Buckling and Postbuckling Behavior of Compression-Loaded Isotropic Plates with Cutouts

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Introduction

INVESTIGATIONS of the buckling behavior of plates with cutouts have appeared in the technical literature since 1943. Analytical and experimental results have been presented that indicate buckling behavior trends for a wide range of plate parameters and also indicate that the buckling behavior of compression-loaded isotropic and orthotropic plates with central circular and square cutouts is well understood.[1,2]

Substantially fewer studies of the postbuckling behavior of plates with cutouts are available in the technical literature. Some of the first studies were presented in Refs. 3–6. More recently, selected results for the postbuckling and failure characteristics of compression-loaded rectangular graphite-epoxy plates with central circular cutouts have been presented.[7] Additional recent studies of the postbuckling collapse of square isotropic plates with square and circular cutouts are presented in Refs. 8 and 9, and a study of the imperfection sensitivity and postbuckling strength of compression-loaded square isotropic and laminated composite plates with central circular cutouts is presented in Ref. 10. Recently, an experimental study of the buckling and postbuckling behavior trends of square compression-loaded graphite-epoxy and aluminum plates with central circular cutouts has been presented.[11]

A review of the studies presented in Refs. 3–11 indicates that the effects of cutout size, plate aspect ratio, cutout shape, and laminate stacking sequence on the postbuckling behavior of plates are still not well understood. This Note summarizes an experimental study of the behavior of selected isotropic compression-loaded square and rectangular plates presented in Ref. 12 and presents overall trends indicating some of the effects of cutout size, cutout shape, and plate aspect ratio on plate buckling and postbuckling behavior.

Overall Behavioral Trends

The experimental results presented in Ref. 12 include a wide range of cutout sizes; circular, square, and elliptical cutout shapes; and three plate aspect ratios. In each experiment, the loaded edges of the plate were clamped, and the unloaded edges were simply supported. Typically, only one specimen was tested for each combination of cutout size, cutout shape, and plate aspect ratio. Because of the limited amount of testing on each specimen type, the actual degree of scatter in the experimental data is not well known. Analytical and experimental buckling strain comparisons presented in Ref. 12, however, suggest that the scatter is not large. Thus, the experimental data are useful in identifying overall behavioral trends.

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Buckling Behavioral Trends

Results showing a trend of increasing buckling load with increasing circular cutout size have been reported for simply supported rectangular isotropic plates with plate aspect ratios of $L/W=1$ and 2 in Ref. 6 where L is the plate length and W is the plate width. The results presented in Ref. 12 indicate a similar behavioral trend for square plates with circular cutouts and for rectangular plates ($L/W=3$ and 5) with circular and square cutouts. In addition, the results indicate that the plates with square cutouts buckle at approximately the same strains as the corresponding plates with circular cutouts. The plates with cutout-width-to-plate-width ratios near 0.6 buckled at strains approximately 50% higher than the corresponding plate without a cutout.

The greater buckling resistance of the plates with the larger circular and square cutout-width-to-plate-width ratios led to the study of square plates with elliptical cutouts. Plates with a constant value of cutout-width-to-plate-width ratio $2b/W_b=0.6$ and with cutout-width-to-plate-width ratios $2a/W_b$ ranging from 0.05 to 0.7 were studied. The parameters a, b, and W_b are defined in Fig. 1. Average buckling strains for the plates with $0.1 \leq 2a/W_b \leq 0.7$ obtained from an approximate analysis (based on nominal plate dimensions and average thickness), and the average buckling strains of the test specimens, are shown in Fig. 1 as a function of the ratio $2a/W_b$. The average buckling strains shown in this figure are defined by the buckling-load-to-prebuckling-stiffness ratio P_{cr}/EA. Accurate analytical results for the plate with $2a/W_b=0.05$ were not obtained due to limitations of the ap-

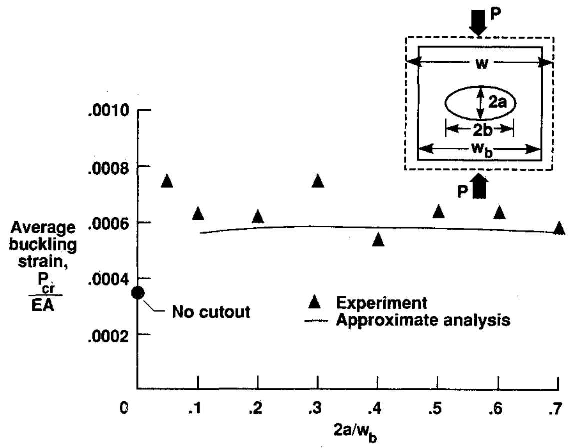

Fig. 1. Average buckling strains for square plates with elliptical cutouts ($2b/W_b=0.60$).

