CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a comprehensive review of the literature dealing with various studies carried out on perforated plate for static, nonlinear, vibration and shock analysis. Many classical books are available on the theory of plate and shell. Compilation of structural responses like displacements and stresses for various configuration of plate and shell for various loading and boundary conditions and which can be used as ready reckoner to arrive at the responses are available and the one authored by Young (1989) has been frequently used. Similarly Blevins (1978) contains the compilation on natural frequencies and mode shapes of plate and shell.

The transient interaction between a flexible structure and the surrounding infinite medium using Doubly Asymptotic Approximation (DAA) approach has been investigated by Geers (1978); Geers and Felippa (1983); Geers and Zhang (1994a; 1994b). These publications give qualitative and quantitative estimations of Fluid Structure Interaction (FSI) of components of spherical geometry immersed in water. The superiority of second order DAA over the first-order DAA technique has been explored as well. Namkoong et al. (2005) have applied P2P1 Galerkin finite element method to Navier-Stokes equation in conjunction with the Arbitrary Lagrangian-Eulerian (ALE) technique for solving FSI problems. The effect of Reynolds’ number, geometry, damping, fluid density and fluid viscosity have been studied. It has been concluded in this paper that the added mass is linearly proportional to the fluid density but independent of fluid viscosity. While using finite element solution for dynamic problems involving elastic structure and fluid, pressure and displacement are taken as unknown parameters and the disadvantages in each case have been discussed in an article appeared in the “letter to the editor” by Everstine (1981). A velocity based finite element formulation is recommended in lieu of pressure based finite element formulation in this study by author.
In case of shell with stiffener, Prusty and Satsangi (2001) carried out static analysis by applying improvement over the degenerated shell concept. The new method to calculate stiffness matrix of arbitrary oriented stiffeners in the plate element on the basis of equal displacements at the junction of plate and stiffener is adopted for static analysis. The authors have used eight nodded shell and three nodded curved element for stiffener.

The detailed review of literature related to the present study has been given under subsequent subheadings viz., perforated plate, vibration of plate and underwater explosion.

2.2 PERFORATED PLATE

Usages of ‘unit cell’ concept and ‘equivalent solid method’ concept have been widely employed for estimating the structural response of perforated plate. The circular perforation geometry with regular penetration pattern for the in-plane loading has been investigated by many and has been reported. However, Imaizumi et al. (1993) have studied the irregular penetration pattern and the procedure for evaluating real stresses has been devised through stress multiplier factor and nominal stresses using equivalent elastic constant method. The deflection and stress estimated from numerical results are validated with the experimental methods. Jones et al. (1999) have developed an algorithm to extend the concept of EQuivalent Solid (EQS) method of perforated plate for elastic-perfectly plastic material and demonstrated this aspect with a number of example problems. Hauptmann et al. (2001) have brought out advantages of “solid-shell” element over the conventional shell element, for the application of metal forming and impact analysis involving large stretching and bending with small radii. Harnau and Schweizerhof (2002) also have discussed the characteristics of “solid-shell” elements including locking phenomenon and in order to avoid the effects of transverse shear and membrane locking, assumed strain method has been proposed. Cantemir et al. (2004) have used equivalent solid method for analyzing perforated plates in the finite element modeling and simulation. The equivalent solid method has been employed for the estimation of equivalent material property for the triangular penetration pattern. In order to compute stresses in the perforated plate with this method, the weakening effect of
holes has been described in terms of the ratios of the elastic properties of perforated and solid plates.

Most of the reported numerical analysis have been carried out using the finite element software ANSYS (2004). The influence of various finite elements on the analysis of perforated plate has been discussed for specific boundary conditions and loadings. Kaap et al. (1997) have discussed the finite element modeling of perforated plates using ANSYS and dynamic effective stiffness has been estimated. SHELL63 element gave better performance in the prediction of static deflection and mode frequencies for solid plate, whereas SHELL93 element has been found suitable for perforated plate. In case of vibration problems, dynamic effective stiffness has been reported to be more appropriate than equivalent static stiffness. Webb et al. (1995) have used unit cell concept for regular perforated plate and have used solid brick shaped module of an equivalent anisotropic plate in lieu of isotropic perforated plate. Stress multiplier factor has been used to predict the behavior of plate on the periphery of perforations for square and triangular patterns. Cantemir et al. (2007) also used the concept of unit cell and also applied equivalent solid method. The ratio of elastic properties, Young’s modulus and Poisson’s ratio for a perforated plate and a solid one have been used in stress estimation.

