CHAPTER - 2

Review of Literature

This chapter deals with review of the research on buckling behaviour of stiffened panels, which has been conducted in recent years by using analytical method experiment work, finite element method (FEM) and development of other Methods. The review chapter also deals with post-buckling behaviour of fiber-reinforced polymers (FRP) stiffened panels with delamination-damage under compression and shear load. Many experimental and analytical studies have been performed on the pre-buckling and post-buckling behaviour on laminated composite panels under axial compression. Most of the researchers have worked on the composite stiffened panel with application of blade-type, I-section, T-section and J-section types stiffener. A very few literatures are available on trapezoidal type stiffener of the panels with respect to the specific depth of stiffeners but variation of depth of stiffener has not been included in parametric studies on buckling behaviour of composites panel by 3D-FE method.

2.1. Methods for Buckling Analysis of Composite Structure

Many different methods have been applied by researchers to find a more efficient solution of the laminated composite stiffened panel. **Xu et al. [2]** presented the detailed studies on buckling of laminated composite stiffened structures under different loading conditions. The review has been done on basis of different methods of analysis of composite panel. **Ni et al. [3]** presented a broad research review on the buckling behaviour of different stiffened structures. The review has been seperatly classified on the basis of applications of methodology for analysis of the different types of the structures as follows:

- Application of Analytical Method
- Experimental and Computational Method
- Application of Finite Element Method
- Development of other Methods.

2.1.1 Application of Analytical Method

Stroud and Anderson [4] studied the numerical formulation to find the buckling of blade type, hat-stiffeners, and corrugated stiffened panel. Smeared stiffeners technique was used to analyze the laminated composite panel under various type of in-plane loading with different types of stiffener **[5]. Wang [6]** employed a power series method in the non-linear analysis of circular plates subjected to uniform radial compression on the edge. In the advanced post-buckling stage, the plate was subjected to a high circumferenential compressive stress in the region near the edge, which induces the plate to buckle for the second time with an asymmetric deformation mode. **Makeev and Armanios [7]** presented an iteratve method for an approximate analytical solution of elasiticity problems in laminate composites. The stress analysis was performed for laminates in the three dimensional strain state independent of the longitudinal direction. **Loughlan and Delaunoy [8]** analyzed the buckling of stiffened panels under edge loads, shear and combination of compression-shear load using finite strip technique. The buckling strength of stiffened panel has been also analyzed by considering parameters like pitch length, stiffener size, and fiber orientation. **Barbero et al. [9]** investigated laminated composite plates and presented a numerical analysis of the connection between them. The orthotropic surface of FRP materials was modeled by using two-friction coefficients (orthogonal) and applying the constitutive law. **Hadi and Matthews [10]** studied to predict the buckling load of a sandwich panel. Parametric studies have been presented by the analytical method and compared with symmetric angle-ply laminated faces, anisotropic faces and (00/core/00) of sandwich panels. **Rikards et al. [11]** performed buckling analysis of stiffened structures by developing a triangular FE. Natural frequencies and buckling loads of stiffened panel are obtained from the present numerical analysis. **Guo et al. [12]** studied the buckling response of stiffened panels under uniaxial compression by using a layer-wise FE formulation. Parametric studies of stiffened panels were presented for skin thickness to length ratios, ply configuration, stiffener depth to skin thickness ratios and panel aspect ratios. **Bisagni and Vescovini [13]** used T-shaped stiffeners in the composite panel as shown in Figure 2.1, to study its local buckling and the post-buckling analysis by using an analytical method. Total potential energy (V) of the stiffened panel is due to plate bending (V_d) and stiffeners torsion(V_d^s) (Bisagni and Vescovini [13]):

$$V = V_d + V_d^s$$

$$V = \left[\frac{1}{2}\int_s \left(-\sigma t w_{/x}^2 + D_{11} w_{/xx}^2 + 2D_{12} w_{/xx} w_{/yy} + D_{22} w_{/yy}^2 + 4D_{66} w_{/xy}^2\right) ds\right]$$

$$+\left[\frac{1}{2}\int_0^a GJ * w_{/xy}^2 dx\,|_{y=0} + \frac{1}{2}\int_0^a GJ * w_{/xy}^2 dx\,|_{y=b}\right] \quad (2.1)$$

And the critical buckling stress (σ) of orthotropic laminated plate is estimated as

$$\sigma = \frac{\pi^2}{t}\left[\left(\frac{m}{a}\right)^2 D_{11} + \left(\frac{a}{m}\right)^2 \left(\frac{1}{b}\right)^4 D_{22}\xi_2 + \left(\frac{1}{b}\right)^2 (D_{12} + 2D_{66})\xi_3\right] \quad (2.2)$$

where D_{ij} (i,j=1,2,6) represents the bending stiffness of laminate, t is thickness of panel, a is length of panel in unloading side and b is length of panel in loading side, w represents out of plane displacement, GJ^* represents half of the stiffeners torsional rigidity, m is number of half waves in longitudinal direction and ξ_2 and ξ_3 are correction factors determined by boundary condition of panel and torsional rigidity of stiffeners. **Ruocco and Fraldi [14]** presented an analytical method for prediction of the buckling of plates with mixed boundary conditions. Separation of variables method was adopted

