DESIGN AND OPTIMIZATION OF STRESS RELIEF SYSTEM FOR LAMINATE COMPOSITE PLATE

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DEDICATION

I would like to dedicate this work

To my wife Maha

To my kids Sara, Marah, Osama & Heba

ACKNOWLEDGMENTS

I'd like to express my great thanks to my home university "University of Jordan" for helping me achieve my mission to earn my Ph.D. degree and for all help they provided to me to get my dreams come true.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

C	Transverse Compression stress
D	Main hole diameter
d	Design hole diameter
s	Distance between the centers of the main hole and the design hole
T	Axial tensile stress
a	Design elliptical hole minor diameter
b	Design elliptical hole major diameter
φ	The angle between centers (main and design holes) line and horizontal
P1	External loads in x-axis
P2	External loads in y-axis
L	Length of plate
W	Width of plate
t	Thickness of plate
FD	Fiber direction /material direction
E1	Fiber modulus of elasticity
E2	Matrix modulus of elasticity
G1	Fiber modulus of rigidity
G2	Matrix modulus of rigidity
ν	Poisons ratio
N	Fringe order
f	Fringe value of coating

2c	Two circular DHS
4c	Four circular DHS
4e	Four elliptical DHS
SCF	Stress concentration factor
RGB	Red Green Blue colors
FEM	Finite Element Method
I-DEAS	Integrated Design Engineering Analysis Software
DHS	Defense hole system

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ABSTRACT

Reducing stress and weight of structures is one of the main goals of designers. Most engineering structures are an assembly of different parts. On most of these structures, parts are assembled by bolts, rivets, etc. The holes that are produced for such joints produce stress concentrations, which are potential sites for fracture initiation.

Defense hole theory deals with introducing auxiliary holes beside the main hole to reduce the stress concentration. In this research, a defense hole system under shear as well as general loading is investigated. This study is intended to determine the optimum defense hole system for a circular hole in an infinite plate. A theoretical study is conducted using finite element method (FEM) by utilizing commercial software package I-DEAS. The FEM model is verified experimentally using RGB-Photoelasticity. MATLAB Digital Image Processing toolbox is utilized to analyze the photoelastic images. The red-green-blue (RGB)–method is used in converting color intensity into stresses for each point in the stress field.

Stress concentrations associated with circular holes in pure biaxial (Tension-Compression ratio of 1) shear-loaded plates can be reduced by up to 20.56%. This significant reduction is made possible by introducing elliptical auxiliary holes along the principal stress direction. These holes are introduced in the areas of low stresses that appear near the main circular hole. The introduction of these holes in such places helps smooth the principal stress trajectories past the main hole. Two main goals are achieved by introducing such holes: maximum stress reduction and material reduction. Finite element and experiment analysis utilizing the new approach is used to optimize the size and location for auxiliary defense hole system.

Stress concentration associated with circular holes in mixed loading (i.e., tension-compression ratios of 0.25, 0.50, and 0.75) achieved maximum reduction of 31.69%. This reduction is obtained by introducing auxiliary elliptical holes along the principal stress direction. In contrast to the pure shear case the auxiliary holes are not all of the same size, shape and location. But each pair lying along the same principal direction is the same.

The same criterion in choosing the position of the auxiliary system applied in the shear case applies here also. These holes are placed in the low stress regions. Same goals are achieved as in the shear case. Finite Element Analysis is used to optimize the size and location for auxiliary defense hole system and the enhanced RGB-photoelasticity is used as a measurement tool to validate the FEM model.

Maximum stress reduction and optimum defense-hole-system parameters are achieved also in uniaxial loaded plate in uniaxial dominant range (pure tension). For the cases under investigation, pure uniaxial load (compression/Tension = 0.0) has Maximum stress reduction of 24.64%. This reduction is achieved by introducing auxiliary circular holes along the principal directions. A two-defense-hole system is proved to be the optimum for uniaxial dominant loaded plate. The same goals in shear loaded and mixed loaded plates are also achieved here. A systematic approach and finite element analysis is also used to optimize the size and the location of the defense hole system.

CHARTER ONE

INTRODUCTION AND LITERTURE REVIEW

1.1 Introduction

A composite material consists of two or more materials mixed together to give a material with good properties. A typical composite material consists of a material with high mechanical strength and stiffness (reinforcement), for example unidirectional or woven fibers, embedded in a material with lower mechanical strength and stiffness (matrix). To tailor the properties of the composite material, a laminate is formed by stacking on top of each other layers of reinforcement oriented in different directions.

Composite materials, if properly used, offer many advantages over metals. Examples of such advantages are: high strength and high stiffness-to-weight ratio, good fatigue strength, corrosion resistance and low thermal expansion. Nevertheless, conventional composites made of pre-impregnated tape or fabric also have some disadvantages, such as poor transverse properties, inability to yield and sensitivity to moisture and high temperatures, which must be accounted for in the design.

Composite materials such as glass fiber, aramide fiber, boron fiber and carbon-fiber-reinforced plastics have been used for a few decades, especially in the aircraft industry. Aircraft structures also include a large number of open holes and cut-outs e.g. holes for electric wires and hydraulic pipes or holes required for assembly or maintenance where a laminate containing open holes is subjected to shear loading i e a two axial loading case. To avoid the problems due to improper design mentioned above, and to fully utilize the material, the design methods must be applicable to general in-plane loading cases.

Reducing stresses in structures and optimizing their weight are the main goals to designers and engineers which improve the structural efficiency, performance and durability . Most engineering structures are assembly of different parts. Parts and components are assembled to the main structure by bolts, rivets, etc. Joining by mechanical fasteners is one of the common practices in the assembly of structural components. Among the most important elements in aircraft structures in general and in composite structures in particular are mechanically fastened joints. Improper design of the joints may lead to structural problems or conservative design leading indirectly to overweight structures and high life-cycle cost of the aircraft. Typical examples of mechanically fastened joints in composite aircraft structures are: the skin-to-spar/rib connections in e.g. a wing structure, the wing-to-fuselage connection and the attachment of fittings etc. Since the failure of the joints can lead to the catastrophic failure of the structures, an accurate design methodology is essential for an adequate design of the joints. Because of the complex failure modes of composite materials, the mechanical joining of structures made of composite materials demands much more rigorous design knowledge and techniques than those currently available to the traditional methodology for metallic joints The holes that are needed for such joints induce stress concentration. These high stress concentration spots are likely places for crack initiation. There have been number of incidents of aircraft fuselage failure resulting from crack initiation in the vicinity of riveted holes. The best known example of this was the Aloha airlines incident in 1988 (Hendricks, 1990) where it was found that many short cracks exist in the row of the riveted lap splice joints. Cracks propagate under fatigue loading and can eventually link up and cause failure for the whole structure. To prevent such scenario from taking place stress relief system usually introduced within the vicinity of these riveted hole to reduce the stress i.e., increasing the load carrying capacity of the structure and reducing the weight. Up to this moment, most Airframe structures (on commercial level) are made of aluminum and some other alloys except the new Boeing Aircraft B787, which is still under production. This new aircraft is made of laminated composite material with many layers of different thicknesses. This research is intended to unveil the stress relief system (Defense Hole System) parameters that achieve the optimum design for laminate composite plate (orthotropic plate).

1.2 Defense Hole System

Introducing auxiliary holes in the neighborhood of a main hole to reduce the stress concentration is called defense hole theory which has been known since the early years of last century. Most of the work that has been done so far deals with defense hole system under uniaxial loading on sheet metals (isotropic material). Some efforts are done for shear loading. Two latest work in this field are stress distribution in a rectangular laminated composite plate with central hole has been studied using finite element method without using defense hole system and the other is study the post buckling response of square symmetric cross-ply laminates with circular cutouts under uniaxial end-shortening displacement by using finite element method. A summary of these works are listed in table 1.1

In this research, design and optimization of stress relief system for laminate composite will be investigated to unveil the optimum design parameters of the defense hole system.

1.3 Photoelasticity

Since there are always substantial differences between the actual stresses in a machine element and those predicted by analytical or computer models, it may be necessary to test parts to substantiate the design calculations. One testing method is Photoelasticity.

Light consists of electromagnetic radiation. It can be thought as a harmonic oscillation with the time axis along the direction of the light beam and the amplitude perpendicular to it in all directions (see Figure 1.1). There are some transparent materials which allow light to be transmitted on a specific plane (see Figure 1.2). Such materials are called polarizing filters and the resulting light is polarized. No light will pass through two polarizing filters that have their polarizing planes perpendicular to one-another (see Figure 3).

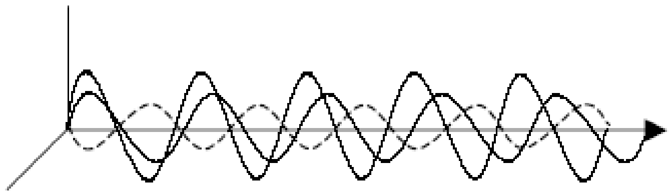


Figure 1. 1 Light Waves.

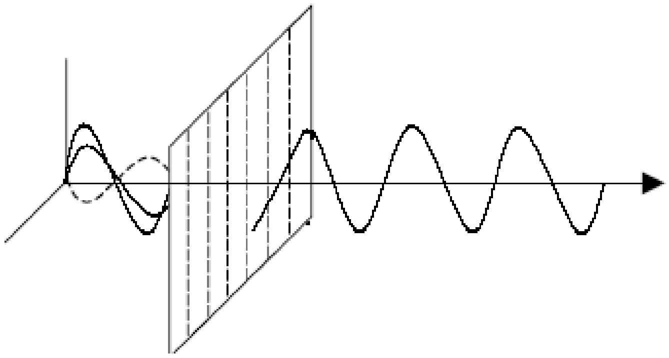


Figure 1. 2 Polarized Light.

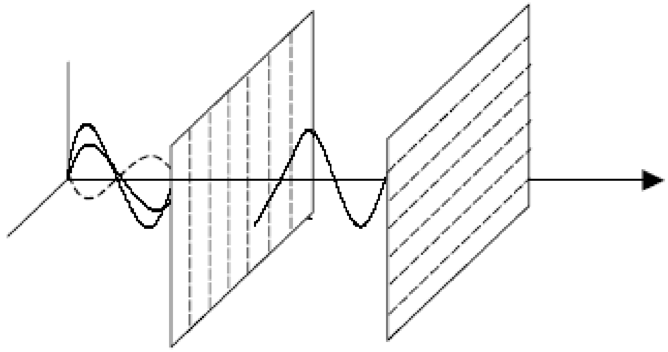


Figure 1. 3 Perpendicular Polarizing Planes.

Some transparent materials have the property that they rotate the plane of polarized light by an angle that is proportional to the difference in the principal stresses:

$$\Delta\phi = \lambda(\sigma_1 - \sigma_2)h \qquad (1)$$

Where λ a constant of the particular material, h is is the plate thickness and σ_1, σ_2 are the principal stresses. The product $c = \lambda h$ is a constant of the particular plate.

These materials are called photoelastic materials (birefringent material).

If $\Delta\phi = \pi/2, 3\pi/2, 5\pi/2, \ldots$ all light will pass through and fringes of full light emittance will appear on the other side of the material. If a single color light source is used, different light intensities between fringes represent values of stresses. For a white light source, different color fringes will appear. The latter is due to the dependence of the angle of rotation on the frequency of the electromagnetic radiation. When a load is applied, different stress magnitudes will form at different points in the plate and different fringes will appear. Each fringe corresponds to a multiple of the stress that will cause one full cycle $\Delta\phi=\pi$). Therefore, every fringe corresponds to a stress

$$\sigma_1 - \sigma_2 = N\pi/\lambda h = Nd \qquad (2)$$

Where d is the photoelastic property of the plate Therefore, if the constant $d = \pi/\lambda h$ is known and the multiplicity number N is determined from the number of fringes, the difference in principal stresses $\sigma_1 - \sigma_2$ at every point in the plate can be determined.

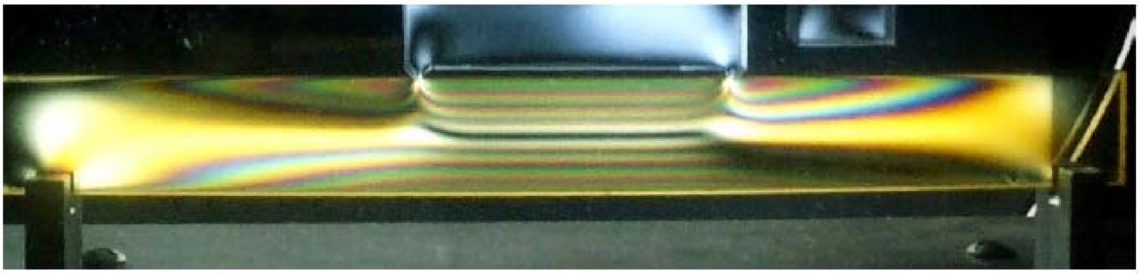


Figure 1.4 Fringe Patterns on a Bar of Photoelastic Material subject to four Point bending (JME394 Mechanical Design Laboratory Aug. 2000)

The constant *d* is given by the plate supplier or can be measured. The multiplicity number N can be found in two ways:

a) Start from an area which is black (zero stress, $0 = \sigma_1 - \sigma_2$) and count the number of fringes between this point and the point at which the stresses are to be determined.

b) While slowly loading the element, observe the changes in color at the point of interest. The number of full color changes is N.

Therefore, in principle, the difference in the principal stresses can be found anywhere, at least to a multiple of the stress that causes one full cycle. But the difference in principal stresses in a plate is of no practical value. However, failure usually occurs near the boundary (edge) of the plate, where the perpendicular component of stress is zero. In the direction along the boundary, the stress is a principal stress because there is no shear at the boundary. Therefore, if the difference of the principal stresses is known, the stress along the boundary σ_b , can be calculated:

$$\sigma_b = N\pi / \lambda h = Nd \tag{3}$$

Since the composite material is not transparent (in general) and does not have the birefringent (doubly refracting) characteristics, reflection photo-elasticity is going to be adopted. This method gives the researcher the opportunity to apply birefringent coating to the composite material while the polariscope in the reflection-polariscope arrangement.

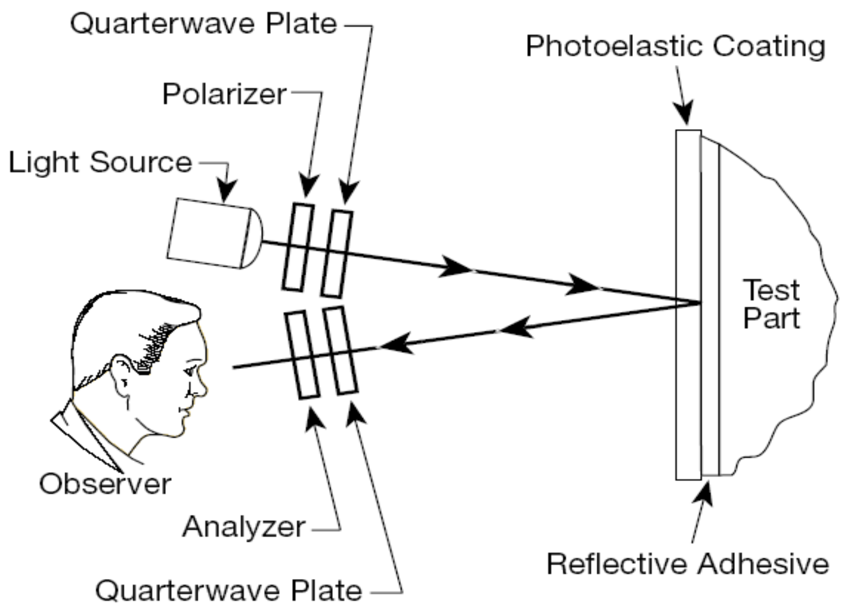


Figure 1.5 Reflection Polariscope arrangement (Rajaiah, 1984)

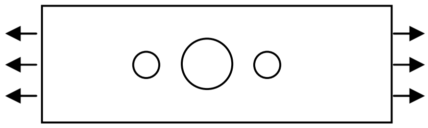
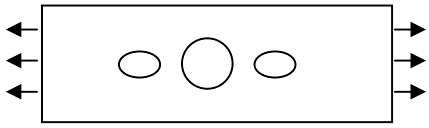
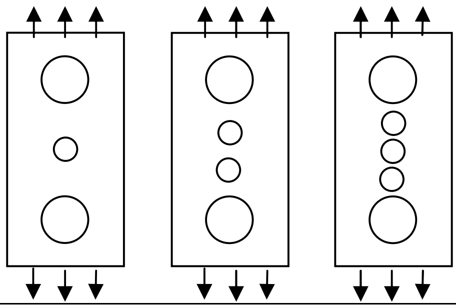
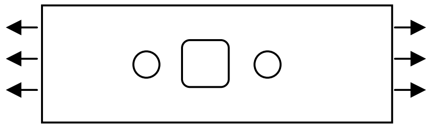
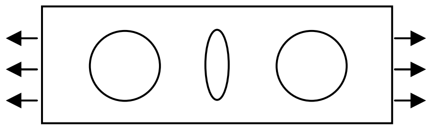
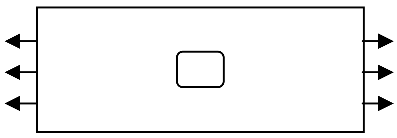
1.4 Literature Review

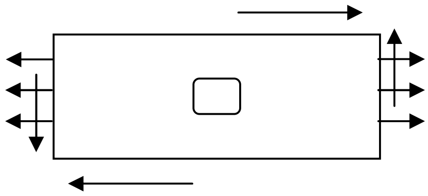
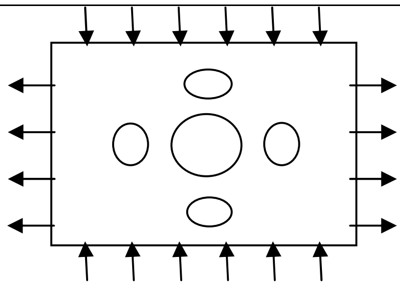
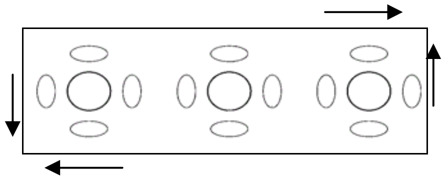
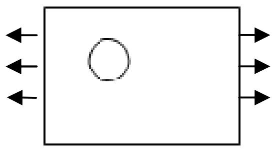
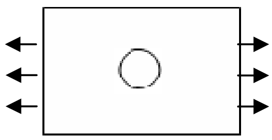
Numerical and experimental studies for reducing stress levels in structures by introducing other geometric discontinuities are very few. Most of the work that has been done so far deals with isotropic material. Table 1 summarizes the most important attempts during the past century (Akour,2003).

Erickson and Riley (1978) investigated the effect of the defense holes on the stress concentration around the original hole using two- dimensional photoelasticity. Jindal (1983) examined the reduction of stress concentration around circular and oblong holes using the Finite Element Method (FEM) and photo-elasticity analysis. Meguid (1986 & 1989) studied the reduction of stress concentration in a uniaxialy-loaded plate with two co axial holes using the Finite Element Analysis (FEA). Rajaih and Naik (1986) investigated hole – shape optimization in a finite plate in the presence of auxiliary holes using the two dimensional photoelastic methods. Ulrich and Moslehy (1995) used boundary element methods to reduce stress concentration in plates by introducing optimal auxiliary holes. Durelli (1978) investigated the optimization geometric discontinuities in stress field under uniaxial loading. Dhir (1981) studied the hole shape optimization in plate structure under tension and shear loading.

High stress concentration points in the structure have the tendency to initiate a crack leading to failure to the structure. Many people have studied radial cracks emanating from circular holes. Their studies dealt with existing cracks.

Table 1.1: Summary of some previous studies of defense hole system as taken from Akour et. al. (2003) and up dated

Author	Type of Load	Specimen	Stress Reduction
Erickson and Riley (1978)	Tension		18%
Jindal, et. al. (1983)	Tension		25%
Meguid (1986, 1989)	Tension		1st specimen=7.4% 2nd specimen=9.4% 3rd specimen=10.9%
Rajaiah and Niaik (1984)	Tension		30%
Ulrich and Moslehy (1995)	Tension		Reduces SCF up to 3.0 for the ellipse
Durelli et. al. (1978)	Tension		25%

Author	**Type of Load**	**Specimen**	**Stress Reduction**
Dhir (1981)	Tension and Shear		Tension = 17.7% Shear = 23.25 %
Akour et.al. (2003)	Shear		13.5%
Tahat et. al. (2005)	Shear		6% to 18%
Mohammadi, Najafi, and Ghannadpour (2006)	Compression Eccentric Hole		Pre-buckling effect
Mittal and Jain (2008)	Tension with Fiber direction		SCF Max at θ =0° or 180°

Previous efforts studied crack propagation by quantifying applicable stress intensity factors. Kamel et. al. (1991) obtained the stress intensity factors for cracks emanating from a fastener hole using the principle of superposition and Green's function for a point force applied in an anisotropic sheet with an elliptical hole.Kamel (1991). He investigated various loading cases, such as a point load, uniform pressure applied on an arc, and a cosine distribution pressure. Guo Wanlin (1993) has studied analytically the stress intensity factor for corner cracks emanating from fastener holes in finite plates subjected to biaxial load and three types of pin load, uniform, concentrated and cosine distribution. Gungor (1995) used optical Photoelasticity to measure stress intensity factors in corner cracks emanating from holes in sheet structures with bolted stiffeners (L-shape stringer). Dong Shan (1995) studied analytically a finite plate with a cracked hole stiffened by a ring with riveted joints. From a practical point of view the sheet structure is always attached to a stiff frame, like an aircraft, and the skin is riveted and bolted to the frame. Figures 2 and 3 show the crack formation and the damage that will occur when these cracks initiate and propagate. Akour et. al (2003) studied the design of a defense hole system for a pure shear-loaded plate. Mohammadi et. al. (2006) studied the influence of eccentric circular cutouts on the prebuckling and post buckling stiffness, and effective widths of compression. Mittal and Jain (2008) investigated the effect of fiber orientation on stress concentration factor in a laminated composite plate with central hole under in-plane static loading.

This research is attempting to introduce optimum-stress relief-system that prevents the initiation of such cracks. In addition, it aims to obtain efficient, economical, reliable and optimum design of stress relief system for laminate composite plate that yields to significant reduction of maximum stress in structure.

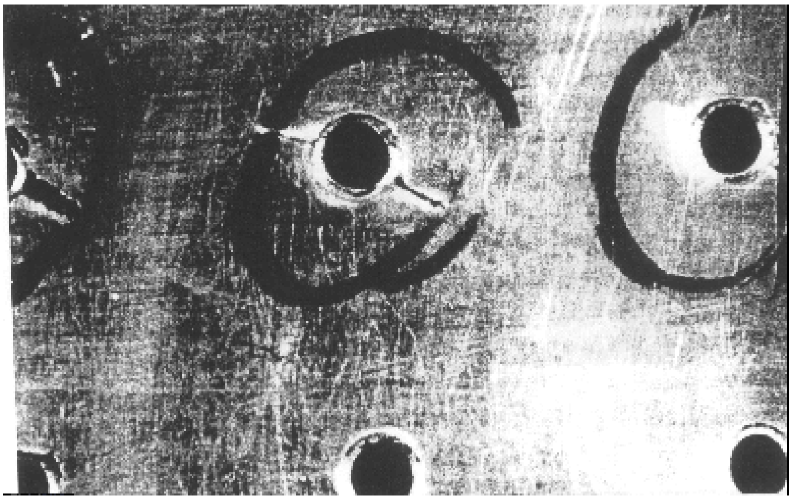


Figure 1.6 A view of cracks emanate from a row of rivet holes (Kanninen and et. al., 1995).

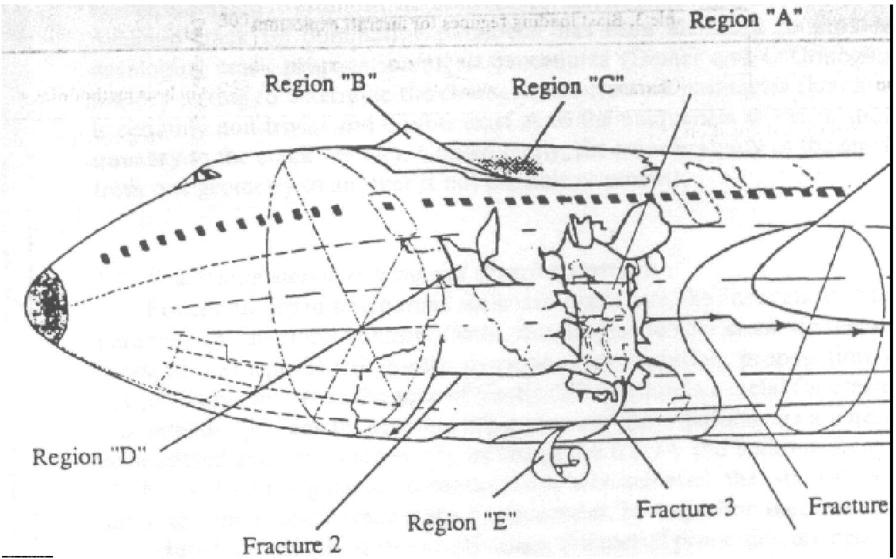


Figure 1.7 Schematic view of fracture due to cracks propagates from holes (Kanninen and et. al., 1995).

Defense hole theory concerns with introducing auxiliary holes beside the main hole in the vicinity of low stress area to reduce the stress concentration, most of the previous efforts were aiming to reduce the stress in sheet metal material (isotropic material). The proposed research is intended to investigate the optimum design of the defense hole system for laminated composite material.

1.5 Contribution

Most of the previous work in defense hole design has been done for sheet metal plates (isotropic material). Some attempts are made for composite plate under uniaxial loading. In the current research, design and optimization of stress relief system for composite laminate is investigated and unveiled the optimum design parameters of the defense hole system.

The research has investigated the optimum design of the defense hole system by utilizing univariate search optimization technique. The investigation has covered the defense hole system under general in-plane loading (uniaxial loading, shear loading and mixed loading). The optimum size, shape and position of the defense holes, the effect of thickness and stacking sequence of the laminate with different types of laminates such as cross-ply and angle ply laminate, in addition to experimental verification for selected cases have been conducted. The Experimental verification for selected cases has been achieved by using RGB photoelasticity techniques.

1.6 Research Objective

The investigation covers the following objectives.

1. Investigating the defense hole system under general in-plan loading (uniaxial loading, shear loading and mixed loading)
2. Obtaining the optimum size, shape and position of the defense holes (see Figure 1.8).

3. Studying the effect of thickness and stacking sequence of the laminate.
4. Studying the effect of the fiber orientation for obtaining the optimum defense hole system.
5. Experimental verification for selected cases is achieved by using Photoelasticity techniques to assure accuracy of results. Also comparison with previous research is carried out for the same purpose.

I-DEAS (Integrated Design Engineering Analysis Software) package is utilized to investigate the above items. The laminate is modeled as infinite plate. Schematic illustration of the model is shown in Figure 1.8.

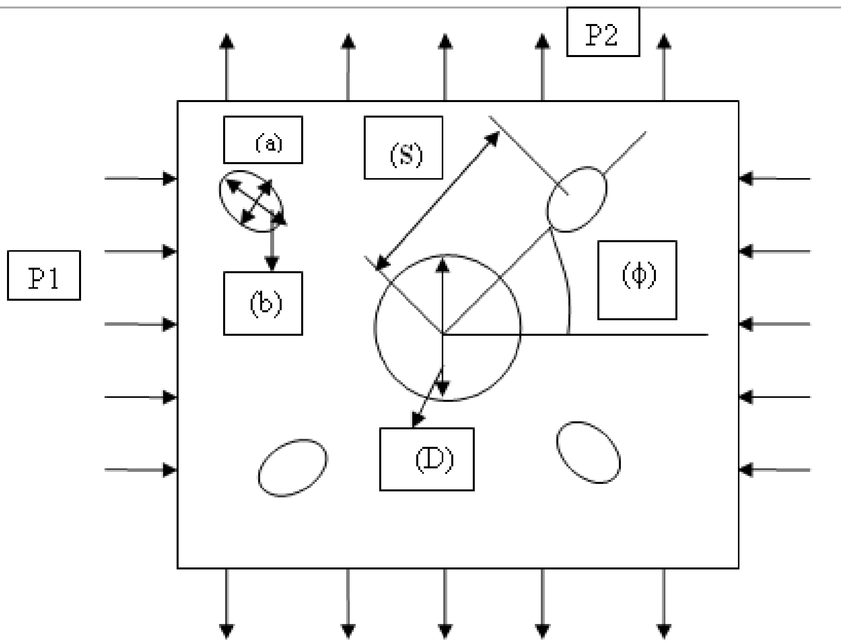


Figure 1.8 Schematic of defense hole system under study (general case)

Where D: is main hole diameter a, b are diameters of design hole, s is the distance between main hole center and design hole center(centers line), ϕ is the angle between centers line and horizontal , P1 and P2 are external loads (Compression and Tension)

Nowadays, composite materials are used in manufacturing commercial aircraft as well as small aircraft with reliability, durability, performance and speed in manufacturing like metals. Composites are the smart choice for Boeing 787 aircraft due to many reasons as reducing maintenance cost and fewer and easier inspections in addition to 30-40 percent reduction in weight that lower fuel usage and landing fees. Reducing the weight to load ratio by applying the defense hole system to such structure where the stress raisers take place is highly appreciated by the aerospace industry. So this research tries to help in relieving the stress around circular holes of such structure by applying the proper defense hole system.

1.7 Scope and Content

Optimum design of the defense hole system by using univariate search optimization technique for laminated composite material is investigated. Baseline data has been generated to help designers make better design for composite material. This study covers the design under uniaxial loading, shear loading and mixed loading.

A composite plate is tested using special biaxial testing machine manufactured for this purpose shown in Figure (4.7) by applying distributed loads acting on all sides of the plate. This scenario is modeled using a finite element analysis tool called 'I-DEAS'. The selection of this scenario is due to the availability of experimental data for validation purposes. The stress distribution in each layer of the composite plate is obtained from the finite element analysis results. Fiber and epoxy mechanical properties in addition to boundary conditions are considered in the simulation.

This dissertation consists of six chapters. A brief description of each chapter is presented below.

Chapter one (Introduction and literature review): this chapter presents introduction to the dissertation, literature review, contribution, and research objectives.

Chapter two (Physical Model): This chapter presents the physical model of the composite plate, which includes geometry, assumptions, boundary plate conditions meshing , fiber orientation and loading.

Chapter three (Finite Element Model): This chapter presents the development of finite element model for laminate plate and utilization of the pre and post processing modules ' I-DEAS ' software.

Chapter four (Model Verification): In this chapter the FEM model is tested against previous experimental and FEM model to assure model accuracy and integrity. Also experimental verification is carried out for selected cases to provide confidence of the results.

Chapter five (Results and Discussion): In this chapter effect of different loading and different fibers and epoxies materials along with material directions are unveiled. The effects of design hole shapes, sizes and directions are included in chapter five.

Chapter six Conclusions and recommendations are provided in this chapter**.**

Appendices all the data obtained to achieve the objectives of the study are presented in appendix A and B. these appendices provide the base line data necessary for any design engineer to make an optimum design for the defense hole system by selecting the parameters that achieves his design constraints. Appendix B contains 68 Tables which presents Stress Reduction Ratios for nine composite materials with two circular holes, four circular holes and four elliptical holes. All are investigated under five different load ratios and seven fiber direction angels. Appendix A presents summary tables of each group of defense hole system; design hole shape study, material study, load ratios study, fiber directions study.

CHAPTER TWO
PHYSICAL MODEL

This chapter presents the physical model of the composite plate, which includes geometry, boundary conditions as well as the materials used in the investigation.

2.1 Composite Plate Geometry

The plate is square in shape with circular hole in the middle. The side length of the plate is too large compared to the thickness and the diameter of the circular hole (L/D=16, L/t=100). So the plate can be considered as infinite. Three models are investigated, one with two circular holes, another with four circular holes, and the last with four elliptical holes as defense hole system. These models are shown in figures 2.1, 2.2 and 2.3 respectively. To reduce the effect of the plate side length and edges effect, the DHS is rotated through an angle equal to the principal angle and a biaxial load (Tension-compression) is applied. Figures 2.1 to 2.3 illustrate the model that is used for the current investigation. The plate is large enough to be considered as infinite plate. Moreover the ratio (D/L) of the main-hole-diameter D to the plate-side-length L is 0.0625 (Fuchs and Stephens 1980).

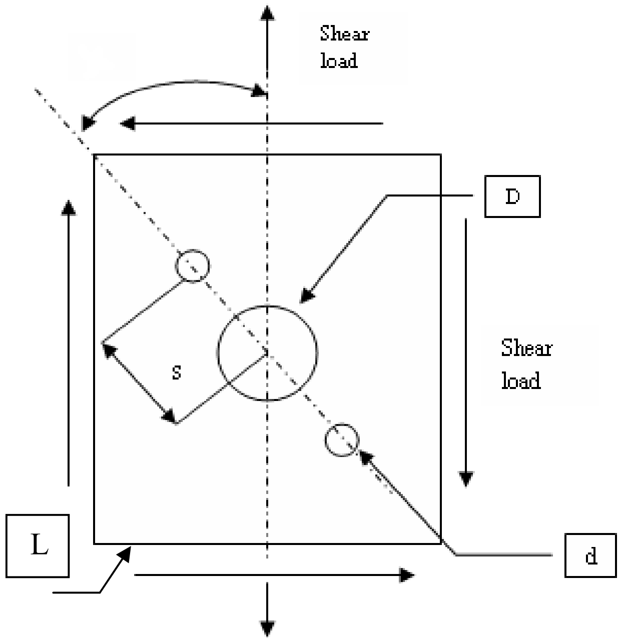


Figure 2.1: Schematic of two circular defense hole system in study.

