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Elastic buckling of uniaxially loaded skew plates containing openings

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ABSTRACT

The paper is concerned with elastic buckling behavior of uniaxially loaded skew plates with openings. Simply supported and clamped plates subject to uniaxial compression in the longitudinal direction are studied. Two different shapes of openings, circular and skew of different sizes, are considered. The finite element software package ABAQUS has been employed to analyze the plates. Effects of parameters such as skew angle, size, shape and position of openings and aspect ratio of the plates are examined. Results are presented in the form of plots showing the variation of buckling coefficient against the parameters studied.

1. Introduction

Thin steel plates that form the basic components in the fabrication of structures such as ships, oil rig platforms, dock gates and plate and box girder bridges have been researched extensively for elastic as well as ultimate load behavior. Closed form solutions and numerical methods were proposed and effects of openings on ultimate load carrying capacity considered. Design methods to evaluate the ultimate capacity of square or rectangular plate elements containing holes and subjected to in-plane axial or shear loading have been proposed by several researchers. It is possible to extend the effective width concept with certain modifications or to apply elasto-plastic analysis to obtain the complete load history until the failure.

One of the earliest works on the elastic behavior of plates containing cutouts is by Rockey et al.[1] who studied experimentally a square plate with openings and subjected to shear loading. Shanmugam and Narayanan [2] examined using the finite element method the elastic buckling behavior of square plates with perforations under different boundary and loading combinations. The earliest analysis of post-buckling behavior of axially compressed perforated plates appears to be those reported by Yu and Davis [3] and Ritchie and Rhodes [4]. Yu and Davis [3] proposed that the effective width concept can be extended to perforated plates with slight modifications to the formula. Ritchie and Rhodes [4] concluded, based on their theoretical and experimental investigations on square and rectangular plates limited to wide plates having plate slenderness ratios in excess of 160, that the failure loads were not affected by small holes. The finite element formulation based on variational principles [5,6] could be used to predict the non-linear behavior of perforated plates, right up to collapse. The theory makes due allowance for material and geometric non-linearity and the initial plate imperfections. Considering the computational costs that would deter the widespread use of such methods at that time, Narayanan and Chow [7,8] and Narayanan [9] suggested an approximate design method for evaluating the ultimate capacity of plates containing openings and subjected to uniaxial or biaxial compression. When plates are skewed and contain openings closed form solutions are fraught with complexities. Researchers have, therefore, resorted to approximate methods and, inelastic analysis of such plates is greatly simplified with the advent of high speed computers and the availability of finite element software packages. Behavior of skew plates has attracted attention of a few researchers. Although there are extensive analytical and experimental investigations of rectangular plates, hitherto far fewer studies have considered the buckling behavior of skew plates, despite their practical importance in skewed bridges, aircraft wing and fuselage panels. Buckling behavior of clamped skew plates under combined loads was considered by Ashton [10]. Other researchers [11–16] applied analytical and numerical techniques to examine the effects of different boundary, loading conditions and orthotropic behavior in plates skewed in plan. More recent works [17–21] have addressed the issues such as corner conditions, flexural vibrations, rotational edge restraints and continuity in skew plates. It is

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possible that these skew plates have to be provided with cut outs in order to meet some practical requirements. The authors have not come across any work so far which consider the effect of openings on the buckling behavior of skew plates. The objective of this paper is, therefore, to examine the elastic buckling behavior of skew plates containing openings and subject to uniaxial in-plane compressive loading. Holes of circular and skew shapes, plate aspect ratio and position of holes along the center line of the plate are some of the parameters that have been studied. Results are presented in the form of plots which depict the variation of buckling coefficient with different parameters such as skew angle, position of opening and aspect ratio of the plate.

2. Problem definition and scope of the study

Elastic buckling of perforated skew plates subjected to uniaxial end compression along its longitudinal direction is considered in the study. The length of the plate in the longitudinal direction is taken as '*a*' and the breadth in the transverse direction as '*b*' and thickness '*t*'. The critical stress, σ_{cr}, at which instability or buckling occurs, is defined by the average stress equal to the uniformly applied compressive load divided by the area of the plate cross-section assuming no opening within the plate. The critical stress σ_{cr} being a function of plate slenderness (b/t), boundary condition along the plate edges and applied stress distribution it is imperative to consider the effects of these parameters on the buckling behavior of the plate. Failure of these plates under uniaxial compression may be due to instability or material failure. For thin plates having large slenderness (b/t) made from a typical strain hardening material with yield stress σ_y, instability occurs at an average stress σ_{cr} much less than the yield stress. On the other hand, for relatively thick plates having low b/t values instability may occur after the material has reached the yield point and this is referred to as *inelastic* buckling. The edge conditions of the plate have significant influence on the buckling behavior of the plate. It is possible, in practice, to have plates with all edges simply supported or clamped or with combinations of these boundary conditions. For example, all edges could be elastically supported, as assumed in the case of box girder flanges and box columns or three edges simply supported or elastically supported with the fourth edge free as in the case of plate girder flanges. The current study is concerned with the elastic buckling of perforated skew plates.