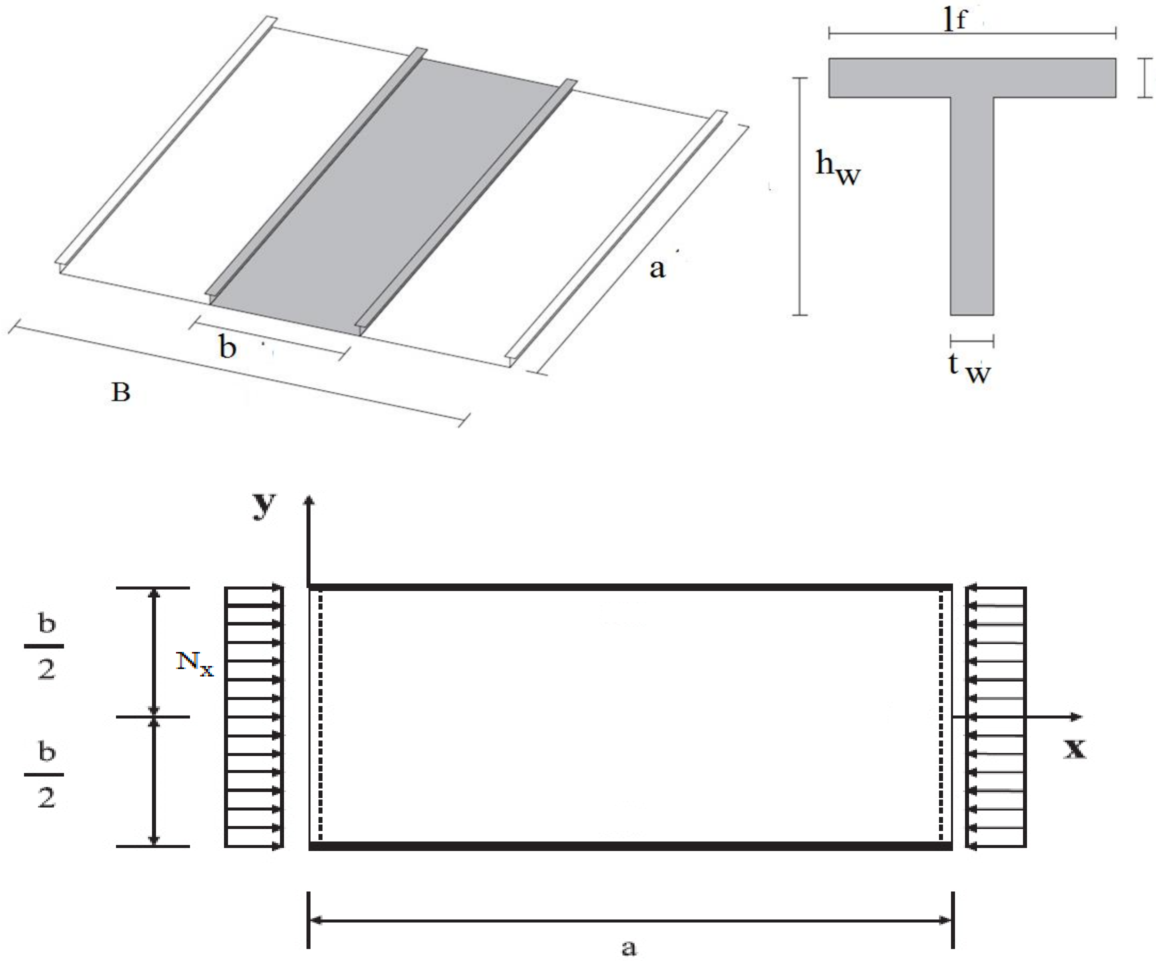

Figure 2.1 Configuration of the panel with T-shaped stiffeners used by Bisagni and Vescovini [13].

to solve the partial differential equation by introducing the displacement field. Exact buckling load was determined due to biaxial compressive loads with mixed boundary condition. **Dung and Hoa [15]** presented the effect of impact number and stiffeners dimension on the buckling and failure strength of cylindrical shell structures due to torsion by using an analytical method. Numerical formulations are derived with an application of classical shell theory and smeared stiffeners technique. **Girish and Ramachandra [16]** presented numerical results of symmetric $0^0/90^0/0^0$ and antisymmetric $0^0/90^0$ cross-ply laminated panels subjected to edge loads, temperature field and initial imperfection. **Dey and Ramachandra [17]** derived the governing partial differential equations describing the post-buckling response of sandwich panel with the application of minimum total potential energy. Numerical results were also exhibited for both flat panels and cylindrical sandwich panels under various non-uniform in-plane edge loading. **Liu et al. [18]** investigated the influence of cohesive parameters on the post-buckling pattern of composite structures subjected to compressive load by 3D FE analysis. The delamination behaviour was studied using parameters of cohesive strength, cohesive shape, and cohesive element thickness. Deformation at delamination stage was found to be non-linear which considerably affected the fracture process zone. In fracture zone, nonlinear deformation was observed during delamination phase between the local buckling and the global buckling. Nonlinear global stiffness equation has been assembled by Liu et al. [18] as:

$$\mathop{A}_{e=1}^{n_{bulk}+n_{coh}}[(K_T + K_C)\Delta U] = F_{ext} - F_s - F_c \quad (2.3)$$

$K_T = K_0 + K_L + K_\alpha$

where, K_T (bulk elements) = elastic stiffness (K_0) + geometry stiffness (K_L) + large displacement stiffness (K_α), K_c (cohesive elements) = stiffness tensor, ΔU = node displacement increment, F_{ext} = external force vector, F_s = node force vector (bulk elements), F_c = node force vector (cohesive elements), n_{bulk} = number (bulk elements) and n_{coh} = number (cohesive elements).

2.1.2 Experimental and Computational Method

Kong et al. [19] studied analytically and experimentally on the two-laminated composite panel using blade-shaped stiffeners and I-shaped. Detailed study was carried out to show the influence of ply orientation and stiffener shaped on buckling strength and failure load of the stiffened panels. **Giannopoulos et al. [20]** presented the numerical study on an Inorganic Phosphate Cement pedestrian bridge and correlated corresponding deformation with experimental results. **Broekel and Prusty [21]**

conducted experimental study on laminated composite structures subjected to uniform transverse loading and compared with FE analysis results. **Bisagni and Cordisco [22]** carried out experimental work on buckling and post-buckling for cylindrical shell panels. Shell panels were designed with different ply orientation and skin thickness for post-buckling application. **Zimmermann et al. [23]** performed experimental studies on buckling behaviour of stiffened panels with different skin thickness and a number of I-shaped stiffeners. The experimental results are compared with computational results obtained from ABAQUS. **Pevzner et al. [24]** proposed an extended effective width method to study the torsion, bending and buckling of curved stiffened panels with T-shaped and J-shaped stiffeners. Also, finite element result was found in good agreement with experimental work. **Orifici et al. [25]** conducted experimental work and numerical investigations on collapse behaviour of stiffened structures for damage growth between skin and stiffeners. The pre-damaged panels are manufactured by changing adhesive between skin and stiffener with a full-width Teflon strip. Undamaged panels were studied to predict the collapse load with the application of ply failure degradation model and global-local approach. **Elaldi [26]** studied composite stiffened panels through experiments and compared post-buckling capacity of structural efficiency of hat-shaped and J-shaped stiffened panels. **Perret et al. [27]** carried out post-buckling analysis to predict the numerical models of composite fuselage panel by experimental work. Two Digital Image Correlation systems were placed on both the sides of the panel to obtain out of plane displacement that was aimed to correlate between numerical and experimental results. **Falzon and Faggiani [28]** presented genetic algorithms and numerical results with ABAQUS for optimization of the global-local modeling of the I-shaped stiffened panel. Global buckling and post-buckling results were validated by experimental results. The solution of the global buckling was used to derive the local model to predict the debonding between skin and stiffeners. **Takeda et al. [29]** fabricated Carbon Fiber Reinforced Plastics (CFRPs) stiffened panel by VaRTM and presented buckling behaviour of the panel subjected to compressive loading by using Fiber Bragg Gratings (FBGs) sensors and strain gauges. **Blazquez et al. [30]** studied the buckling response of stiffened panel with varying thickness, ply orientation and shape of the stringers. A FEM model has been developed by ABAQUS software to predict the pre-buckling behaviour of the panel with the application of solid elements for modeling of adhesive layers between skin and stiffeners. Buckling mode shape 2 to 30 modes are taken for analysis of stiffened panel. **Boni et al. [31]** developed a validated procedure of modeling strategies. Pre-buckling and post-buckling simulation were done by the commercial software ABAQUS. The strains from FEM are compared to the strain gauge readings at mid-bay between the stiffeners and the buckling phenomena are identified by strain-load curves. **Reinoso et al. [32]** used ABAQUS software with a local-global approach for comparing sub-modeling and shell-to-solid modeling techniques, and for global modeling of panels with shell element, typology was applied. **Liu et al. [33]** performed an experimental study of buckling behaviour and failure mode of the stiffened panel with M-type stiffeners subjected to compressive loading. Numerical simulation was used for predicting buckling and post-buckling behaviour of the panel and it was compared with experimental results. **Zhu et al. [34]** conducted experimental work to study the buckling load and failure load of I-section composite laminated stiffened panel subjected to compressive loading. For this study, stiffened panels were manufactured with different plates and stiffeners. The effect on buckling strength of stiffened panels were studied and compared with FEM results by varying the plate and stiffener thickness. **Riccio et al. [35]** presented inter-lamina damages propagation in composite stiffened structure. The delamination growth between skin-stringer in the stiffened panel was investigated in ABAQUS using cohesive elements parameters under compressive load. **Borrelli et al. [36]** investigated kinematic coupling approaches for buckling behaviour of laminated stiffened structures. Stress distributions have been compared at domains interfaces with the results obtained from the model with mesh continuity and merged modes.