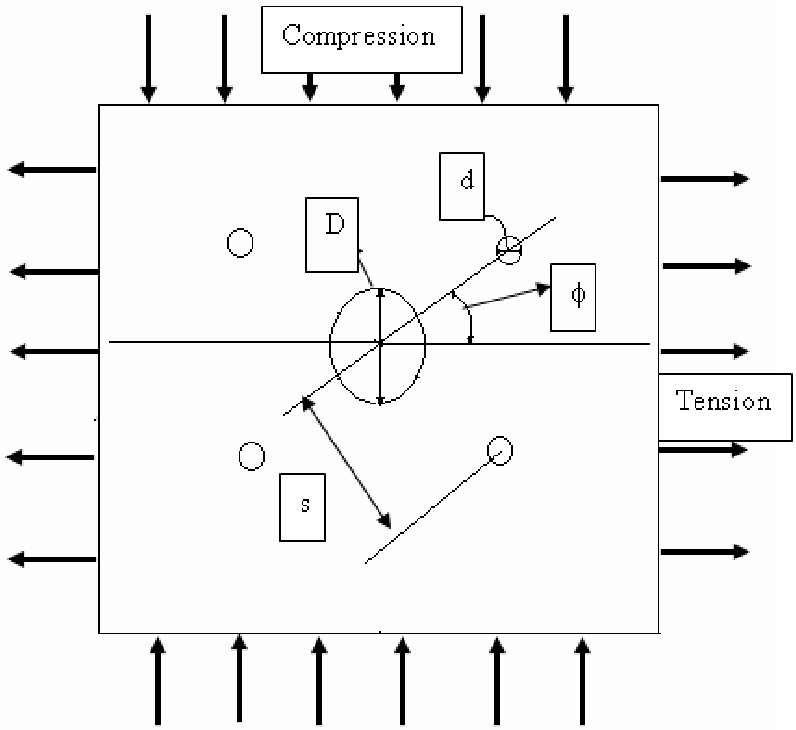


Figure 2.2: Schematic of four circular defense hole system in study.

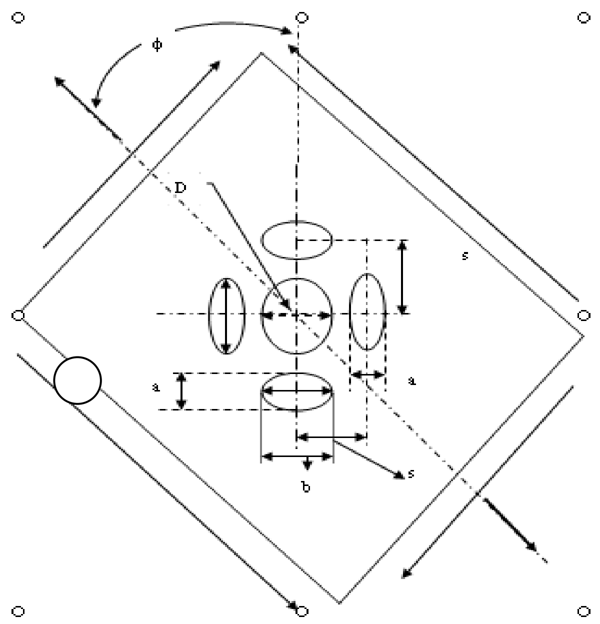


Figure 2.3: Schematic of defense hole system for shear and transient state.

Table 2.1. Geometry parameters values

Parameter	**Dimension**	**Note**
Length L	400mm	constant
Width W	400mm	constant
Main Hole Diameter D	25mm	constant
Thickness t	4mm, 8mm, and16mm	variable
Design Hole Diameter (circular) d	3mm-25mm	variable
Design Hole (elliptical) diameters (a, b)	3mm-20mm	variable
Distance between two holes centers s	15mm-50mm	variable
Angle between centers line s and horizontal ϕ	0^o - 90^o	variable

Material direction (Fiber Direction) FD	0^o - 90^o	variable

All the geometric parameters are dimensionlized with respect to the main circular hole diameter. This has been done for generalizing the base line date that has been produced by this research.

2.2 Assumptions

The following assumptions are considered:

1. The bonding between the plies of the laminate is considered perfectly bonded and the fibers are unbroken.
2. No delaminating occur between layers
3. Linear static loading
4. The plate is large enough to be considered as infinite plate.
5. Compression load is below buckling (within elastic range)

2.3 Boundary Condition

Two of the plate edges are clamped, and the edge parallel to the x-axis is allowed to move freely in that direction while the other one which is parallel to the y- direction is allowed to move freely in that direction. So the bottom left corner is fixed. The other two edges are loaded in tension and compression as shown in figure 2.4, so we have compression to tension ratio ranging from zero to one. Zero ratio means pure tension, none zero ratio means mixed loading i.e. tension and compression, while unity ratio means pure shear loading.

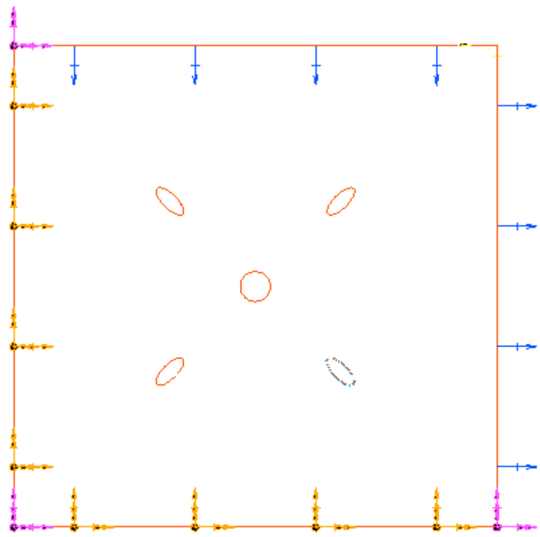


Figure 2.4 Boundary Conditions of composite plate

2.4 Study Parameters

The main parameters that have influence on the stress reduction ratio of laminate plate are; first is the material i.e. the ratio of modulus of elasticity for the fiber to the matrix, nine different materials are investigated each has different mechanical properties (modulus of elasticity , density, fiber epoxy ratio and others. Second is the dimensions of defense hole diameter **d** in case of circular design hole or minor diameter **a** and major diameter **b** in case of elliptical defense hole. Third is the distance s between main hole center and defense hole center. Fourth is the angle ϕ between **s** line and the x-axis of the plate. Fifth is the material orientation i.e. fiber direction. Sixth is the loading ratio ranging from pure tension to pure shear. Effect of layers stacking sequence (symmetric, anti-symmetric) and thickness for some cases is highlighted. Table 2.2 below shows all study parameters

Table 2.2. Study parameters values

Study Parameters	
Materials	E1/E2=1.0(Woven Glass), 1.72(Boron Aluminum), 10, 15, 20, 30, 43.94(Graphite Epoxy), 50, 63.77(Carbon Epoxy).
Design Hole	Two circular holes, Four circular holes, Four elliptical holes
Distance s	Varies from 25 mm to 150 mm
Angle ϕ	Varies from 0^o to 90^o
Fiber Directions	Varies from 0^o to 90^o
Loading ratio	0.0 (Pure Tension), 0.25, 0.5, 0.75 (Mixed Load), 1.0 (Pure Shear)
Layers	2 layers, 4 layers, 8 layers, and 16 layers
Stacking Sequence	Symmetric, Anti-symmetric
Thickness	4 mm, 8 mm and 16 mm

2.5 Loading

The load is applied to the composite plate as a distributed load along two edges as shown in Figure 2.4. Tension is applied to one side while compression is applied to the other side. The compression side is varied from zero N to 1000 N by 250 N step on each edge which is increased gradually (step by step) so we get different mixed loading.

2.6 Applications

Composites are increasingly being used in the aerospace industry because of their bending stiffness-to-weight ratio. Floorboards, composite wing, horizontal stabilizer, composite rudder, landing gear door, speed brake, flap segments, aircraft interior and wingspans are typically made of sandwich composites. Also composites are ideally suited for the marine industries most advanced designs.

High strength-to-weight ratios of composites offer great advantages to the transportation industry. The insulating, sound damping properties and low cost properties make them the choice materials for the constructions of walls, panels and roofs

CHAPTER THREE

FINITE ELEMENT MODEL

This chapter presents the development of finite element models for composite plate. Detailed descriptions of the boundary conditions, element types, and the loading are presented in this chapter. The finite element software used in the development of the finite models is I-DEAS Master Series 10, 1999. The relatively robust and user-friendly solid modeling and finite element meshing interface are the main advantages of this solid modeling/ finite element software. A finite element model is the complete idealization of the entire structure problem, including the node locations, the elements, physical and material properties, loads and boundary conditions.

3.1 Construction of composite plate

A plate of 400 mm x 400 mm with hole at center of 25 mm, the thicknesses of the composite plates are 4mm, 6mm, and 8mm which is the maximum size that biaxial testing machine could take. This laminate is built by numbers of plies, each ply material consists of fiber and epoxy which have been fed into I-DEAS program according to Table 2.3 so we can create the ply. There are three ways to stack the plies in I-DEAS that are presented in Figure 3.1. repeated, symmetric or antisymmetric.

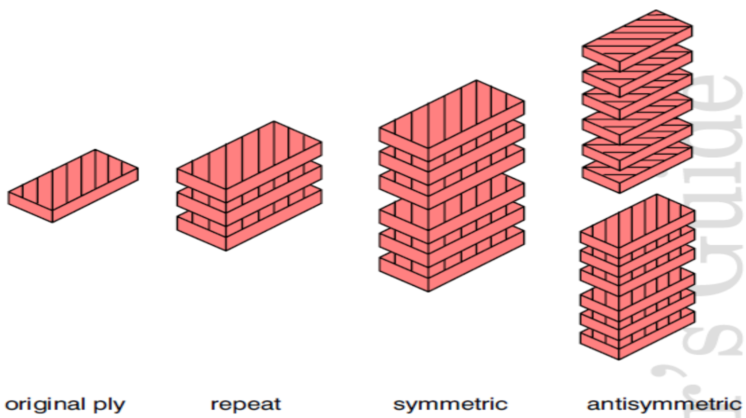


Figure 3.1 Laminate Stacking Sequence

Figures 3.2 through 3.4 present the stiffness matrices for some of the materials used in the investigation. The coupling matrix B is null because the stacking sequence is symmetric.

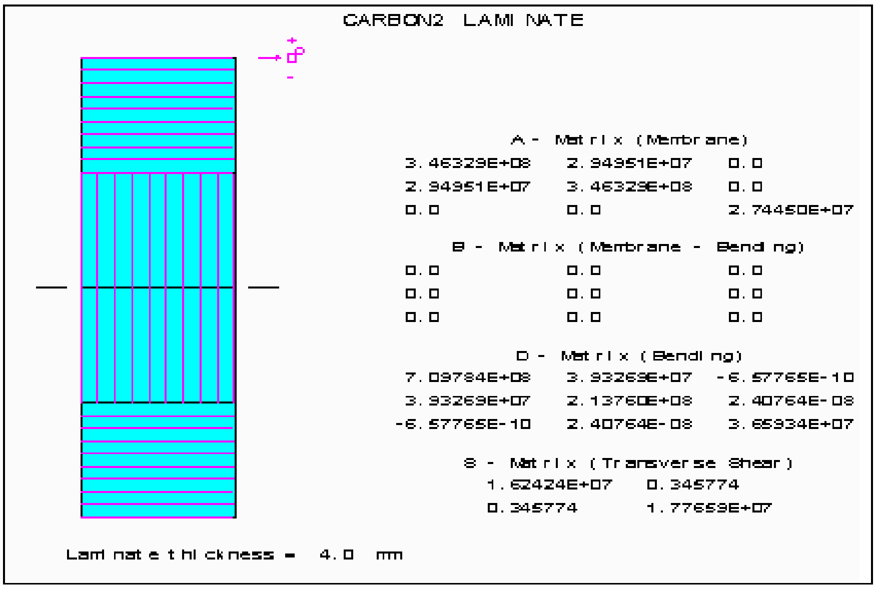


Figure 3.2 Carbon Epoxy Laminate Stiffness Matrix

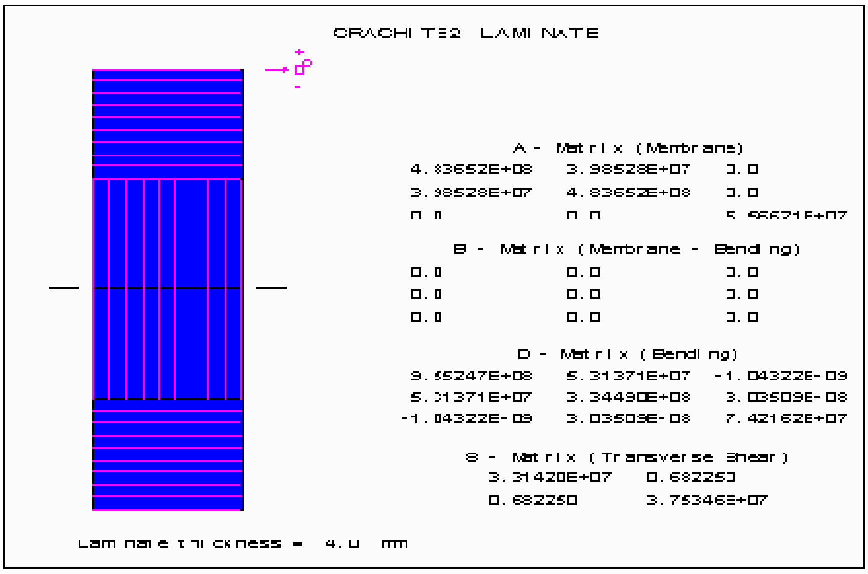


Figure 3.3 Graphite Epoxy Laminate Stiffness Matrix

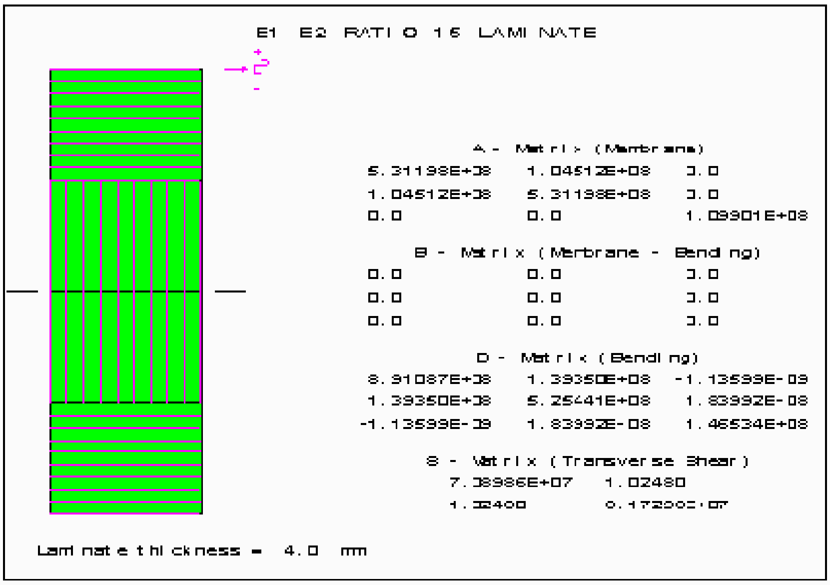


Figure 3.4 Material E1/E2=15 Laminate Stiffness Matrix

3.2. Problem Description

Circular and Elliptical defense hole systems with different geometric parameters for a plate with main circular hole under different loading conditions are investigated. A defense hole system is introduced in the vicinity of the main hole. An infinite plate with circular hole of diameter D is clamped on two sides (lower side is free to move in x-axis while left side is free to move in y-axis) (see figure 2.1). the right side is loaded by total force of 1000 N while the upper side is loaded by compression load starting from 0 N to 1000 N, so for pure tension (uniaxial load) there is no load from upper and lower sides while in mixed load the upper side changed till 1000 N at which we have pure shear case.

Laminate plate has different material properties, Fiber modulus of elasticity (E1), modulus of rigidity (G1) and Poisson's ratio (ν1). The Matrix has also modulus of elasticity (E2), modulus of rigidity (G2) and poisons ratio (ν2). We used dimensionless material ratio E1/E2 to specify different materials which makes the results applicable for any composite material.

Stacking sequence of 0°, 90° ,90°, 0° of laminates is studies for most cases of this research using I-DEAS laminates procedures by creating one ply of certain material (fiber and epoxy) then we start stacking the plies over each other in certain directions. Another parameter which has been investigated in this study is the fiber direction in each laminate used under different loads for different material ratios (E1/E2).

Figure 1.8 represents the model that is used in the current investigation. S is the distance between the centers of the main hole and the auxiliary holes. The diameter of the main hole is denoted by D. The major and minor axes of the auxiliary system are denoted by a and b respectively. Circular and elliptical defense hole systems are investigated. The optimum number of auxiliary holes for shear and mixed loading is four holes; while the optimum number for uniaxial tension in some cases is two holes.

Reduced stresses with defense hole system are divided by stresses without DHS under the same conditions of material E1/E2 ratio, loading, boundary conditions, fiber directions, laminate sequences and same FEM so it becomes dimensionless value. Same as all other parameters ; all divided by main hole diameter D, i.e results collected by varying s/D, a/D, and b/D.

The software package SDRC I-DEAS is used to produce the Finite Element Model (Lawry, 1998). Due to the limitations on mesh size in the software and to reduce computation time, element sizes around main hole and auxiliary holes are chosen smaller than areas where no high stresses is expected.

A two circular defense hole system and four circular hole system are investigated against stresses reduction for different material (nine material ratios E1/E2 =1.0, 1.72, 10, 20, 30, 40, 45.94, 50, and 63.77) under different load ratios.

A four elliptical defense hole system is then introduced to reduce stress concentration around main hole after small reduction gained by two and four circular holes.

A huge amount of data are tabulated in appendices A and B as base line data for researchers, the final results are analyzed and discussed in chapters five and six of this dissertations.

3.3 Boundary Conditions

Restraints are used to restrain the plate to ground. Restraints also have six values at each node: three translation and three rotations. Each entry can either have a value for the fixed displacement or is left free to move, the plate should be held in space by restraints so that it is not free to move in any direction to be able to solve the problem, so two sides of plate are clamped and which one of them (lower side) is free to move in x-direction only and the other five degrees of freedom are fixed while the other side (left side) is free to move in y-direction only as shown in figure below.

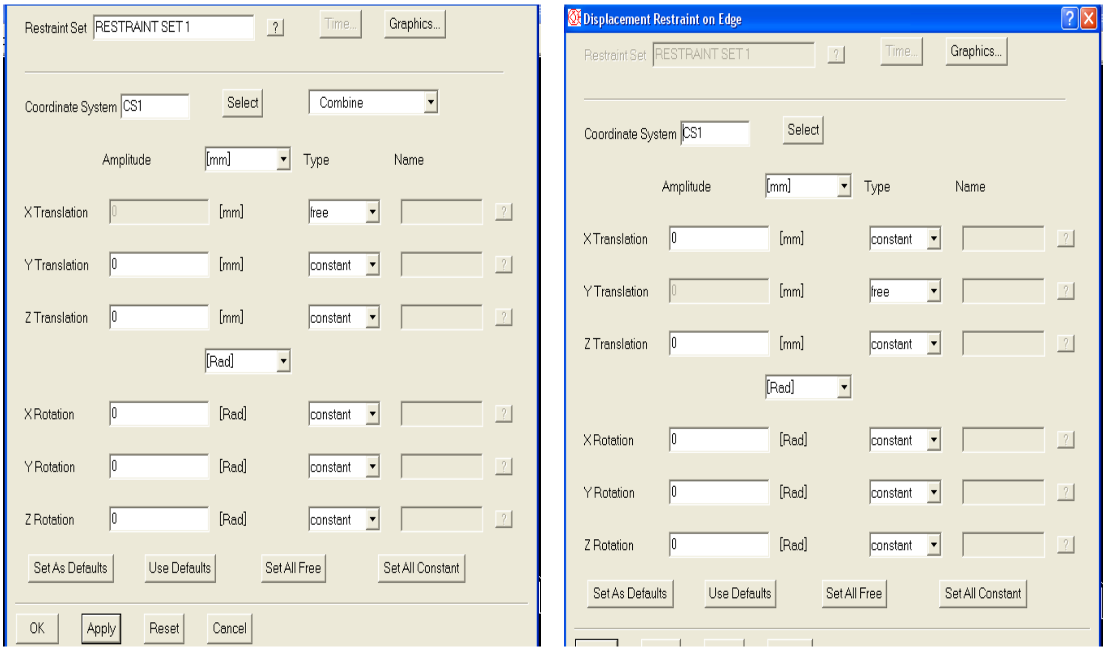


Figure 3.5 Boundary conditions at edges

3.4 Loading

The plate is subjected to a tension of 1000 N and a compression ranging from 0-1000 N in increments of 250.

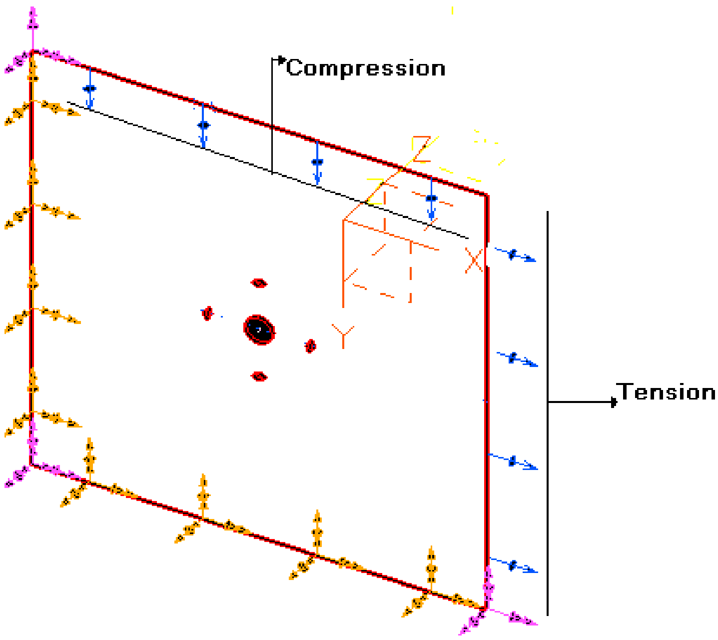


Figure 3.6 Loading at edges

3.5 Meshing

The plate is meshed with a thin shell mesh on one surface to analyze the stress at the main hole radius, Even though the part model is 3-D solid plate model, a 2-D finite element is needed since there is no bending load applied and only in plane forces are applied. In addition that the load difference and non symmetry may cause membrane effect i.e. out of plane loading so solid mesh and plane stress (stress in depth) are not working.

Also shells for large dimensions are considered as flat plates since the curvatures are small. In comparison with steel, composites have the same behaviors for stress concentration. A fine mesh is utilized in the areas where the stress concentration is expected to be high. Figure 3.3 below illustrates the mesh that has been used in the analysis. Since this research investigate infinite plate, large enough plate is used (L/D = 16, L/t =100) to give accurate results for infinite plate.

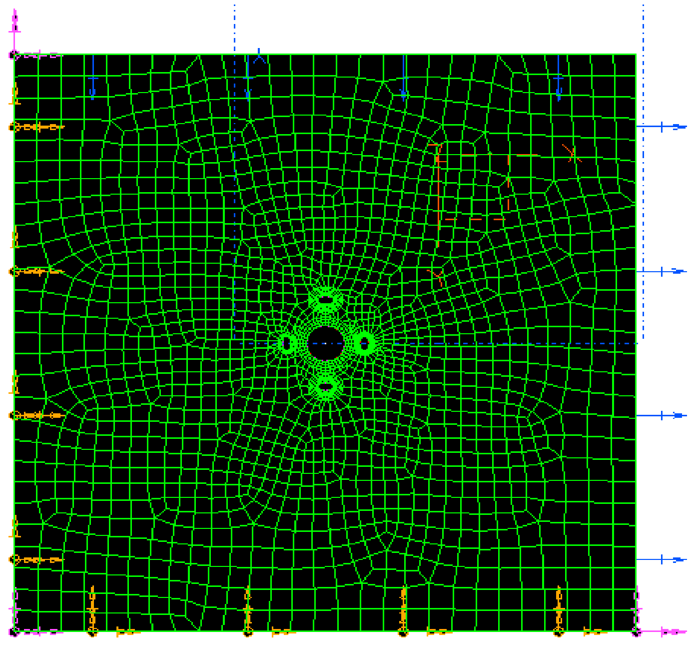


Figure 3.7 a Plate Thin Shell Meshing

A gradual change in the element size is employed to assure convergence and to obtain accurate results, as such, smaller elements near the points of high stress concentration are used, while larger elements far from the high stress are used. Also the size of the overall elements is decreased until the change in the results is lower than 1%.

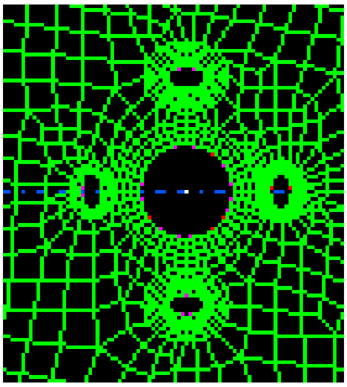


Figure 3.7b Design hole Shell Meshing

CHAPTER FOUR

MODEL VERIFICATION AND EXPERIMENTAL

To assure validity and accuracy of the FEM model comparison is carried out by two ways, first by reproducing other researches findings, second by carrying out experimental investigation for some selected cases using RGB photoelasticity which has some advantages on monochromatic photoelasticity, RGB not only gives better accuracy (ranging from zero fringe order up to five fringe order) but also has the capability of analyzing the whole stress field at once. The experimental study is conducted to be more confident of the finite element model and its results. The comparison with the previous finite element analysis (FEA) and experimental findings shows very good agreement.

Redesign optimization technique is used in this study to find the optimum parameters of design hole system, this technique is already used in many dissertations and scientific papers that are published in the past three decades and has showed good results. This technique works in iterative manner based on the sensitivity analysis of each parameter involved in the analysis. Redesign allows you to vary aspects of the design (the design parameters), set limits on the design (e.g., stress), and set goals for the design (e.g., minimize mass). The software then tries to find the optimal structure that satisfies these criteria.

You can use redesign to:

- Automatically find the optimal design using an iterative process: Automatic redesign, especially when the design contains many design parameters and limits on structural behavior, enables you to rapidly evaluate and converge on the best design.
- Obtain sensitivities: You can list and review sensitivities obtained from a redesign.

Univariate search optimization technique is also utilized to produce the baseline data. Using this method allows recording the variation of each parameter with objective of the study. It is one of the efficient optimization techniques that does not require derivative evaluation. The basic strategy underlying the univariate search method is to change one variable at a time to improve the approximation while the other variables are held constant. Since only one variable is changed, the problem reduces to a sequence of one dimensional search (Chapra and Canale, 2006).

4.1 Comparison with previous research:

- National Aeronautical and Space administration (NASA) investigated the stress behavior around a small circular hole in the HiMAT composite plate William L.K. (1985). The results of our model show very good agreement against NASA's results. The stress concentration in our model appears at 54^{o} as shown in figure 4.1 while in NASA's study appears at an angle of 55^{o} as shown in figure 4.2. the difference is less than 2%.(William 1985)

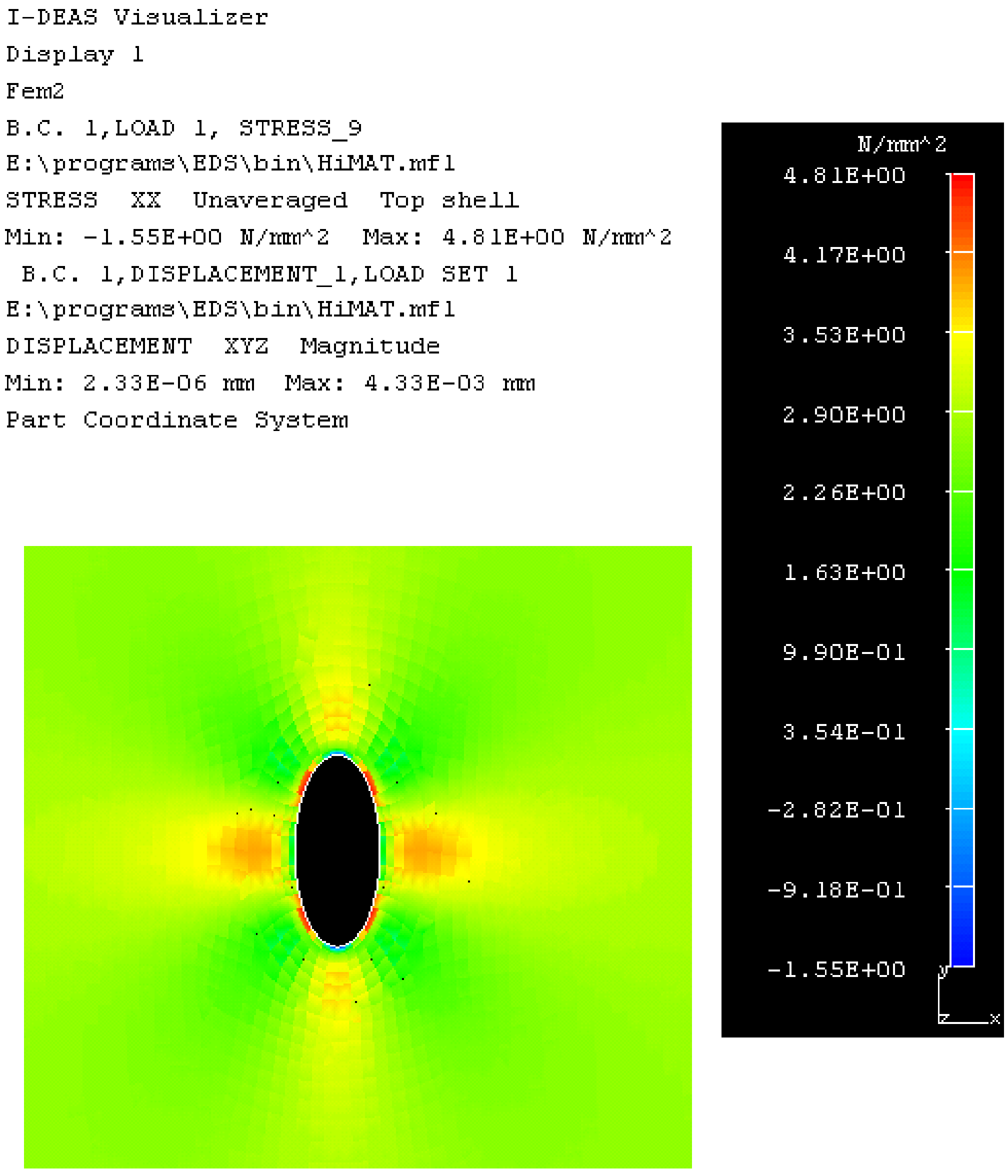


Figure 4.1a: Comparison with NASA results for single ply laminate showing the stress concentration at 54^o.

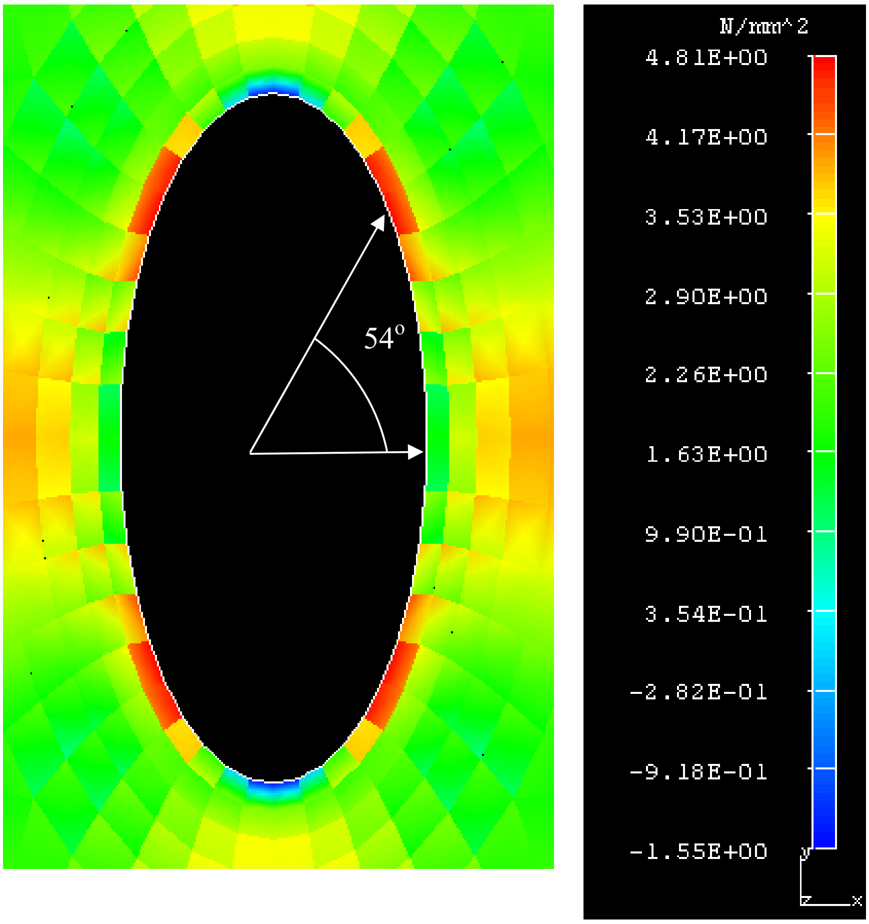
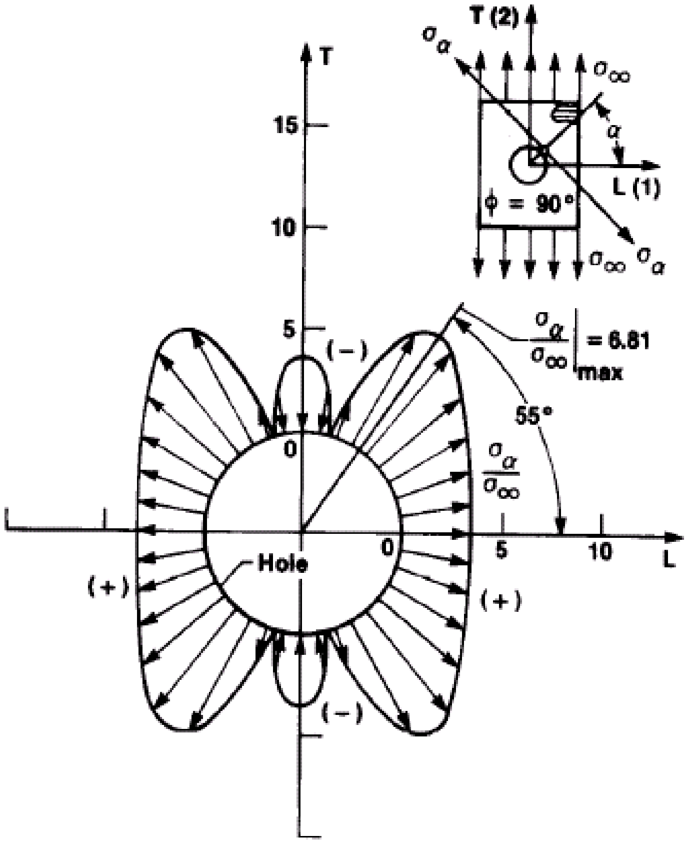


Figure 4.1b: Comparison with NASA results for single ply laminate showing the stress concentration at 54^o.