Analyses by using the finite element software package ABAQUS were carried out on skew plates under in-plane loading

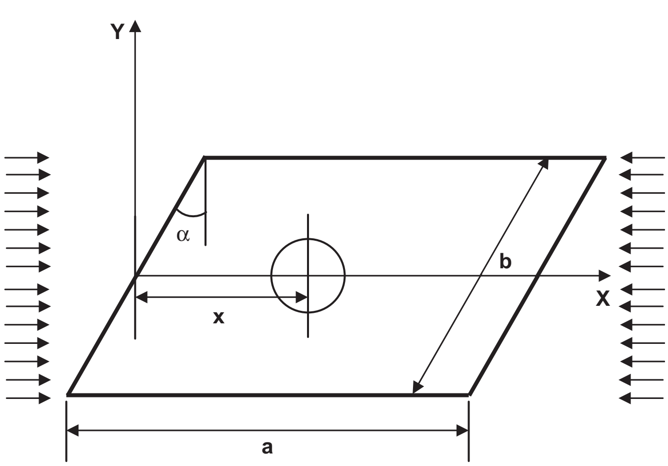

Fig. 1. Typical skew plate with opening subjected to in-plane loading.

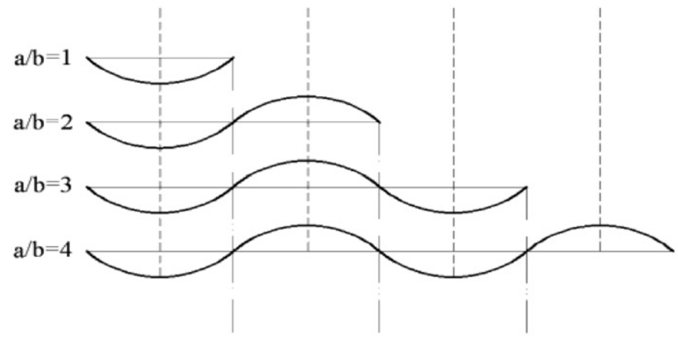

Fig. 2. Fundamental buckling modes for solid plates.

and containing openings of circular or skew shapes as shown in Fig. 1. A number of parameters such as shape, size and position of the openings, plate aspect ratio, simply supported or clamped edge conditions and skew angle of the plates have been considered in the analyses. Openings larger than half the size of the plate are unlikely to be used in practice. The studies were, therefore, confined to cutouts having a maximum diameter or side, equal to half the width of the plate with opening size ranging from 0.1 to 0.5 of the plate width parallel to the transverse edges. The elastic buckling mode of the perforated skew plates and the associated number of half-waves depend on the aspect ratio (a/b) of the plates and location of openings within the plate. Plate aspect ratio (a/b) was varied from 1 to 4 whilst the position of openings was varied along the center line of plate width. Fundamental buckling modes for solid plates with different integer aspect ratios (a/b) are shown in Fig. 2.

3. Assumptions

In order to eliminate or reduce complications in the solution process it is necessary to make some simplifying assumptions. Assumptions made in this study are as follows:

1. The material of the plate is homogeneous, isotropic, elastic and perfectly plastic; the effect of strain hardening is neglected.
2. The stress normal to the mid-plane, σ_z, is small compared to other stress components and may be neglected.
3. Plane sections initially normal to the mid-surface remain plane and normal to that surface after bending.
4. The in-plane displacement in the x and y directions are considered to be very small compared to the transverse deflection in the z direction.
5. In plates with equal length and breadth only a single wave of buckling is considered; however, the plate buckles into a number of half-waves when the length is larger than the width.

4. Method of analysis

Finite Element Method was employed in this study to analyze the elastic buckling behavior of plates skewed in plan. The finite element package, ABAQUS version 6.6 in which both material and geometric non-linear effects can be considered was used. Material non-linearity was modeled using an incremental plasticity theory assuming the material to be elastic–plastic with strain hardening. In ABQUS large displacement analysis is used whenever such behavior is anticipated. In this case, the solution procedure is based on an updated stiffness matrix and changing load vector.