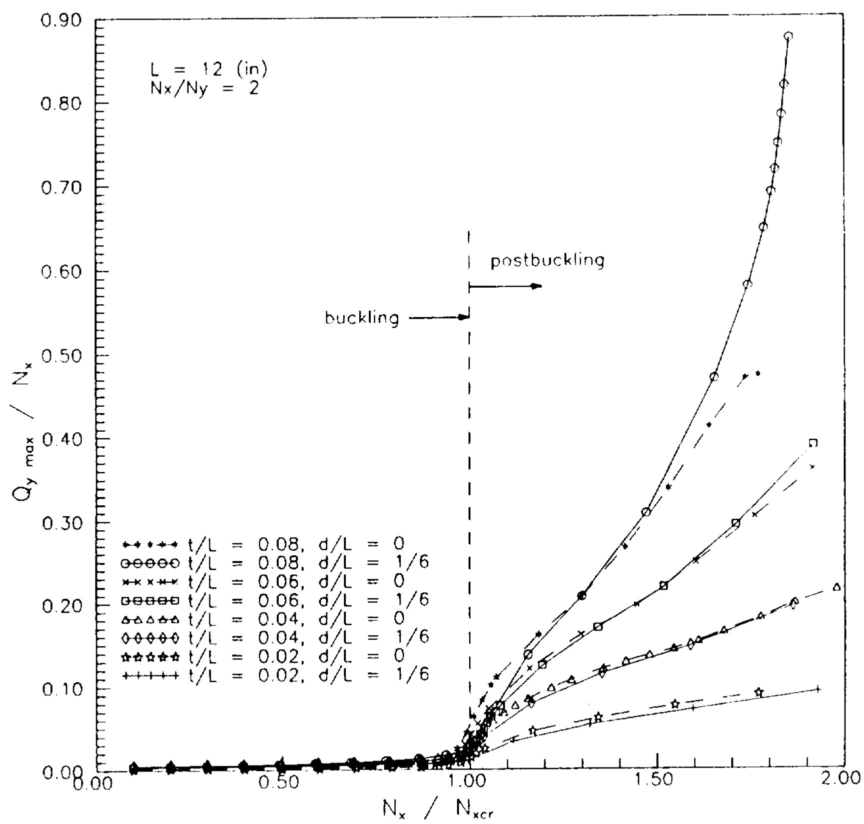
With cutout, $|Q_{x\,max}|$ is located at (±3.5,±1.8) for t/L = 0.02 and t/L = 0.04, and for t/L = 0.06 before activation of higher modes ($N_x < 1.7\ N_{xcr}$). However, for t/L = 0.08, $|Q_{x\,max}|$ is located at the hole free edge at (0.38,±0.92) before activation of higher modes. After activation of higher modes for t/L = 0.06 and t/L =0.08, the location is at (±6.,±4.7).



**Effects of cutout and laminate thickness on maximum shear $Q_y$ in buckling and postbuckling response of a clamped $[0/90/\pm45]_{ns}$ plate under biaxial compression**