Tangential stress distribution around a circular hole in a single-ply composite plate. ϕ = 90°.

Figure 4.2 NASA Study of stress concentration of circular hole in composite material (William, 1985)

- Yoshiaki Yasui and Kiyoshi Tsukamura (1987) have studied stress concentration for FRP (Fiber Reinforced Plate) plates with a circular hole under biaxial tension. The calculation of stress is carried out using finite element method. The stress distribution around the hole in the plate is examined with respect to the fiber direction while the model is under biaxial load. The maximum stress concentration factor obtained by them at 90° for θ=0° is 5.1 while the stress concentration factor obtained by our model is 4.98. the difference between our results and their results is 2.2%.

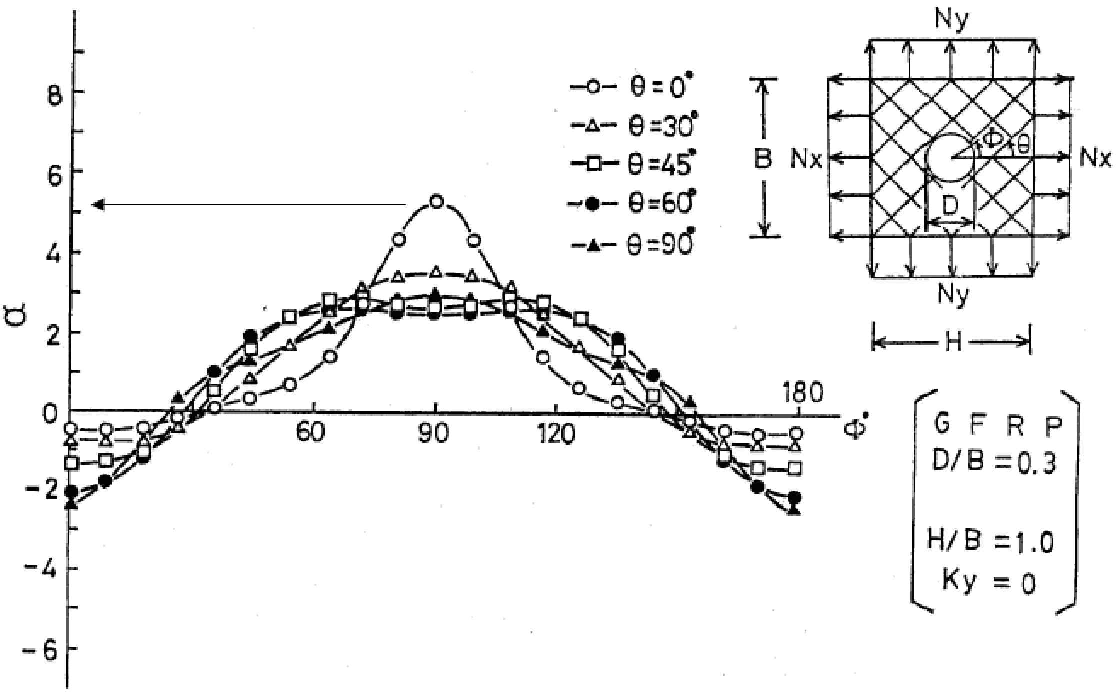


Figure 4.3: Stress distribution around a circular showing the maximum at 90° where $K_y=N_y/N_x$. (Yoshiaki, 1987)

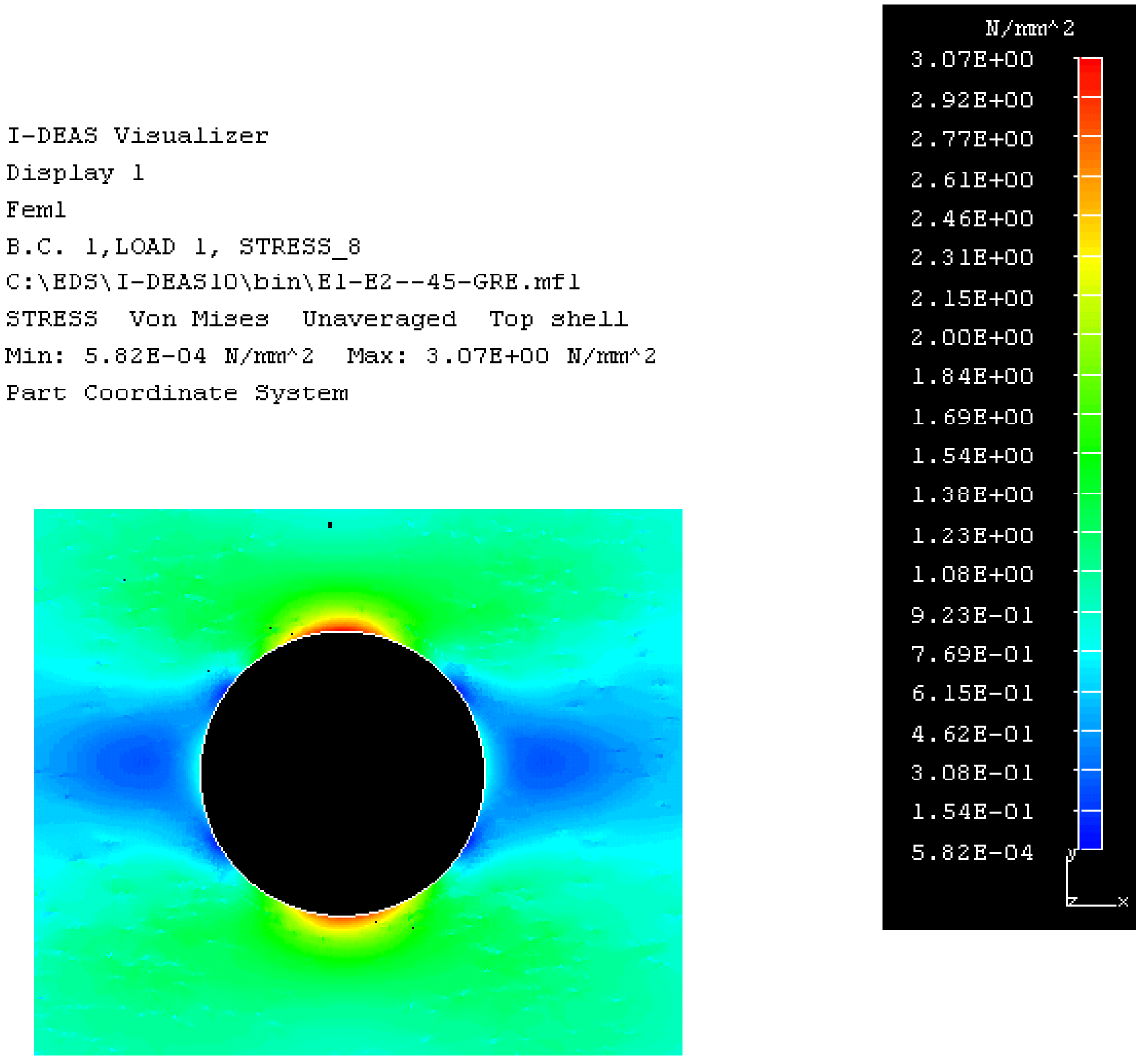


Figure 4.4: Illustration of the stress distribution around circular hole with similar conditions as in figure 4.3.

4.2 Material Mechanical Properties

Material properties for the composite materials such as woven Glass, boron Aluminum, Graphite Epoxy and Carbon epoxy are taken from (material handbook, 1991) where as the other materials are assumed theoretically to cover the study range for E1/E2 ratios from 1.0 to 63.77 so we have equally periods coverage.

Table 4.1: Material Mechanical Properties (WWW.MATWEB.COM)

Material		Young's modulus (E) (GPA)	Poisson's Ratio (v1)	Shear modulus (G) (GPA)	E1/E2 Ratio
Woven Glass	Fiber	29.7	0.3	11.4	1.0
	Epoxy	29.7	0.3	11.42	
Boron Aluminum	Fiber	235	0.3	90.38	1.72
	Epoxy	137	0.3	52.69	
Material 10	Fiber	250	0.3	96.15	10
	Epoxy	25	0.3	9.62	
Material 15	Fiber	250	0.3	96.15	15
	Epoxy	16.67	0.3	6.41	
Material 20	Fiber	250	0.3	96.15	20
	Epoxy	12.5	0.3	4.81	
Material 30	Fiber	250	0.3	96.15	30
	Epoxy	8.33	0.3	3.21	
Graphite Epoxy	Fiber	294	0.3	113.08	45.94
	Epoxy	6.4	0.3	2.64	
Material 50	Fiber	250	0.3	96.15	50
	Epoxy	5.0	0.3	1.92	
Carbon Epoxy	Fiber	220	0.3	84.62	63.77
	Epoxy	3.45	0.3	1.33	

This gives designer the opportunity to fit any material by using dimensionless E1/E2 ratio in stress reductions figures by using interpolation or extrapolation. Table 2.3 shows the mechanical properties of different composite material

The composite plate is assumed to remain elastic at all times. Therefore only elastic material properties are required for the plates and they are presented in the above table. Example of feeding the material properties of Carbon Fiber to I-DEAS is shown in figure 2.5 below

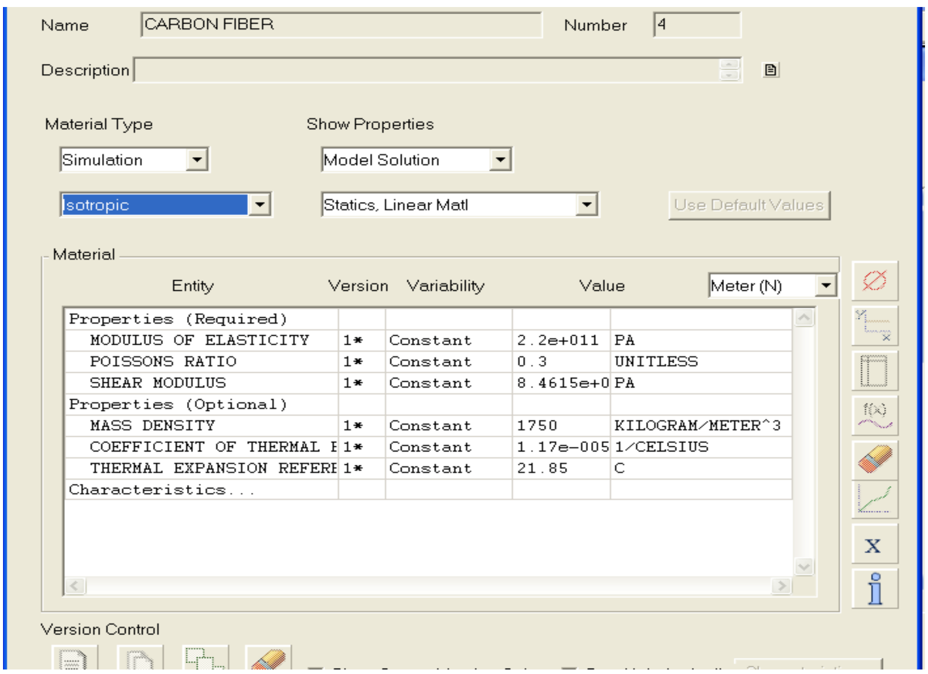


Figure 4.5 Carbon Fiber properties

4.3 Experimental Setup:

Schematic illustration of the experimental setup is shown in Figures 4.5 and 4.7. It consists of Light Source, Polarizer, two Quarter-wave plates, Analyzer and Specimen (that is coated by birefringent material). Figure 1.5 represent the machine that has been manufactured to load the specimens. The calibration curve for the identical springs installed in the testing machine is shown in figure 4.8.

Figure 4.6: photo of reflection polariscope setup that is manufactured for experimental verification.

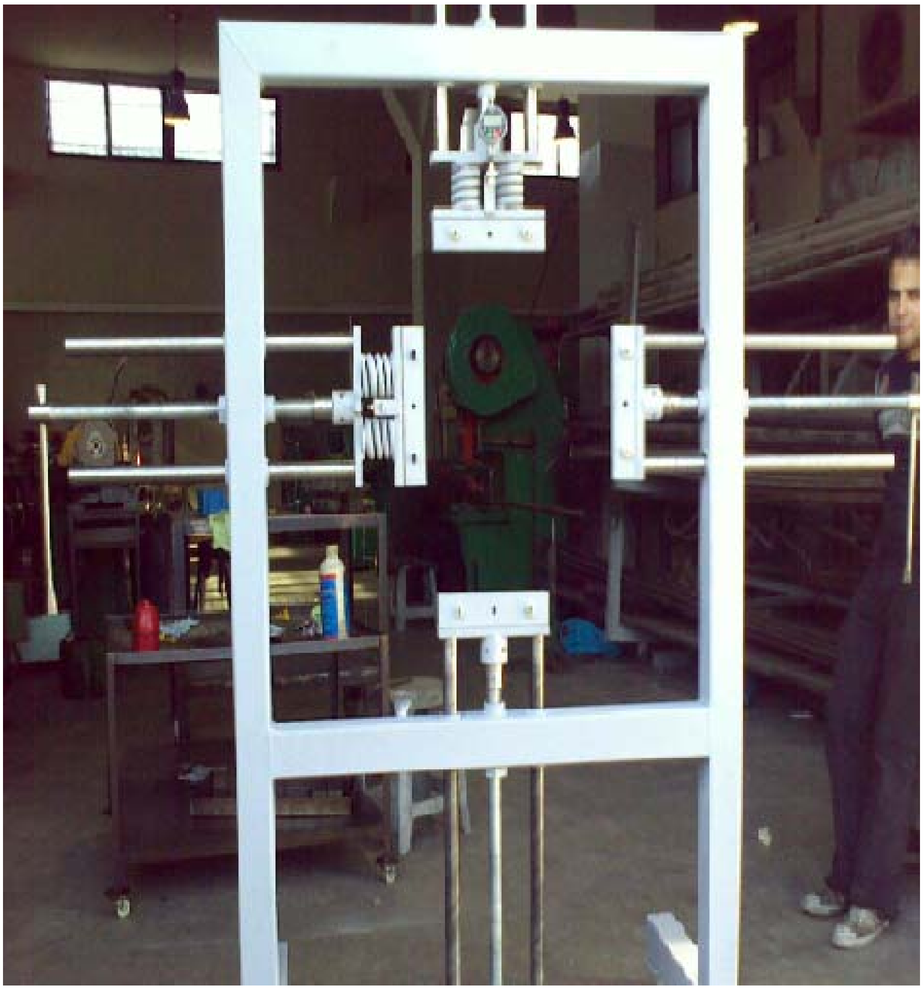


Figure 4.7: photo of manufactured biaxial loading machine for carrying out the experimental verification.

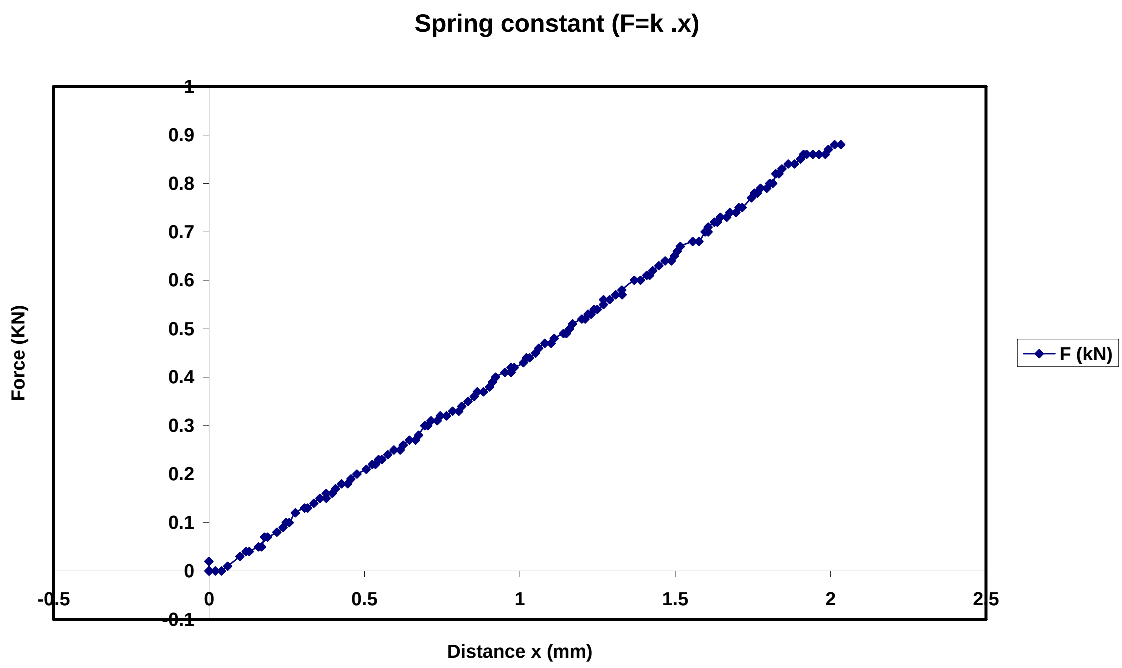


Figure 4.8.—Experimental measurement of installed springs constants

4.3 Experimental Procedure

1. Specimens are produced that match the numerical model.
2. Reflective adhesive is applied to the specimen.
3. Photo-elastic coating is applied.
4. Calibration specimen is produced under the same conditions that the test specimens are produced as shown in Figure 4.9 Akour (2003).
5. Correlation between the calibrated specimen and the test specimen will be carried out and Table 4. 2 Akour (2003) will be produced.

Each color represents fringe order that at the end represent strain (this could be related to the stress) level according the equation shown below. The equations below represent the relation for isotropic material. However the relation of the fringe order with the principle stress is going to be a matrix rather than just a constant ($Ef/(1+v)$). Figure 4.9 and table 4.2 represent the calibration specimen for isotropic material and the corresponding fringe order for each color intensity.

$$\varepsilon_x - \varepsilon_y = N f \quad (4\text{-}1)$$

Where $\varepsilon_x - \varepsilon_y$ principle strains, N = fringe order, and f = fringe value of coating

$$\sigma_x - \sigma_y = \frac{E}{1+\nu} N f \quad (4\text{-}2)$$

Where: $\sigma_x - \sigma_x =$ Principal stresses in test part surface

$E = E_f \upsilon_f + E_m \upsilon_m$ (Elastic modulus of test part)

$\nu = \nu_f \upsilon_f + \nu_m \upsilon_m$ (Poisson's ratio of test part)

Where: E_f modulus of the fiber , E_m modulus of the matrix

υ_f fiber volume fraction, υ_m matrix volume fraction

ν_f Poisson's ratio of the fiber, ν_m Poisson's ratio of the matrix (Reddy,2004)

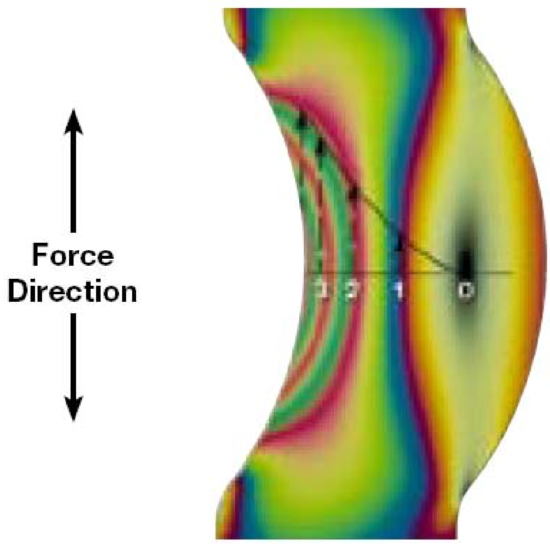


Figure 4.9: Calibration Specimen

Table 4.2: Correlations between the color and the fringe order for isotropic material Akour (2003).

ISOCHROMATIC FRINGE CHARACTERISTICS			
COLOR	APPROXIMATE RELATIVE RETARDATION		FRINGE ORDER N
	nm	in × 10^{-6}	
Black	0	0	0
Pale Yellow	345	14	0.60
Dull Red	520	20	0.90
Red/Blue Transition	575	22.7	1.00
Blue-Green	700	28	1.22
Yellow	800	32	1.39
Rose Red	1050	42	1.82
Red/Green Transition	1150	45.4	2.00
Green	1350	53	2.35
Yellow	1440	57	2.50
Red	1520	60	2.65
Red/Green Transition	1730	68	3.00
Green	1800	71	3.10

For the case of fiber reinforced composite material the calibration specimen is shown in figure 4.10. Due to the anisotropic behavior of such material (carbon fiber composite), the fringe trajectories are not as smooth as those of isotropic material. The color intensities along the line shown are collected to be the reference that the specimen should be compared with to find the corresponding fringe order. The line is selected where the variation of the stress is linear. The maximum value for the fringe order is 2.0 at the edge of the calibration specimen. Using MATLAB Image Processing toolbox the color intensity of the test specimen is compared to those obtained from the calibration specimen. For uniaxial tension case (see Figures 4.11 through 4.14) with circular defense hole system the reduction obtained is 6.6% (± 2%) compared to the one obtained from the FEM study 7.5%. The four circular hole defense system for biaxial load (pure shear) shows that the situation is worse than without defense hole system. The increase in the stress by applying defense hole system is 14.3%+/-2% compared to the increase obtained by the FEM analysis of 12.74% (see Figures 4.15 through 4.18). The experimental testing and analysis has been repeated to assure the results. The differences between the experiment and FEM results are due to many reasons. Even though the testing setup is covered completely with a black cloth still some light from the environment has passed to reach the camera and the test specimen. It is better to have a dark room for testing but since this is not currently available this primitive method to prevent outside light is used. The loads applied by the biaxial loading machine that has been manufactured for this purpose is not 100% aligned.

Figures 4.19 through 4.22 present images of the specimens used in the investigation. Figure 4.19 presents the calibration specimen. The specimen without defense system is shown in figure 4.20 a&b . The specimens of two and four defense system are shown in figures 4.21

and 4.22 respectively.

Calibration error is eliminated by using the same conditions and environment; the same source light, specimens distances, camera focusing, ..etc. A black shelter is used to isolate any light distortion, So if there is some un accuracy, it will be cancelled out with specimen. Cutting operations of specimens samples are done slowly, and all samples are tested under no load to to be sure that there is no any residual stresses, any specimen has residual stress is phased out of experiment verification.

High stress areas are investigated, since they are true candidate to be starting points for failure.

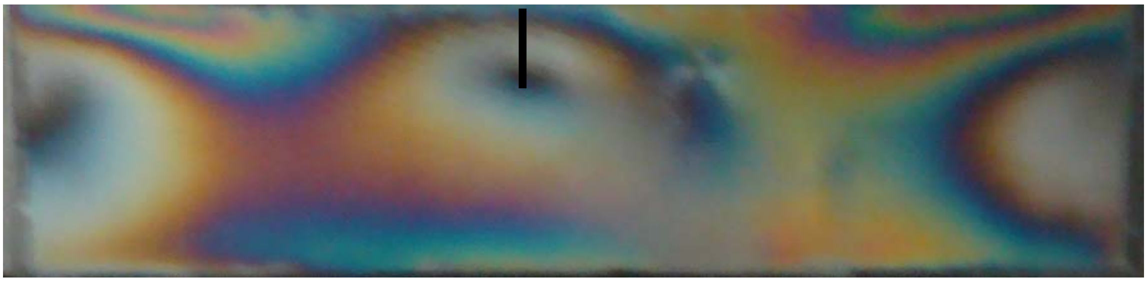


Figure 4.10: Photoelastic image of the calibration specimen of carbon fiber composite material using reflection polariscope arrangement. The black line represents the color intensities that have been extracted for correlation with test specimens.

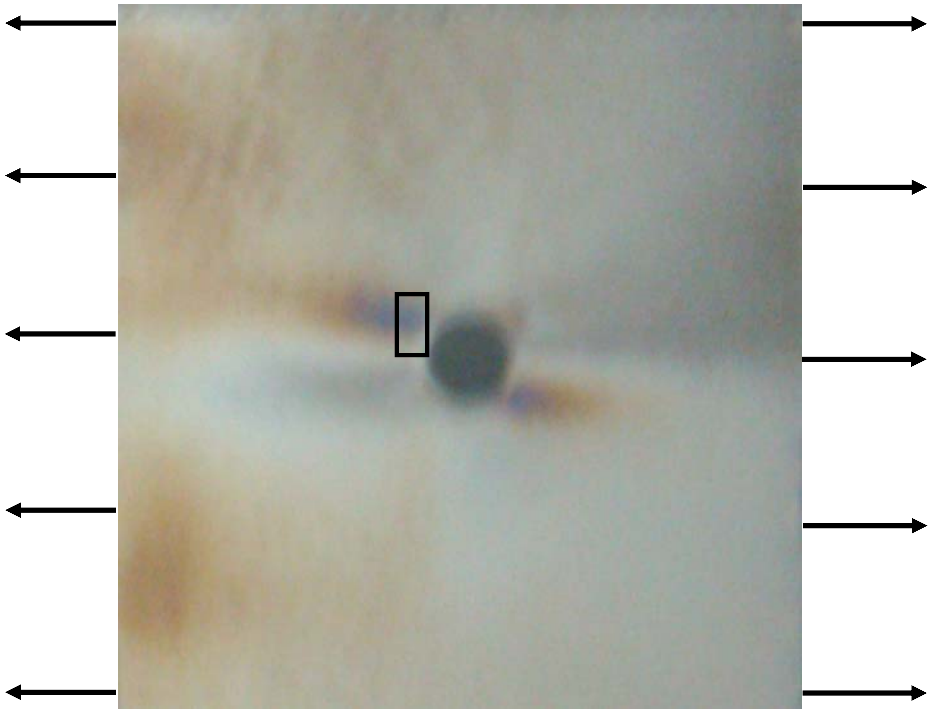


Figure 4.11: photoelastic image of carbon-fiber laminate with main hole under uniaxial loading.

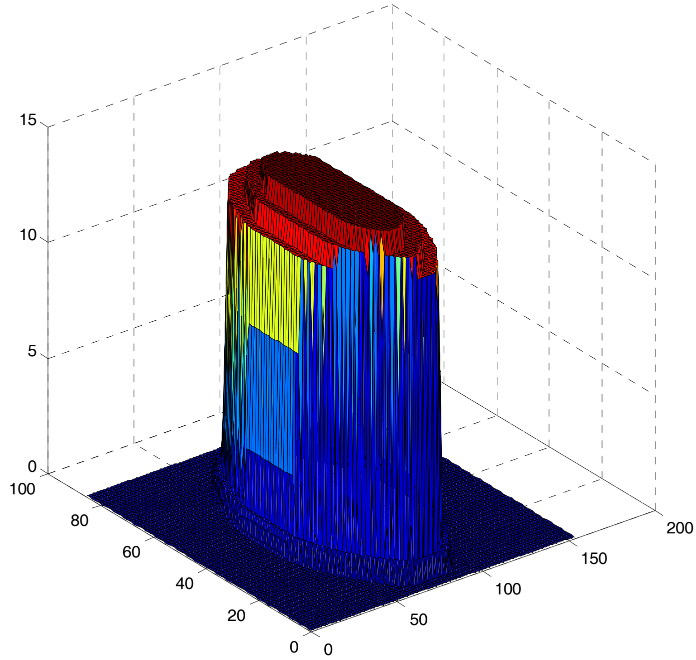


Figure 4.12: Illustration of the fringe order for the area enclosed in the box shown in Figure 4.11. Each division in the z axis represent 0.1 fringe order i.e., 15 divisions equal 1.5 fringe order. The values on the x-y axes represent the pixel coordinates.

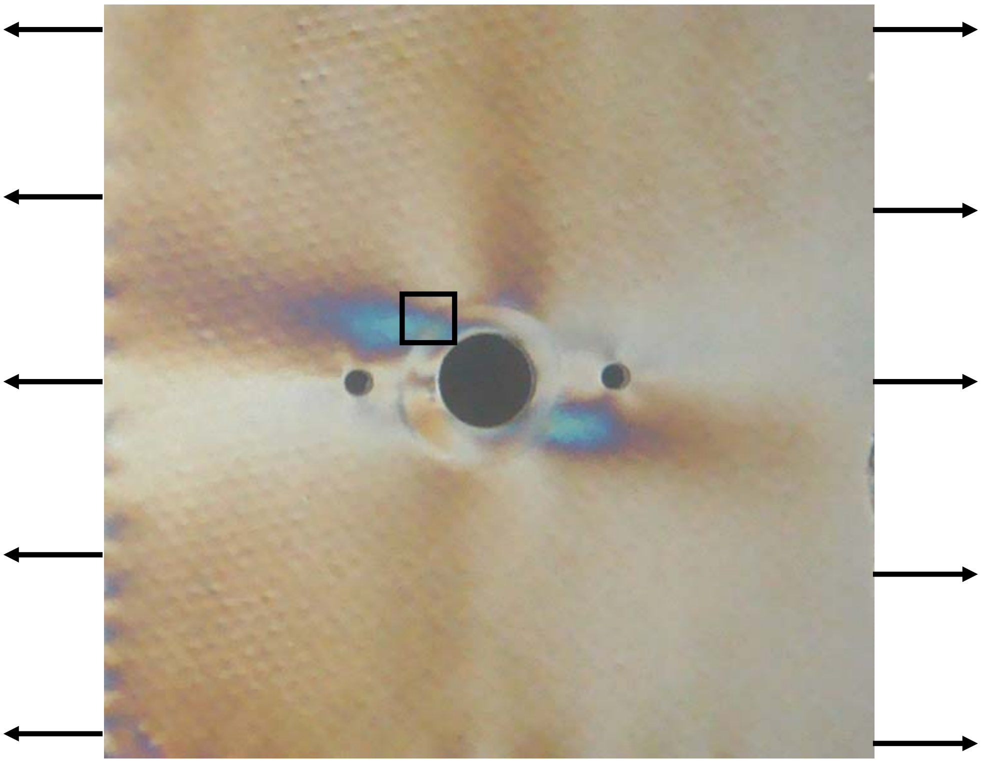


Figure 4.13: Photoelastic image of laminate under uniaxial loading with defense hole system under the same conditions of the specimen shown in figure 4.11.

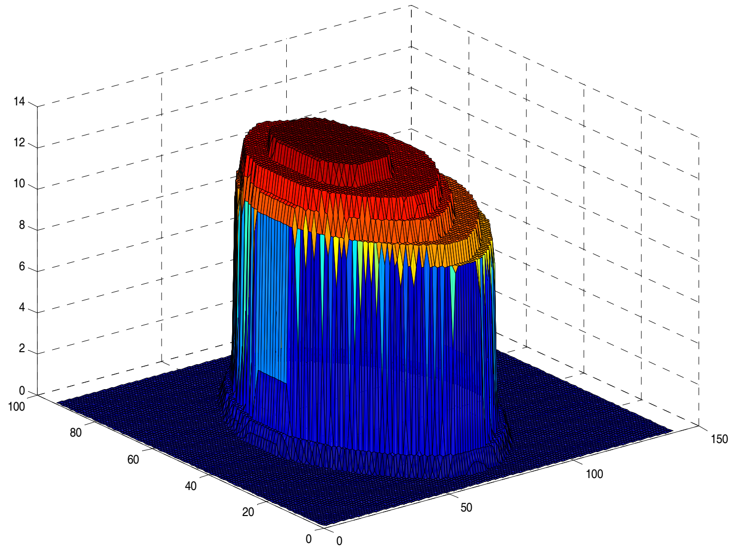


Figure 4.14: Illustration of the fringe order of the area enclosed in figure 4.13. Each division in the z axis represents 0.1 of the fringe order i.e. 14 divisions' equal 1.4 fringe order. The values on the x-y axes represent the pixel coordinates.

