CHAPTER 3

LITERATURE REVIEW

Rectangular plates with cutouts are used in several engineering applications in the field of marine, aeronautics and mechanical structures. Vibrations of plates with cutouts are often encountered in various engineering practices from baffles in noisy machinery to vibration of aircraft components including the instrument panels.

Studies on static and dynamic characteristics of plates have been carried out extensively in literature. A vast literature exists on the free vibration of rectangular plates with free edges. Except for cases with two opposite edges simply supported, exact solutions do not exist as mentioned in Leissa’s work (1969 & 1973).

Wood (1994) gave a general finite element algorithm and flow chart for the analysis of multi layered composite plates.

K.H.Low (1993) has done useful work on the free vibration of rectangular plate with mounted weights, using equivalent center weight method. The study included the effects of changing the locations of the weights in both the directions on the natural frequencies. The natural frequency of the plate was found to decrease as the weight of the component mass was increased and increase as the mass was moved away from the center of the plate.
Panda and Natarajan (1979) have presented a finite element analysis technique using a super parametric quadratic plate element with 5 degrees of freedom for an arbitrary laminated anisotropic plate for the static deformation studies. The element was proved to be very efficient compared to the elements presented earlier.

Reddy (1993) has proposed layer wise theories for the analysis of composite laminates and evaluated an equivalent single layer composite. The assumption though found to be not very effective, can be used for approximate analysis.

Liew et al (1995) have presented the vibration analysis of shear deformable plates using boundary characteristic orthogonal polynomials. The natural frequencies for various boundary conditions, aspect ratios and thickness ratios are presented to demonstrate the effects of each factor on the vibration frequencies of moderately thick plates.

Kaushal and Bhat (1993) have presented a comparative study of vibration of plates using the finite element method and Rayliegh-Ritz method.

Singh et al (2001) have investigated the natural frequencies of composite plates with random material properties using higher order deformation theory. The composite materials are known to show scattered material properties due to large number of parameters associated with the manufacturing and fabrication processes. An approach has been outlined for obtaining closed form expressions for the variances of eigen solutions. The effects of side to thickness ratio and variation in standard deviation of the material properties have been investigated for cross-ply symmetric and anti-symmetric laminates.
Jenq-Yiing Yang and Lien-Wen Chen (1993) have studied the non-linear large amplitude vibration of initially stressed anti-symmetric imperfect cross-ply laminated plates. A multi-mode solution is formulated for the simply supported imperfect cross-ply laminates and it is found that the existence of geometric imperfections may result in a drastic change in the vibration behavior.

Attempts were made to predict the modal behavior of holed plates, to know about their characteristics, which is of great interest. The dynamic characteristics of plates with cutouts have been studied only by a few, with plates and cutouts of similar nature. The dynamic behavior of plates with multiple cutouts has been the subject of intensive study in the recent past.

A variety of numerical methods have been used to analyze the vibration of rectangular plates with cutouts. The use of Rayleigh-Ritz method with B-spline functions was presented by Misuzuwa (1986), in which accurate values of the natural frequencies of rectangular plates were obtained for different aspect ratios and boundary conditions in comparison with the results obtained by other numerical methods. It was also observed that the Poisson’s ratio significantly influences the natural frequencies of square plates with free edges. However, these studies were confined to plates with rectangular and circular cutouts only.

The natural frequencies and mode shapes of plates with interior cutouts were studied by Monahan et al (1970), using the finite element analysis and experiments using holographic interferometry and are found to be in good agreement.

Asku and Ali (1976) have studied the dynamic characteristics of mild steel rectangular plates based on the variational principles in the two dimensional finite difference scheme for one or two cutouts and verified
experimentally. The cutouts have considerable influence on the natural frequencies and the mode shapes. The theoretical natural frequencies obtained were found to be lower than the experimental values and the differences were found to increase for the higher modes due to the increased complexity in the mode shapes.

Lee et al (1990) have presented a simple numerical method based on the Rayleigh quotient for predicting the natural frequencies of the fundamental and some higher modes of a rectangular plate with an arbitrarily located rectangular cutout. The edges of the cutout were parallel to the edges of the complete plate. The nodal patterns of these higher modes were pre-selected based on the symmetry of the mode shapes about the geometrical axes. The method was applied to the study of linear vibration of rectangular plates simply supported along one pair of opposite edges with any other boundary conditions at the remaining edges. The predicted results were compared favorably with the corresponding results produced by a variety of numerical methods such as Rayleigh-Ritz method presented by Thakahashi (1958) and Basdecas and Chi (1970). However, these were confined to plates with rectangular and circular cutouts.

Ali and Atwal (1980) have presented a simplified method based on Rayleigh's principle, for the dynamic analysis of plates with cutouts. Although the method is general, its application was demonstrated for the case of simply supported square plates with square and rectangular cutouts only. Results obtained by the application of this method to plates with different size cutouts were compared with the results obtained by the application of the finite element technique.