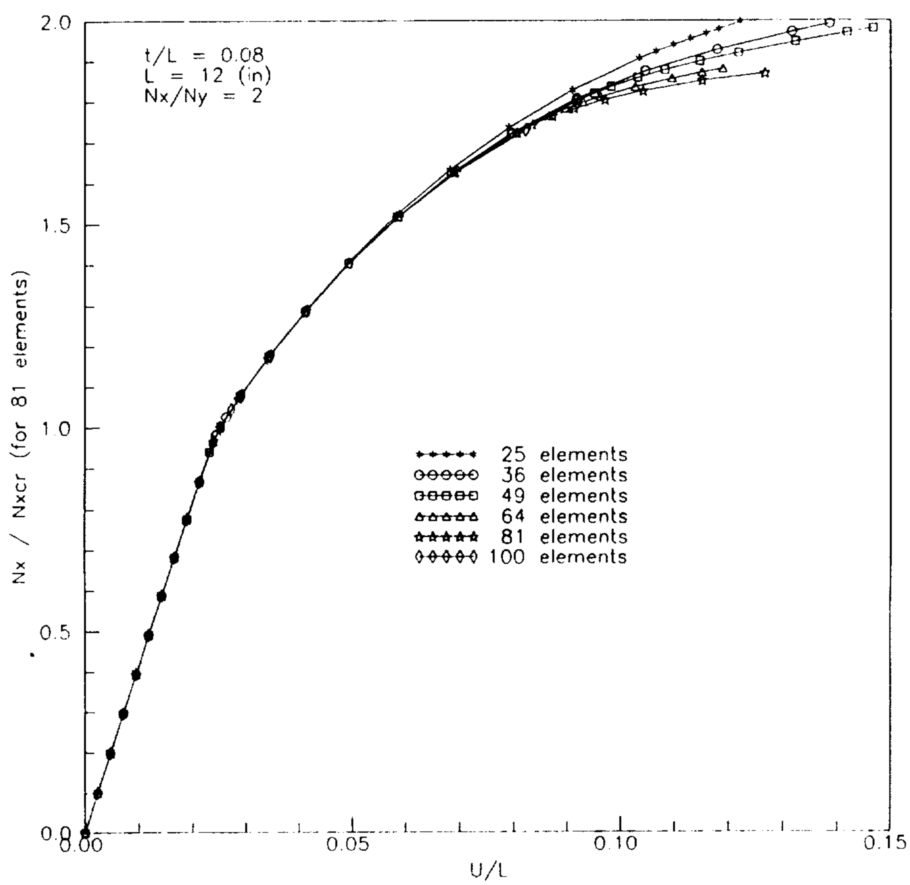
Without cutout, $|Q_{y\,max}|$ is located at (0.,±6.) for t/L = 0.02 and t/L = 0.04, and also for t/L = 0.06 and t/L = 0.08 before activation of higher modes takes place (beyond $N_x = 1.7\ N_{xcr}$ and $N_x = 1.5\ N_{xcr}$, respectively). After activation of higher modes, the location is at (0.,±4.7) for t/L = 0.06 and t/L =0.08.

With cutout, $|Q_{y\,max}|$ is located at (0.,±6.) for all four thickness/length ratios considered. Activation of higher modes for t/L = 0.06 and t/L = 0.08 does not change the location of $|Q_{y\,max}|$.



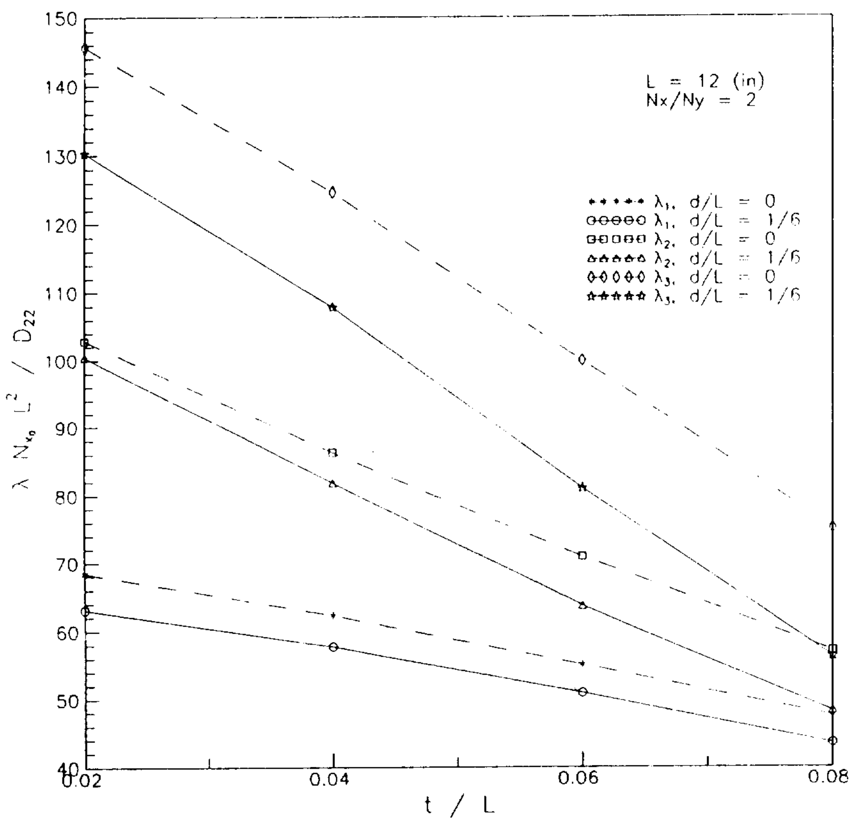
**Effect of mesh refinement on buckling and postbuckling solution convergence for a clamped plate $[0/90/\pm45]_{24s}$ without cutout under biaxial compression ($N_x/N_y = 2$, $t/L = 0.08$)**