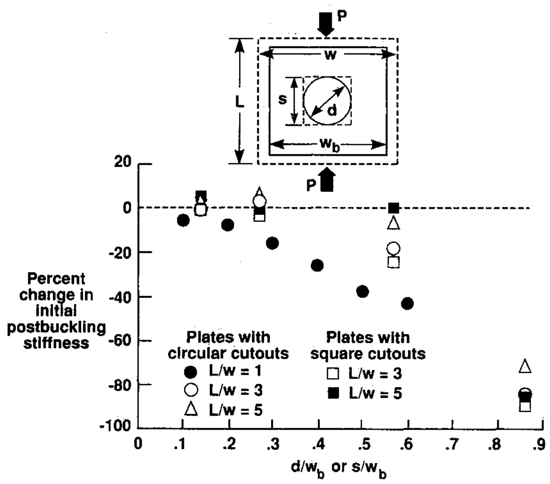

Fig. 2 Change in initial postbuckling stiffness of square and rectangular plates with circular and square cutouts (change in stiffness is with respect to the stiffness of the corresponding plate without a cutout).

proximate analysis. These analytical and experimental results indicate that the buckling strain is approximately constant for $0.1 \leq 2a/W_b \leq 0.7$, with the exception of the plates with $2a/W_b = 0.3$ and 0.05. Moire fringe data indicate that the plate with $2a/W_b = 0.3$ buckled into an unusual mode shape that occupied the right half of the plate, which appears to be due to a nonuniform load introduction into the plate. The plate with $2a/W_b = 0.05$ exhibited the largest buckling load of the plates with elliptical cutouts and exhibited a somewhat smaller prebuckling stiffness than the plates with $2a/W_b = 0.1$ and 0.2. Most of the plates buckled at approximately 50% higher strain than the corresponding plate without a cutout. The result shown in Fig. 1 for the plate without a cutout is in good agreement with the buckling strain determined from the approximate analysis. The plate with $2a/W_b = 0.05$ buckled at approximately 100% higher strain than the corresponding plate without a cutout.

Postbuckling Behavioral Trends

Results showing the change in initial postbuckling stiffness due to circular or square cutouts are presented in Fig. 2. The results presented in this figure show stiffness changes as a function of the plate aspect ratio L/W and the cutout-width-to-plate-width ratio (d/W_b and s/W_b for plates with circular and square cutouts, respectively). The stiffness changes in this figure are depicted with respect to the initial postbuckling stiffness of the corresponding plates without a cutout.

The results presented in Fig. 2 indicate that in all cases the initial postbuckling stiffness of a plate generally decreases as cutout size increases. The results also show that the reduction in stiffness becomes substantially less pronounced as the plate aspect ratio increases for d/W_b and $s/W_b \leq 0.6$. The plates with d/W_b and $s/W_b = 0.86$ did not exhibit this trend due to the more local nature of their deformation states. Moreover, differences in initial postbuckling stiffness due to differences in cutout shape become more pronounced as the cutout size increases (on the order of 10% difference). Results presented in Ref. 12 indicate that the reduction in plate axial stiffness due to buckling ranges from 31 to 44% for the plate aspect ratios and square and circular cutout sizes considered in this study.

Results showing the reduction in prebuckling stiffness and initial postbuckling stiffness due to changes in elliptical cutout height (semiminor axis radius) are presented in Ref. 12 as a function of the cutout-height-to-plate-width ratio $2a/W_b$. These stiffness changes are with respect to the initial postbuckling stiffness of the corresponding plate without a cutout. The results shown in Fig. 1 and presented in Ref. 12 indicate that the prebuckling and initial postbuckling stiffnesses generally decrease with increasing cutout size and that the postbuckling stiffness is more sensitive to changes in elliptical cutout height than the prebuckling stiffness and the buckling strain. These results indicate that the plates with the smaller cutout heights have nearly the same prebuckling stiffness and buckling strain as the other plates, and that the plates with the smaller cutout heights have the largest initial postbuckling stiffness.

Concluding Remarks

A summary of an experimental study of the buckling and postbuckling behavior of square and rectangular compression-loaded isotropic plates with centrally located cutouts has been presented. Overall behavioral trends for a wide range of cutout sizes, three different cutout shapes, and three plate aspect ratios have been presented.

Experimental results indicate that the prebuckling and initial postbuckling stiffnesses of the plates generally decrease with increasing cutout size. The buckling strains, however, generally increase with increasing cutout size. Morever, the results indicate that the buckling strains and initial postbuckling stiffnesses of identical plates with circular and square cutouts with the same radius and width are nearly equal.

The results also indicate that the initial postbuckling stiffness of square plates is more sensitive to changes in elliptical cutout height than are the prebuckling stiffness and the buckling strain. In addition, the results show that most of the square plates with elliptical cutouts buckle at approximately 50% higher strain than a corresponding plate without a cutout and that the plate with the smallest elliptical cutout height buckled at approximately 100% higher strain.

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