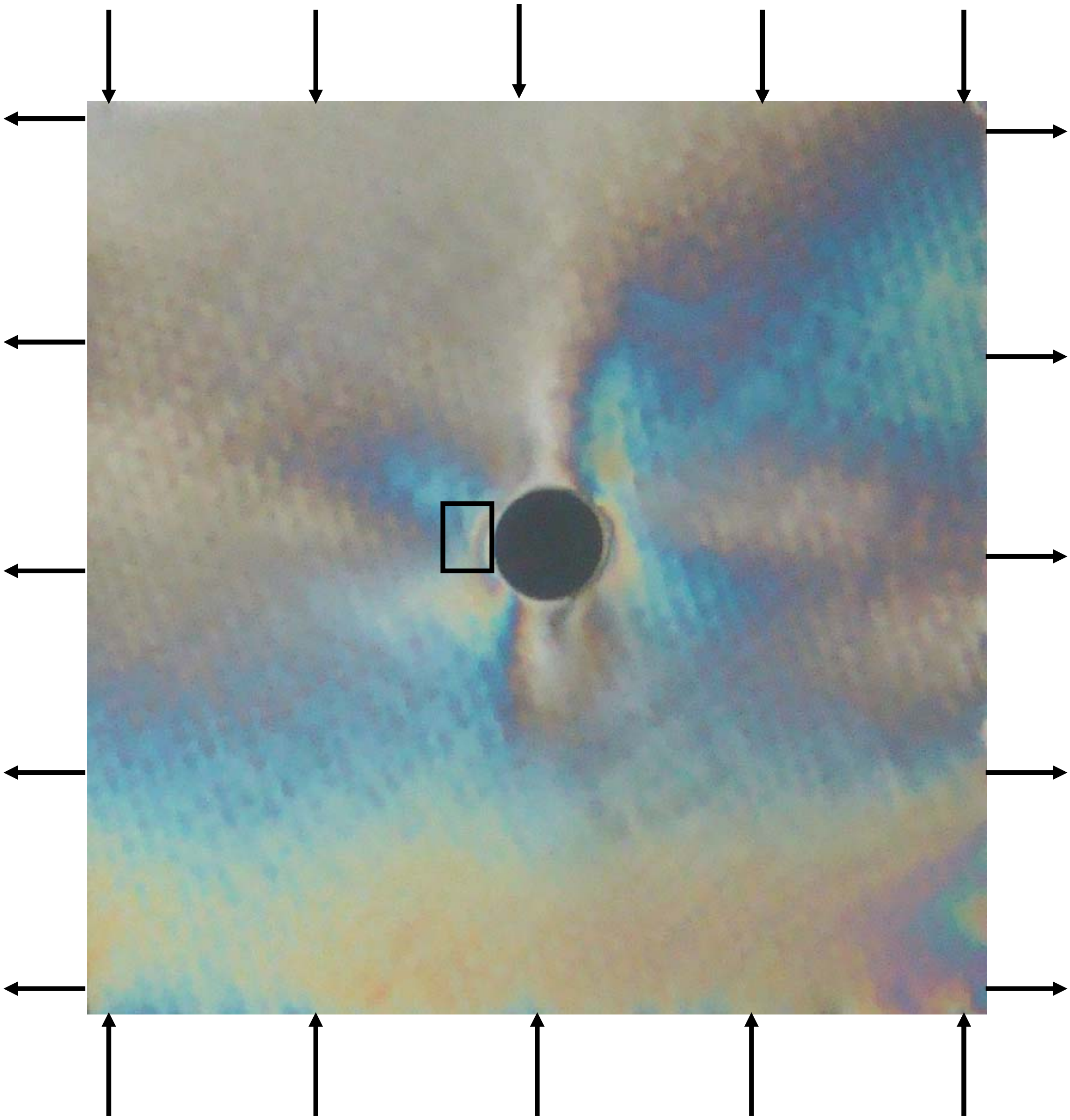


Figure 4.15: Photoelastic image under biaxial loading without defense hole system.

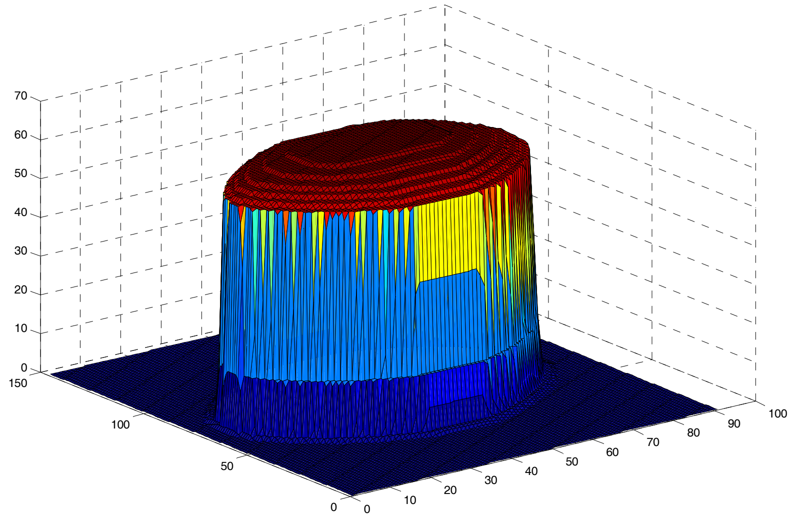


Figure 4.16: Illustration of the fringe order for the area enclosed in the box shown in Figure 4.15. Each division in the z axis represent 0.02 fringe order i.e., 70 divisions equal 1.4 fringe order. The values on the x-y axes represent the pixel coordinates.

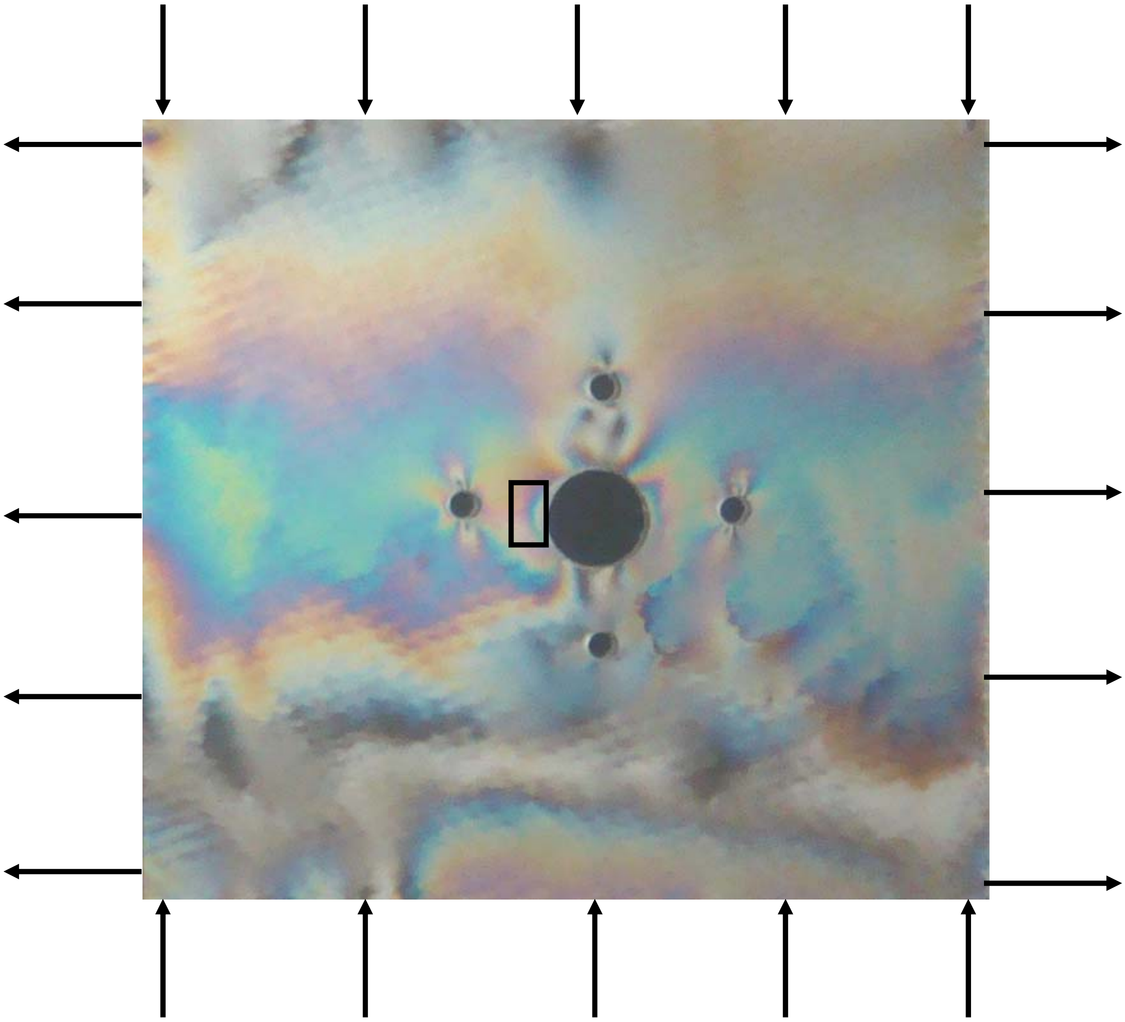


Figure 4.17: Photoelastic image under biaxial loading with defense hole system under the same conditions of figure 4.15.

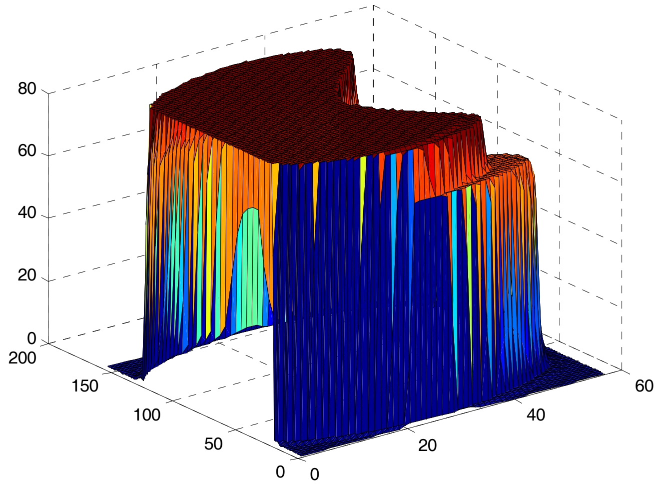


Figure 4.18: Illustration of the fringe order for the area enclosed in the box shown in Figure 4.17. Each division in the z axis represent 0.02 fringe order i.e., 80 divisions equal 1.6 fringe order. The values on the x-y axes represent the pixel coordinates.

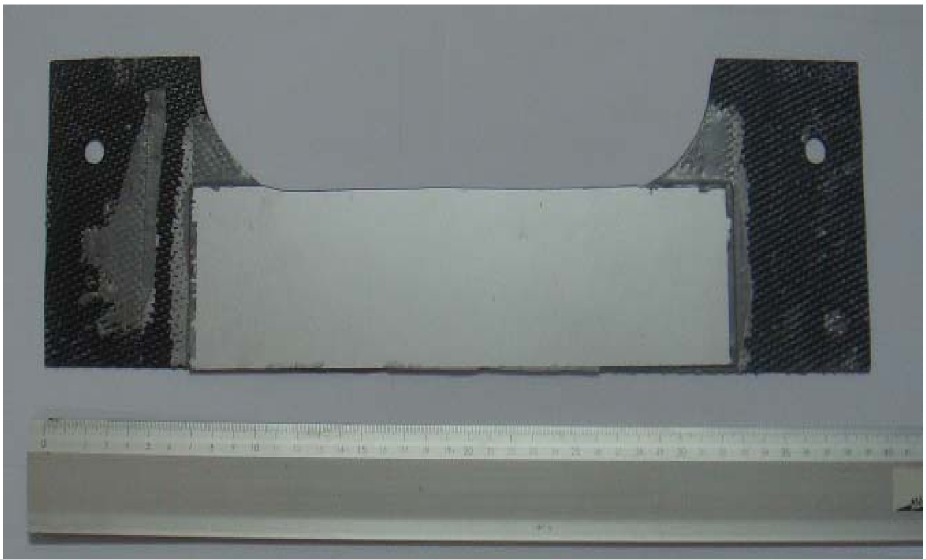


Figure 4.19 Calibration Specimen

Figure 4.20a Specimen without defense system

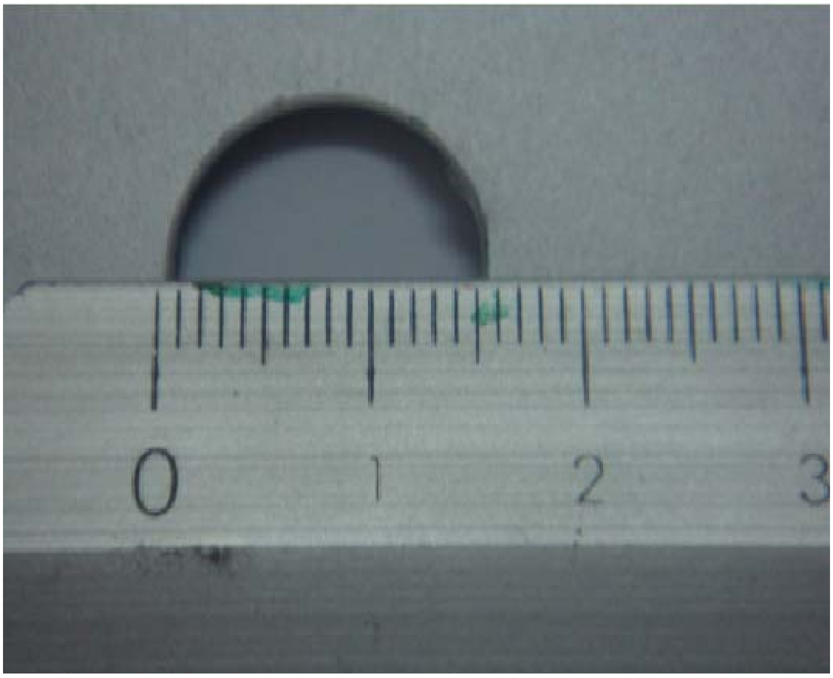


Figure 4.20b Specimen without defense system (Main Hole)

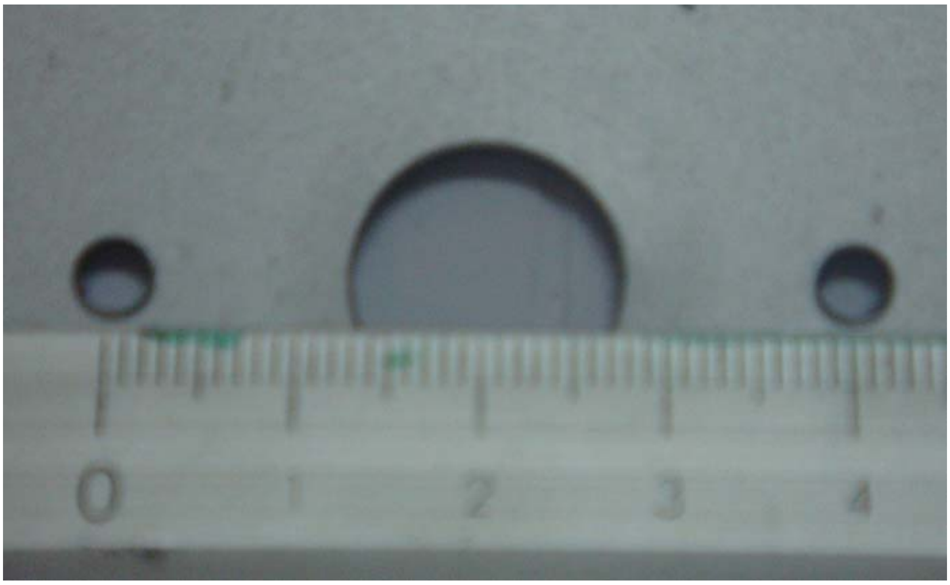


Figure 4.21 Specimens of two defense system

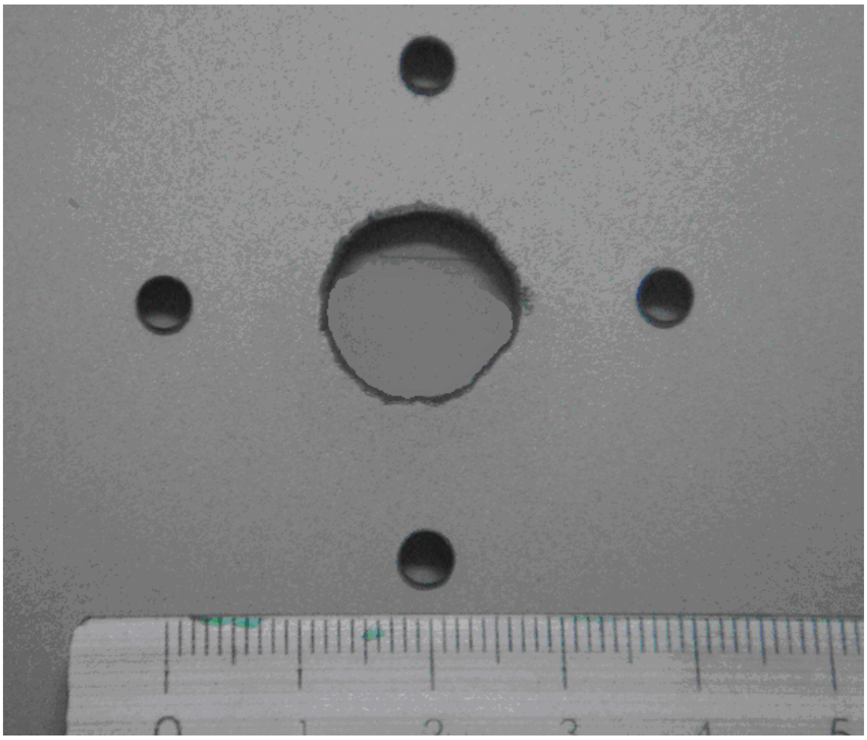


Figure 4.22 Specimens of four defense system

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction:

The results of computational procedures involved numerous iterations. The optimization scheme focused on the following variables: shape of the design hole system; i.e. two circular, four circular or four elliptical shapes, size of the DHS i.e. diameters of the hole, the angle ϕ between the horizontal and the line between the main and DHS holes centers (refer to figure 1.8) and the placement of the DHS. Redesign optimization module is utilized to find the optimum solution for each optimum case (refer to I-DEAS user guide, Optimization book). The redesign optimization technique is based on sensitivity analysis in reaching the optimum design parameters. To maximize the benefit of this study the univariate search optimization technique is adopted to record the stress variation through the utilization of the parametric optimization module of I-DEAS. The parametric analysis is applied in a systematic iterative manner to exhaust all possible scenarios to reach the optimum design.

The defense hole system theory is based on introducing the holes in the low stress spots within the vicinity of the main hole. So these holes raise the stress in these low stress spots to smooth the stress flow through the whole model.

All computations are represented and tabulated in Appendices A and B. This chapter investigates two circular and four circular defense hole system as well as four elliptical defense hole system. All detailed data for this study are illustrated in appendix B tables B.1 to B.9 for two circular defense hole system where tables B.10 to B.18 shows the results of four circular defense hole systems. Four elliptical defense hole system results are tabulated in tables B.19 to B.B.68. All the stress variation versus the dimensionless quantities of the minor (a/D), the major (b/D) and the location (s/D) for compression to tension load ratio are considered. Only summary of the results in tabular and graphic formats are presented in this chapter and repeated in Appendix A just to have a complete appendix package.

A shape study of the defense hole system for infinite plate has revealed that four Elliptical design hole system has the best stress reduction. Nine Different E1/E2 material ratios starting with Woven Glass composite material with E1/E2 ratio 1.0 to Carbon Graphite composite material with E1/E2 ratio equal to 63.77 are studied. Four of them are real material while the other five materials are assumed to cover the range of E1/E2 ratios. So E1/E2 ratio of 1.00, 1.72, 10.0, 20.0, 30.0, 40.0, 45.94, 50.0, and 63.77 are investigated. Table 5.1 below shows the results. Maximum stress reduction for two circular design hole system reaches 5.69% for material E1/E2 equal to1.0 while there is no reduction after E1/E2 of 20 so the range for stress reduction does not exceed 5.69% and only for lower E1/E2 material ratios.

Four circular design hole system gives worse results and reaches to 4.07% as a maximum stress reduction ratio for same material E1/E2 ratio.

The four elliptical design hole system gives the best stress reduction ratio which reaches 20.56% and not less than 15.59% and valid for all investigated materials.

The figure below gives better picture for design hole system shape study under pure shear loads of 1000 N in tension and 1000 N in compression

Table 5.1 : Design hole study for :Two Circle(2C), Four Circle(4C) and Four Elliptical(4E) DHS for Material E1/E2 ratios 1.0, 1.72, 10.0, 20.0, 30.0, 40.0, 45.94, 50.0 and 63.77, Tension 1000 N, Compression 1000 N, Load ratio=1.0

Table 5.1: Design hole study for :Two Circle(2C), Four Circle(4C) and Four Elliptical(4E) DHS for Material E1/E2 ratios 1.0, 1.72, 10.0, 20.0, 30.0, 40.0, 45.94, 50.0 and 63.77, Tension 1000 N, Compression 1000 N, Load ratio=1.0

Material	E1\E2 ratio	Max. Stress without DHS (Pa)	Max. Reduction with 2C DHS (Pa)	Stress Reduction Ratio 2C DHS	Max. Reduction with 4C DHS (Pa)	Stress Reduction Ratio 4C DHS	Max. Reduction with 4E DHS (Pa)	Stress Reduction Ratio 4E DHS
Woven Glass	1.00	2.46E+03	2.32E+03	5.69%	2.36E+03	4.07%	2.08E+03	15.45%
Boron Aluminium	1.72	2.51E+03	2.36E+03	5.98%	2.44E+03	2.79%		16.50%
E1/E2 10	10.00	3.23E+03	3.12E+03	3.41%	3.22E+03	0.31%	2.92E+03	18.21%
E1/E2 20	20.00	3.85E+03	3.77E+03	2.08%	3.93E+03	-2.08%	2.92E+03	18.21%
E1/E2 30	30.00	4.28E+03	4.82E+03	-12.62%	4.22E+03	1.40%	3.40E+03	20.56%
E1/E2 40	40.00	4.63E+03	5.24E+03	-13.17%	5.01E+03	-8.21%		16.50%
Graghite Eopxy	45.94	4.77E+03	5.42E+03	-13.63%	5.35E+03	-12.16%	4.10E+03	14.05%
E1/E2 50	50.00	4.90E+03	5.86E+03	-19.59%	5.40E+03	-10.20%		14.50%
Carbon Epoxy	63.77	5.26E+03	6.38E+03	-21.29%	5.93E+03	-12.74%	4.44E+03	15.59%

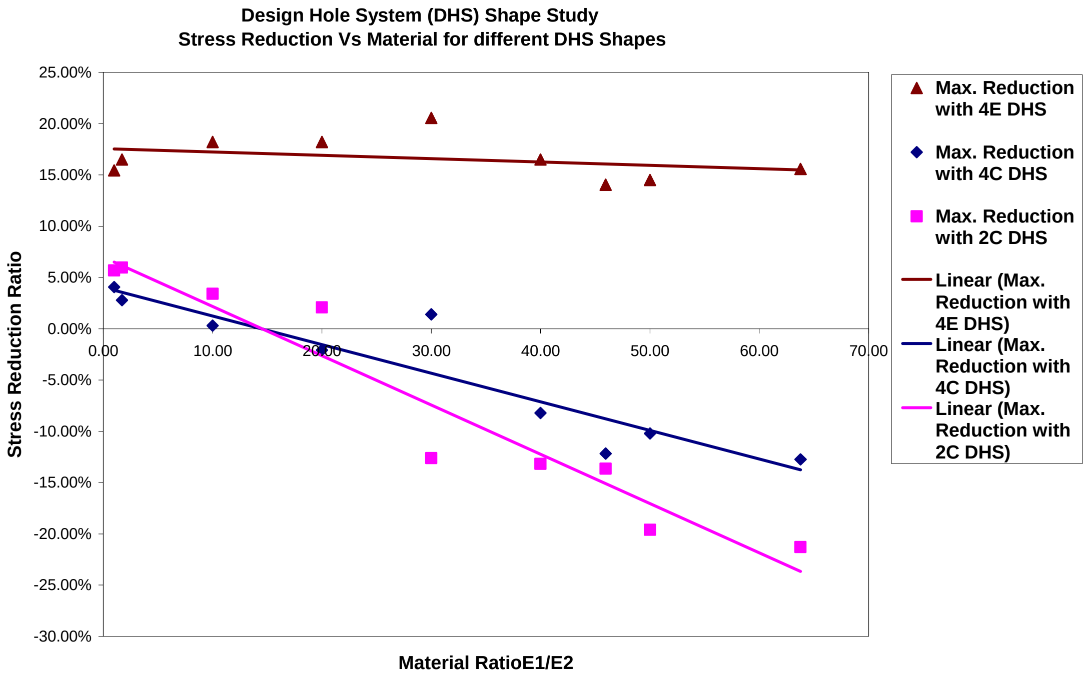


Figure 5.1 Design Hole System Shape Study

5.2 Defense hole system design for a shear loaded plate:

There are four variables or parameters controlling the optimization of the stress for infinite plate loaded by shear. These parameters are a/D, b/D, ϕ, S/D. Optimum value of a/D, b/D and S/D is assumed to be in the range 1.16-1.4 for a/D ,0.3-0.5 for b/D and 1.16-2.0 for s/D while all angles are investigated

The range in which the optimum value for S/D is expected not to be very far from the optimum value for uniaxial tension case (Erickson 1978). The expected range is S/D=1 to 1.4. An iterative procedure is applied for each value of S/D to get the optimum values of a/D and b/D.

The study of two circular and four circular DHS gives an indications for the optimum ranges of the variable parameters.

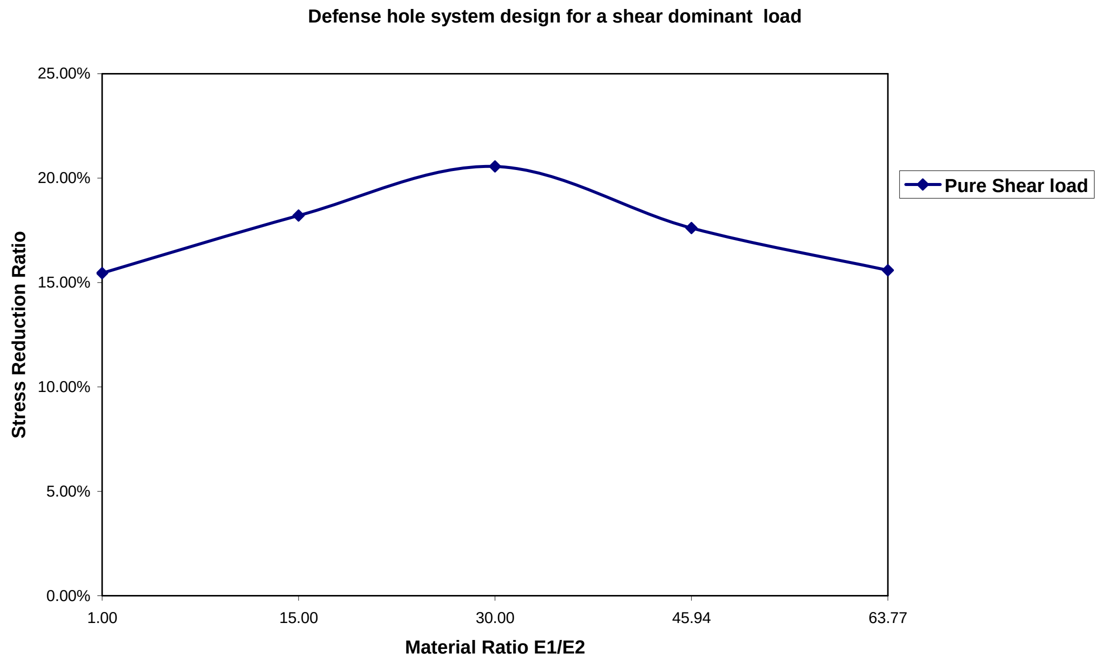


Figure 5.2 Defense hole system for a shear dominant load

Figure 5.2 shows stress reduction ratio for different E1/E2 material ratios 1.00, 15.0, 30.0, 45.94, and 63.77.

Results indicate that the stress reduction reaches up to 20.56% of stress obtained in a plate (E1/E2=30.0) that has the same boundary conditions compared to the same plate with the same loads without introducing defense hole system. The lowest reduction for pure shear load is 15.45%.

Concerning the fiber directions contribution in pure shear loaded composite plate; figure 5.3 illustrates these results which indicate that the best reduction occurs at zero angle fibers for all materials i.e. the tension load is aligned with the fiber direction. Due to the symmetry of the curve around the fiber angle 45 only half of it is illustrated in figure 5.3.

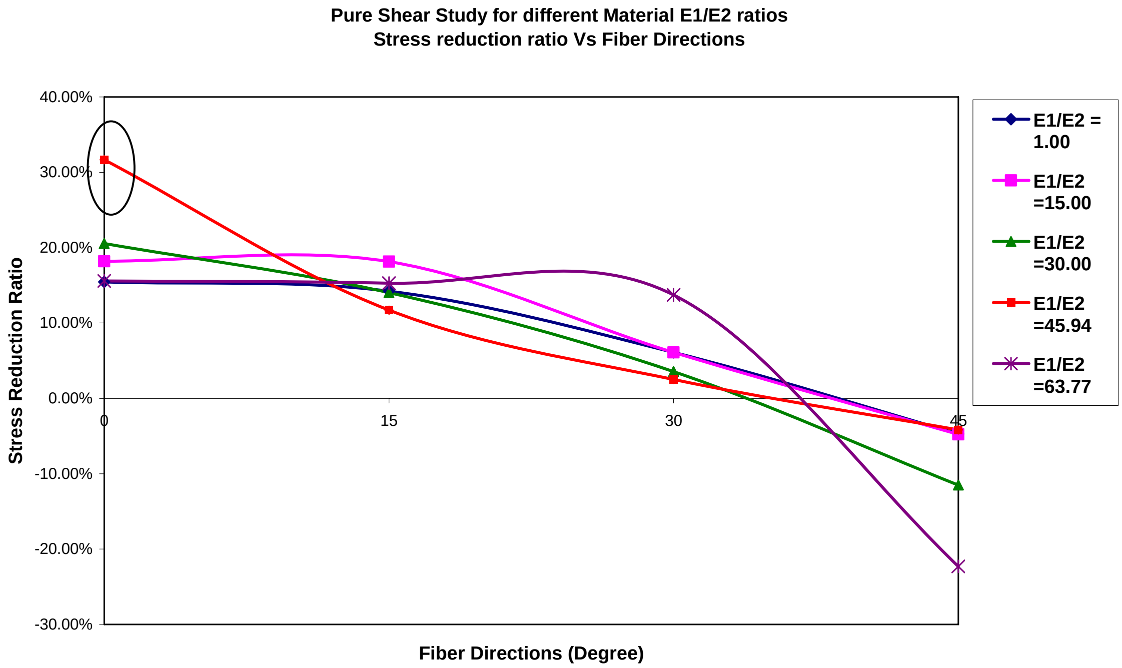


Figure 5.3 Stress Reduction Ratio Vs Fiber Direction for pure shear load

5.3 Discussion of DHS for a shear loaded plate:

As we note in figure 5.2 that the reduction reaches its maximum ratio for material E1/E2 ratio then it is decreased till in both sides, the reduction occurred when the DHS placed at ϕ equal to zero. Also when we investigated the fiber direction influence on the reduction ratio we found that the best angle is zero degree for all materials. Since the load is obtained with fiber material direction, the load will be carried totally by the fiber. Figure 5.4 shows the stress reduction for Martial (E1/E2=30.0) that can be achieved by using such a defense hole system for pure shear case, so if the main hole diameter, the modulus of elasticity ratio and the fiber direction for the plate is known, the optimum defense hole system for pure shear case can be obtained.