Perforated plate modeling and analysis using finite element method is illustrated in this paper. However Prabu et al. (2004) have applied the concept of unit cell in the metal matrix composites to analyse the effects of volume, fraction, fiber shape, fiber distribution and matrix on stress and strain status as well as potential damage to fiber cracking or interface debonding. A thick plate with large number of holes has been analysed by David and Hoshi (1983) using an equivalent homogeneous material with numerically modified effective elastic constants and yield stress. Maiorana et al. (2009) have dealt with the perforated plates subjected to in-plane compressive loads. Four nodded plate element has been used for the numerical analysis. Elastic instability has been studied for square and rectangular plate with centralized or eccentric circular holes.

The nonlinear analysis of perforated plate has been dealt by Paik (2007) with parametric study on perforation dimension using ANSYS and he has come up with the predominant status of ultimate strength over buckling strength. The author has derived an empirical
formula for first-cut strength estimates in reliability analysis. Suneel et al. (2007) have discussed the ultimate strength analysis using nonlinear static method with ANSYS. With proper validation and convergence studies, authors have extended the study to stiffened plate with opening. Using Statistical Package for the Social Sciences (SPSS), regression analysis has been carried out and design equations are developed and reported. The dynamic behavior of perforated plate submerged in water has been studied by Jo and Jo (2006a). The authors have brought out the difficulty to model perforated plate submerged in fluid and an attempt has been made to make an equivalent solid model with effective elastic constants. In order to study the impact analysis on perforated plate, Guo et al. (2003) used LSDYNA (2007) tool. Investigation has been focused on the usage of shell elements compared to conventional modeling with solid element for thin target plates. The behavior of the perforated plate at elevated temperature has been analysed by Nakamura et al. (2003) with equivalent solid material and validated with experimental results.

2.3 VIBRATION OF PLATE

Literature available on dynamic analysis of perforated plate is only a few. Peter (2001) has given an elaborate experimental procedure for the determination of the vibration characteristics of a plate. Chen et al. (1994) have developed a spline compound strip theory for the free vibration analysis of one directional stiffened and cross stiffened plates. The outcome of this method is in good agreement with that of experiment and analysis using finite difference method.

The easiness in usage of finite element method and computational effectiveness of the finite element formulations for free vibration analysis is brought out by Singh and Smith (1994). Four general finite element formulations viz., h – formulations, p – formulations, exact and mixed formulations and the dynamic element formulation have been discussed for simple cases like undamped, linear beam, frame and truss systems. From the studies based on these formulations, the relevance of free vibration analysis of slender structures like ship and submarine has been emphasized. George (1970) has studied slender structure like ship on flexural vibrations due to underwater explosion. The effect of
parameters like charge composition, weight, stand off distance, and volume of explosion bubble have been considered in this study. The principal mode patterns are verified by independent experiments. While carrying out dynamic analysis of this type of water backed structures, the added mass becomes a very important factor. Hagedorn (1994) brought out the difference in natural frequency for a plate ‘in vacuum’ and for water backed condition. An exact solution method is formulated to include “added virtual mass factor” in this study. Hence thrust has been given to estimate the added mass. Equations are formulated for different configuration of the plates and are tabulated by Blevins (1978). However such details are not available for perforated plates. Sinha et al. (2003) have brought out an approximate method to arrive at the effect of added mass and damping for plate and for perforated plate. The effect of perforation on these two factors has been brought out. The validation is done with experimental approach. The effect of damping becomes negligible while water medium is considered as incompressible. Considering the difficulties with perforated plate and surrounding fluid medium, Jo and Jo (2006b) have restored to finite element method and solution is arrived at using ANSYS. The free vibration analysis of perforated plate submerged in fluid is modeled using elements SHELL63 and FLUID80 of ANSYS. Authors have attempted to place an equivalent solid, considering weakening effect of perforations.

While considering acoustic transmission and reflection characteristics of submerged plates, Nedwell et al. (1989) used plane wave theory to determine transmission and reflection coefficient. The authors have considered elastic properties of material and have verified these experimentally. The scattering of waves at the edge of the panel and boundaries of the tank are also considered. An experimental method of transmission coefficient is presented.