The experimental studies have been carried out on graphite-epoxy blade stiffened composite panels subjected to axial compression load at the Aircraft Structures Laboratory of the Technion, Israel Institute of Technology and observed that all of the specimens were buckled at approximately the similar buckling strain **[37]. Wang et al. [38]** studied on two I-shaped stiffened panel as shown in Figure 2.2 to find out their buckling load and ultimate load carrying capacity. The numerical results were correlated with experimental results up to the buckling and the collapse load. The multiple delaminations between skin and stiffeners had also been shown by post-buckling failure

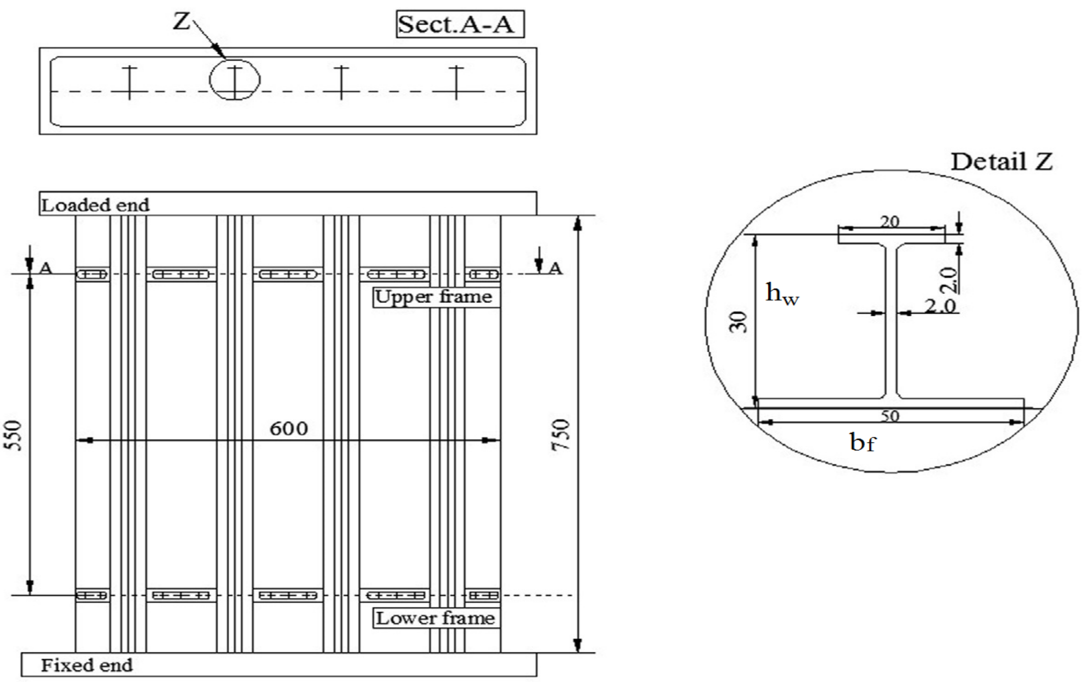

Figure 2.2 Configuration of stiffened panel with I-shape stiffeners used by Wang et al. [38].

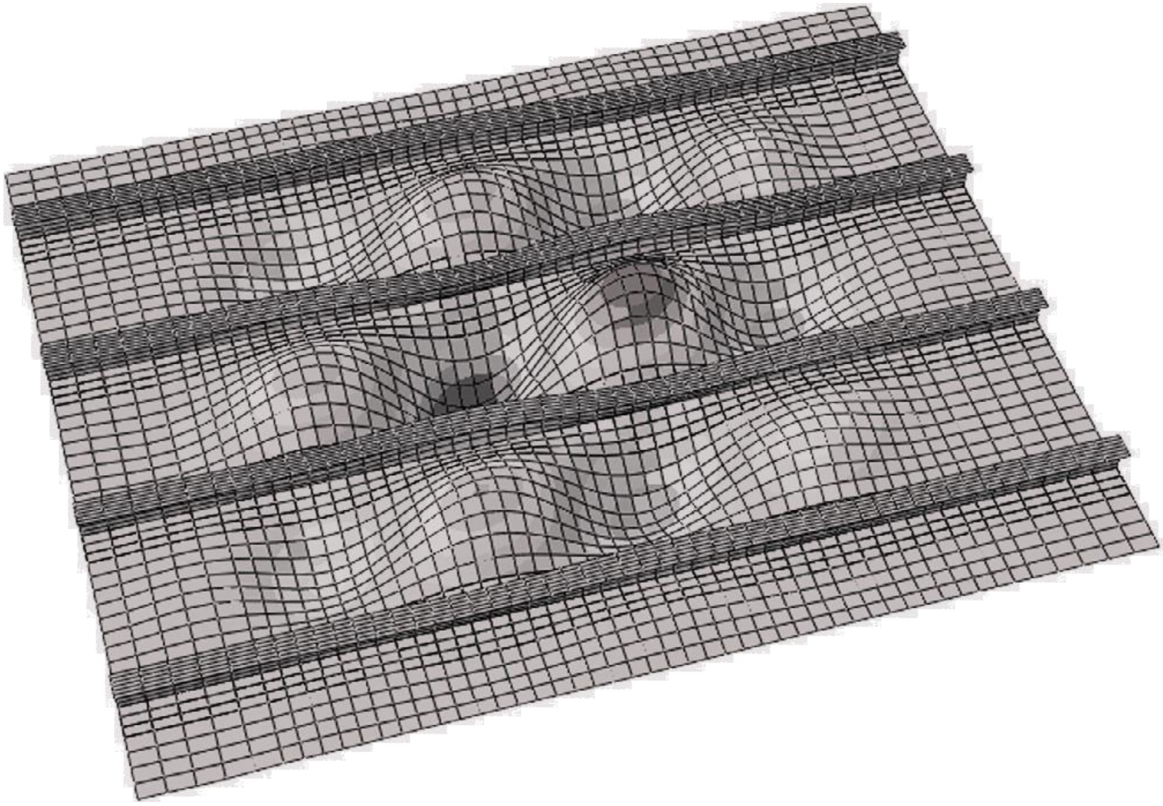

Figure 2.3 The deformed shape of 1st mode buckling by Wang et al. [38].