For this thick laminate, activation of second and third lowest eigenmodes takes place beyond $N_x = 1.5\ N_{x_{cr}}$, but no change in buckling mode occurs as the structure gradually loses its stiffness and becomes unstable.



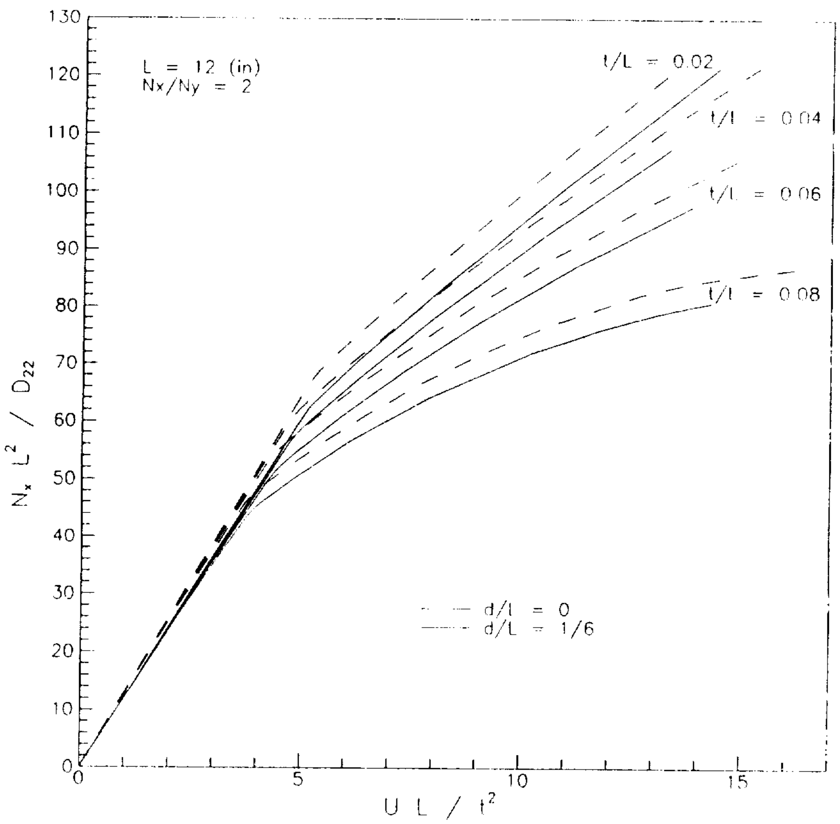
**Effects of cutout and laminate thickness of lowest three eigenvalues of a clamped $[0/90/\pm 45]_{ns}$ plate under biaxial compression ($N_x/N_y = 2$)**

The eigenvalue parameter ($\lambda N_{x_o} L_2 / D_{22}$) is defined in such form that the lowest eigenvalue would have the same value for all thickness/length ratios if transverse shear was not present. This parameter is plotted with respect to the thickness/length ratio.