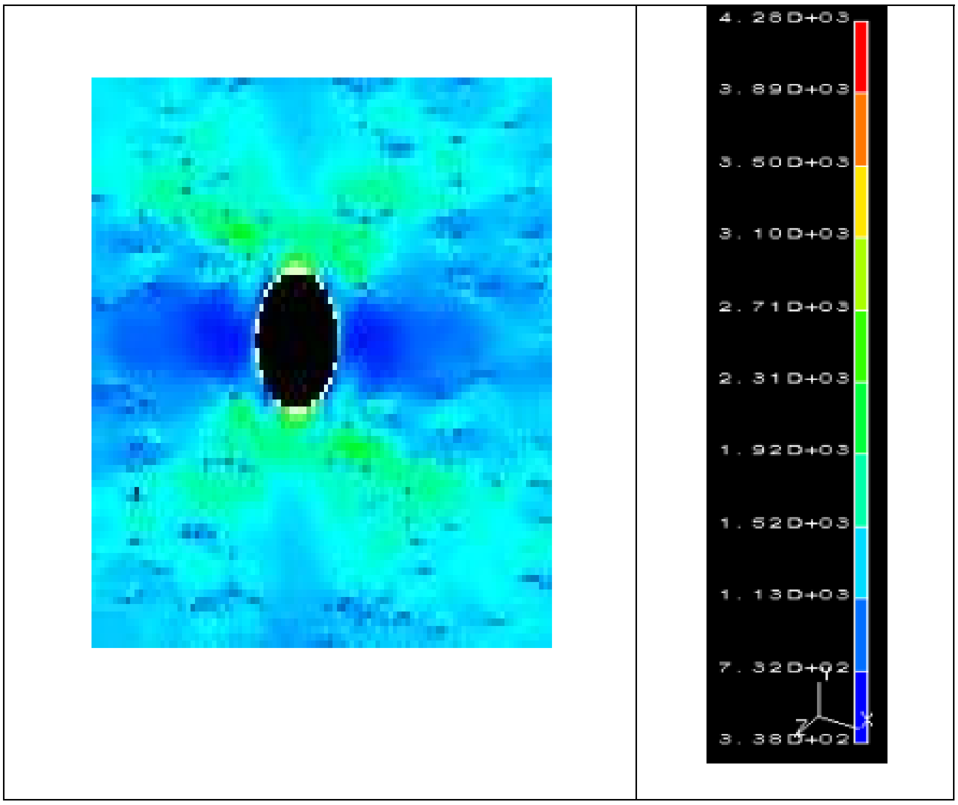


Figure 5.4a Stress distribution for E1/E2 30.0 composite plate without DHS

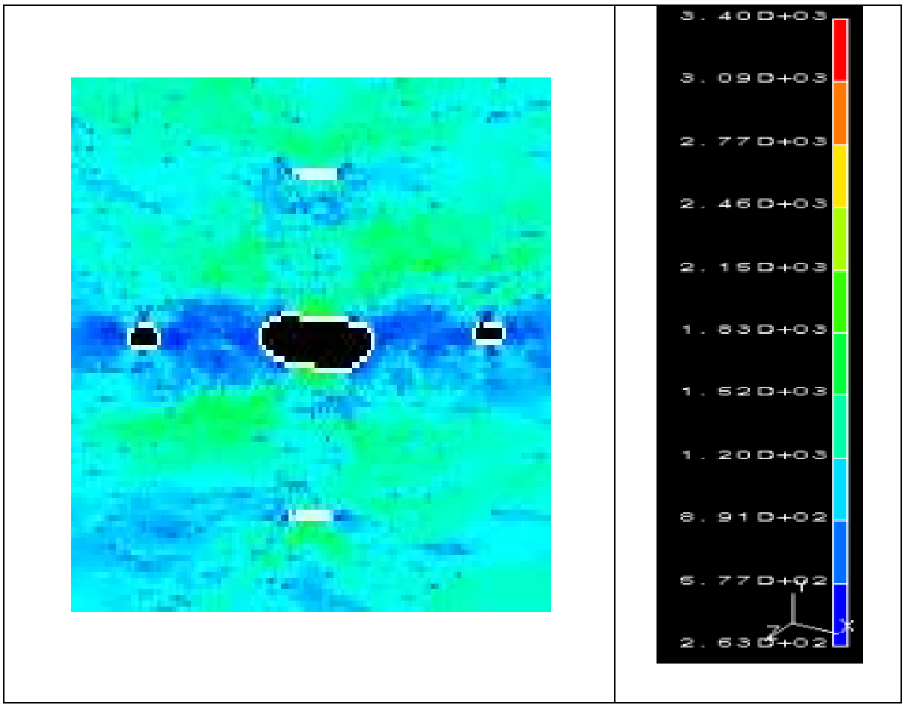


Figure 5.4b Stress distribution for E1/E2 30.0 composite plate with DHS.

5.4 Design of Defense hole system for mixed loaded plate –Load ratio results:

Stress concentration associated with circular holes in a generally loaded plate in the range of compression to tension ratio from zero to 75 % is reduced by a 31.69 % as a maximum reduction and 4.79 % as a minimum reduction. This reduction is achieved by introducing auxiliary elliptical holes along the fiber directions. This reduction depends on mechanical properties of composite material. All dimensions are divided by D the main hole diameter and all stresses are also normalized by the maximum stress of the corresponding plate without defense hole system, so all parameters are dimensionless.

The same criterion in choosing the position of the auxiliary system applied in the shear case also applies here. Two main goals are achieved by introducing such holes: load carrying capacity has been increased and material reduction. The same systematic approach that is used in the shear case is used here. Finite Element Analysis is used to optimize the size and location for auxiliary defense hole system.

This section investigates the defense hole system for the mixed load case, which starts from pure shear loading to pure tension loading. Elliptical auxiliary holes are introduced in the regions of low stress to reduce the maximum stress. A two-defense-hole and four-defense-hole systems are investigated as well. Stress reduction in the range of less than 5% is achieved. The stress reduction increases for four elliptical defense hole system as the compression/tension ratio increases as well as E1/E2 ratios increases.

Stress reduction for different materials of the composite plate under mixed loads are tabulated in Table 5.2, this indicate that stress reduction increases as load ratio (compression /tension) increases. Also stress reduction increases as E1/E2 increases up to certain limit around 54.94 then it starts to decrease. Maximum reduction reaches to 31.69 % for Graphite epoxy at 0.75 load ratio, and minimum reduction reaches 4 % for Woven Glass at 0.25 load ratio. Figure 5.4 shows these results.

Table 5.2 : Four Elliptical Design Hole System for Materials E1/E2 ratios 1.0, 15.0, 30.0, 45.94, and 63.77, Tension 1000 N, Compression, 250 N, 500 N, and750 N, N (load ratios 0.25, 0.5, and 0.75).

Material	E1/E2 Ratio	Stress Reduction Ratio at Load Ratio 0.25	Stress Reduction Ratio at Load Ratio 0.5	Stress Reduction Ratio at Load Ratio 0.75
Woven Glass	1.00	4.00%	9.77%	13.48%
E1/E2 15	15.00	13.24%	17.00%	18.26%
E1/E2 30	30.00	21.51%	22.31%	20.75%
Graphite Epoxy	45.94	29.35%	23.97%	31.69%
Carbon Epoxy	63.77	20.86%	19.87%	22.09%

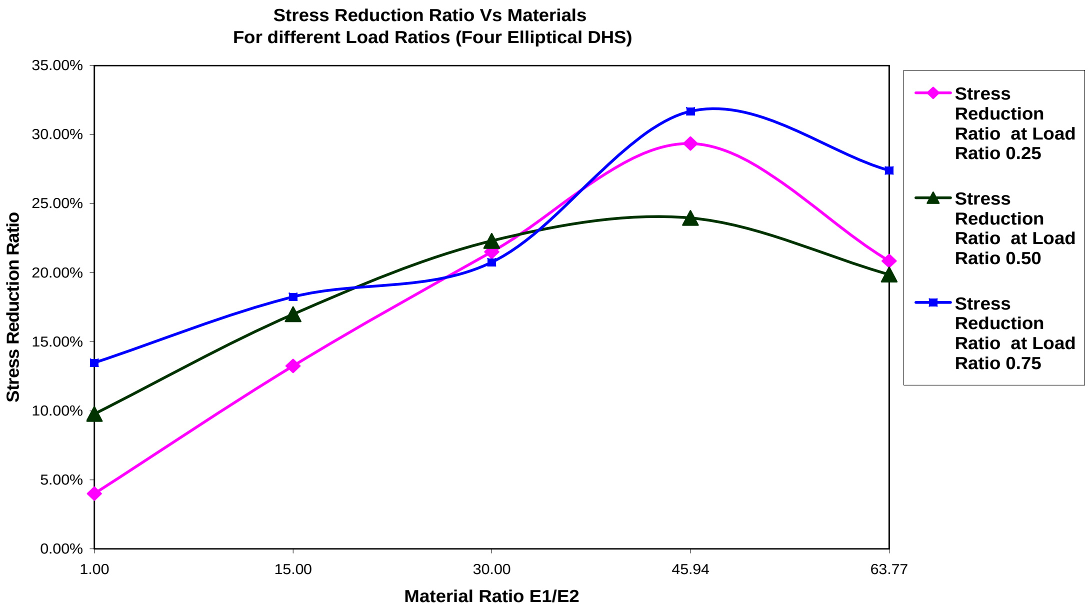


Figure 5.5 Stress reduction ratio Vs material for different load ratio

5.5 Discussion of DHS for mixed loaded plate martial –load ratio:

The criterion that has been considered in applying mixed loads in software is compression force divided by tension force ratio, so we have a dimensionless load, this gives the designers the opportunity to use the charts for any load ratio from pure tension load (load ratio =0.0) up to pure shear load (load ratio 1.0) to select the optimum case that specially fits his design if there are restriction on the position of the defense hole system. So it covers all possible combinations that can be faced.

Same systematic approach that has been used for previous cases is used here. The modulus of elasticity ratio is taken as an indication for the material, so any material with known mechanical properties can be utilized in our baseline data (charts and tables) by using interpolation or extrapolation techniques.

The case of load ratio 0.75 and modulus ratio 30 is repeated to be sure it is converging. It is obvious that all loads have same amount of stress reduction approximately at E1/E2=33. The main reason behind this behavior is the interaction between the loading and the elasticity. The more the fiber is rigid the lower the elongation in the fiber direction the lower is the deformation of the defense hole shape, i.e. less deformation in the lateral direction of tension axis (fiber direction).

5.6 Design of Defense hole system for mixed loaded plate Fiber direction –Load ratio results:

An investigation of the effect of fiber directions is carried out for different materials and different load ratios. This investigation reveals important results for stress reduction ratio versus fiber directions, that is a symmetry of stress reductions for angles less than 45 degrees and angles more than 45 degrees which means there is line of symmetry at 45 degrees, this results gives the opportunity to study only the angles between 0 to 45 degrees.

These results are illustrated in figures 5.4, 5.7, 5.8 and 5.10 below.

Figure 5.6 through Figure 5.11 show the results for each material ratio E1/E2 15, 30, 45.94 and 63.77 under three different load ratios 0.25, 0.50 and 0.75.

Each material is investigated for full range of angles i.e. 0°, 15°, 30°, 45°, 60°, 75° and 90° to be sure that is symmetry about 45° and then investigated only for angles less than 45°.see table 5.3

Figure 5.6 Stress Reduction Ratio Vs Fiber Direction for different Load Ratio

For Material E1/E2 = 15

Table 5.3 : Four Elliptical Design Hole System for E1/E2 = 30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, 250 N, 500 N, 750 N, and 1000 N (load ratios 0.0, 0.25, 0.5, 0.75, 1.0)

Load Ratio	Stress Reduction Ratio Fiber Direction 0°	Stress Reduction Ratio Fiber Direction 15°	Stress Reduction Ratio Fiber Direction 30°	Stress Reduction Ratio Fiber Direction 45°	Stress Reduction Ratio Fiber Direction 60°	Stress Reduction Ratio Fiber Direction 75°	Stress Reduction Ratio Fiber Direction 90°
0.00	15.87%	13.64%	2.91%	0.51%	8.98%	9.09%	15.24%
0.25	21.51%	16.78%	0.45%	-11.48%	0.45%	16.00%	21.00%
0.50	22.31%	16.29%	4.78%	-10.31%	-4.20%	16.33%	23.12%
0.75	20.75%	16.77%	0.36%	-15.13%	-7.52%	12.53%	17.25%
1.00	20.56%	14.04%	3.56%	-11.51%	5.21%	9.17%	20.56%

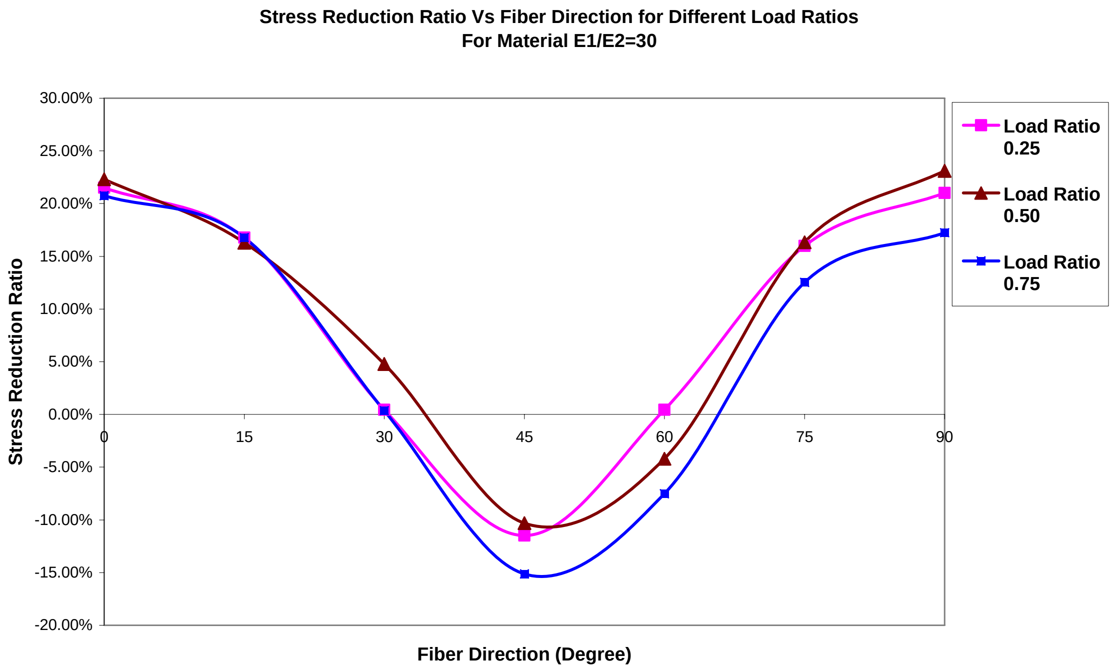


Figure 5.7 Stress Reduction Ratio Vs Fiber Direction for Different Load Ratios For Material E1/E2=30 (all angels)

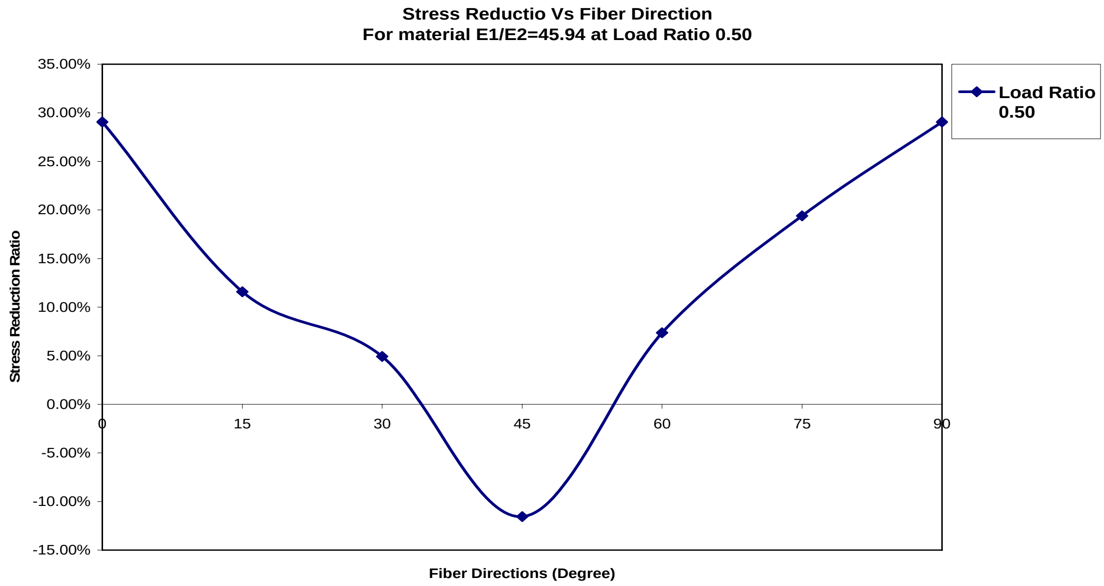


Figure 5.8 Stress Reduction Ratio Vs Fiber Direction for Load Ratios 0.50 For Material E1/E2=45.94 (all angels)

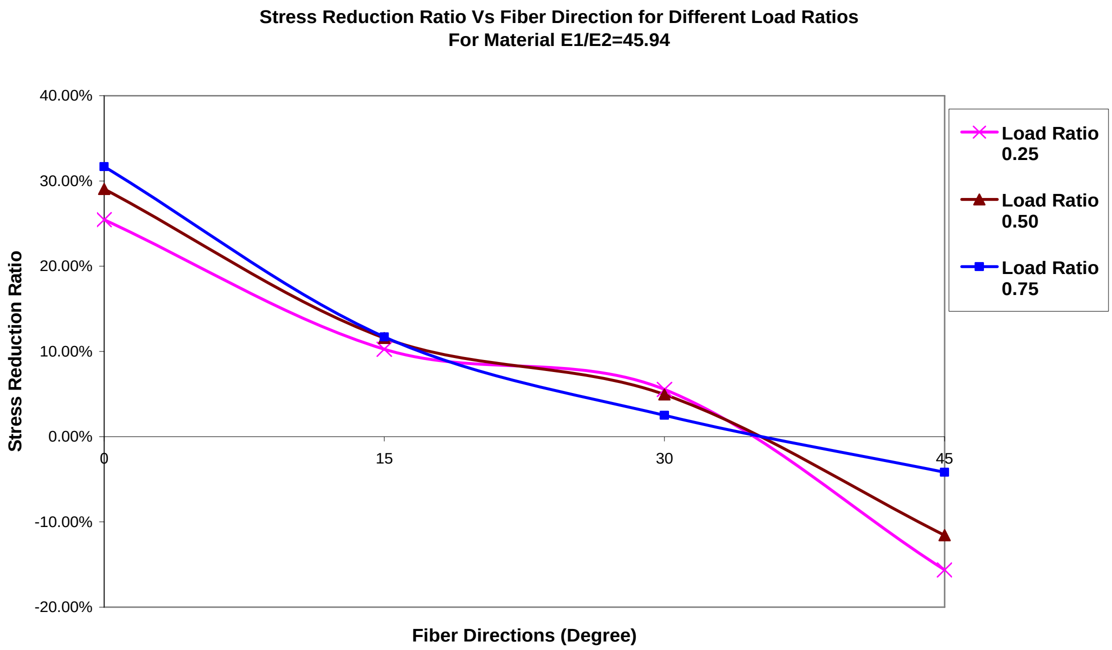


Figure 5.9 Stress Reduction Ratio Vs Fiber Direction for Different Load Ratios For Material E1/E2=45.94

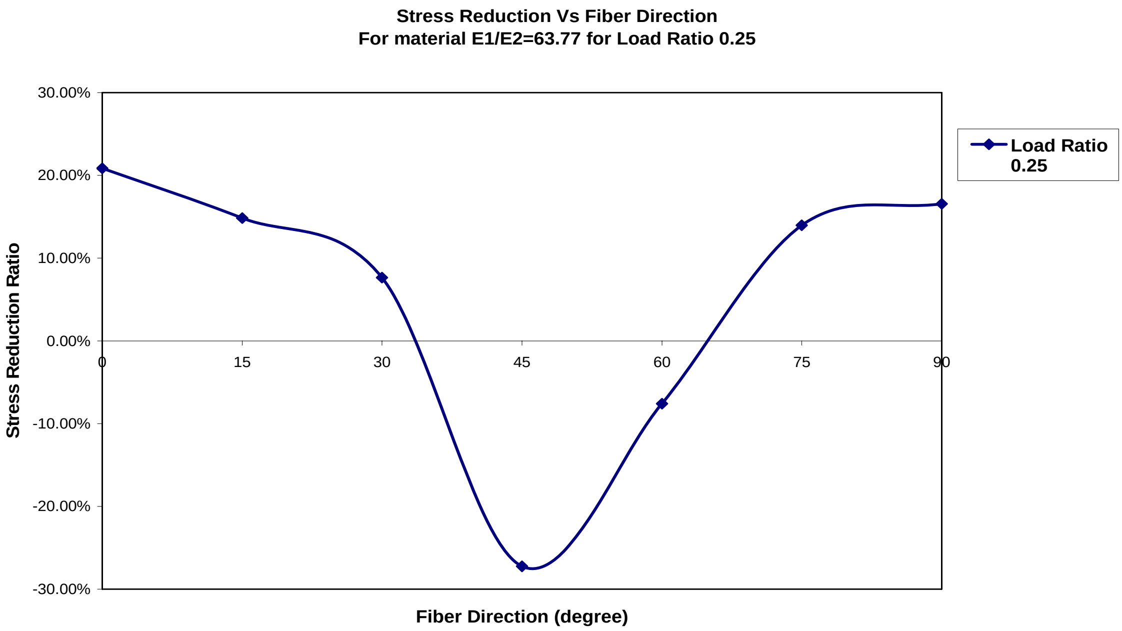


Figure 5.10 Stress Reduction Ratio Vs Fiber Direction for Load

Ratios 0.25 For Material E1/E2=63.77 (all angels)

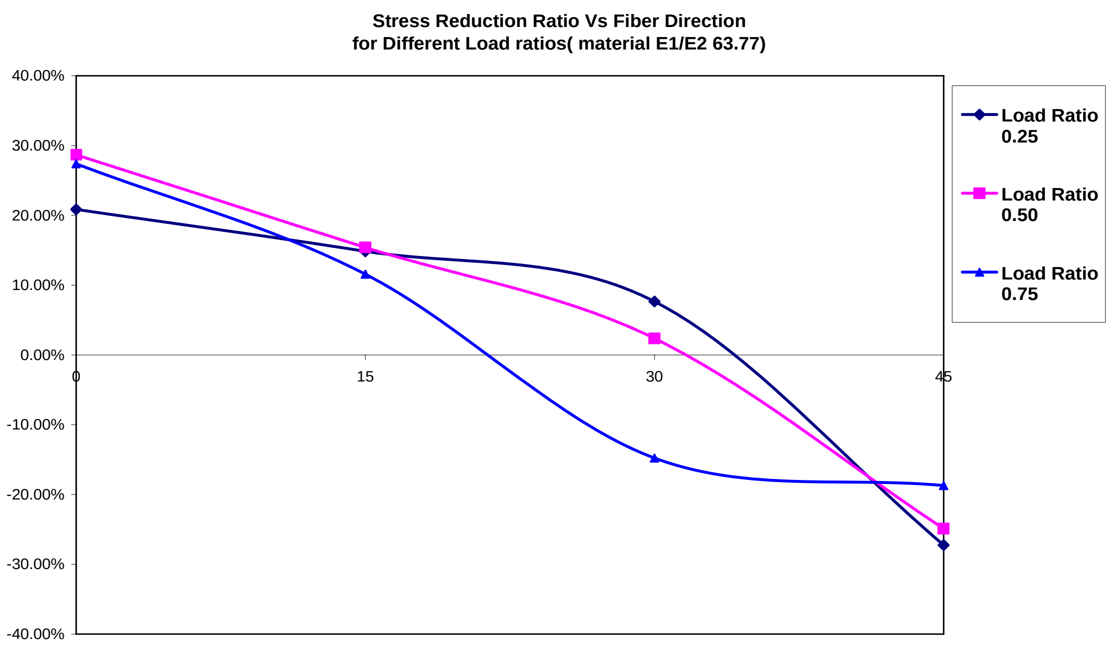


Figure 5.11 Stress Reduction Ratio Vs Fiber Direction for Different Load

Ratios For Material E1/E2=63.77

5.7 Discussion of DHS for mixed loaded plate Fiber direction –Load ratio:

Maximum stress reduction that has been obtained in composite fiber direction occurred at angle zero degree, this trend is followed by all materials and it is applicable for all investigated load ratios. Results show that there is no any reduction at fiber direction at 45 degrees since the stresses have the minimum values.

There is a symmetric behavior for stress reduction at fiber direction 45 degrees which matches the symmetry of the four elliptical DHS which is distributed perpendicular to each other over the plate (every 90° each). Figure 5.12 presents the stress contours for different values of fiber directions for material E1/E2 = 30.0

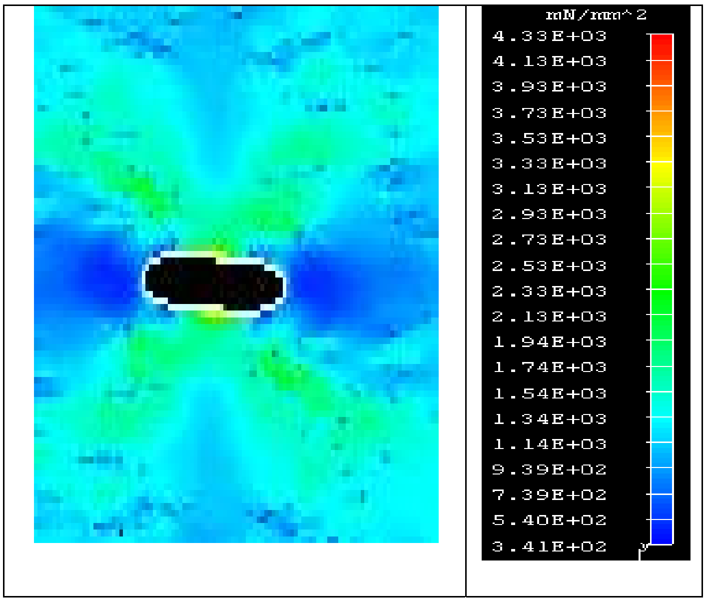


Figure 5.12a Stress reduction Vs fiber direction without DHS

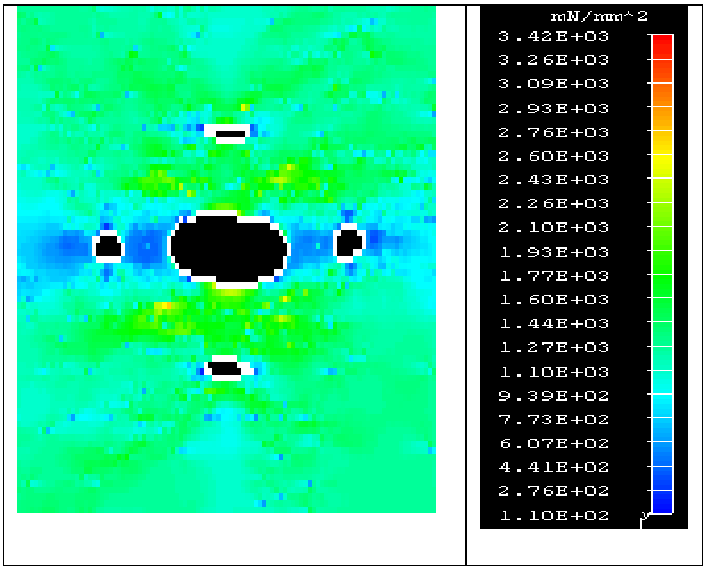


Figure 5.12b Stress reduction Vs fiber direction at angle 0°

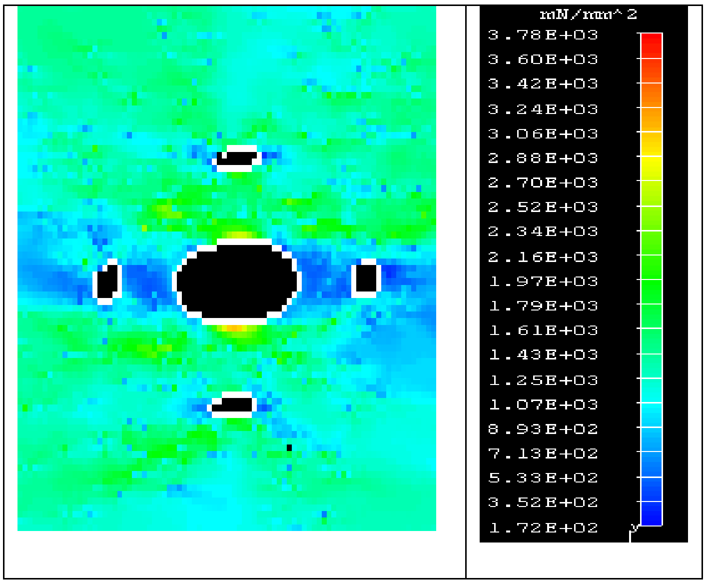


Figure 5.12c Stress reduction Vs fiber direction at angle 15°

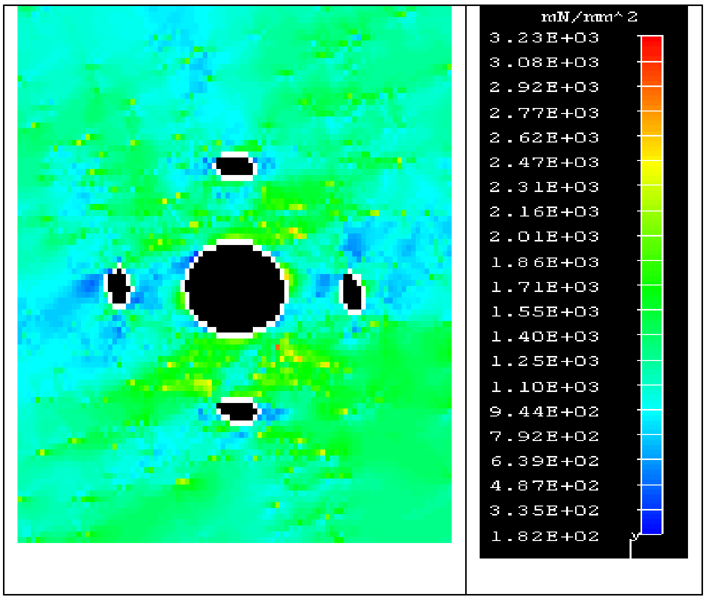


Figure 5.12d Stress reduction Vs fiber direction at angle 30°

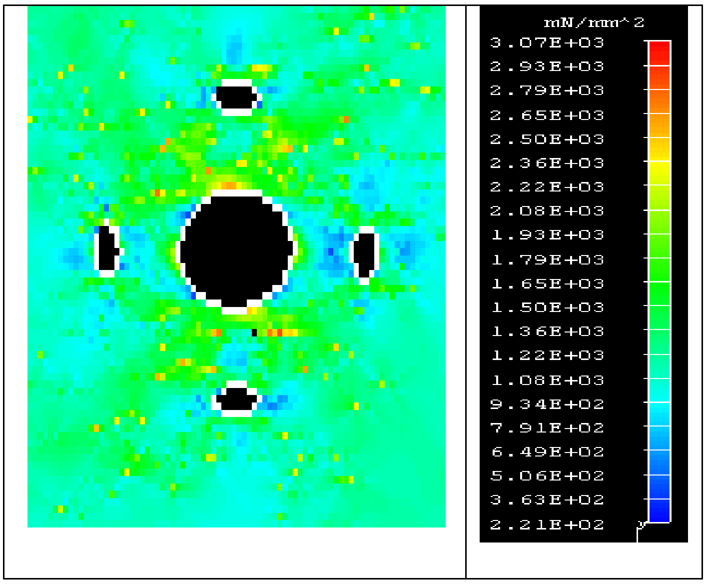


Figure 5.12e Stress reduction Vs fiber direction at angle 45°

5.8 Defense hole system design for a uniaxial loaded plate results:

Maximum stress reduction and optimum defense hole system parameters are achieved in a uniaxial dominant loaded plate in the range where the tension load is dominant i.e. load ratio (Compression /Tension) equal to zero. For the cases under investigation, pure uniaxial load has the maximum stress reduction of 21%. This reduction is achieved by introducing four elliptical defense holes around the main hole. A two elliptical defense satisfy the stress reduction but less than four elliptical defense hole system. A systematic approach is used to investigate this problem. Finite element analysis is used to optimize the size and the location of the defense hole system.

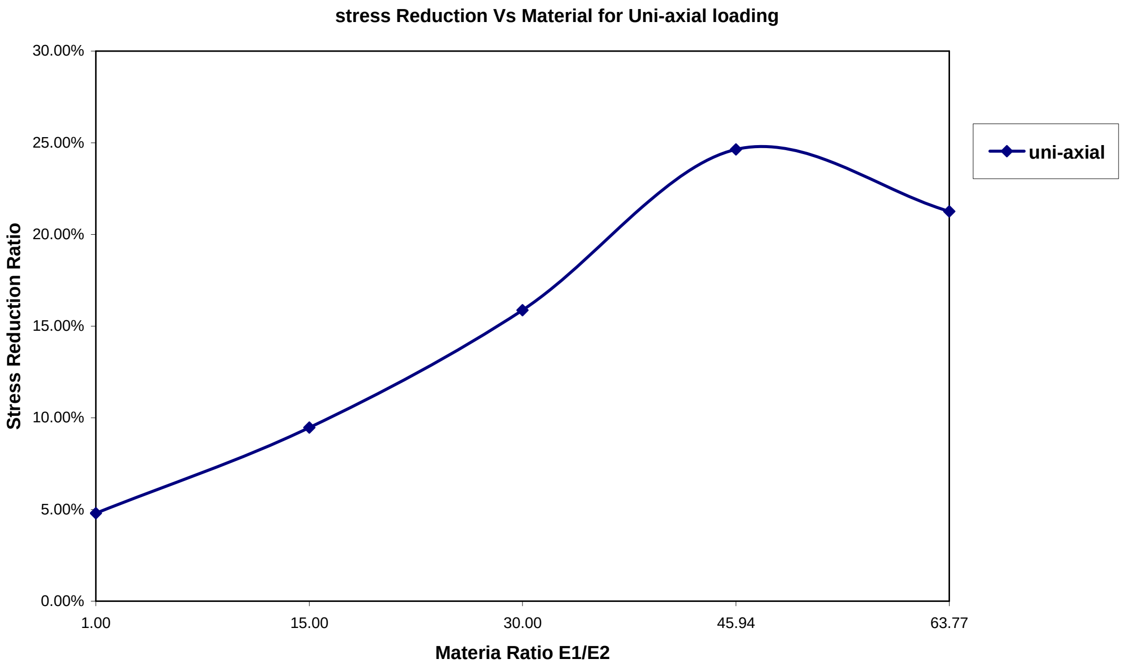


Figure 5.13 Defense hole system for a uni-axial load

Figure 5.13 shows the results of stress reduction versus different materials under uni-axial loading, the reduction increases as material E1/E2 ratio increases up to 45.94 ratios then starts descending.

When fiber directions are investigated for different materials under load ratio zero, the results shows the same trend for mixed loading. The maximum reduction is obtained at zero fiber direction, while there is no any reduction at fiber direction 45 degrees for all materials see figure 5.14.