pattern. The deformed shape of the first buckling mode is shown in Figure 2.3 with six buckling waves situated in the part of the skin of the panel. **Lanzi [39**] carried out experimental studies on composite stiffened structures subjected to axial load for post-buckling behaviour, damage and failure mechanisms leading to collapse. In the case of good bonding, delaminations and fracture in the skin were caused due to severe stress concentrations in the stiffener flanges at these locations.

2.1.3 Application of Finite Element Method

Kalyanaraman and Upadhyay [40] discussed the behaviour of FRP box girders and proposed a computationally efficient method to study the single cell FRP box-girder bridges made with angle-shaped, T-shaped or blade-shaped stiffened panels using FEM based software ANSYS. **Mallela and Upadhyay [41]** performed a parametric study of the laminated stiffened panel under in-plane shear. Models were analyzed using FEM based software ANSYS and a database was provided for various skin-stiffeners combination. Few parameters are identified based on the buckling response of the stiffened panel. **Mallela and Upadhyay [42]** presented parametric studies on simply supported laminated blade type stiffened panel under linearly varying in-plane loading by changing the panel orthotropy ratio, smeared extensional stiffness ratio of stiffener to that of the plate and load distribution factor**. Rahimi et al. [43]** analyzed the buckling response of shell structure due to stiffeners subjected to axial compressive load by ANSYS software. **Tserpes et al. [44]** presented numerical buckling analysis of stiffened panel under compressive load and determined state of strain of the stiffened panel. The stiffened panel was modeled by using ANSYS SHELL63 element. Fiber sensors were engrained into the stiffened panel to capture the developed strains during delamination of stiffened panel under compressive load, hence reducing the risk of fiber damage. **Huang et al. [45]** computed the performance of stiffened panels using FE technique and arbitrated the accuracy of proposed model. Parametrical studies were performed to assess influence of skin thickness, stiffener spacing and stiffener depth on the buckling strength of grid panels. **Fathallah et al. [46]** studied the optimization of ply orientation and number of layer of composite structure with T700/5505 Born and others laminated composite materials to find the minimum buoyancy factor for composite elliptical submersible pressure hull. ANSYS software was used to perform the analysis and optimization of laminated composite structures. **SudhirSastry et al. [47]** performed the analysis of buckling of laminated stiffened panels using ABAQUS based on FEM with carbon fiber and others composite materials. Square stiffened panel was fabricated with plies of 8 layers for plate and plies of 16 layers for different shapes of stiffeners. The variation of the numerical results of stiffened panels were analyzed and correlated with the experimental results. The linear buckling analysis (pre-buckling analysis) as the eigenvalue problem was estimated by SudhirSastry et al. [44] as:

$$\left([K_0] - \lambda[K_p]\right)\{x\} = 0 \tag{2.4}$$

where, $[K_0]$ is stiffness matrix, $[K_p]$ is geometrical stiffness matrix, λ is critical loads and $\{x\}$ is eigen-vector. **Yetman et al. [48]** studied the hat-stiffened panel to provide an efficient structure and observed debonding between stiffener and plate. It was found that the position and debonding size influence the mode of damage of stiffened panel significantly. Buckling capacity of top-hat-stiffened structures was computed considering debonding between the skin and the stiffener. A non-linear FE model was employed to work out parametric studies on influence of both delamination and failure modes of the geometry of panel.

The influence of imperfection shape and amplitude on critical loads of laminated composite cylindrical shells was investigated. It was determined that the initial geometric imperfections have a more effect on the dynamic buckling of the shells, but the sensitivity to initial geometric imperfection depends on the ply configuration of the laminated shells **[49, 50].** It was determined dynamic buckling loads of an aluminum externally stiffened cylindrical shell structure with application of finite element and found that the initial geometric imperfections and half-wave sine shape load have more effect on the dynamic buckling of the shell structure **[51]. Farooq and Myler [52]** studied failure prediction of laminated composite panel with damage due to low velocity impact by using ABAQUS software. Known damaged size and shape was inscribed at different positions in the laminated panel to predict buckling load on the basis global-local buckling approach with mixed-mode buckling. The buckling load was predicted for eight, sixteen and twenty-four ply laminated composite panel with considering failure and ply level strength.

The critical buckling load was correlated well corresponding to soft-inclusions to predict ply level failure of eight, sixteen, and twenty four ply laminates against the data available in the literature. It was obtained the imperfections lead to a significant reduction in the final collapse load of the complex steel silo transition junction structures but the amplitude of the imperfection has small influence on the collapse load of the structure **[53, 54].** The influence of the heat-affected zone on the buckling and post-buckling have been performed to determine the post-buckling behaviour and ultimate strength of stiffened aluminum plates subjected to axial compression **[55, 56].** The initial imperfections had not important role on the buckling behaviour and collapse of the some structures but the critical buckling loads had been determined of the optimized flat and curved composite plates with a geometric imperfection subjected to shear and in-plane loading **[57, 58].** The influence of stiffeners to increase the buckling capacity of plates without increasing the plate thickness was performed and it was also determined that by addition of stiffeners a flat rectangular plate, its critical shear stress had increased. Increase of the buckling strength depends on the number of stiffeners, types of stiffener and aspect ratio of the panel **[59]. Fenner and Watson [60]** performed buckling analysis on a stiffened panel by using the finite element (FE) program MSC NASTRAN and proposed the influence of fillet radius along the line junction between the stiffener webs and skin on buckling of the panel. Early the buckling capacity was significantly enhanced by addition of the fillet radius. The buckling capacity was improved by 1.8% with an increase of 5 mm fillet radius for ratio of breadth to thickness of skin portion of 100. The maximum buckling capacity was increased by inducing helical rib or hoop rings to the cylinder, but number of helical rib was greater influence than inducing number of hoop rings for buckling capacity of the structure. **Mostafa and Waheed** [61] presented parametric studies on the buckling analysis of the laminated composite stiffened panel**. Zingoni and Balden [62]** carried out a numerical study on the buckling behaviour of light weight stiffened elliptic parabolic steel panels proposed for various application of floors, walkways and lightweight concrete bridge decks. It was found that the buckling capacity of the panel depend upon on the increase of (h/b) of the panel. **Sidharth [63]** studied the corrosion effect on plates with application of FE analysis technique. The progressive failure of panel and damage in the post-buckling regime of the stiffened panels were presented including matrix cracking, fibre failure and shear failure between fibre-matrix **[64]**. **Satishkumar and Paik [65]** determined the buckling loads of plates subjected to uniaxial compressive load, biaxial compressive load and in-plane shear by using a finite element method based on hierarchical trigonometric functions. The ultimate strength reduction characteristics of plate structure were investigated considering cracking damage at different location by application of ANSYS nonlinear finite element analyses **[66]**. **Morozov et al. [67]** carried out a parametric analysis to determine the influence of the length of the shells and orientation of the helical ribs on buckling of composite cylindrical lattice shells under different types of loading. To assess the influence of initial geometric imperfections and boundary conditions on the dynamic buckling capacity. A wide range of parametric numerical dynamic buckling analyses of a laminated composite stringer-stiffened curved panel had been performed under an axial impact load with application of ANSYS.