Beslin and Gayader (1996) have proposed ectoplasm to predict higher order eigen frequencies and mode shapes using Hamilton principle with a
functional basis to remove ghost modes which are obtained due to the non-uniqueness of the problem for plates with cutouts and simple supports. The study revealed that for small size holes, a decrease of stiffness is the main effect and the eigen frequencies shift towards lower frequencies and the tendency gets reversed for larger sized holes, the decrease of mass dominates the decreasing stiffness.

Huang and Sakiyama (1999) have worked on the free vibration analysis of rectangular plates with variously shaped holes such as circular, semi-circular, elliptical, rectangular, triangular rhombic etc. by an approximate method. A hole in a plate can be considered as an extremely thin part of the plate and the plate can be considered as a plate with non-uniform thickness.

Lam et al (1989 & 1995) have evolved an efficient and accurate numerical method to study the vibration of rectangular plates with cutouts and non-homogeneity by using a boundary characteristic polynomial function in the Rayleigh-Ritz procedure. The total domain of the plate is divided in to smaller areas and used a modified form of the Rayleigh-Ritz method.

Mundkur et al (1994) have studied the dynamic characteristics of a square plate with a square cutout using boundary characteristic orthogonal polynomial function in the Rayleigh-Ritz method. Results for plates with different boundary conditions were tabulated. The trend for the first six frequencies was discussed in all these cases. Reasons for disagreement between the finite element method and the method presented were discussed.

Ganesan and Nagaraja Rao (1985) have reported the dynamic analysis of isotropic plates with cutouts. The variations of natural frequencies for square plates with single square cutout for different aspect ratios were studied.
The natural frequency analyses of orthotropic square plates with centrally located single square cutout and different modular ratios were presented for simply supported and clamped edge conditions by Rajamani and Prabhakaran (1977). Symmetric laminates are analytically considered as homogeneous anisotropic plates and the effect of cutout is considered equivalent to an external loading on the plate. The reports conclude that natural frequencies for each mode vary with cutout factor in different ways and do not uniformly increase or decrease.

A simple and accurate two-step (global/local) Ritz method for calculating the static response of stepped, simply supported, isotropic and composite plates with circular and elliptical cutouts was studied and developed by Kapania et al (1997).

Wang and Wu (2002) have presented an effective numerical technique for determining the optimal location of a cutout in rectangular Mindlin plates for maximum fundamental frequency. Instead of the finite element method, which requires remeshing and redefining the connectivity for each iteration, the study has used the Ritz method and the sensitivity of the fundamental frequency to the location of the cutout is investigated.

Sakiyama et al (2003) have discussed the free vibration of orthotropic square plates with a square hole using an approximate method. The square plate with a square hole was transformed into an equivalent square plate with non-uniform thickness by considering the hole as an extremely thin part of the equivalent plate. The dynamic characteristics of a plate with a hole were obtained by analyzing the equivalent plate. The Green function, which is the discrete solution for the deflection of the equivalent plate, was used to obtain the characteristic equation of the free vibration. The effects of the side to thickness ratio, hole side to plate side ratio and the variation of the thickness on
the frequencies were considered. Numerical analyses are carried out for the simply supported orthotropic square plate with a square hole. The efficiency and accuracy of the numerical solutions by the method have been investigated.

Liew et al (1989) have studied the effect of fiber orientation, plate aspect ratio and boundary conditions using plate functions in the Rayleigh-Ritz procedure. The vibration analysis of shear deformable plates formulated on the basis of first order Mindlin theory was presented. The displacement and rotational functions of the plates were approximated by sets of boundary characteristic orthogonal polynomials. The ease of generation and manipulation of these polynomial functions greatly enhances the computational efficiency of the numerical method. The energy functional of the shear deformable plates derived from the Mindlin plate theory is minimized in the Ritz procedure to arrive at the governing eigenvalue equation. Corresponding natural frequencies and mode shapes can be obtained by solving the eigenvalue equation. Computed frequency results for various boundary conditions, aspect ratios and thickness ratios were presented to demonstrate the effects of each factor on the vibration frequencies of moderately thick plates. Vibration mode shapes in the form of contour plots were presented for a thickness ratio of $t/b = 0.1$.

A composite rectangular plate with an elliptical cutout was optimized based on the free vibration response using the genetic algorithm by Sivakumar et al (1997 & 2002).

Malhotra et al (1998a) and (1998b) have investigated the effects of the fiber orientations and boundary conditions on the vibration of orthotropic square plates with single centrally placed square cutout of different sizes. The boundary conditions include all sides clamped, three sides clamped and one side free, two sides clamped and two sides simply supported, three sides clamped and one side simply supported and all the four sides simply supported.
Viswanath (1999) has reported the dynamic analysis of an aircraft panel board made of 2mm thick aluminium alloy. The first three natural frequencies were determined for the panel board without cutouts and masses, with cutouts only and with cutouts and masses. Optimization of the panel board to avoid certain frequency ranges were attempted using uniform and non-uniform thicknesses of the panel board.

From the above literature review, it can be concluded that efforts are being made to study the effects of single and multiple cutouts, fiber orientations, layer arrangements and boundary conditions on the free vibration characteristics of orthotropic plates. However, no specific conclusions are arrived yet due to the complexity in assessing the material and elastic properties of the composites to predict their behavior to free vibrations.