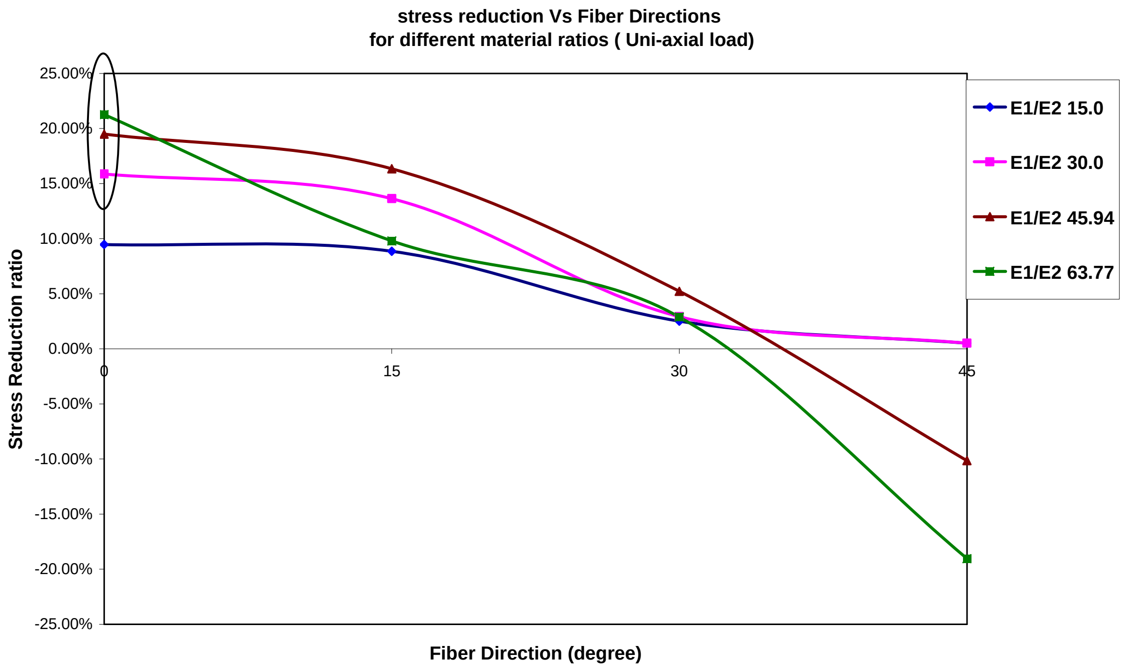


Figure 5.14 Stress Reduction Ratio Vs Fiber Directions for uni-axial load

5.9 Discussion of DHS for uniaxial loaded plate:

The optimum location and size of the defense hole system is identified for an infinite composite plate under uniaxial loading, and a baseline data for optimization is generated for different material ratios and different fiber directions.

Maximum stress reduction is achieved at zero angle as previous results, and as material ratio increases the stress reduction increases up E1/E2 45.94 then stress reduction ratio starts decreasing.

Two elliptical defense hole system is the optimum number and shape of auxiliary holes for the case where uniaxial stress dominant while introducing four defense hole system serves to increase the maximum stress instead of reducing it. Figure 5.15 below shows the above investigation.

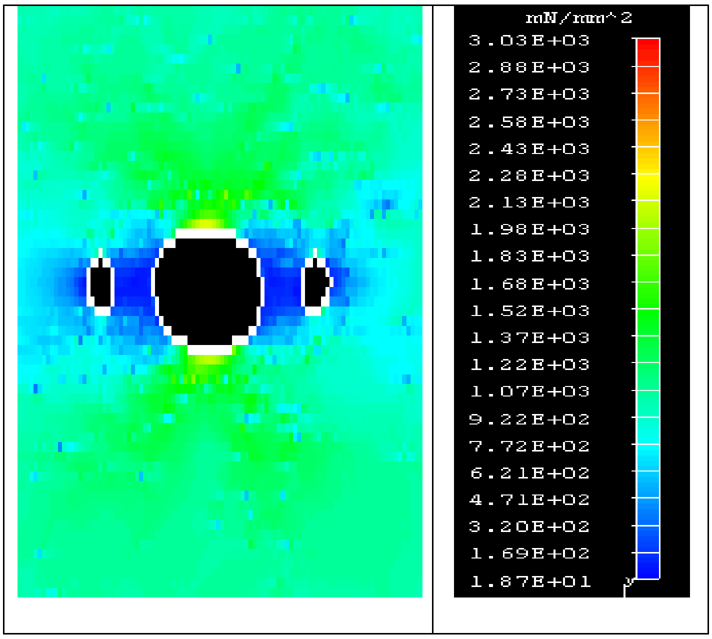


Figure 5.15 a Material ratio E1/E2 30.0 under uniaxial loads (two elliptical DHS)

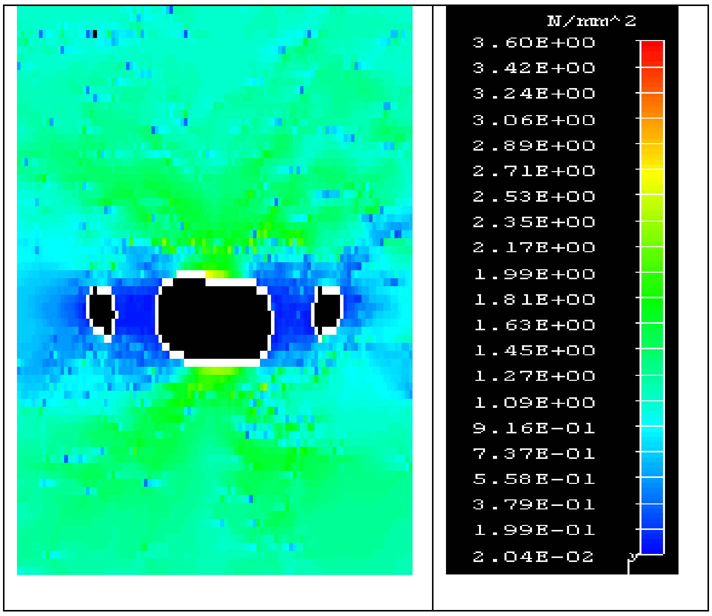


Figure 5.15 b Material ratio E1/E2 63.77 under uniaxial loads (two elliptical DHS)

5.10 Stacking sequence Results

To find the stacking effect on the defense hole system, some optimum cases with 2, 4, 8 and 16 layers are studied for the same laminate thickness. Symmetric and anti-symmetric laminates have been considered. All of them show the same results with differences less that 1%. However the anti-symmetric laminates experienced an out of plane deformation even though the loading is in plane loading. This is due to non zero B stiffness matrix which is responsible for the coupling of the membrane and bending effect.

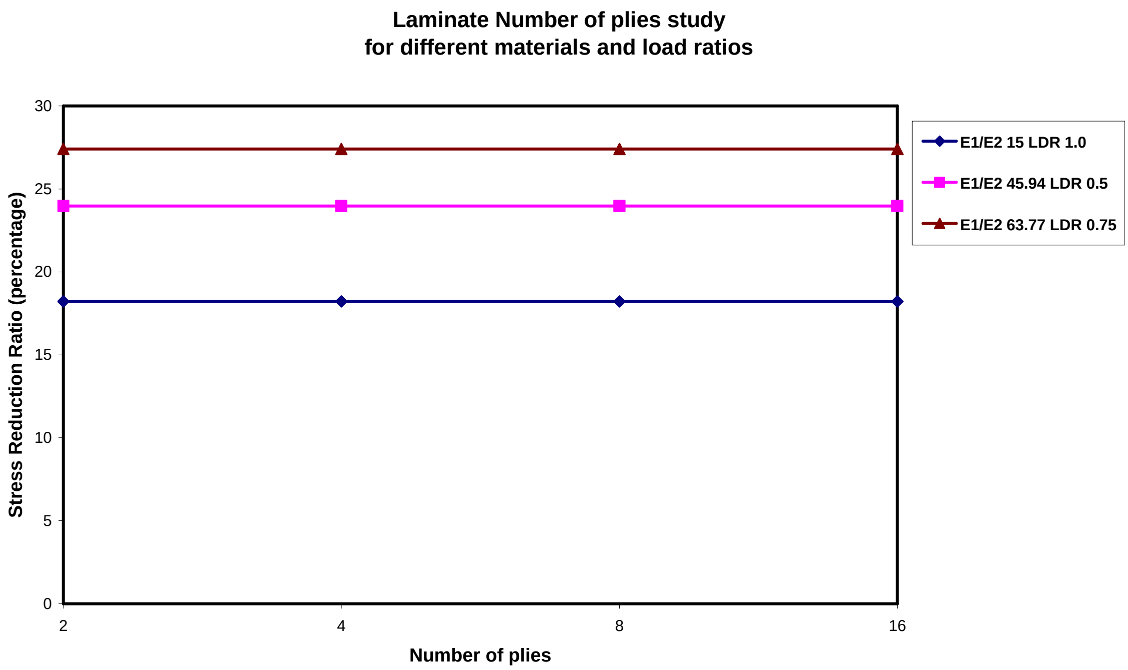


Figure 5.16 Laminate plies study for different material ratios under different load ratios

Figure 5.17 shows the stacking sequence results , three material are studied under load ratio 0.75 , symmetry stacking sequence 0°,90°,90°,0° is investigated against anti symmetry 0°,0°,90°,90° with fixed and free movement in Z direction , results shows two issues, first there is no big difference in case of fixing the edges from moving and the other issue is that the reduction in anti symmetry is less than symmetry stacking sequence.

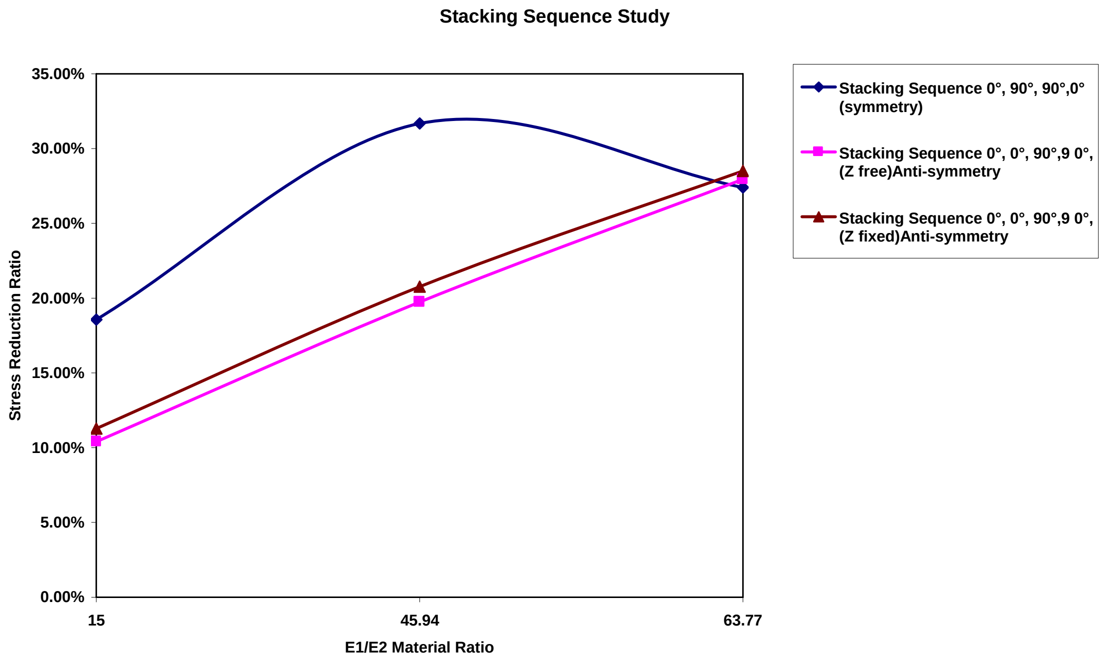


Figure 5.17 Stacking sequence study

Figure 5.18 illustrates out of plane deflection for stacking sequence - Anti symmetric 0°,0°,90°,90° for material ratio E1/E2 15.0 & 45.94 Graphite Epoxy without Design Hole System) and with four elliptical design hole system respectively.

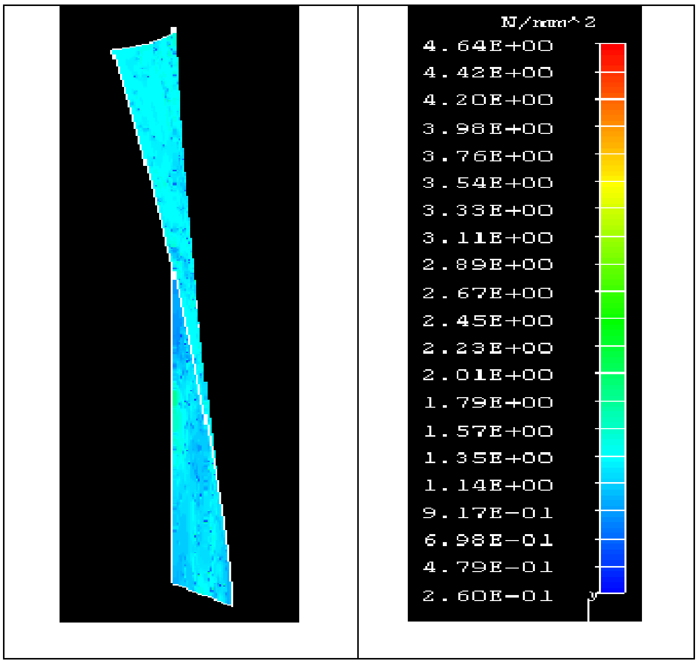


Figure 5.18 a Out of plane deflection of anti symmetric laminate stacking sequence E1/E2 15.0 without DHS

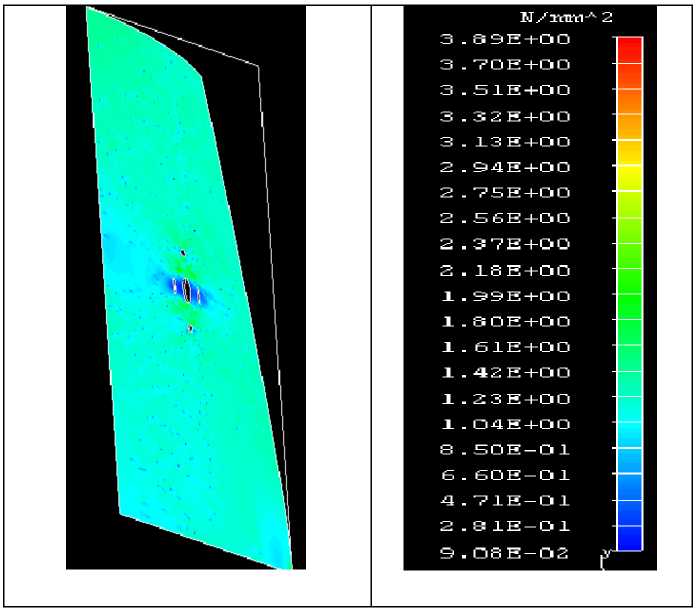


Figure 5.18 b Out of plane deflection of anti – symmetric laminate stacking sequence E1/E2 15.0 with DHS

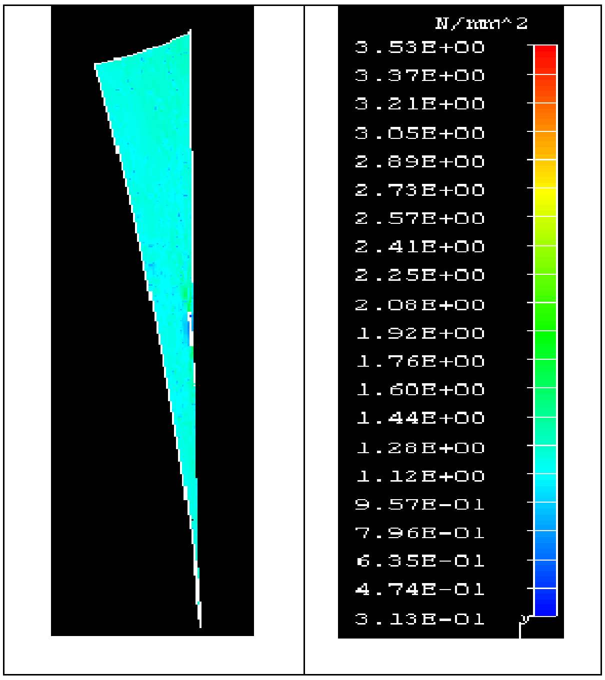


Figure 5.19 a Out of plane deflection of anti symmetric laminate stacking sequence E1/E2 45.77 without DHS

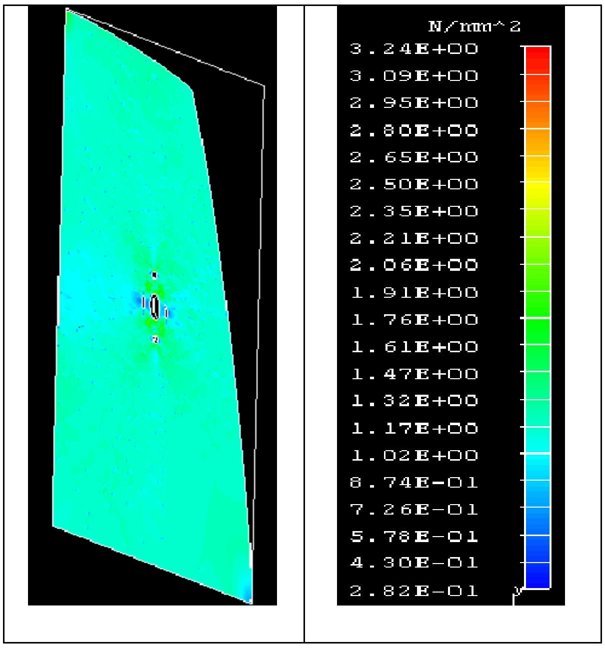


Figure 5.19 b Out of plane deflection of anti – symmetric laminate stacking sequence E1/E2 45.77 with DHS

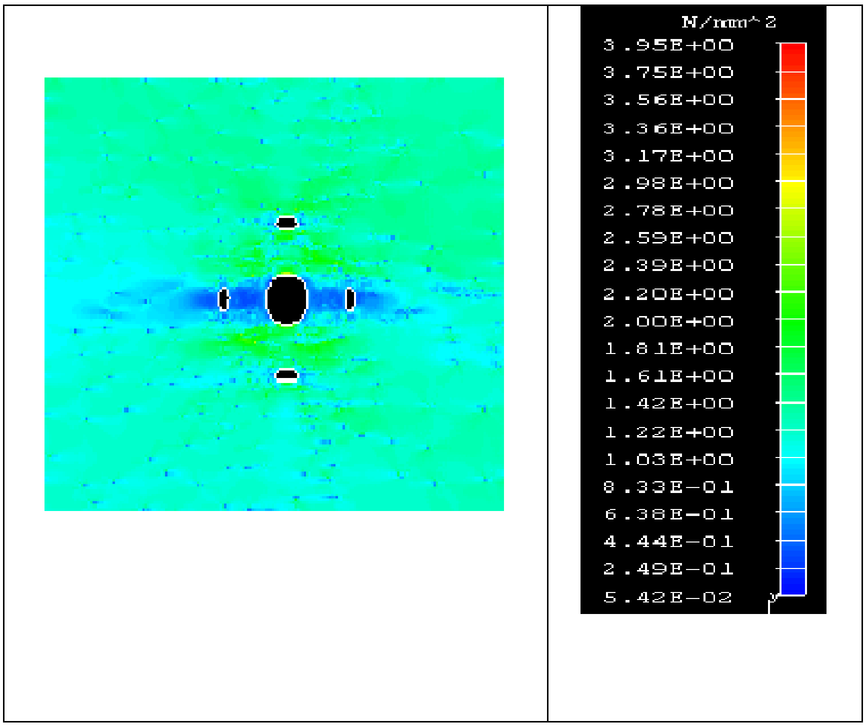


Figure 5.20a Anti – symmetric laminate stacking sequence with free movement in Z direction (Material E1/E2 =45.94)

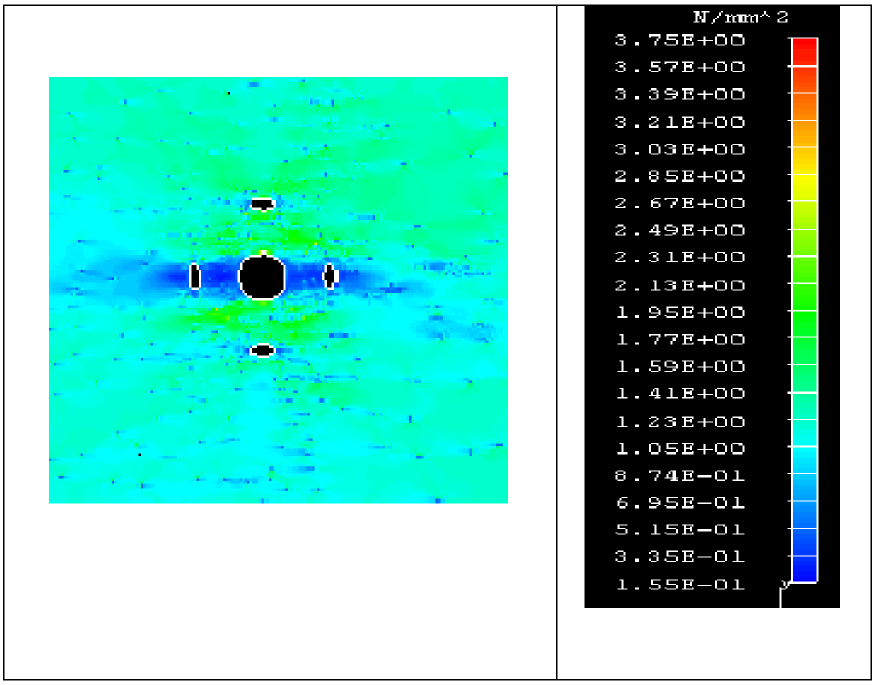


Figure 5.20b Anti – symmetric laminate stacking sequence with zero movement in Z direction (Material E1/E2 =45.94)

5.11 Laminate Thickness Study:

The effect of laminate thickness is investigated for four different material under same load ratio 0.75, three sizes of laminate thickness are studied 4 mm, 6 mm, and 8 mm (t/D = 0.16, 0.24, and 0.32. Figure 5.16 shows that the reduction ratio has the same value with the thickness changed as the load ratios maintain the same 0.75, i.e. for the plate with thickness 8mm (t/D=0.32) has Compression/Tension equal 1500 N/2000 N, While the compression /Tension 1125 N/1500 N has been assigned for the plate thickness 6mm (t/D =0.24).it can be seen that the stress reduction remains the same with variations less than 1%.

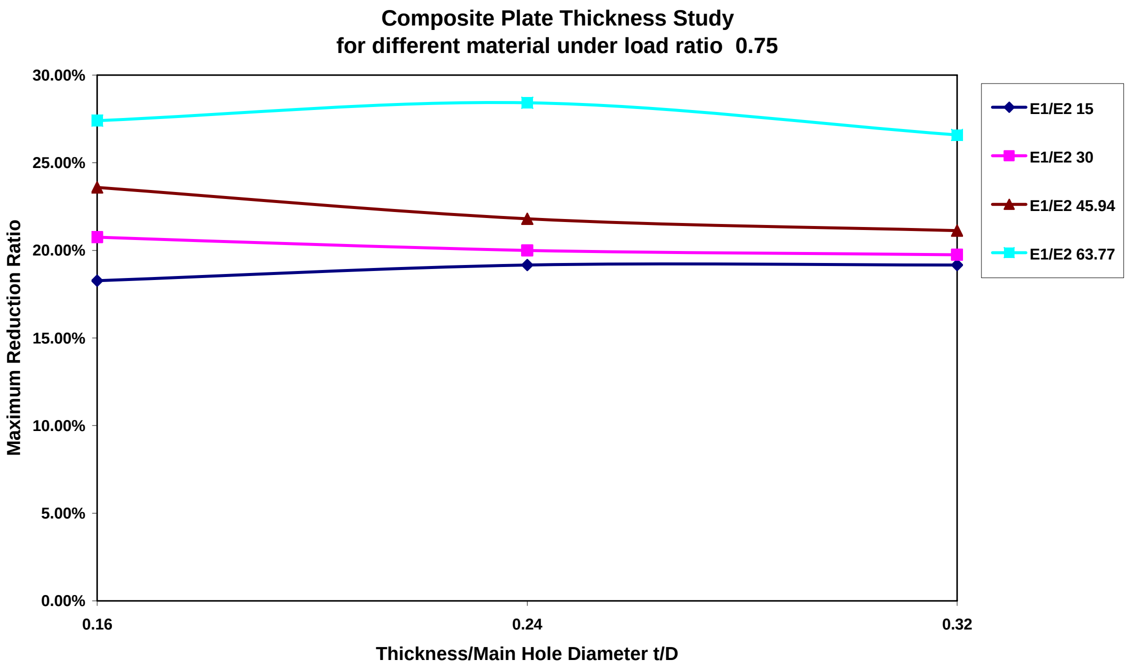


Figure 5.21 Composite Laminate Thickness study

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Most of the previous work in defense hole optimization has been performed for isotropic plates. The maximum reduction has been achieved for uniaxial tension is 30%. In this research, baseline data for optimizing defense hole systems under shear and general load are introduced and achieved. This research determines the size and placement for the defense holes that produce the maximum reduction of stress concentration.

The defense hole system investigation is divided into three parts based on loading type and range. In addition to fiber direction study, some cases are investigated for stacking sequence which revealed no differences as the plate thickness does not change. The optimum location and size of the defense hole system is identified by using redesign optimization technique and the parametric study is carried out by utilizing univariate search optimization technique in an iterative manner for laminated composite material. The finite element model is verified by reproducing previous well known cases and also by carrying out experimental investigation for some selected cases using RGB photoelasticity. The First case of an infinite plate with shear dominate load (load ratio 1.0) is investigated. In this case the number of optimization parameters is nearly doubled due to asymmetry of loading. Optimum defense systems are obtained. The second is an infinite plate with mixed load (load ratios 0.25, 0.50 and 0.75). In this case the optimal design of the defense system is also achieved. The last is an infinite plate with uni-axial load (load ratio equal zero) is achieved.

6.1 Conclusions:

- FEA study for all types of loaded plate with and without defense hole systems are conducted. The model show good agreement along with previous work available in the literature. Also experimental verification for the FEM model is carried out using RGB photelasticity. Introduction of circular defense hole system is not beneficial in the pure shear case. However the elliptical defense system shows good results. The stress reduction achieved by the elliptical defense system is 31.69 for shear loaded plates and 21%.for mixed and uniaxial loaded plates.
- Optimum size, shape and position of the auxiliary holes are identified for each case under certain conditions.
- Thickness of plates has very small effect in stress reduction ratio while number of laminate plies have no effect on stress reduction.
- Out of plane deflection appears by using anti-symmetric stacking sequence plates.
- Fiber direction has the largest stress reduction at zero and 90^o degrees and the smallest reduction at 45^o.
- Base line data has been produced and presented in Appendices A and B to help design engineer in selecting the composite material that fits his application best. The effects of main parameters that are necessary in designing composite plates are unveiled.
- The defense system that is introduced (four DHS) has many advantages other than stress reduction, for example weight reduction.

6.2 Recommendations:

When trying to determine mechanical properties from testing, a way of reducing the error is to follow one of the standard tests already created for the kind of material from which we try to get characteristics.

A future possible investigation is to:

- Apply the same procedure to narrow composite structures, i.e., plates of finite width.
- Extend the study to different shapes of holes such as square holes, slots, triangular holes, etc.
- Study the effect of defense hole system on a series of main holes in an infinite plate and obtaining the optimum spacing between main holes.
- Investigate the effect of stacking sequence for different ply orientations.
- Study the behavior of the defense hole system beyond the yield limit of the matrix material.
- Study the behavior of the defense hole system when delimitation takes place.

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Appendix A

Tables A1 through A5 : Summary of Four Elliptical Design hole system for E1/E2 1.0, ,15.0, 30.0, 45.94, and 63.77 under load ratio 0.0, 0.25, 0.50, 0.75, 1.00 Laminate Stacking sequence 0°,90°,90°,0°.With ϕ DHS angles 0°, 15°, 30°, 45°, 60°, 75°, and 90° and Fiber Directions FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°

Table A6: Summary of Composite Plates without DHS for Materials E1/E2=1.0, 15.00, 30.0, 45.94, 63.77. Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0N, 250N, 500N, 750N, 1000N, Load ratios=0.0, 0.25, 0.50, 0.75, 1.00.

Table A 7 : Summary of Four Elliptical Design with Hole System for Materials E1/E2 ratios 1.0, 15.0, 30.0, , 45.94, and 63.77, Tension 1000 N, Compression 0.0 N, 250 N, 500 N, 750 N, and 1000 N (load ratios 0.0, 0.25, 0.5, 0.75 and 1.0) Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0).

Table A.1 : Four Elliptical Design Hole System for Woven Glass E1/E2 = 1.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, 250 N, 500 N, 750 N, and 1000 N (load ratios 0.0, 0.25, 0.5, 0.75 and 1.0)

Load Ratio	Fiber Direction 0°			Fiber Direction 15°			Fiber Direction 30°			Fiber Direction 45°			Fiber Direction 60°			Fiber Direction 75°			Fiber Direction 90°		
	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stres Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio
0.00	1.85	1.79	-3.24%	1.85			1.85			1.85			1.85								
0.25	2.00	1.92	-4.00%	2.00			2.00			2.00			2.00								
0.50	2.16	1.94	-10.19%	2.16			2.16			2.16			2.16								
0.75	2.30	1.99	-13.48%	2.30			2.30			2.30			2.30								
1.00	2.46	2.08	-15.45%	2.46	2.11	-14.23%	2.46	2.31	-6.10%	2.46			2.46								

Table A.2 : Four Elliptical Design Hole System for E1/E2 = 15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, 250 N, 500 N, 750 N, and 1000 N (load ratios 0.0, 0.25, 0.5, 0.75, 1.0)

Load Ratio	Fiber Direction 0°			Fiber Direction 15°			Fiber Direction 30°			Fiber Direction 45°			Fiber Direction 60°			Fiber Direction 75°			Fiber Direction 90°		
	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stres Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio
0.00	2.64	2.39	-9.47%	2.37	2.16	-8.86%	2.00	1.95	-2.50%	1.92	1.91	-0.52%	2.26	2.16	-4.42%	2.57	2.45	-4.67%	2.64	2.39	-9.47%
0.25	2.87	2.49	-13.24%	2.56	2.27	-11.33%	2.15	2.07	-3.72%	2.07	2.12	2.42%	2.45			2.79			2.87		
0.50	3.10	2.64	-14.84%	2.75	2.38	-13.45%	2.31	2.17	-6.06%	2.21	2.34	5.88%	2.63			3.02			3.10		
0.75	3.34	2.73	-18.26%	2.96	2.46	-16.89%	2.46	2.34	-4.88%	2.36	2.43	2.97%	2.82	2.85	1.06%	3.24	2.81	-13.27%	3.34	2.73	-18.26%
1.00	3.57	2.92	-18.21%	3.14	2.57	-18.15%	2.62	2.46	-6.11%	2.51	2.63	4.78%	3.00			2.46			3.57		

Table A.3 : Four Elliptical Design Hole System for E1/E2 = 30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, 250 N, 500 N, 750 N, and 1000 N (load ratios 0.0, 0.25, 0.5, 0.75, 1.0)

	Fiber Direction 0°			Fiber Direction 15°			Fiber Direction 30°			Fiber Direction 45°			Fiber Direction 60°			Fiber Direction 75°			Fiber Direction 90°		
Load Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stres Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio
0.00	3.15	2.65	-15.87%	2.64	2.28	-13.64%	2.06	2.00	-2.91%	1.95	1.96	0.51%	2.46	2.24	-8.94%	2.97	2.70	-9.09%	3.15	2.67	-15.24%
0.25	3.44	2.70	-21.51%	2.86	2.38	-16.78%	2.22	2.21	-0.45%	2.09	2.33	11.48%	2.66			3.23			3.44		
0.50	3.72	2.89	-22.31%	3.07	2.57	-16.29%	2.51	2.39	-4.78%	2.23	2.46	10.31%	2.86	2.98	4.20%	3.49	2.92	-16.33%	3.72	2.86	-23.12%
0.75	4.00	3.17	-20.75%	3.28	2.73	-16.77%	2.80	2.79	-0.36%	2.38	2.74	15.13%	3.06	3.29	7.52%	3.75	3.28	-12.53%	4.00	3.31	-17.25%
1.00	4.28	3.40	-20.56%	3.49	3.00	-14.04%	3.09	2.98	-3.56%	2.52	2.81	11.51%	3.26	3.09	-5.21%	3.49	3.17	-9.17%	4.28	3.40	-20.56%

TableA.4 : Four Elliptical Design Hole System for E1/E2 = 45.94, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, 250 N, 500 N, 750 N, and 1000 N (load ratios 0.0, 0.25, 0.5, 0.75, 1.0)

Load Ratio	Fiber Direction 0°			Fiber Direction 15°			Fiber Direction 30°			Fiber Direction 45°		
	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stres Reduction (10^3 Pa)	Stress Reduction Ratio
0.00	3.49	2.81	-19.48%	2.80	2.34	-16.43%	2.49	2.36	-5.22%	1.97	2.17	10.15%
0.25	3.81	2.84	-25.46%	3.02	2.71	-10.26%	2.89	2.73	-5.54%	2.11	2.44	15.64%
0.50	4.13	2.93	-29.06%	3.28	2.90	-11.59%	3.24	3.08	-4.94%	2.25	2.51	11.56%
0.75	4.45	3.04	-31.69%	3.67	3.24	-11.72%	3.58	3.49	-2.51%	2.39	2.49	4.18%
1.00	4.77	4.10	-14.05%	4.05	3.68	-9.14%	3.96	3.96	0.00%	2.53	2.98	17.79%

Load Ratio	Fiber Direction 60°			Fiber Direction 75°			Fiber Direction 90°		
	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio
0.00	2.65			3.20			3.49		
0.25	2.77			3.48			3.81		
0.50	2.98	3.20	7.38%	3.76	3.03	-19.41%	4.13	2.93	-29.06%
0.75	3.19			4.03			4.45		
1.00	3.40			4.31			4.77		

