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Parametric instability of laminated longitudinally stiffened curved panels with cutout using higher order FSM

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ABSTRACT

The dynamic instability of longitudinally stiffened panels having rectangular internal cutouts under parametric in-plane loading is studied by using a developed finite strip method (FSM). The loading is considered as uniform stresses throughout the whole area. The effects of perforations on the instability load frequency regions are investigated using the Bolotin's first order method and a negative stiffness modeling approach. In order to demonstrate the capabilities of the developed methods in predicting the structural dynamic behavior, some representing results are obtained and compared with those in the literature wherever available.

1. Introduction

Aerospace and marine structures are two main fields where the structural weight besides the necessary strength is important. Thus, thin-walled structures will usually come to play wherever the weight becomes an issue. Being more efficient, these structural elements could be stiffened by attaching to the stiffeners or some stiffening ribs. These stiffening elements slightly increase the structure weight, but have valuable effects on the structural stability and strength. Furthermore, in the interior parts of such structures, the need for cable and pipe transmission or weight loss will lead to some perforations in the panel. So knowing about the behavior of these structural elements is of high importance. In sizing plate and shell structures, where it is under in-plane loading, the stability becomes a critical design criterion. Under a general in-plane dynamic loading scheme, with a constant mean value and a varying harmonic part with an arbitrary loading frequency, there are situations where the instability conditions may appear. These conditions are termed as the parametric/dynamic instability. These excitation conditions are prevalent in case of mechanical structures as well as fluid-structural interactions.

Previous works on the dynamic instability of complicated models have mainly used finite element method (FEM). Sahu and Datta [1] have utilized FEM to study the parametric instability of perforated panels. The first order shear deformation theory has been used to model the curved panels, considering the effects of transverse shear deformation and rotary inertia effects. The effects of some model parameters on the principal instability regions of curved panels with cutouts have been investigated using Bolotin's first order method. Srivastava et al. [2] have studied the effects of square cutouts and stiffening scheme on the problem of dynamic instability for the case of stiffened plates. A FEM approach has been utilized and a uniform loading scheme has been considered. The same authors [3] have studied the dynamic instability of eccentrically stiffened plates having rectangular cutouts subjected to harmonic in-plane partial loading. They have utilized FEM and extracted the instability regions for different boundary conditions, partial loadings at different locations, cutout size and stiffener parameters using Bolotin's first order method as well as Hill's infinite determinants. The plate has been modeled with nine noded isoparametric quadratic elements considering shear deformation and rotary inertia.

Patel et al. [4] have performed a finite element dynamic instability analysis for stiffened shell panels containing cutouts. The panels have been subjected to uniform in-plane harmonic edge loading along the two opposite edges. The eight-noded isoparametric degenerated shell element and a compatible three-noded curved beam element have been formulated to model the shell panels and the stiffeners, respectively. The first order Bolotin's method has been applied to extract the instability regions.

Recently, the authors of the current paper have developed a semi-analytical finite strip (S-a FSM) formulation as well as a B-spline finite strip (spline FSM) formulation to investigate the parametric instability of composite laminated flat and cylindrical thin-walled structures [5]. The authors have also developed a S-a

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FSM based on the Reddy's higher order shells theory to investigate the parametric instability of moderately thick structures [6]. Furthermore, the dynamic stability of moderately thick cylindrical panels made from FG materials has been studied under in-plane harmonic excitation [7]. The analysis of flat and curved composite panels containing cutouts with different shapes has been performed utilizing two different cutout modeling approaches [8,9]. The buckling stresses, natural frequencies and dynamic instability regions have been extracted for the panels under study.

In the present work an attempt is made to investigate the parametric stability of stiffened shell and plate panels with cutout through the application of finite strip method. Two versions of FSM, namely the S-a FSM and spline FSM are developed and adapted to deal with the stiffened shell models containing cutouts. The formulations are based on the Reddy's type higher order shell theory in order to include the transverse shear stresses effect in case of moderately thick panels. The Koiter–Sanders theory of shallow cylindrical shells is utilized and the loading is considered as a uniform stress distribution throughout the whole panel. The governing equations are derived using full energy concepts (Lagrange's formulation). The instability load frequency regions corresponding to the assumed in-plane parametric loading are derived using the Bolotin's first order method. In line with the previous works of the authors [8,9], the second approach, which is conducted by the multi-part energy integration in the strips longitudinal direction, is utilized in order to model the cutout effects. Also the stiffener effects are considered by satisfying the continuity conditions at the junctions. The equations are solved by using QZ eigen solution algorithm and some sample thin-walled and moderately thick composite panels are studied.

2. Theoretical developments

The structure geometry is assumed to be made up of a series of longitudinal strips. Fig. 1 depicts a general cylindrical finite strip with length L, radii R, width b_s and thickness t. The spline strip is divided into q sections with $q + 3$ calculation knots. The strip is subjected to a uniform time varying longitudinal loading which is assumed to result in a corresponding uniform time-varying stresses throughout the strip. It is presumed that the loading consists of a static (constant) and a harmonically time-varying dynamic component with S and D superscripts, respectively. These load component coefficients can be expressed with regards to the critical static buckling load of the structure, N_{cr}. Thus

$$N_x = a^S N_{cr} + a^D N_{cr} \cos \omega t \tag{1}$$

where ω, a^S and a^D are the excitation frequency, static and dynamic load coefficient, respectively. It is also considered that the strip has a cutout between the L_a and L_b longitudinal positions.