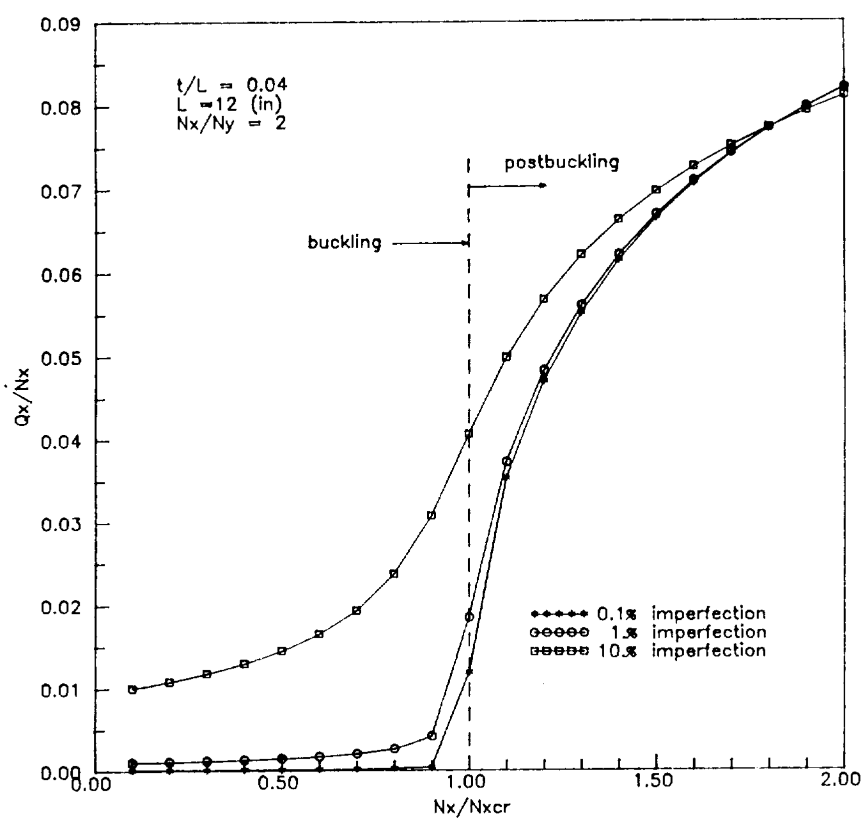
**Effects of cutout and laminate thickness on buckling and postbuckling response of a clamped $[0/90/\pm45]_{ns}$ plate under biaxial compression ($N_x/N_y = 2$)**

The load parameter ($N_x L^2 / D_{22}$) is defined in such form that buckling would occur at the same value for all thickness/length ratios if transverse shear was not present. Likewise, the strain parameter $U L / t^2$ is such that all load/end-shortening curves for the cases with cutout and for the cases without cutout are identical prior to buckling, respectively.