Table A.5 : Four Elliptical Design Hole System for E1/E2 =63.77, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, 250 N, 500 N, 750 N, and 1000 N (load ratios 0.0, 0.25, 0.5, 0.75, 1.0)

	Fiber Direction 0°			Fiber Direction 15°			Fiber Direction 30°			Fiber Direction 45°			Fiber Direction 60°			Fiber Direction 75°			Fiber Direction 90°		
Load Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stres Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio	Max. Stress without DHS (10^3 Pa)	Max. Stress Reduction (10^3 Pa)	Stress Reduction Ratio
0.00	3.81	3.00	-21.26%	3.27	2.95	-9.79%	3.12	3.03	-2.88%	1.89	2.25	19.05%	2.56			2.81			3.81		
0.25	4.17	3.30	-20.86%	3.84	3.27	-14.84%	3.66	3.38	-7.65%	2.02	2.57	27.23%	2.77	2.98	7.58%	3.58	3.08	-13.97%	4.17	3.48	-16.55%
0.50	4.53	3.23	-28.70%	4.41	3.73	-15.42%	4.20	4.10	-2.38%	2.21	2.76	24.89%	3.11			3.85			4.53		
0.75	4.89	3.55	-27.40%	4.75	4.20	-11.58%	3.47	4.33	24.78%	2.46	2.92	18.70%	3.47			4.13			4.89		
1.00	5.26	4.44	-15.59%	3.14	2.66	-15.29%	2.62	2.26	-13.74%	2.51	3.07	22.31%	3.00			3.46			5.26		

Table A. 6:Composite Plates without DHS for Materials E1/E2=1.0, 15.00, 30.0, 45.94, 63.77. Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0N, 250N, 500N, 750N, 1000N, Load ratios=0.0, 0.25, 0.50, 0.75, 1.00.								
Load ratio	**Material E1/E2**	**max.stress (Pa) at FD=0°**	**max.stress (Pa) at FD=15°**	**max.stress (Pa) at FD=30°**	**max.stress (Pa) at FD=45°**	**max.stress (Pa) at FD=60°**	**max.stress (Pa) at FD=75°**	**max.stress (Pa) at FD=90°**
0.00	**1.00**	1.85E+03	1.85E+03	1.85E+03	1.85E+03	1.85E+03	1.85E+03	1.85E+03
	15.00	2.64E+03	2.37E+03	2.00E+03	1.92E+03	2.26E+03	2.57E+03	2.64E+03
	30.00	3.15E+03	2.64E+03	2.06E+03	1.95E+03	2.46E+03	2.97E+03	3.15E+03
	45.94	3.49E+03	2.80E+03	2.49E+03	1.97E+03	2.65E+03	3.20E+03	3.49E+03
	63.77	3.81E+03	3.27E+03	3.12E+03	1.89E+03	2.56E+03	2.81E+03	3.81E+03
0.25	**1.00**	2.00E+03	2.00E+03	2.00E+03	2.00E+03	2.00E+03	2.00E+03	2.00E+03
	15.00	2.87E+03	2.56E+03	2.15E+03	2.07E+03	2.45E+03	2.79E+03	2.87E+03
	30.00	3.44E+03	2.86E+03	2.22E+03	2.09E+03	2.66E+03	3.23E+03	3.44E+03
	45.94	3.81E+03	3.02E+03	2.89E+03	2.11E+03	2.77E+03	3.48E+03	3.81E+03
	63.77	4.17E+03	3.84E+03	3.66E+03	2.02E+03	2.77E+02	3.58E+03	4.17E+03
0.50	**1.00**	2.16E+03	2.16E+03	2.16E+03	2.16E+03	2.16E+03	2.16E+03	2.16E+03
	15.00	3.10E+03	2.75E+03	2.31E+03	2.21E+03	2.63E+03	3.02E+03	3.10E+03
	30.00	3.72E+03	3.07E+03	2.51E+03	2.23E+03	2.86E+03	3.49E+03	3.72E+03
	45.94	4.13E+03	3.28E+03	3.24E+03	2.25E+03	2.98E+03	3.76E+03	4.13E+03
	63.77	4.53E+03	4.41E+03	4.20E+03	2.21E+03	3.11E+03	3.85E+03	4.53E+03
0.75	**1.00**	2.30E+03	2.30E+03	2.30E+03	2.30E+03	2.30E+03	2.30E+03	2.30E+03
	15.00	3.34E+03	2.96E+03	2.46E+03	2.36E+03	2.82E+03	3.24E+03	3.34E+03
	30.00	4.00E+03	3.28E+03	2.80E+03	2.38E+03	3.06E+03	3.75E+03	4.00E+03
	45.94	4.45E+03	3.67E+03	3.58E+03	2.39E+03	3.19E+03	4.03E+03	4.45E+03
	63.77	4.89E+03	4.75E+03	3.47E+03	2.46E+03	3.47E+03	4.13E+03	4.89E+03

Table A. 6:Composite Plates without DHS for Materials E1/E2=1.0, 15.00, 30.0, 45.94, 63.77. Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0N, 250N, 500N, 750N, 1000N, Load ratios=0.0, 0.25, 0.50, 0.75, 1.00.								
Load ratio	**Material E1/E2**	**max.stress (Pa) at FD=0°**	**max.stress (Pa) at FD=15°**	**max.stress (Pa) at FD=30°**	**max.stress (Pa) at FD=45°**	**max.stress (Pa) at FD=60°**	**max.stress (Pa) at FD=75°**	**max.stress (Pa) at FD=90°**
1.00	**1.00**	2.46E+03	2.46E+03	2.46E+03	2.46E+03	2.46E+03	2.46E+03	2.46E+03
	15.00	3.57E+03	3.14E+03	2.62E+03	2.51E+03	3.00E+03	2.46E+03	3.57E+03
	30.00	4.28E+03	3.49E+03	3.09E+03	2.52E+03	3.26E+03	3.49E+03	4.28E+03
	45.94	4.77E+03	4.05E+03	3.96E+03	2.53E+03	3.40E+03	4.31E+03	4.77E+03
	63.77	5.26E+03	3.14E+03	2.62E+03	2.51E+03	3.00E+03	3.46E+03	5.26E+03

Table A. 7 : Four Elliptical Design Hole System for Materials E1/E2 ratios 1.0, 15.0, 30.0, , 45.94, and 63.77, Tension 1000 N, Compression 0.0 N, 250 N, 500 N, 750 N, and 1000 N (load ratios 0.0, 0.25, 0.5, 0.75 and 1.0)

Material	E1\E2 ratio	Load Ratio 0.0			Load Ratio 0.25			Load Ratio 0.5			Load Ratio 0.75			Load Ratio 1.0		
		Max. Stress without DHS	Max. Stress Reduction	Stress Reduction Ratio	Max. Stress without DHS	Max. Stress Reduction	Stress Reduction Ratio	Max. Stress without DHS	Max. Stress Reduction	Stress Reduction Ratio	Max. Stress without DHS	Max. Stres Reduction	Stress Reduction Ratio	Max. Stress without DHS	Max. Stress Reduction	Stress Reduction Ratio
Woven Glass	1.00	1.88E+03	1.79E+03	-4.79%	2.00E+03	1.92E+03	-4.00%	2.15E+03	1.94E+03	-9.77%	2.30E+03	1.99E+03	-13.48%	2.46E+03	2.08E+03	-15.45%
xxx	15.00	2.64E+03	2.39E+03	-9.47%	2.87E+03	2.49E+03	-13.24%	3.10E+03	2.64E+03	-14.84%	3.34E+03	2.73E+03	-18.26%	3.57E+03	2.92E+03	-18.21%
xxx	30.00	3.15E+03	2.65E+03	-15.87%	3.44E+03	2.70E+03	-21.51%	3.72E+03	2.89E+03	-22.31%	4.00E+03	3.17E+03	-20.75%	4.28E+03	3.40E+03	-20.56%
Graghite Eopxy	45.94	3.49E+03	2.63E+03	-24.64%	4.02E+03	2.84E+03	-29.35%	4.13E+03	3.14E+03	-23.97%	4.45E+03	3.04E+03	-31.69%	4.97E+03	4.10E+03	-17.51%
Carbon Epoxy	63.77	3.81E+03	3.00E+03	-21.26%	4.17E+03	3.30E+03	-20.86%	4.53E+03	3.63E+03	-19.87%	4.89E+03	3.55E+03	-27.40%	5.26E+03	4.44E+03	-15.59%

Appendix B

Tables B1 through B9 : Two Circular design hole system for E1/E2 1.0, 1.72,10.0, 20.0, 30.0, 40.0, 45.94, 50.0, and 63.77 under load ratio 1.00 Laminate Stacking sequence 0,90,90,0.

Tables B10 through B18 :Four Circular design hole system for E1/E2 1.0, 1.72,10.0, 20.0, 30.0, 40.0, 45.94, 50.0, and 63.77 under load 1.00 Laminate Stacking sequence 0,90,90,0.

Tables B19 through B43 : Elliptical Design hole system for E1/E2 1.0, ,15.0, 30.0, 45.94, and 63.77 under load ratio 0.0, 0.25, 0.50, 0.75, 1.00 Laminate Stacking sequence 0,90,90,0. With ϕ DHS angles 0°,15°,30°,45°,60°,75°,90°

Tables B44 through B68 : Elliptical Design hole system for E1/E2 1.0, ,15.0, 30.0, 45.94, and 63.77 under load ratio 0.0, 0.25, 0.50, 0.75, 1.00 Laminate Stacking sequence 0,90,90,0. With Fiber Directions FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°

Table B.1:(Two Circle) Material WOVEN GLASS E1/E2=1.0, Fiber direction 0 °, Laminates stacking sequence (0-90-90-0),Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 2.46E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	2.45E+03	2.66E+03	2.70E+03	2.67E+03	2.49E+03	2.45E+03	-1.00E+01	-0.41%
0.20	3.00	2.49E+03	2.66E+03	2.68E+03	2.66E+03	2.48E+03	2.48E+03	2.00E+01	0.81%
0.20	4.00	2.48E+03	2.52E+03	2.62E+03	2.49E+03	2.62E+03	2.48E+03	2.00E+01	0.81%
0.20	5.00	2.50E+03	2.60E+03	2.64E+03			2.50E+03	4.00E+01	1.63%
0.20	6.00	2.47E+03	2.49E+03	2.54E+03			2.47E+03	1.00E+01	0.41%
0.40	2.00	2.42E+03	2.74E+03	2.76E+03	2.71E+03	2.47E+03	2.42E+03	-4.00E+01	-1.63%
0.40	3.00	2.49E+03	2.57E+03	2.68E+03			2.49E+03	3.00E+01	1.22%
0.40	4.00	2.51E+03	2.53E+03	2.62E+03			2.51E+03	5.00E+01	2.03%
0.40	5.00	2.51E+03	2.60E+03	2.61E+03			2.51E+03	5.00E+01	2.03%
0.40	6.00	2.50E+03	2.50E+03	2.54E+03	2.49E+03	2.49E+03	2.49E+03	3.00E+01	1.22%
0.60	2.00	2.32E+03	2.87E+03	2.85E+03	2.98E+03		2.32E+03	-1.40E+02	-5.69%
0.60	3.00	2.45E+03	2.61E+03	2.69E+03			2.45E+03	-1.00E+01	-0.41%
0.60	4.00	2.47E+03	2.53E+03	2.55E+03			2.47E+03	1.00E+01	0.41%
0.60	5.00	2.47E+03	2.51E+03	2.56E+03			2.47E+03	1.00E+01	0.41%
0.60	6.00	2.50E+03	2.51E+03	2.56E+03			2.50E+03	4.00E+01	1.63%
0.80	2.00	2.43E+03	3.03E+03	2.90E+03	2.93E+03		2.43E+03	-3.00E+01	-1.22%
0.80	3.00	2.42E+03	2.65E+03	2.66E+03			2.42E+03	-4.00E+01	-1.63%
0.80	4.00	2.45E+03	2.66E+03	2.60E+03	2.58E+03	2.45E+03	2.45E+03	-1.00E+01	-0.41%
0.80	5.00	2.46E+03	2.54E+03	2.56E+03	2.54E+03	2.46E+03	2.46E+03	0.00E+00	0.00%
0.80	6.00	2.50E+03	2.52E+03	2.54E+03	2.53E+03	2.55E+03	2.50E+03	4.00E+01	1.63%

Table B.2 :(Two Circle)Material BORON ALUMINIUM E1/E2=1.72, Fiber direction 0 ° ,Laminates stacking sequence (0-90-90-0),Tension 1000 N, Compression 1000 N, Load ratio =1, Maximum Stress without design holes = 2.51E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	2.49E+03	2.67E+03	2.74E+03	2.71E+03	2.54E+03	2.49E+03	-2.00E+01	-0.80%
0.20	3.00	2.51E+03	2.56E+03	2.62E+03			2.51E+03	0.00E+00	0.00%
0.20	4.00	2.53E+03	2.54E+03	2.55E+03			2.53E+03	2.00E+01	0.80%
0.20	5.00	2.53E+03	2.53E+03	2.56E+03			2.53E+03	2.00E+01	0.80%
0.20	6.00	2.53E+03	2.56E+03	2.56E+03			2.53E+03	2.00E+01	0.80%
0.40	1.00	2.50E+03					2.50E+03	-1.00E+01	-0.40%
0.40	2.00	2.42E+03	2.47E+03	2.80E+03			2.42E+03	-9.00E+01	-3.59%
0.40	3.00	2.48E+03	2.57E+03	2.62E+03			2.48E+03	-3.00E+01	-1.20%
0.40	4.00	2.51E+03	2.54E+03	2.57E+03			2.51E+03	0.00E+00	0.00%
0.40	5.00	2.54E+03	2.54E+03	2.56E+03			2.54E+03	3.00E+01	1.20%
0.40	6.00	2.53E+03	2.54E+03	2.56E+03			2.53E+03	2.00E+01	0.80%
0.60	2.00	2.36E+03	2.87E+03	2.83E+03			2.36E+03	-1.50E+02	-5.98%
0.60	3.00	2.45E+03	2.61E+03	2.64E+03			2.45E+03	-6.00E+01	-2.39%
0.60	4.00	2.48E+03	2.56E+03	2.61E+03			2.48E+03	-3.00E+01	-1.20%
0.60	5.00	2.50E+03	2.55E+03	2.58E+03			2.50E+03	-1.00E+01	-0.40%
0.60	6.00	2.51E+03	2.56E+03	2.58E+03			2.51E+03	0.00E+00	0.00%
0.80	2.00	2.43E+03	3.04E+03	2.90E+03			2.43E+03	-8.00E+01	-3.19%
0.80	3.00	2.42E+03	2.66E+03	2.83E+03			2.42E+03	-9.00E+01	-3.59%
0.80	4.00	2.46E+03	2.57E+03	2.66E+03			2.46E+03	-5.00E+01	-1.99%
0.80	5.00	2.46E+03	2.57E+03	2.62E+03			2.46E+03	-5.00E+01	-1.99%
0.80	6.00	2.53E+03	2.56E+03	2.60E+03			2.53E+03	2.00E+01	0.80%

Table B.3 :(Two Circle)Material E1\E2= 10.0, Fiber direction 0 °, Laminates stacking sequence(0-90-90-0),Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 3.23E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	3.23E+03	3.66E+03	3.68E+03	3.87E+03		3.23E+03	0.00E+00	0.00%
0.20	3.00	3.41E+03	3.62E+03	3.86E+03			3.41E+03	1.80E+02	5.57%
0.20	4.00	3.64E+03	3.74E+03	3.90E+03			3.64E+03	4.10E+02	12.69%
0.20	5.00	3.74E+03	3.63E+03	3.98E+03			3.63E+03	4.00E+02	12.38%
0.20	6.00	3.53E+03	3.84E+03	4.11E+03			3.53E+03	3.00E+02	9.29%
0.40	2.00	3.60E+03	3.55E+03	3.65E+03			3.55E+03	3.20E+02	9.91%
0.40	3.00	3.53E+03	3.52E+03	3.79E+03			3.52E+03	2.90E+02	8.98%
0.40	4.00	3.62E+03	3.66E+03	3.82E+03			3.62E+03	3.90E+02	12.07%
0.40	5.00	3.69E+03	3.77E+03	3.84E+03			3.69E+03	4.60E+02	14.24%
0.40	6.00	3.76E+03	4.00E+03	4.04E+03			3.76E+03	5.30E+02	16.41%
0.60	2.00	3.30E+03	3.51E+03	3.73E+03			3.30E+03	7.00E+01	2.17%
0.60	3.00	3.45E+03	3.47E+03	3.75E+03			3.45E+03	2.20E+02	6.81%
0.60	4.00	3.54E+03	3.66E+03	3.81E+03			3.54E+03	3.10E+02	9.60%
0.60	5.00	3.59E+03	3.65E+03	3.86E+03			3.59E+03	3.60E+02	11.15%
0.60	6.00	3.73E+03	3.77E+03	4.00E+03			3.73E+03	5.00E+02	15.48%
0.80	2.00	3.12E+03	3.69E+03	3.93E+03			3.12E+03	-1.10E+02	-3.41%
0.80	3.00	3.38E+03	3.60E+03	3.75E+03			3.38E+03	1.50E+02	4.64%
0.80	4.00	3.53E+03	3.81E+03	3.88E+03			3.53E+03	3.00E+02	9.29%
0.80	5.00	3.59E+03	3.68E+03	3.87E+03			3.59E+03	3.60E+02	11.15%
0.80	6.00	3.71E+03	3.76E+03	4.04E+03			3.71E+03	4.80E+02	14.86%

Table B.4 :(Two Circle)Material E1\E2 =20.0, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio =1, Maximum Stress without design holes = 3.85E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	4.64E+03	4.94E+03	4.65E+03	5.27E+03		4.64E+03	7.90E+02	20.52%
0.20	3.00	4.27E+03	4.47E+03	5.12E+03			4.27E+03	4.20E+02	10.91%
0.20	4.00	4.78E+03	5.04E+03	5.42E+03			4.78E+03	9.30E+02	24.16%
0.20	5.00	5.14E+03	4.70E+03	5.49E+03			4.70E+03	8.50E+02	22.08%
0.20	6.00	4.53E+03	5.00E+03	5.76E+03			4.53E+03	6.80E+02	17.66%
0.40	2.00	4.55E+03	4.43E+03	4.54E+03	5.26E+03		4.43E+03	5.80E+02	15.06%
0.40	3.00	4.47E+03	4.51E+03	5.05E+03			4.47E+03	6.20E+02	16.10%
0.40	4.00	4.78E+03	4.85E+03	5.16E+03			4.78E+03	9.30E+02	24.16%
0.40	5.00	4.92E+03	5.05E+03	5.24E+03			4.92E+03	1.07E+03	27.79%
0.40	6.00	5.14E+03	5.62E+03	5.63E+03			5.14E+03	1.29E+03	33.51%
0.60	2.00	4.25E+03	4.26E+03	5.69E+03			4.25E+03	4.00E+02	10.39%
0.60	3.00	4.50E+03	4.35E+03	4.90E+03			4.35E+03	5.00E+02	12.99%
0.60	4.00	4.64E+03	4.82E+03	5.03E+03			4.64E+03	7.90E+02	20.52%
0.60	5.00	4.72E+03	4.76E+03	5.16E+03			4.72E+03	8.70E+02	22.60%
0.60	6.00	5.05E+03	5.06E+03	5.58E+03			5.05E+03	1.20E+03	31.17%
0.80	2.00	4.05E+03	4.54E+03	4.95E+03			4.05E+03	2.00E+02	5.19%
0.80	3.00	4.45E+03	4.77E+03	4.75E+03			4.45E+03	6.00E+02	15.58%
0.80	4.00	4.69E+03	5.15E+03	5.12E+03			4.69E+03	8.40E+02	21.82%
0.80	5.00	4.76E+03	4.86E+03	5.18E+03			4.76E+03	9.10E+02	23.64%
0.80	6.00	5.03E+03	5.03E+03	5.62E+03			5.03E+03	1.18E+03	30.65%

Table B.5 :(Two Circle)Material E1\E2= 30.0, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 4.28E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	5.52E+03	6.14E+03	5.52E+03	6.44E+03		5.52E+03	1.24E+03	28.97%
0.20	3.00	4.95E+03	5.22E+03				4.95E+03	6.70E+02	15.65%
0.20	4.00	5.79E+03	6.11E+03				5.79E+03	1.51E+03	35.28%
0.20	5.00	6.33E+03	5.72E+03	6.75E+03			5.72E+03	1.44E+03	33.64%
0.20	6.00	5.36E+03	6.04E+03				5.36E+03	1.08E+03	25.23%
0.40	2.00	5.40E+03	5.11E+03	5.23E+03			5.11E+03	8.30E+02	19.39%
0.40	3.00	5.64E+03	5.31E+03				5.31E+03	1.03E+03	24.07%
0.40	4.00	5.75E+03	5.85E+03				5.75E+03	1.47E+03	34.35%
0.40	5.00	6.01E+03	6.11E+03				6.01E+03	1.73E+03	40.42%
0.40	6.00	6.37E+03	7.02E+03				6.37E+03	2.09E+03	48.83%
0.60	2.00	5.03E+03	4.82E+03	5.44E+03			4.82E+03	5.40E+02	12.62%
0.60	3.00	5.36E+03	5.02E+03	5.82E+03			5.02E+03	7.40E+02	17.29%
0.60	4.00	5.54E+03	5.76E+03	6.03E+03			5.54E+03	1.26E+03	29.44%
0.60	5.00	5.66E+03	5.65E+03				5.65E+03	1.37E+03	32.01%
0.60	6.00	6.18E+03	6.15E+03				6.15E+03	1.87E+03	43.69%
0.80	2.00	4.82E+03	5.22E+03				4.82E+03	5.40E+02	12.62%
0.80	3.00	5.33E+03	5.67E+03				5.33E+03	1.05E+03	24.53%
0.80	4.00	5.66E+03	6.27E+03				5.66E+03	1.38E+03	32.24%
0.80	5.00	5.74E+03	5.81E+03				5.74E+03	1.46E+03	34.11%
0.80	6.00	6.16E+03	6.09E+03				6.09E+03	1.81E+03	42.29%

Table B.6 :(Two Circle)Material E1\E2= 40.0, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 4.63E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	6.28E+03	7.22E+03				6.28E+03	1.65E+03	35.64%
0.20	3.00	5.53E+03	5.84E+03				5.53E+03	9.00E+02	19.44%
0.20	4.00	7.29E+03	7.01E+03	8.00E+03			7.01E+03	2.38E+03	51.40%
0.20	5.00	7.54E+03	6.51E+03				6.51E+03	1.88E+03	40.60%
0.20	6.00	6.05E+03	6.90E+03				6.05E+03	1.42E+03	30.67%
0.40	2.00	6.13E+03	5.67E+03	5.83E+03	7.29E+03	6.08E+03	5.67E+03	1.04E+03	22.46%
0.40	3.00	6.21E+03	5.99E+03				5.99E+03	1.36E+03	29.37%
0.40	4.00	6.60E+03	6.72E+03				6.60E+03	1.97E+03	42.55%
0.40	5.00	6.97E+03	7.02E+03				6.97E+03	2.34E+03	50.54%
0.40	6.00	7.49E+03	8.26E+03				7.49E+03	2.86E+03	61.77%
0.60	2.00	5.70E+03	5.24E+03	6.05E+03			5.24E+03	6.10E+02	13.17%
0.60	3.00	6.10E+03	5.56E+03				5.56E+03	9.30E+02	20.09%
0.60	4.00	6.32E+03	6.56E+03				6.32E+03	1.69E+03	36.50%
0.60	5.00	6.48E+03	6.39E+03				6.39E+03	1.76E+03	38.01%
0.60	6.00	7.20E+03	7.10E+03				7.10E+03	2.47E+03	53.35%
0.80	2.00	5.49E+03	5.72E+03				5.49E+03	8.60E+02	18.57%
0.80	3.00	6.08E+03	6.43E+03				6.08E+03	1.45E+03	31.32%
0.80	4.00	6.50E+03	7.24E+03				6.50E+03	1.87E+03	40.39%
0.80	5.00	6.59E+03	6.62E+03				6.59E+03	1.96E+03	42.33%
0.80	6.00	7.17E+03	6.99E+03				6.99E+03	2.36E+03	50.97%
0.40	2.00	6.44E+03				**120°**	6.44E+03	1.81E+03	39.09%

Table B.7 :(Two Circle) Material GRAGHITE EPOXY E1/E2=45.94, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 4.77E+3

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	2.06E+05	7.65E+03	2.19E+04	5.59E+04	5.83E+04	7.65E+03	2.88E+03	60.38%
0.20	3.00	2.04E+04	6.46E+04	1.95E+05	1.71E+04	6.29E+04	1.71E+04	1.23E+04	258.49%
0.20	4.00	2.08E+05	5.88E+04	3.93E+04	8.11E+03	4.89E+05	8.11E+03	3.34E+03	70.02%
0.20	5.00	2.53E+04	1.77E+04	4.75E+04	1.32E+04	4.82E+04	1.32E+04	8.43E+03	176.73%
0.20	6.00	6.71E+03	7.21E+03	8.84E+04	7.61E+03	7.03E+03	6.71E+03	1.94E+03	40.67%
0.40	2.00	6.40E+03	5.89E+03	6.05E+03	7.63E+03	6.35E+03	5.89E+03	1.12E+03	23.48%
0.40	3.00	6.50E+03	6.25E+03	7.26E+03	7.25E+03	6.67E+03	6.25E+03	1.48E+03	31.03%
0.40	4.00	6.91E+03	7.04E+03	7.61E+03	7.63E+03	6.68E+03	6.68E+03	1.91E+03	40.04%
0.40	5.00	7.32E+03	7.35E+03	7.78E+03	8.57E+03	6.41E+03	6.41E+03	1.64E+03	34.38%
0.40	6.00	7.89E+03	8.70E+03	8.66E+03	9.14E+03	7.17E+03	7.17E+03	2.40E+03	50.31%
0.60	2.00	5.96E+03	5.42E+03	6.28E+03	7.81E+03	5.98E+03	5.42E+03	6.50E+02	13.63%
0.60	3.00	6.37E+03	5.77E+03	6.88E+03	7.26E+03	5.96E+03	5.77E+03	1.00E+03	20.96%
0.60	4.00	6.61E+03	6.86E+03	7.18E+03	7.92E+03	6.54E+03	6.54E+03	1.77E+03	37.11%
0.60	5.00	6.77E+03	6.67E+03	7.42E+03	7.81E+03	6.88E+03	6.67E+03	1.90E+03	39.83%
0.60	6.00	7.66E+03	7.44E+03	8.55E+03	9.08E+03	6.65E+03	6.65E+03	1.88E+03	39.41%
0.80	2.00	5.74E+03	5.93E+03	6.72E+03	6.97E+03	6.07E+03	5.74E+03	9.70E+02	20.34%
0.80	3.00	6.36E+03	6.71E+03	6.45E+03	6.48E+03	6.50E+03	6.36E+03	1.59E+03	33.33%
0.80	4.00	6.81E+03	7.69E+03	7.29E+03	7.62E+03	6.99E+03	6.81E+03	2.04E+03	42.77%
0.80	5.00	6.90E+03	6.92E+03	7.43E+03	8.41E+03	7.02E+03	6.90E+03	2.13E+03	44.65%
0.80	6.00	7.54E+03	7.32E+03	8.61E+03	9.09E+03	6.67E+03	6.67E+03	1.90E+03	39.83%

table B.8 :(Two Circle) Material E1\E2 =50.0, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0),Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 4.90E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	6.95E+03	8.21E+03	6.92E+03	8.36E+03	8.53E+03	6.92E+03	2.02E+03	41.22%
0.20	3.00	6.69E+03	6.38E+03				6.38E+03	1.48E+03	30.20%
0.20	4.00	7.49E+03	7.80E+03				7.49E+03	2.59E+03	52.86%
0.20	5.00	8.29E+03	7.02E+03				7.02E+03	2.12E+03	43.27%
0.20	6.00	8.21E+03	8.89E+03				8.21E+03	3.31E+03	67.55%
0.40	2.00	6.76E+03	6.15E+03				6.15E+03	1.25E+03	25.51%
0.40	3.00	6.88E+03	6.59E+03				6.59E+03	1.69E+03	34.49%
0.40	4.00	7.36E+03	7.50E+03				7.36E+03	2.46E+03	50.20%
0.40	5.00	7.84E+03	7.81E+03				7.81E+03	2.91E+03	59.39%
0.40	6.00	8.53E+03	9.39E+03				8.53E+03	3.63E+03	74.08%
0.60	2.00	6.29E+03	6.59E+03				6.29E+03	1.39E+03	28.37%
0.60	3.00	6.75E+03	6.01E+03				6.01E+03	1.11E+03	22.65%
0.60	4.00	7.01E+03	7.27E+03				7.01E+03	2.11E+03	43.06%
0.60	5.00	7.20E+03	7.03E+03				7.03E+03	2.13E+03	43.47%
0.60	6.00	8.12E+03	7.94E+03				7.94E+03	3.04E+03	62.04%
0.80	2.00	6.08E+03	6.16E+03				6.08E+03	1.18E+03	24.08%
0.80	3.00	6.75E+03	7.09E+03				6.75E+03	1.85E+03	37.76%
0.80	4.00	7.25E+03	8.11E+03				7.25E+03	2.35E+03	47.96%
0.80	5.00	7.35E+03	7.33E+03				7.33E+03	2.43E+03	49.59%
0.80	6.00	8.09E+03	7.79E+03				7.79E+03	2.89E+03	58.98%

Table B.9 :(Two Circle) Material CARBON EPOXY E1/E2=63.77, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N,Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 5.26E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	7.99E+03	9.84E+03	7.94E+03	9.77E+03		7.94E+03	2.68E+03	50.95%
0.20	3.00	6.81E+03	7.19E+03	9.55E+03			6.81E+03	1.55E+03	29.47%
0.20	4.00	9.75E+03	9.02E+03	1.10E+04			9.02E+03	3.76E+03	71.48%
0.20	5.00	9.82E+03	8.25E+03	1.03E+04			8.25E+03	2.99E+03	56.84%
0.20	6.00	7.58E+03	8.74E+03	1.12E+04			7.58E+03	2.32E+03	44.11%
0.40	2.00	7.73E+03	6.84E+03	7.07E+03	9.38E+03		6.84E+03	1.58E+03	30.04%
0.40	3.00	7.51E+03	7.57E+03	8.86E+03			7.51E+03	2.25E+03	42.78%
0.40	4.00	8.58E+03	8.73E+03	9.48E+03			8.58E+03	3.32E+03	63.12%
0.40	5.00	9.26E+03	9.03E+03	9.72E+03			9.03E+03	3.77E+03	71.67%
0.40	6.00	1.03E+04	1.12E+04	1.09E+04	1.20E+04		1.03E+04	5.04E+03	95.82%
0.60	2.00	7.21E+03	6.38E+03	7.28E+03			6.38E+03	1.12E+03	21.29%
0.60	3.00	7.78E+03	6.63E+03	8.27E+03			6.63E+03	1.37E+03	26.05%
0.60	4.00	8.09E+03	8.34E+03	8.70E+03			8.09E+03	2.83E+03	53.80%
0.60	5.00	8.33E+03	7.97E+03	9.07E+03			7.97E+03	2.71E+03	51.52%
0.60	6.00	9.63E+03	9.26E+03	1.09E+04			9.26E+03	4.00E+03	76.05%
0.80	2.00	6.99E+03	6.75E+03	7.84E+03			6.75E+03	1.49E+03	28.33%
0.80	3.00	7.78E+03	8.12E+03	7.55E+03	8.09E+03		7.55E+03	2.29E+03	43.54%
0.80	4.00	8.44E+03	9.48E+03	8.84E+03	9.37E+03	8.56E+03	8.44E+03	3.18E+03	60.46%
0.80	5.00	8.55E+03	8.40E+03	8.98E+03			8.40E+03	3.14E+03	59.70%
0.80	6.00	8.58E+03	9.00E+03	1.10E+04			8.58E+03	3.32E+03	63.12%

Table B.10 :(Four Circle) Material WOVEN GLASS E1/E2=1.00, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0),Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 2.46E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	2.43E+03	2.68E+03	2.73E+03			2.43E+03	-3.00E+01	-1.22%
0.20	3.00	2.50E+03		2.59E+03			2.50E+03	4.00E+01	1.63%
0.20	4.00	2.48E+03		2.51E+03			2.48E+03	2.00E+01	0.81%
0.20	5.00	2.52E+03		2.62E+03			2.52E+03	6.00E+01	2.44%
0.20	6.00	2.50E+03					2.50E+03	4.00E+01	1.63%
0.40	2.00	2.36E+03	2.76E+03	2.74E+03			2.36E+03	-1.00E+02	-4.07%
0.40	3.00	2.44E+03		2.59E+03			2.44E+03	-2.00E+01	-0.81%
0.40	4.00	2.47E+03		2.53E+03			2.47E+03	1.00E+01	0.41%
0.40	5.00	2.49E+03		2.52E+03			2.49E+03	3.00E+01	1.22%
0.40	6.00	2.49E+03		2.58E+03			2.49E+03	3.00E+01	1.22%
0.60	2.00	2.48E+03	2.87E+03	2.87E+03			2.48E+03	2.00E+01	0.81%
0.60	3.00	2.44E+03		2.68E+03			2.44E+03	-2.00E+01	-0.81%
0.60	4.00	2.46E+03		2.60E+03			2.46E+03	0.00E+00	0.00%
0.60	5.00	2.46E+03		2.56E+03			2.46E+03	0.00E+00	0.00%
0.60	6.00	2.48E+03		2.54E+03			2.48E+03	2.00E+01	0.81%
0.80	2.00	2.56E+03	2.94E+03	3.14E+03			2.56E+03	1.00E+02	4.07%
0.80	3.00	2.50E+03	2.69E+03	2.84E+03			2.50E+03	4.00E+01	1.63%
0.80	4.00	2.47E+03	2.59E+03				2.47E+03	1.00E+01	0.41%
0.80	5.00	2.48E+03	2.56E+03				2.48E+03	2.00E+01	0.81%
0.80	6.00	2.56E+03	2.54E+03	2.58E+03			2.54E+03	8.00E+01	3.25%