2.1. Displacement functions in the higher order theory

In order to include the effects of through the thickness transverse shear strains as parabolic variation functions of the thickness dimension, a third order Reddy's type algebraic interpolation is assigned for the displacement field approximation. The displacement fields for the case of cylindrical strip can be expressed as:

$$\begin{cases} u(x,y,z;t) = u^0 + \beta_x\left(z + \frac{-4}{3t^2}z^3\right) + \frac{\partial w^0}{\partial x}\left(\frac{-4}{3t^2}z^3\right) \\ v(x,y,z;t) = v^0\left(1 - \frac{1}{R}C_0 z^2 + \frac{8}{R}C_1 z^3\right) + \beta_y\left(-z + 2C_0 z^2 + C_1\left(8 - \frac{1}{R^2}t^2\right)z^3\right) \\ \quad + \frac{\partial w^0}{\partial y}\left(C_0 z^2 - 8C_1 z^3\right) \\ w(x,y,z;t) = w^0 \end{cases} \tag{2}$$

$$\left\{ C_0 = 4R^{-1}\left(-24 + \frac{1}{R^2}t^2\right)^{-1}, \quad C_1 = 4t^{-2}\left(-24 + \frac{1}{R^2}t^2\right)^{-1} \right\}$$

where (u, v, w) are the displacement components of an arbitrary point whilst (u^0, v^0, w^0) are related to the displacements of the corresponding coordinate on the middle surface. β_x and β_y are the rotations of the normal to the mid-surface about the y and x axis, respectively. It is noted that there are five undetermined functions in the displacement approximation Eq. (2). This is the same in the FSDT approach, but the difference is that the HSDT approach has the advantage of not requiring any shear correction factors due to the higher order approximation of shear strains in the thickness direction.

2.2. Mid-surface displacement field

The mid-surface displacement field functions (u^0, v^0, w^0, β_x, β_y) are the same unknown functions designated in the right-hand sides of Eq. (2). The overall functions are considered to be a product of two independent sub-functions in two main directions of the strip (i.e. in the longitudinal and transverse directions in the geometry field) by the time varying function (time field) that is assumed to be of exponential form. The selection of these functions is the major distinction between S-a and spline versions of finite strip method. In case of S-a FSM, the trigonometric functions which present any order of continuity are assumed as the longitudinal approximation functions while a series of Bezier-spline of third order are utilized in the same direction for the spline version (Fig. 1). Representing the in-plane displacement and also rotations across a strip, the linear Lagrange polynomials are used in transverse direction, whilst in representing w^0 the cubic Hermitian polynomial (with displacement as well as slope degrees of freedom) is utilized to support C1-type continuity [9].

The boundary conditions at the two ends are assumed to be of simply supported type for S-a FSM. But the spline version is

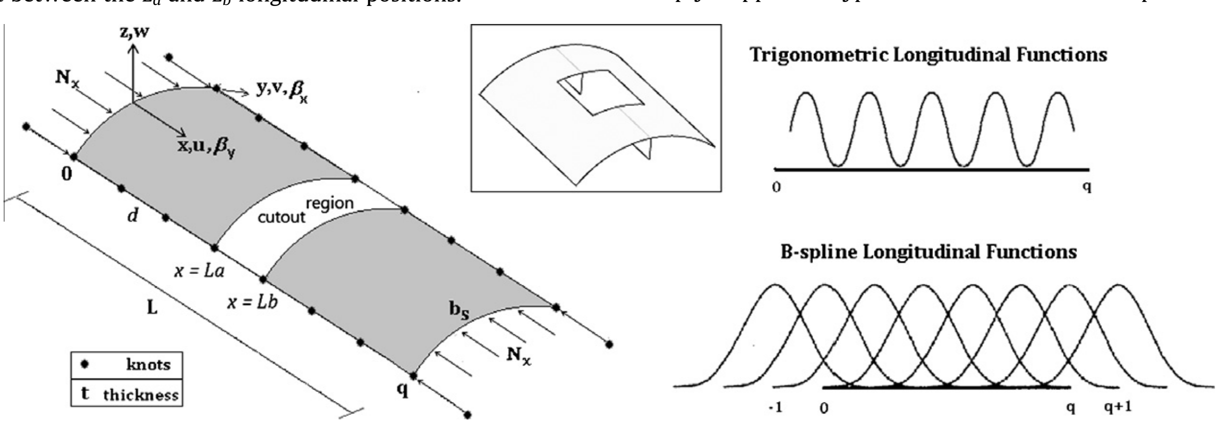

Fig. 1. Geometry, loading configuration and longitudinal approximating functions for a panel and typical strip having cutout.