Parametric studies of stiffened steel panel under axial compression **[68, 69]** as well as combination of uniaxial compression and bending moment **[70]** were carried out to determine the different parameters for buckling behaviour of the panel. A parametric study was conducted to check the influence of geometrical parameters on the buckling load for different types of cylindrical stiffened composite panels. The effect of various parameters like panel geometry, stiffening shape, static and dynamic load factors and boundary conditions were considered in buckling and dynamic instability analysis of stiffened panels under uniform in-plane periodic loads along the boundaries **[71, 72]**. A parametric study had been conducted to find the permissible spacing of intermittent fillet welds to prevent the local buckling of structural members and early failure of the whole stiffened panel **[73].** Parametric studies were performed for local shear buckling of thin walled structures **[74]** and to study the influence of important design parameters on the pre buckling load of stiffened composite panels **[75]**. **Mahapatra and Panda [76]** investigated the nonlinear free vibration behaviour of the laminated composite spherical shell panel under the elevated hydrothermal environment by he concept of FEM based on higher-order shear deformation theory. **Sridharan and Zeggane [77]** analyzed local buckling and overall buckling in stiffened plates and cylindrical shells with application of a specially formulated shell element, which had additional degrees of freedom to generate and control the relevant local buckling modes together with the associated second order fields.

Cohesive elements have been taken to build an accurate and realistic post-buckling model for prediction of realistic behaviour in the post-buckling region of a stiffened composite panel and debonding between skin and stiffener **[78]**. **Nayak et al. [79]** investigated a nine-node plate bending element with assumed strains based on a refined higher order theory, which considers the effect of initial stresses in the dynamic analysis of plates, to determine the small deflection transient response of composite sandwich plates due to initial stresses effect. **Xie and Ibrahim [80]** analyzed buckling mode localization in rib stiffened plates with randomly spaced stiffeners. The finite strip method was given satisfactory results for studying the localization phenomenon in buckling models of rib-stiffened plates. A smeared model has been developed to solve the buckling problem of a grid-stiffened composite cylinder, by considering influence of moment and different types of geometric of the stiffeners [**81-82].** The buckling of flat and curved panels was analyzed under different types of loading condition for optimized distribution of Shape Memory Alloy fibers **[83].** Numerical model was developed to simulate the dynamic response of the laminated composite glass panel subjected to blast loading **[84**].

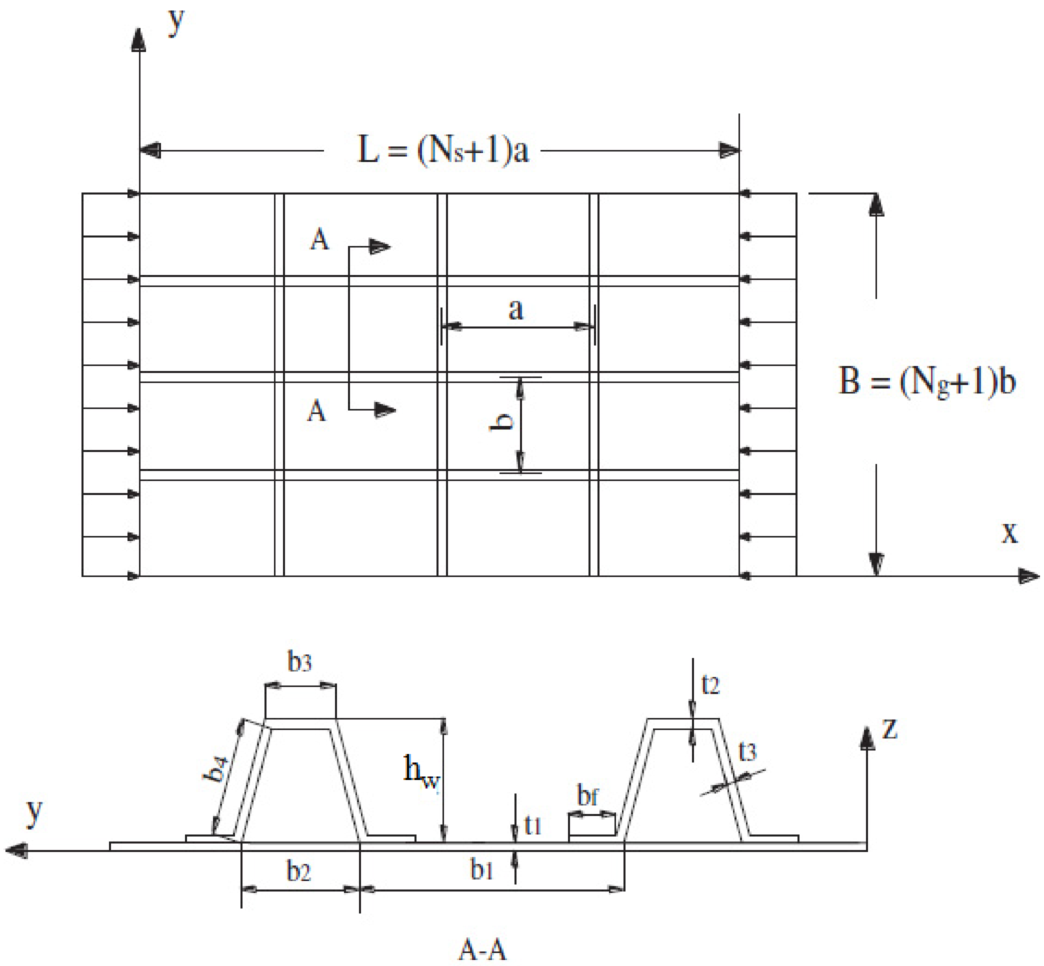

Figure 2.4 Configuration of stiffened panel with hat stiffeners used by Yang et al. [86].