2.4 UNDERWATER EXPLOSION

The literature available on the study of air blast and the subsequent loading sequence and after effect on the structures has been reviewed. Nagesh (2005) has brought out with brief introduction on the propagation of pressure wave due to air blast at near field and far field. A typical solid plate with unstiffened and stiffened condition has been
considered for the finite element analysis and the responses are compared with those available from experimental method. However less number of literature are available on the study of underwater explosion and corresponding damage potential for the structures surrounded with water. Cole (1948) has brought out the theory of explosion with sequence of events in underwater explosion, its initial conditions and the dynamical properties of water in his text book. The author has used propagation theories to establish hydrodynamic relations for shock waves. He has performed detailed evaluation of shock wave propagation, and described the features of shock waves and stated a comparison of various shock wave theories. The author has given details on measurement of underwater explosion pressure using various equipments and provides photographs of various explosion cases. Details regarding motion of gas sphere, secondary pressure waves and surface effects of underwater explosion are also given. Similar studies are carried out by Singh (1982) for the propagation and attenuation of spherical shock waves in water using Whitham’s method and Energy Hypothesis method. This theoretical study is validated experimentally and concluded that energy hypothesis method is more realistic towards experimental one.

Mair (1999a) has discussed four hydrocode methodologies based Lagrangian, Eulerian, Coupled Eulerian – Lagrangian (CEL) and Arbitrary Lagrangian – Eulerian formulations to deal with Fluid Structure Interaction. It has been concluded that ALE is best suited to study structural response to underwater explosions from among the four. Similar results are reported by Kim and Shin (2008) on the application of ALE technique for an underwater structural design problem and they have concluded with the suitability of ALE based code to evaluate structural damage due to underwater explosion. Their investigations extended to the numerical experimentations with various mesh densities for finite element models at sea water and the explosives. The reported research are on the air backed structures like ship and submarine pressure hull structures rather than water backed structures like sonar dome. For example, Liang and Tai (2006) have developed a procedure to examine the transient responses of a ship hull subjected to noncontact underwater explosions. They have coupled the nonlinear finite element method with DAA method. The transient dynamic effect, geometric nonlinearities,
elastoplastic material behavior and fluid-structure interaction have been considered in the formulation. The authors have concluded the importance of Keel Shock Factor (KSF) to describe shock severity considering various charge weights, distance and incident angle. They obtained acceleration, velocity and displacement time histories due to underwater shock at different locations. Ramajeyathilagam (2000) has described various FSI techniques that can be applied to shock related problem and explained structural analysis methodologies under shock loads. The author proposed mathematical formulation of the problem for nonlinear dynamic analysis and proposed elastoplastic model for dealing with material nonlinearity. He has also explained the failure criterion in detail. The importance of FSI interaction on submerged structure was also brought out by Lai (2007). Transient dynamic analysis of a spherical shell with an opening and exposed to underwater explosion is carried out. The effect of stand off distance and shock waves in sea and in air are compared. In order to carry out experimental study for the failure of air backed structure, Explosive Bulge Test (EBT) is a standard procedure to be followed and Keith (2007) has studied on air backed ship like structures for a given underwater explosion and EBT experiment has been carried out on sample plates using Tri Nitro Toluene. The author has also discussed various numerical solvers available on FSI problems and recommendations are given for usage. Rajendran (2009a) has provided a method to carryout numerical study of the air backed plate for explosion bulge test. The outcomes of the numerical investigations are experimentally validated.

A number of commercial software packages are available to deal with underwater explosion problems along with FSI. Mair (1999b) has attempted the comparison of DAA and various hydrocodes like DYNA, FSI ADINA, USA, DYNA3D, LSDYNA, MSC DYTRAN. Shin and Santiago (2002) have used USA code coupled with NASTRON CFA code for underwater shock problems. The fluid cavitation effect has been studied on the surface ship modeling and method of avoidance / implementation of cavitation has been suggested. They have recommended for the inclusion of cavitation effect within the DAA boundary.

Many of the studies are based on sample specimen of circular and rectangular plates for air backed conditions whereas those on water backed structure are only a few. Rajendran
and Narasimhan (2006) have developed mathematical models for circular and rectangular plates. It is observed that maximum von Mises stress for rectangular plate is 1.132 times more than that of the circular plates and this has been validated with experiments. Detailed phenomena of reloading effects on a circular and rectangular air backed plates are enumerated by Rajendran (2008). The author has also brought out that the cavitation and gas bubble loading are part of reloading. Damage due to reloading is maximum and equal to that of primary shock loading for a depth of explosion that is twice the stand off. The phenomena of air and underwater explosions and their effects on plates have been brought out by Rajendran and Lee (2009) in a detailed review. Various phases of the explosion have been discussed thoroughly. On study of potential damage due to air backed and water backed condition, Rajendran and Lee (2008) have brought out the damage potential due to noncontact underwater explosion for air and water backed plates. The analytical approach is adopted to find out maximum velocity and displacement of the plate for the two conditions. The authors have concluded that water backed plates attain a maximum kick off velocity of 65% to that of air backed plates and 50% displacement to that of air backed plates. Rajendran (2009b) has discussed on the effect of coupling factor and its influences on shock factor. The concept of shock factor is introduced for inelastic damage of target plate. This is applied for air backed and water backed plates for comparison. It is concluded that inelastic deformation undergone by the water backed plates is significant in comparison with that of the air backed plates. Comparison of air blast and underwater explosion has also been made by Lal and Rajesh Kumari (2004). The authors have brought out a method to correlate shock decay pattern of air blast and underwater explosion using bulk modulus of medium. This has been experimentally validated.