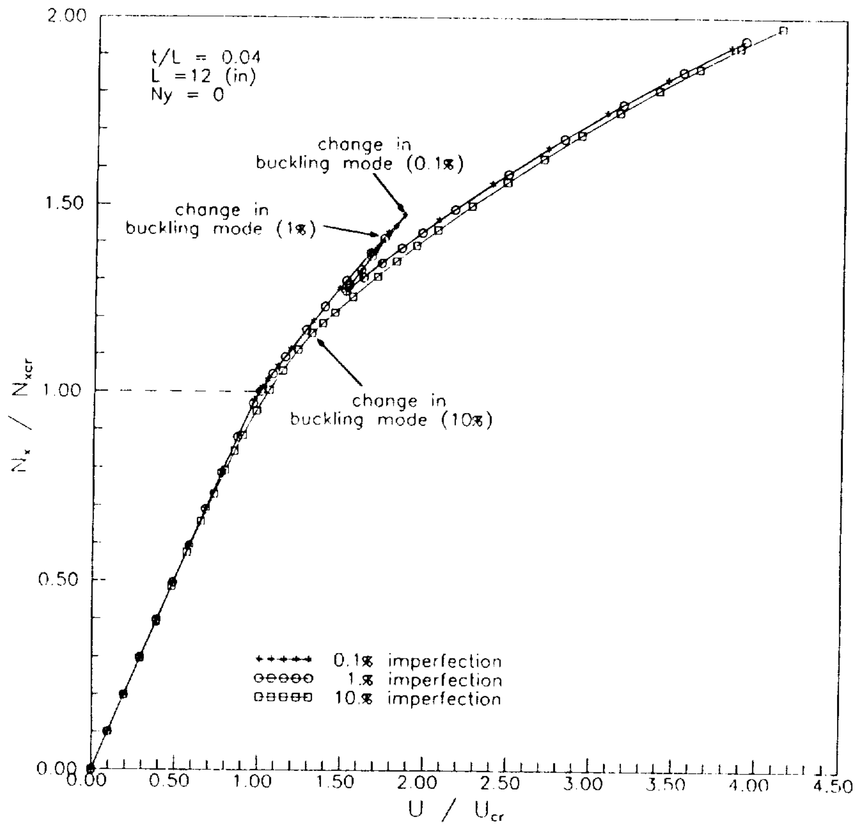


Effect of imperfection sensitivity on transverse shear $Q_x$ at (-3.,-3.) (in) in a clamped $[0/90/\pm45]_{12s}$ plate without cutout under biaxial compression ($N_x/N_y$ = 2, t/L = 0.04)

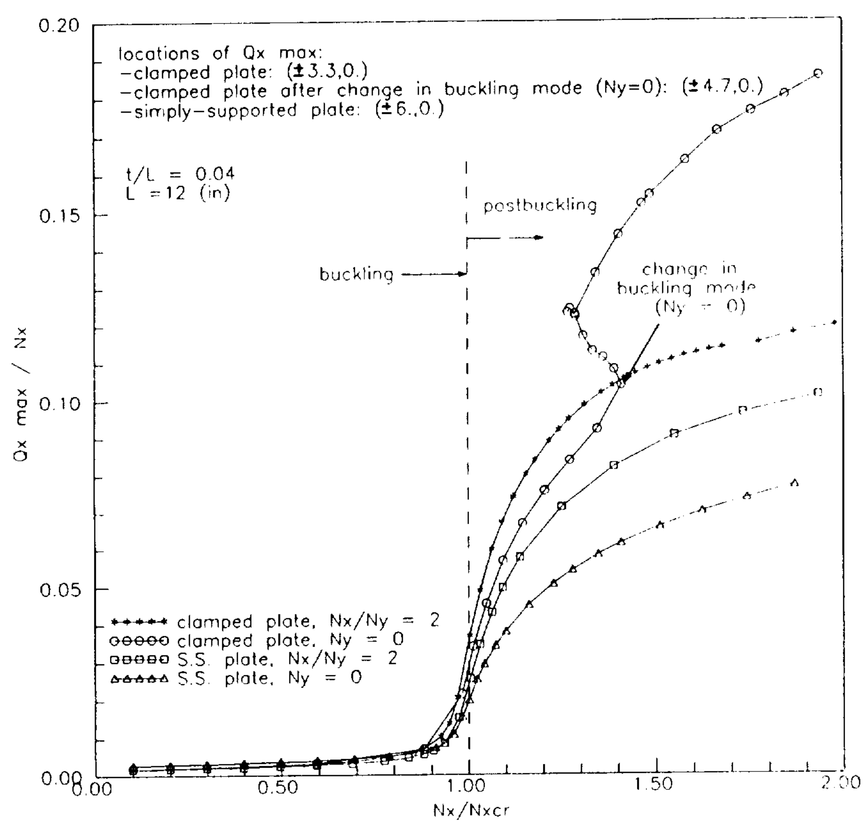
Three imperfection magnitudes (with respect to the laminate thickness) are considered: 0.1%, 1% and 10%. The imperfections are made of a linear combination of the normalized three lowest eigenmodes. The resulting imperfection geometry is close to the first eigenmode (buckling mode).



Effect of imperfection sensitivity on buckling and postbuckling response (with a change in buckling mode) of a clamped $[0/90/\pm45]_{12s}$ plate without cutout under uniaxial compression ($N_y = 0$, $t/L = 0.04$)



**Effects of boundary conditions and stress-biaxiality ratio on maximum transverse shear $Q_x$ in a clamped $[0/90/\pm45]_{12s}$ laminate without cutout (t/L = 0.04)**



Effects of boundary conditions and stress-biaxiality ratio on maximum transverse shear $Q_y$ in a clamped $[0/90/\pm45]_{12s}$ laminate without cutout (t/L = 0.04)