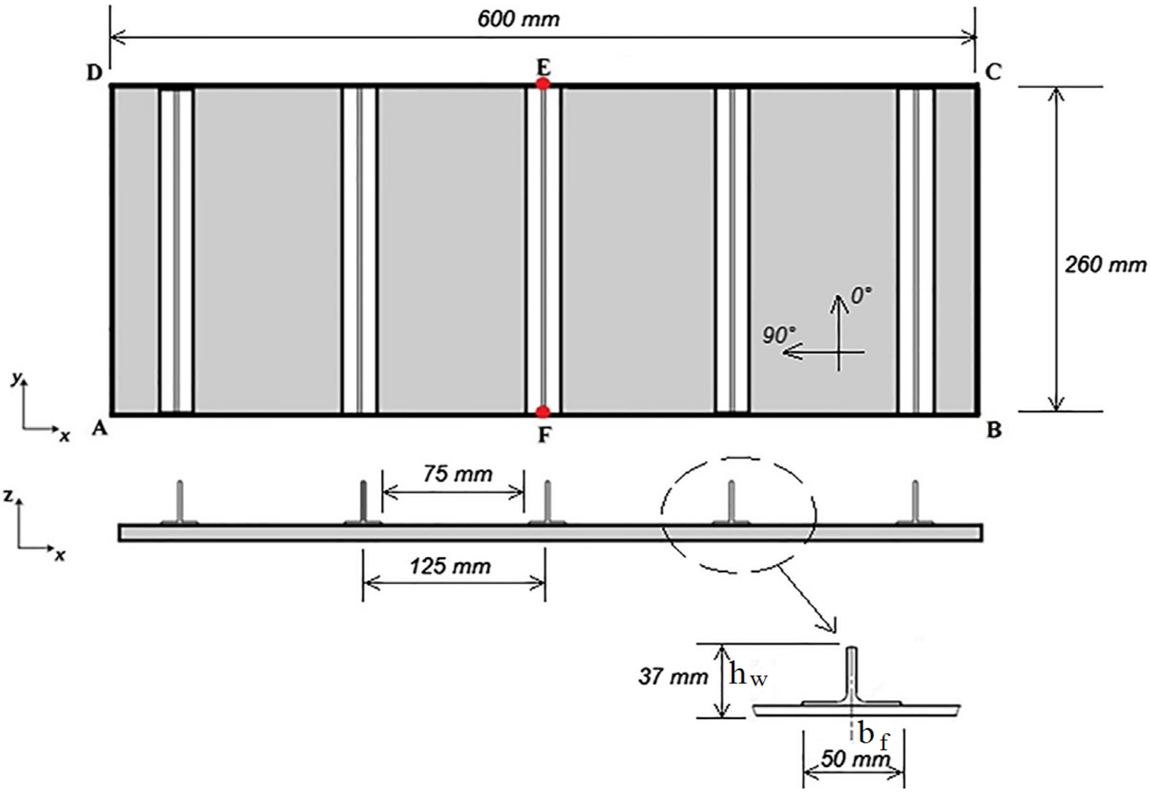

Figure 2.5 Configuration of the panel with blade-shaped stiffeners used by Romano et al. [88].

2.1.4 Development of other Methods

Chen and Soares [85] presented reliability assessment of the post-buckling capacity of composite structures subjected to axial compression. The post-buckling capacity structure was predicted by a progressive failure analysis (PFA). Parametric studies were performed on composite stiffened panels to find out the post-buckling capacity improvement with increasing thickness of the panels. **Yang et al. [86]** presented the reliability assessment of the buckling capacity of top-hat stiffened panels under uniaxial compressive load. A reliability method is used to design the laminated stiffened panel as shown in Figure 2.4. **Riccio et al. [87]** proposed novel numerical methodology, by which the compressive response of composite panels with skin-stiffener separation was predicted successfully. The same methodology was used to test single stiffener composite panels. Response of buckling of the stiffened panels with debonding between skin-stiffener was confirmed by comparisons with a load-displacement curve and debonding size at failure. **Romano et al. [88]** used PFA methodology for the post-buckling analysis of damaged composite panels and studied its final failure response. In addition, its collapse load was also calculated accounting damage at different locations. Geometry of the stiffened panel with blade-shaped stiffeners is shown in Figure 2.5.

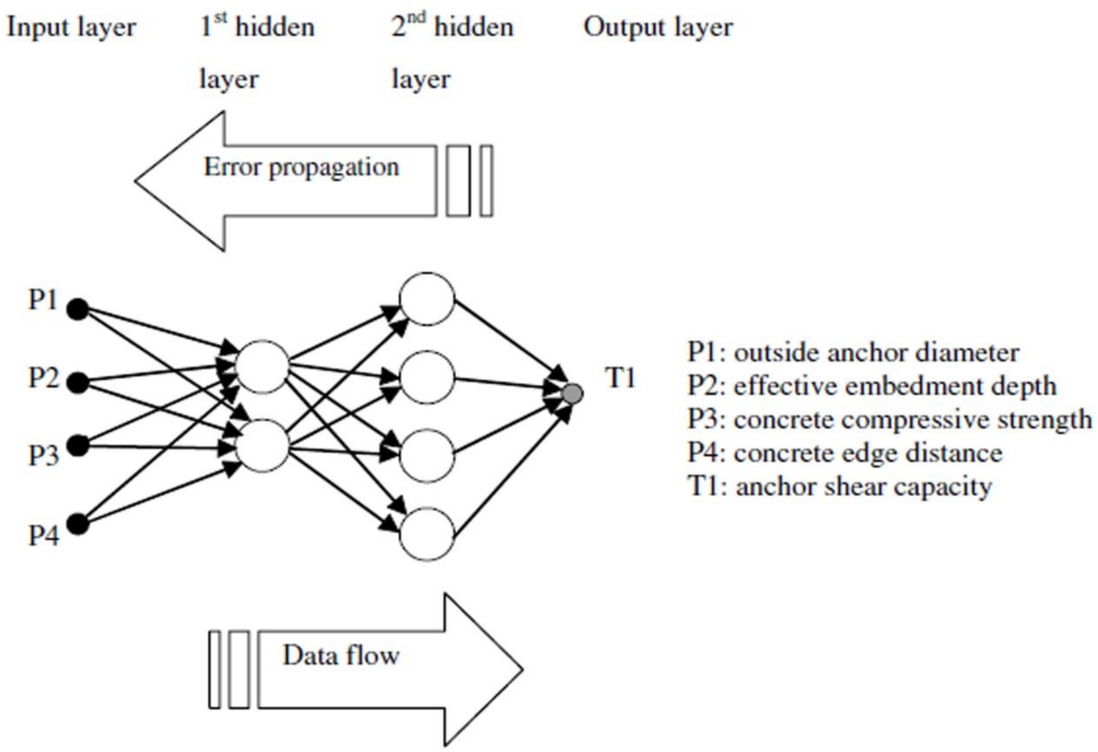

Figure 2.6 Architecture diagram of 4-2-4-1 neural network by Alqedra and Ashour [93].