In order to study the effect of underwater explosion using numerical methods, many authors used different software existing in this field. MSC Dytron and UNDEX were among the few of such software used during initial days. Peiran and Arjaan (2006) have described the method to carry out simulation of underwater explosion for air backed structures using MSC Dytron. The procedure is compared with UNDEX and advantages of MSC Dytron are brought out. Now a days, software such as ABAQUS and LSDYNA
are used for the study of underwater explosion. D’Souza et al. (2006) have used ABAQUS to study the stresses in the water backed structure due to underwater explosion. An overall concept on the modeling and methodology on the design of sonar dome has been presented. The design and analysis have been based on with the finite element analysis software package ABAQUS. This model includes water flooded compartment and exterior fluid region where FSI is relevant and the stress field in the structure has been examined. Ma and Andrews (2001) brought out the pros and cons of cavitations in the underwater explosion scenario and also highlighted various methods of implementation while using LSDYNA software. The investigation using LSDYNA includes variety of explosives, its orientation, stand off distance and results are established with validation through experiments. Adamik et al., (2004) have discussed the effect of orientation of charges; and suitability of Jones – Wilkens – Lee (JWL) method as Equation Of State (EOS) for TNT, and ideal gas equation for air. The outcome of the analysis using LSDYNA has been validated with experimental results. The study is based on air blast waves. A brief summary on advantages and disadvantages on Eluerian and Lagrangian codes have been given. Vulitsky and Karni (2009) have used LSDYNA for the shock analysis of air backed ship structure. EOS of JWL has been used for high explosive TNT. They also brought out the limitations of carrying out shock analysis in two stages. A quarter of the physical problem was made in LSDYNA and physical quantities such as stresses, displacements etc have been computed. Urtiew et al. (2008) investigated pressure gauge data during shock initiation process with explosive Composition B and Composition 4 (C4). They used modeling and then experimentally validated pressure. Sourne et al. (2003) have studied the structural response of submarine for underwater explosion using LSDYNA and has been experimentally validated. The various effects of shock wave and bubble pulsation on ship structure have been studied. The response parameters viz., deflection and stresses are the output from the analysis. Hung et al. (2009) have analysed cylindrical shell structures for underwater explosion and experimentally validated. Three structures with varying stand off distance have been analysed. It is concluded that the response received by structure in shallow depth gives less energy and smaller strains.
Few authors have studied the effect of underwater explosion for the fiber reinforced composites and sandwich structures. Batra and Hassan (2007) have discussed the effect of underwater explosion load to fiber reinforced composites. The structural damage due to fiber breakage, matrix cracking, fiber or matrix debonding and delamination have been studied. The results give preliminary information on composite structure’s design for maximizing the energy absorption and hence increasing structure’s resistance to blast loads. Similarly, Qiu et al (2003) have analysed sandwich beam for pressure due to shock loading and compared with that available in literature. The effect of material elasticity and strain hardening of steel on the beam response have been studied and the influence of the core of sandwich beam on dynamic response has also been brought out.

2.5 COMMENTS

Knowledge and information base are available in the form of several text books and volumes of research publications in analysis of plate and shell structures. But the source is not exhaustive as far as perforated plates are concerned. A definite dearth of research especially regarding the assessment of behavior of structural components constituted with PP subjected to underwater explosion has been felt. From the review of literature the extensive application of finite element method for the structural analysis has been noted and relevance of experimental investigations for the validation has also been felt. Application of finite element software ANSYS for the structural analysis and ANSYS LS-DYNA for shock analysis have been recognized by the earlier authors. Based upon these observations, the objective of the present investigations have already been set as the numerical investigations on PP and PPL using ANSYS and ANSYS LS-DYNA and experimental investigations on PPL using shock tank facility.