A review work of thoughtfulness showed the various philosophies of ANN prediction in the area of laminated composite property, design and optimization **[89,90**]. **Mallela and Upadhyay [91]** used artificial neural network (ANN) to obtain an analytical tool for the prediction of the buckling capacity of laminated composite stiffened panel under shear load. The results of ANN were in good correlation with FEM results of shear buckling of stiffened panels. **Rogers [92]** developed a guideline for designing and training an ANN to simulate the structural analysis program. **Alqedra**

and Ashour [93] performed ANN to study the significant parameters on the concrete shear capacity of anchor bolts. Few researchers have used ANNs for predictions of the behaviour of laminated composite materials [**94**]. The neural network is a computational technique, which was inspired by the working pattern of human biological brains **[95-96]**. Multilayer feedforward networks are universally accepted and gives result in the desired accuracy with a specific sense [**97-98].** Results from one hidden layer were given desired output with different weight value connection for continuous function but the selection of the second layer for the discontinuous function **[99]**. The hidden layer can be one or more than one, but there is no fix theory for selection of hidden layers. The hidden layer should contain a total number of neurons was equal to the one greater than twice the number of input parameters and some cases the hidden layer selection based quality and quantity of the training data **[100]**. Some situation the multi hidden layer was given better result over the single hidden layer**[101-102]**. **Chakraborty [103]** developed an optimum network with application of computational tool (ANN) for predicting of the presence of a delamination of laminated composite panel at different location along with its shape and size from FE analysis generated input data (natural frequencies). Hundreds FE models were analysised to generate input data of natural frequencies and these data were used to train the network for achieving optimum network architecture to predict the presence of a delamination as shown in Figure 2.6.

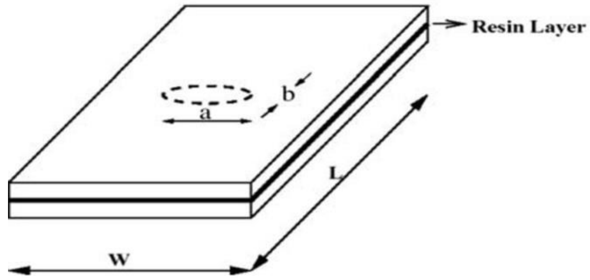

Figure 2.7 Plate made with plies and resin layer used by Chakraborty [103].

Table 2.1 Literature Review and Research Gap

Author	Type of stiffeners	Methodology / Tool	Type of loading	Limitations
Stroud and Anderson [4]	Blade-type T-Shaped, Angle-type, Hat-stiffener	Analytical formulation by using Classical Plate theory.	Axial compression load	• Smeared stiffeners technique • Fixed depth of stiffener. • Material: Carbon fiber composite and Aluminum • B.C: Simply supported all sides.
Stroud et. al [5]	Blade-type, T-Shaped, Angle-type, Hat-stiffener	Engineering Analysis Language based on FE	Axial compression load	• Eigen value FE analysis • Fixed depth of stiffener. • Material: Carbon fiber composite and Aluminum • B.C: Simply supported all sides.
Guo et al. [12]	Blade-type,	Layer-wise finite element formulation	Axial compression load	• Parametric studies have been presented for different plate aspect ratios, ply orientations, and fixed stiffener depth to plate thickness ratios. • Material: Carbon fiber composite • B.C: Simply supported all sides
Bisagni and Vescovini [13]	I-Shaped, T-Shaped	Analytical solution based on Kirchhoff and Ritz Method.	Axial compression load	• Fixed depth of stiffener. • Material: Carbon/epoxy, isotropic • B.C1: Simply supported all sides • B.C2. Simply supported along loaded edges and

Author	**Type of stiffeners**	**Methodology / Tool**	**Type of loading**	**Limitations**
				clamped along unloaded edges
Falzon and Faggiani [28]	I-Shaped	Experimental (Strain Gauges) study and Genetic algorithms	Axial compression load	• Delamination damage skin–stiffener interface. • Fixed depth of stiffener. • Material: Carbon/epoxy with same skin • B.C: Mixed boundary condition.
Takeda et al. [29]	Blade-type	Experimental study (Strain Gauges)	Axial compression load	• Impact damages and debonding between skin-stringer. • Fixed depth of stiffener. • Material: Carbon fiber composite • B.C: Clamped for the loaded edges and free along unloaded side.
Blazquez et al. [30]	I-Shaped, T-Shaped, Angle-type, Hat-stiffener	Experimental study (Strain Gauges) and ABAQUS	Axial compression load	• Delamination damage skin–stiffener interface. • Fixed depth of stiffener. • Material: Carbon fiber composite and Aluminum • B.C: Simply supported two sides.
Boni et al. [31]	I-Shaped	Experimental study (Strain Gauges) and ABAQUS	Axial compression load	• Co-related experimental results with FE results of stiffened panel. • Fixed depth of stiffener. • Material: Carbon fiber composite and Aluminum

Author	Type of stiffeners	Methodology / Tool	Type of loading	Limitations
				• B.C: Fixed two sides.
Falzon and Faggiani [28]	I-Shaped	Experimental study (Strain Gauges) and Genetic algorithms	Axial compression load	• Delamination damage skin–stiffener interface. • Fixed depth of stiffener. • Material: Carbon/epoxy with same skin • B.C: Mixed boundary condition.
Liu et al. [33]	Hat-stiffeners	Experimental measurement (optical measurement)	Axial compression load	• Effects of ply orientation • Fixed depth of stiffener. • Material: Carbon/epoxy with same skin • B.C: Fixed upper and bottom.
Zhu et al. [34]	I-Shaped	Experimental study (Strain Gauges) (optical measurement)	Axial compression load	• Buckling load is not increased with increase depth of stiffener • Fixed depth of stiffener (33 mm, 38 mm, 43mm). • Material: Carbon/epoxy with same skin • B.C: Fixed upper and bottom
Riccio et al. [35]	Blade-type	Experimental study (Strain Gauges)	Axial compression load	• Skin–stringer debonding growth in the stiffened panel • Fixed depth of stiffener (14mm, 28.9 mm). • Material: Carbon fiber composite • B.C: Different types of B.C.

Author	Type of stiffeners	Methodology / Tool	Type of loading	Limitations
Wang et al. [38]	I-Shaped	Experimental study (Strain Gauges) and Numerical analysis by ABAQUS	Axial compression load	• The multiple delaminations during failure pattern. • Fixed depth d = 30 mm of stiffener. • Material: Carbon fiber composite and Aluminum • B.C: Clamped at bottom and at the top and simply-supported (SS) along the side.
Mallela and Upadhyay [41]	Blade-type	FE analysis by ANSYS 7.1	In-Plane shear load	• Parametric Study on the panel. • Fixed depth of stiffener varried. • Material: Carbon/epoxy with same skin. • B.C: S.S. all sides.
SudhirSastry et al. [47]	Blade-type I-Shaped, T-Shaped	FE analysis by ABAQUS	Axial compression load	• Comparative analysis with application of different material for skin and stiffeners. • CFC/epoxy, E-glass/epoxy, Kevlar/epoxy • B.C.: Clamped along loaded edges and SS along unloaded edges.
Yang et al. [86]	Hat-stiffener	Navier grillage theory and first-order Reliability Methods	In plane compression load	• Buckilng analysis of the panel with safety index. • Fixed depth of stiffener (39 mm). • Material: E-Glass-Epoxy • B.C: Different types of B.C.

Author	Type of stiffeners	Methodology / Tool	Type of loading	Limitations
Romano et al. [88]	Blade-type	FE analysis by MSC Nastran	Axial compression load	• Progressive failure analysis (PFA) methodology • Fixed depth of stiffener (37 mm, 50 mm). • Material: graphite–epoxy composite • B.C: Different types of B.C.
Mallela and Upadhyay [91]	I-Shaped	ANSYS 7.1 Matlab ANN	In-Plane shear load	• Parametric Study on the panel. • Fixed depth of stiffener varried. • Material: Carbon/epoxy with same skin • B.C: S.S. all sides.
Chakraborty [103]	Laminated plate	ANSYS 7.1 Matlab ANN	Dynamic load	• To predict the presence of a delamination at different location along with its shape and size • Input data (natural frequencies. • Thickness of palte = 2.54 mm • Material: Carbon/epoxy with same skin

Among the range of available non-gradient method, the genetic alogarithm (GA) is one of the most popular non-convex global search techniques **[104, 105].** A genetic algorithm is a computerized optimization algorithmbased on the principals of natural genetics and natural selection. GA makes use of probabilistic transition rules and derivatives of objective function are not needed. The essential steps in GA are reproduction, crossover and mutation. A possible solution to the problem is represented by a bit-string manner. An initial population is generated by random selections of the individual bits in the binary strings of a given length. Reproduction is a process in which individual strings are copied according to their objectve function values. A crossover operator is mainly responsible for the search of new strings (a new solution of the given problem). The opration of mutation safeguards against a premature loss of the genetic information. **Rao and Pan [106]** located the discrete optimal actuator lacotions in controlled stuctures within the framework of a wide range of other stuctural optimization problem. The GA had been successfully used to solve a wide range of the structural optimization problems **[107-112]. Galante [113]** developed a new approach based on GA for design optimization of truss stuctures. **Madhusudan et al. [114]** obtained the post buckling behaviour of a cantilever column with variable cross-section and subjected to the combined of concentrated load and distributed axial load. **Ghanem and Francesco [115]** proposed a wavelet-based solution procedure for the solution of a class of non-leaner differential equations of interest in engineering mechanics. **Goldberg and Kuo [116]** applied GA in the steady state optimization problem of the liquid pipeline. **Keane [117]** used the Genetic procedure for optimization of a multi-diminsional problem where in the geometrical parameters are the design variables and the band avaraged noise transmission is the object function. **Friswell et al. [118]** determined damage location in the structures using GAs. **Yin [119]** used the genetic alogarithm for polygonal approximations of digital curves by minimizing the number of sides of polygon. **Rafiq and Southcombe [120]** reported the optimal design and detailing of reinforcements in the biaxial bending of columns using a genetic alogarithm. **Goldberg [121]** developed more conventional optimization and search procedures in many ways by using genetic alogarithms. **Dimou and Koumousis [122]** proposed a GA based on approach and used it to two differrent problems. They have also dertemined the effect of genetic alogarithmparameters on the results of the proposed scheme. **Botello et al. [123]** presented the performance of GA in the optimization of pin joined steel bar structures for optimum design of truss structures.

2.2 Research Gaps in the Study

From the above review of literature (Table-2.1), it has been observed that the substantial research work have been carried out on the panels which are manufactured with laminated composite materials and stabilized with different shape of stiffeners to attain lightweight structures with superior buckling capacity. Guidelines for design of FRP panel are not available which assume importance for further study on computation of buckling strength and failure load of the stiffened panel. Therefore, it is important to give emphasis on parametric studies (ratio of smeared extensional stiffness of stiffener to that of skin, stiffener depth to plate thickness, orthotropy ratio of the panel, variation of pitch length stiffeners, depth of stiffeners and skin with different plies configuration) for determination of buckling capacity and failure load of the stiffened panel. Also, a database is not provided for maximum buckling capacity of the hat-stiffened panel with different inclination of trapezoidal type of stiffener (hat-stiffener) panels with variation different parameters like panel orthotropy ratio and smeared extensional stiffness ratio of stiffeners to that of skin, pitch length of stiffeners and depth of stiffeners with different plies configuration.

2.3. Research Objectives

This Chapter reviewed the existing research works on the behaviour of FRP stiffened composite panels with I section, T section, hat stiffeners and blade type stiffeners of the panel. It is observed that buckling load of the panels is not increased with unnecessarily increase of the depth of I section, T section, and blade type stiffeners of composite panels. In this context, it is important to study further the optimum depth of stiffeners of FRP stiffened panels to provide maximum buckling load and economical panels. Most of the researchers have worked on I section, T section, hat stiffeners, and Blade type stiffeners panel. However, a very few literature is available on trapezoidal type stiffener (60^0-hat-stiffened and 75^0-hat-stiffened) of the panels. It is also observed that effect of variation of depth of trapezoidal hat-stiffener on buckling behaviour has not been reported in the literature. On the basis of literature review and problem description, the following parametrical study has been considered for study of the FRP hat-stiffened composite panels by FE analysis, ANN and experiment.

1. Determination of optimum depth and pitch length of the trapezoidal type (hat-stiffener) to prevent the local buckling of the stiffened panel for different orthotropy ratio D_1/D_2 of the panel and different types of ply configuration of skin.
2. To determine optimum $(EA)_S/(EA)_P$ of the panel of different ply configuration of the skin (A_{11}/A_{22}) for all different D_1/D_2.
3. To perform comparative study between different types of the hat-stiffened panel for obtained the maximum buckling capacity of the stiffened panel.
4. Determination of the buckling load and failure load of the hat-stiffened panel by experimental study and compare experimental results with finite element results.