Table B.11 :(Four Circle) Material BORON ALUMINIUM E1/E2=1.72, Fiber direction 0 ° ,Laminates stacking sequence (0-90-90-0),Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 2.51E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	2.50E+03	2.75E+03	2.79E+03	2.71E+03	2.54E+03	2.50E+03	-1.00E+01	-0.40%
0.20	3.00	2.52E+03					2.52E+03	1.00E+01	0.40%
0.20	4.00	2.52E+03					2.52E+03	1.00E+01	0.40%
0.20	5.00	2.53E+03		2.58E+03			2.53E+03	2.00E+01	0.80%
0.20	6.00	2.54E+03					2.54E+03	3.00E+01	1.20%
0.40	2.00	2.44E+03	2.76E+03	2.75E+03			2.44E+03	-7.00E+01	-2.79%
0.40	3.00	2.45E+03					2.45E+03	-6.00E+01	-2.39%
0.40	4.00	2.49E+03		2.59E+03			2.49E+03	-2.00E+01	-0.80%
0.40	5.00	2.51E+03					2.51E+03	0.00E+00	0.00%
0.40	6.00			2.63E+03			2.63E+03	1.20E+02	4.78%
0.60	2.00	2.53E+03	2.87E+03	2.91E+03			2.53E+03	2.00E+01	0.80%
0.60	3.00	2.48E+03		2.73E+03			2.48E+03	-3.00E+01	-1.20%
0.60	4.00	2.47E+03		2.66E+03			2.47E+03	-4.00E+01	-1.59%
0.60	5.00	2.51E+03		2.63E+03			2.51E+03	0.00E+00	0.00%
0.60	6.00	2.53E+03		2.61E+03			2.53E+03	2.00E+01	0.80%
0.80	2.00	2.61E+03	2.99E+03	3.20E+03			2.61E+03	1.00E+02	3.98%
0.80	3.00	2.53E+03		2.89E+03			2.53E+03	2.00E+01	0.80%
0.80	4.00	2.51E+03		2.76E+03			2.51E+03	0.00E+00	0.00%
0.80	5.00	2.53E+03		2.69E+03			2.53E+03	2.00E+01	0.80%
0.80	6.00	2.62E+03		2.65E+03			2.62E+03	1.10E+02	4.38%

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
Table B.12 : (Four Circle) Material E1\E2= 10, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0),Tension 1000 N,Compression 1000 N, Load ratio =1, Maximum Stress without design holes = 3.23E+03									
0.20	2.00	3.46E+03	3.87E+03	4.00E+03			3.46E+03	2.30E+02	7.12%
0.20	3.00	3.50E+03	4.02E+03	3.89E+03			3.50E+03	2.70E+02	8.36%
0.20	4.00	3.79E+03		3.81E+03			3.79E+03	5.60E+02	17.34%
0.20	5.00	3.73E+03		3.98E+03			3.73E+03	5.00E+02	15.48%
0.20	6.00	3.70E+03		4.26E+03			3.70E+03	4.70E+02	14.55%
0.40	2.00	3.46E+03	3.89E+03	3.74E+03			3.46E+03	2.30E+02	7.12%
0.40	3.00	3.28E+03		3.74E+03			3.28E+03	5.00E+01	1.55%
0.40	4.00	3.43E+03		3.96E+03			3.43E+03	2.00E+02	6.19%
0.40	5.00	3.66E+03		4.07E+03			3.66E+03	4.30E+02	13.31%
0.40	6.00	3.69E+03		4.17E+03			3.69E+03	4.60E+02	14.24%
0.60	2.00	3.33E+03	4.02E+03	3.82E+03			3.33E+03	1.00E+02	3.10%
0.60	3.00	3.23E+03		3.78E+03			3.23E+03	0.00E+00	0.00%
0.60	4.00	3.35E+03		4.03E+03			3.35E+03	1.20E+02	3.72%
0.60	5.00	3.61E+03		3.45E+03			3.45E+03	2.20E+02	6.81%
0.60	6.00	3.76E+03		4.23E+03			3.76E+03	5.30E+02	16.41%
0.80	2.00	3.42E+03	3.87E+03	4.28E+03			3.42E+03	1.90E+02	5.88%
0.80	3.00	3.22E+03		4.02E+03			3.22E+03	-1.00E+01	-0.31%
0.80	4.00	3.31E+03		4.12E+03			3.31E+03	8.00E+01	2.48%
0.80	5.00	3.58E+03		4.13E+03			3.58E+03	3.50E+02	10.84%
0.80	6.00	3.71E+03		4.28E+03			3.71E+03	4.80E+02	14.86%

Table B.13 :(Four Circle) Material E1\E2 =20, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio =1, Maximum Stress without design holes = 3.85E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	4.77E+03	4.99E+03	5.26E+03			4.77E+03	9.20E+02	23.90%
0.20	3.00	4.74E+03		5.00E+03			4.74E+03	8.90E+02	23.12%
0.20	4.00	5.10E+03		5.27E+03			5.10E+03	1.25E+03	32.47%
0.20	5.00	5.12E+03					5.12E+03	1.27E+03	32.99%
0.20	6.00	5.11E+03					5.11E+03	1.26E+03	32.73%
0.40	2.00	4.47E+03	5.18E+03	4.74E+03			4.47E+03	6.20E+02	16.10%
0.40	3.00	4.11E+03		4.83E+03			4.11E+03	2.60E+02	6.75%
0.40	4.00	4.56E+03		5.34E+03			4.56E+03	7.10E+02	18.44%
0.40	5.00	4.69E+03		5.61E+03			4.69E+03	8.40E+02	21.82%
0.40	6.00	4.94E+03					4.94E+03	1.09E+03	28.31%
0.60	2.00	4.12E+03	5.17E+03	4.68E+03			4.12E+03	2.70E+02	7.01%
0.60	3.00	3.95E+03		4.81E+03			3.95E+03	1.00E+02	2.60%
0.60	4.00	4.25E+03		5.46E+03			4.25E+03	4.00E+02	10.39%
0.60	5.00	4.76E+03		5.63E+03			4.76E+03	9.10E+02	23.64%
0.60	6.00	5.07E+03					5.07E+03	1.22E+03	31.69%
0.80	2.00	4.26E+03	4.73E+03	5.34E+03			4.26E+03	4.10E+02	10.65%
0.80	3.00	3.93E+03		5.14E+03			3.93E+03	8.00E+01	2.08%
0.80	4.00	4.17E+03		5.47E+03			4.17E+03	3.20E+02	8.31%
0.80	5.00	4.77E+03		5.45E+03			4.77E+03	9.20E+02	23.90%
0.80	6.00	4.80E+03					4.80E+03	9.50E+02	24.68%

Table B.14 :(Four Circle) Material E1\E2= 30.0, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes =4.28E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	6.59E+03	5.93E+03	7.47E+03			5.93E+03	1.65E+03	38.55%
0.20	3.00	6.65E+03		2.52E+04			6.65E+03	2.37E+03	55.37%
0.20	4.00	1.32E+04					1.32E+04	8.92E+03	208.41%
0.20	5.00	1.71E+04					1.71E+04	1.28E+04	298.36%
0.20	6.00	1.72E+04					1.72E+04	1.29E+04	301.87%
0.40	2.00	5.27E+03	6.26E+03	5.60E+03			5.27E+03	9.90E+02	23.13%
0.40	3.00	4.82E+03		5.73E+03			4.82E+03	5.40E+02	12.62%
0.40	4.00	5.49E+03					5.49E+03	1.21E+03	28.27%
0.40	5.00	5.66E+03					5.66E+03	1.38E+03	32.24%
0.40	6.00	5.67E+03					5.67E+03	1.39E+03	32.48%
0.60	2.00	4.78E+03	6.10E+03	5.33E+03			4.78E+03	5.00E+02	11.68%
0.60	3.00	4.54E+03		5.66E+03			4.54E+03	2.60E+02	6.07%
0.60	4.00	4.95E+03		6.65E+03			4.95E+03	6.70E+02	15.65%
0.60	5.00	5.70E+03					5.70E+03	1.42E+03	33.18%
0.60	6.00	5.72E+03					5.72E+03	1.44E+03	33.64%
0.80	2.00	4.22E+03	5.40E+03	6.18E+03			4.22E+03	-6.00E+01	-1.40%
0.80	3.00	4.57E+03		6.00E+03			4.57E+03	2.90E+02	6.78%
0.80	4.00	4.87E+03		6.54E+03			4.87E+03	5.90E+02	13.79%
0.80	5.00	5.78E+03					5.78E+03	1.50E+03	35.05%
0.80	6.00	5.79E+03					5.79E+03	1.51E+03	35.28%

Table B.15 :(Four Circle) Material E1\E2= 40.0, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 4.63E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	6.03E+03	6.73E+03	7.22E+03			6.03E+03	1.40E+03	30.24%
0.20	3.00	6.37E+03		6.67E+03			6.37E+03	1.74E+03	37.58%
0.20	4.00	7.42E+03		7.70E+03			7.42E+03	2.79E+03	60.26%
0.20	5.00	7.45E+03					7.45E+03	2.82E+03	60.91%
0.20	6.00	7.47E+03					7.47E+03	2.84E+03	61.34%
0.40	2.00	5.39E+03	7.20E+03	6.33E+03			5.39E+03	7.60E+02	16.41%
0.40	3.00	5.43E+03		6.55E+03			5.43E+03	8.00E+02	17.28%
0.40	4.00	6.30E+03		7.44E+03			6.30E+03	1.67E+03	36.07%
0.40	5.00	6.50E+03					6.50E+03	1.87E+03	40.39%
0.40	6.00	6.52E+03					6.52E+03	1.89E+03	40.82%
0.60	2.00	5.31E+03	6.89E+03	5.88E+03			5.31E+03	6.80E+02	14.69%
0.60	3.00	5.01E+03		6.39E+03			5.01E+03	3.80E+02	8.21%
0.60	4.00	5.52E+03		7.67E+03			5.52E+03	8.90E+02	19.22%
0.60	5.00	6.50E+03					6.50E+03	1.87E+03	40.39%
0.60	6.00	6.51E+03					6.51E+03	1.88E+03	40.60%
0.80	2.00	5.40E+03	5.95E+03	6.87E+03			5.40E+03	7.70E+02	16.63%
0.80	3.00	5.10E+03		6.75E+03			5.10E+03	4.70E+02	10.15%
0.80	4.00	5.45E+03		7.43E+03			5.45E+03	8.20E+02	17.71%
0.80	5.00	6.66E+03					6.66E+03	2.03E+03	43.84%
0.80	6.00	6.67E+03					6.67E+03	2.04E+03	44.06%
0.40	2.00	6.44E+03				**120°**	6.44E+03	1.81E+03	39.09%

Table B.16 :(Four Circle) Material GRAGHITE EPOXY E1/E2=45.94, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0),Tension 1000 N,Compression 1000 N,-Load ratio =1.0, Maximum Stress without design holes = 4.77E+4

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	6.31E+03	7.04E+03	7.55E+03			6.31E+03	1.54E+03	32.29%
0.20	3.00	6.64E+03		6.99E+03			6.64E+03	1.87E+03	39.20%
0.20	4.00	7.80E+03		8.09E+03			7.80E+03	3.03E+03	63.52%
0.20	5.00	7.84E+03					7.84E+03	3.07E+03	64.36%
0.20	6.00	7.95E+03					7.95E+03	3.18E+03	66.67%
0.40	2.00	6.18E+03	7.54E+03	6.61E+03			6.18E+03	1.41E+03	29.56%
0.40	3.00	5.65E+03		6.85E+03			5.65E+03	8.80E+02	18.45%
0.40	4.00	6.59E+03					6.59E+03	1.82E+03	38.16%
0.40	5.00	6.80E+03					6.80E+03	2.03E+03	42.56%
0.40	6.00	6.84E+03					6.84E+03	2.07E+03	43.40%
0.60	2.00	5.52E+03	7.18E+03	6.10E+03			5.52E+03	7.50E+02	15.72%
0.60	3.00	5.35E+03	6.35E+03	6.66E+03			5.35E+03	5.80E+02	12.16%
0.60	4.00	5.74E+03					5.74E+03	9.70E+02	20.34%
0.60	5.00	6.80E+03					6.80E+03	2.03E+03	42.56%
0.60	6.00	6.83E+03					6.83E+03	2.06E+03	43.19%
0.80	2.00	5.63E+03	6.17E+03	7.14E+03			5.63E+03	8.60E+02	18.03%
0.80	3.00	5.30E+03		7.04E+03			5.30E+03	5.30E+02	11.11%
0.80	4.00	5.68E+03		7.75E+03			5.68E+03	9.10E+02	19.08%
0.80	5.00	6.98E+03					6.98E+03	2.21E+03	46.33%
0.80	6.00	7.01E+03					7.01E+03	2.24E+03	46.96%

Table B.17 :(Four Circle) Material E1\E2 =50.0, Fiber direction 0 ° , Laminates stacking sequence(0-90-90-0),Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 4.90E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	6.69E+03	7.61E+03	8.03E+03			6.69E+03	1.79E+03	36.53%
0.20	3.00	6.98E+03		7.98E+03			6.98E+03	2.08E+03	42.45%
0.20	4.00	8.39E+03		8.67E+03			8.39E+03	3.49E+03	71.22%
0.20	5.00	8.41E+03					8.41E+03	3.51E+03	71.63%
0.20	6.00	8.43E+03					8.43E+03	3.53E+03	72.04%
0.40	2.00	5.74E+03	8.04E+03	6.97E+03			5.74E+03	8.40E+02	17.14%
0.40	3.00	5.95E+03		7.28E+03			5.95E+03	1.05E+03	21.43%
0.40	4.00	7.02E+03					7.02E+03	2.12E+03	43.27%
0.40	5.00	7.08E+03					7.08E+03	2.18E+03	44.49%
0.40	6.00	7.11E+03					7.11E+03	2.21E+03	45.10%
0.60	2.00	5.75E+03	7.63E+03	6.35E+03			5.75E+03	8.50E+02	17.35%
0.60	3.00	5.40E+03		7.04E+03			5.40E+03	5.00E+02	10.20%
0.60	4.00	6.00E+03					6.00E+03	1.10E+03	22.45%
0.60	5.00	7.24E+03					7.24E+03	2.34E+03	47.76%
0.60	6.00	7.26E+03					7.26E+03	2.36E+03	48.16%
0.80	2.00	5.81E+03	6.42E+03	7.46E+03			5.81E+03	9.10E+02	18.57%
0.80	3.00	5.55E+03	7.23E+03	7.45E+03			5.55E+03	6.50E+02	13.27%
0.80	4.00	5.98E+03		8.19E+03			5.98E+03	1.08E+03	22.04%
0.80	5.00	6.01E+03					6.01E+03	1.11E+03	22.65%
0.80	6.00	6.12E+03					6.12E+03	1.22E+03	24.90%

Table B.18 :(Four Circle) Material CARBON EPOXY E1/E2=63.77, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio =1.0, Maximum Stress without design holes = 5.26E+03

DHS d/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	2.00	6.46E+03	8.78E+03	9.30E+03			6.46E+03	1.20E+03	22.81%
0.20	3.00	7.84E+03		8.61E+03			7.84E+03	2.58E+03	49.05%
0.20	4.00	7.98E+03		1.05E+04			7.98E+03	2.72E+03	51.71%
0.20	5.00	8.01E+03					8.01E+03	2.75E+03	52.28%
0.20	6.00	8.11E+03					8.11E+03	2.85E+03	54.18%
0.40	2.00	7.33E+03	9.37E+03	7.92E+03			7.33E+03	2.07E+03	39.35%
0.40	3.00	6.76E+03		8.44E+03			6.76E+03	1.50E+03	28.52%
0.40	4.00	8.15E+03					8.15E+03	2.89E+03	54.94%
0.40	5.00	8.21E+03					8.21E+03	2.95E+03	56.08%
0.40	6.00	8.23E+03					8.23E+03	2.97E+03	56.46%
0.60	2.00	6.42E+03	8.85E+03	6.98E+03			6.42E+03	1.16E+03	22.05%
0.60	3.00	5.93E+03		8.12E+03			5.93E+03	6.70E+02	12.74%
0.60	4.00	6.70E+03					6.70E+03	1.44E+03	27.38%
0.60	5.00	6.75E+03					6.75E+03	1.49E+03	28.33%
0.60	6.00	6.81E+03					6.81E+03	1.55E+03	29.47%
0.80	2.00	6.38E+03	7.14E+03	8.35E+03			6.38E+03	1.12E+03	21.29%
0.80	3.00	6.23E+03		8.53E+03			6.23E+03	9.70E+02	18.44%
0.80	4.00	6.75E+03					6.75E+03	1.49E+03	28.33%
0.80	5.00	6.91E+03					6.91E+03	1.65E+03	31.37%
0.80	6.00	7.12E+03					7.12E+03	1.86E+03	35.36%

Table B.19 : Four Elliptical Design Hole System, Material WOVEN GLASS E1/E2=1.00, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0 N, Load ratio=0.0, Maximum Stress without design holes =1.88E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	1.79E+03					1.79E+03	-9.00E+01	-4.79%
0.24	0.40	1.20	1.81E+03					1.81E+03	-7.00E+01	-3.72%
0.24	0.40	1.40	1.79E+03					1.79E+03	-9.00E+01	-4.79%
0.24	0.40	1.60	1.84E+03					1.84E+03	-4.00E+01	-2.13%
0.24	0.40	1.00	1.80E+03					1.80E+03	-8.00E+01	-4.26%
0.24	0.40	1.32	1.79E+03					1.79E+03	-9.00E+01	-4.79%
0.24	0.48	1.32	1.81E+03					1.81E+03	-7.00E+01	-3.72%
0.20	0.40	1.32	1.79E+03					1.79E+03	-9.00E+01	-4.79%

Table B.20 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0 N, Load ratio=0.0, Maximum Stress without design holes = 2.64E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	2.64E+03					2.64E+03	0.00E+00	0.00%
0.24	0.40	1.00	2.39E+03					2.39E+03	-2.50E+02	-9.47%
0.24	0.40	0.80	2.60E+03					2.60E+03	-4.00E+01	-1.52%
0.24	0.48	1.00	2.40E+03					2.40E+03	-2.40E+02	-9.09%
0.20	0.40	1.00	2.44E+03					2.44E+03	-2.00E+02	-7.58%
0.24	0.40	0.96	2.39E+03					2.39E+03	-2.50E+02	-9.47%
0.24	0.40	1.04	2.68E+03					2.68E+03	4.00E+01	1.52%

Table B.21 : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0 N, Load ratio=0.0, Maximum Stress without design holes =3.15E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.01E+03					3.01E+03	-1.40E+02	-4.44%
0.24	0.40	1.00	2.67E+03					2.67E+03	-4.80E+02	-15.24%
0.24	0.40	0.80	3.07E+03					3.07E+03	-8.00E+01	-2.54%
0.24	0.40	1.00	2.92E+03					2.92E+03	-2.30E+02	-7.30%
0.24	0.48	1.00	2.74E+03					2.74E+03	-4.10E+02	-13.02%
0.20	0.40	1.00	2.65E+03					2.65E+03	-5.00E+02	-15.87%
0.16	0.40	1.00	2.69E+03					2.69E+03	-4.60E+02	-14.60%

Table B.22 : Four elliptical Design Hole System Material Graghite Epoxy E1/E2=45.94, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0 N, Load ratio=0.0, Maximum Stress without design holes =3.49+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.31E+03					3.31E+03	-1.80E+02	-5.16%
0.24	0.40	1.40	3.33E+03					3.33E+03	-1.60E+02	-4.58%
0.24	0.40	1.00	2.63E+03					2.63E+03	-8.60E+02	-24.64%
0.24	0.40	0.80	3.35E+03					3.35E+03	-1.40E+02	-4.01%
0.24	0.40	0.96	2.81E+03					2.81E+03	-6.80E+02	-19.48%
0.24	0.40	0.92	2.92E+03					2.92E+03	-5.70E+02	-16.33%
0.20	0.40	0.96	2.88E+03					2.88E+03	-6.10E+02	-17.48%
0.24	0.48	0.96	2.93E+03					2.93E+03	-5.60E+02	-16.05%

Table B.23 : Four elliptical Design Hole System Material Carbon Epoxy E1/E2=63.77, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum Stress without design holes =3.81E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.00	3.86E+03					3.86E+03	5.00E+01	1.31%
0.24	0.40	0.96	3.80E+03					3.80E+03	-1.00E+01	-0.26%
0.24	0.40	1.04	3.66E+03					3.66E+03	-1.50E+02	-3.94%
0.24	0.40	0.92	3.00E+03					3.00E+03	-8.10E+02	-21.26%

Table B.24 : Four elliptical Design Hole System Material WOVEN GLASS E1/E2=1.00, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum Stress without design holes =2.00E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	1.93E+03					1.93E+03	-7.00E+01	-3.50%
0.24	0.40	1.40	1.92E+03					1.92E+03	-8.00E+01	-4.00%
0.24	0.40	1.00	1.97E+03					1.97E+03	-3.00E+01	-1.50%
0.24	0.48	1.40	1.95E+03					1.95E+03	-5.00E+01	-2.50%
0.20	0.40	1.40	1.93E+03					1.93E+03	-7.00E+01	-3.50%

Table B.25 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum Stress without design holes = 2.87E+03											
DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	2.61E+03					2.61E+03	-2.60E+02	-9.06%
0.24	0.40	1.40	2.66E+03					2.66E+03	-2.10E+02	-7.32%
0.24	0.40	1.00	2.60E+03					2.60E+03	-2.70E+02	-9.41%
0.24	0.48	0.80	2.93E+03					2.93E+03	6.00E+01	2.09%
0.24	0.40	1.04	2.61E+03					2.61E+03	-2.60E+02	-9.06%
0.24	0.48	1.00	2.63E+03					2.63E+03	-2.40E+02	-8.36%
5.00	0.40	1.00	2.72E+03					2.72E+03	-1.50E+02	-5.23%
0.24	0.40	1/1.2	2.49E+03					2.49E+03	-3.80E+02	-13.24%
0.24	0.40	1/1.4	2.50E+03					2.50E+03	-3.70E+02	-12.89%

Table B.26 : Four elliptical Design Hole System Material E1/E2=30, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum Stress without design holes =3.44E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.40	3.09E+03					3.09E+03	-3.50E+02	-10.17%
0.24	0.40	1.20	3.02E+03					3.02E+03	-4.20E+02	-12.21%
0.24	0.40	1.00	3.05E+03					3.05E+03	-3.90E+02	-11.34%
0.24	0.40	1.2/1	3.00E+03					3.00E+03	-4.40E+02	-12.79%
0.24	0.40	1/1.2	2.70E+03					2.70E+03	-7.40E+02	-21.51%
0.24	0.40	1/1.4	2.96E+03					2.96E+03	-4.80E+02	-13.95%
0.20	0.40	1/1.2	2.73E+03					2.73E+03	-7.10E+02	-20.64%
0.24	0.48	1/1.2	2.98E+03					2.98E+03	-4.60E+02	-13.37%

Table B.27 : Four elliptical Design Hole System Material Graghite Epoxy E1/E2=45.94, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum Stress without design holes =4.02+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.27E+03					3.27E+03	-7.50E+02	-18.66%
0.24	0.40	1.40	3.37E+03					3.37E+03	-6.50E+02	-16.17%
0.24	0.40	1.00	3.49E+03					3.49E+03	-5.30E+02	-13.18%
0.24	0.40	1.2/1.4	3.09E+03					3.09E+03	-9.30E+02	-23.13%
0.24	0.40	1.16/1.44	3.18E+03					3.18E+03	-8.40E+02	-20.90%
0.24	0.48	1.2/1.4	3.14E+03					3.14E+03	-8.80E+02	-21.89%
0.20	0.40	1.2/1.4	2.96E+03					2.96E+03	-1.06E+03	-26.37%
0.16	0.40	1.2/1.4	2.84E+03					2.84E+03	-1.18E+03	-29.35%
0.12	0.40	1.2/1.4	3.69E+03					3.69E+03	-3.30E+02	-8.21%

Table B.28 : Four elliptical Design Hole System Material Carbon Epoxy E1/E2=63.77, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum Stress without design holes =4.17E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.84E+03					3.84E+03	-3.30E+02	-7.91%
0.16	0.40	1.2/1.4	3.30E+03					3.30E+03	-8.70E+02	-20.86%
0.20	0.44	1.2/1.4	3.35E+03					3.35E+03	-8.20E+02	-19.66%

Table B.29 : Four elliptical Design Hole System Material WOVEN GLASS E1/E2=1.00, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum Stress without design holes =2.15E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	2.05E+03					2.05E+03	-1.00E+02	-4.65%
0.24	0.40	1.40	2.05E+03					2.05E+03	-1.00E+02	-4.65%
0.24	0.40	1.60	2.06E+03					2.06E+03	-9.00E+01	-4.19%
0.24	0.40	1.80	2.12E+03					2.12E+03	-3.00E+01	-1.40%
0.24	0.40	1.00	2.08E+03					2.08E+03	-7.00E+01	-3.26%
0.24	0.40	1.32	2.05E+03					2.05E+03	-1.00E+02	-4.65%
0.24	0.48	1.32	2.01E+03					2.01E+03	-1.40E+02	-6.51%
0.32	0.48	1.32	1.99E+03					1.99E+03	-1.60E+02	-7.44%
0.32	0.56	1.32	1.96E+03					1.96E+03	-1.90E+02	-8.84%
0.32	0.64	1.32	2.09E+03					2.09E+03	-6.00E+01	-2.79%
0.32	0.60	1.32	2.02E+03					2.02E+03	-1.30E+02	-6.05%
0.32	0.56	1.20	1.94E+03					1.94E+03	-2.10E+02	-9.77%
0.32	0.56	1.16	1.95E+03					1.95E+03	-2.00E+02	-9.30%
0.32	0.56	1.24	1.94E+03					1.94E+03	-2.10E+02	-9.77%

Table B.30 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum Stress without design holes = 3.10E+03										
DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	2.73E+03					2.73E+03	-3.70E+02	-11.94%
0.24	0.40	1.40	2.81E+03					2.81E+03	-2.90E+02	-9.35%
0.24	0.40	1.00	2.64E+03					2.64E+03	-4.60E+02	-14.84%
0.24	0.40	0.80	3.05E+03					3.05E+03	-5.00E+01	-1.61%
0.24	0.48	1.00	2.76E+03					2.76E+03	-3.40E+02	-10.97%
0.20	0.40	1.00	2.85E+03					2.85E+03	-2.50E+02	-8.06%
0.24	0.40	1.04	2.73E+03					2.73E+03	-3.70E+02	-11.94%
0.24	0.40	0.96	2.89E+03					2.89E+03	-2.10E+02	-6.77%

Table B.31: Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum Stress without design holes =3.72E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.16E+03					3.16E+03	-5.60E+02	-15.05%
0.24	0.40	1.40	3.02E+03					3.02E+03	-7.00E+02	-18.82%
0.24	0.40	1.00	3.17E+03					3.17E+03	-5.50E+02	-14.78%
0.24	0.40	1.60	3.19E+03					3.19E+03	-5.30E+02	-14.25%
0.24	0.48	1.40	3.25E+03					3.25E+03	-4.70E+02	-12.63%
0.20	0.40	1.40	2.98E+03					2.98E+03	-7.40E+02	-19.89%
0.16	0.40	1.40	3.24E+03					3.24E+03	-4.80E+02	-12.90%
0.20	0.40	1.44	2.89E+03					2.89E+03	-8.30E+02	-22.31%
0.20	0.40	1.48	3.12E+03					3.12E+03	-6.00E+02	-16.13%

Table B.32 : Four elliptical Design Hole System Material Graghite Epoxy E1/E2=45.94, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum Stress without design holes =4.13+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.42E+03					3.42E+03	-7.10E+02	-17.19%
0.24	0.40	1.40	3.55E+03					3.55E+03	-5.80E+02	-14.04%
0.24	0.40	1.00	3.64E+03					3.64E+03	-4.90E+02	-11.86%
0.24	0.48	1.20	3.25E+03					3.25E+03	-8.80E+02	-21.31%
0.24	0.56	1.20	3.92E+03					3.92E+03	-2.10E+02	-5.08%
0.24	0.52	1.20	3.72E+03					3.72E+03	-4.10E+02	-9.93%
0.20	0.48	1.20	3.14E+03					3.14E+03	-9.90E+02	-23.97%
0.16	0.48	1.20	3.15E+03					3.15E+03	-9.80E+02	-23.73%
0.20	0.48	1.24	3.31E+03					3.31E+03	-8.20E+02	-19.85%

Table B.33 : Four elliptical Design Hole System Material Carbon Epoxy E1/E2=63.77, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum Stress without design holes =4.53E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.93E+03					3.93E+03	-6.00E+02	-13.25%
0.24	0.40	1.00	4.38E+03					4.38E+03	-1.50E+02	-3.31%
0.24	0.40	1.40	3.86E+03					3.86E+03	-6.70E+02	-14.79%
0.20	0.40	1.20	4.25E+03					4.25E+03	-2.80E+02	-6.18%
0.20	0.48	1.20	3.63E+03					3.63E+03	-9.00E+02	-19.87%
0.20	0.52	1.20	3.94E+03					3.94E+03	-5.90E+02	-13.02%
0.20	0.48	1.2/1.4	3.98E+03					3.98E+03	-5.50E+02	-12.14%

Table B.34 : Four elliptical Design Hole System Material WOVEN GLASS E1/E2=1.00, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum Stress without design holes =2.30E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	2.00	2.29E+03					2.29E+03	-1.00E+01	-0.43%
0.40	0.40	2.00	2.23E+03					2.23E+03	-7.00E+01	-3.04%
0.24	0.40	1.80	2.21E+03					2.21E+03	-9.00E+01	-3.91%
0.24	0.40	1.60	2.19E+03					2.19E+03	-1.10E+02	-4.78%
0.24	0.40	1.40	2.18E+03					2.18E+03	-1.20E+02	-5.22%
0.24	0.40	1.20	2.17E+03					2.17E+03	-1.30E+02	-5.65%
0.24	0.40	1.00	2.20E+03					2.20E+03	-1.00E+02	-4.35%
0.32	0.40	1.20	2.16E+03					2.16E+03	-1.40E+02	-6.09%
0.32	0.48	1.20	2.10E+03					2.10E+03	-2.00E+02	-8.70%
0.24	0.48	1.20	2.12E+03					2.12E+03	-1.80E+02	-7.83%
0.36	0.48	1.20	2.09E+03					2.09E+03	-2.10E+02	-9.13%
0.40	0.48	1.20	2.13E+03					2.13E+03	-1.70E+02	-7.39%
0.36	0.52	1.20	2.06E+03					2.06E+03	-2.40E+02	-10.43%
0.36	0.56	1.20	2.03E+03					2.03E+03	-2.70E+02	-11.74%
0.36	0.60	1.20	1.99E+03					1.99E+03	-3.10E+02	-13.48%
0.36	0.64	1.20	2.06E+03					2.06E+03	-2.40E+02	-10.43%
0.36	0.60	1.24	2.01E+03					2.01E+03	-2.90E+02	-12.61%
0.36	0.60	1.16	2.00E+03					2.00E+03	-3.00E+02	-13.04%

Table B.35 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum Stress without design holes =3.34E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	2.86E+03					2.86E+03	-4.80E+02	-14.37%
0.24	0.40	1.40	2.97E+03					2.97E+03	-3.70E+02	-11.08%
0.24	0.40	1.00	2.92E+03					2.92E+03	-4.20E+02	-12.57%
0.24	0.48	1.20	2.73E+03					2.73E+03	-6.10E+02	-18.26%
0.24	0.56	1.20	3.05E+03					3.05E+03	-2.90E+02	-8.68%
0.24	0.52	1.20	2.83E+03					2.83E+03	-5.10E+02	-15.27%
0.20	0.48	1.20	2.75E+03					2.75E+03	-5.90E+02	-17.66%
0.24	0.48	1.16	2.75E+03					2.75E+03	-5.90E+02	-17.66%

Table B.36 : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum Stress without design holes =4.00E+03										
DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.31E+03					3.31E+03	-6.90E+02	-17.25%
0.24	0.40	1.40	3.17E+03					3.17E+03	-8.30E+02	-20.75%
0.24	0.40	1.60	3.34E+03					3.34E+03	-6.60E+02	-16.50%
0.24	0.40	1.44	3.48E+03					3.48E+03	-5.20E+02	-13.00%
0.24	0.40	1.36	3.39E+03					3.39E+03	-6.10E+02	-15.25%
0.24	0.48	1.40	3.37E+03					3.37E+03	-6.30E+02	-15.75%
0.20	0.40	1.40	3.25E+03					3.25E+03	-7.50E+02	-18.75%

Table B.37 : Four elliptical Design Hole System Material Graghite Epoxy E1/E2=45.94, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum Stress without design holes =4.45+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.51E+03					3.51E+03	-9.40E+02	-21.12%
0.24	0.40	1.60	3.62E+03					3.62E+03	-8.30E+02	-18.65%
0.24	0.40	1.00	4.05E+03					4.05E+03	-4.00E+02	-8.99%
0.24	0.40	1.40	3.60E+03					3.60E+03	-8.50E+02	-19.10%
0.24	0.48	1.40	3.66E+03					3.66E+03	-7.90E+02	-17.75%
0.20	0.40	1.20	3.04E+03					3.04E+03	-1.41E+03	-31.69%
0.20	0.48	1.20	3.04E+03					3.04E+03	-1.41E+03	-31.69%

Table B.38 : Four elliptical Design Hole System Material Carbon Epoxy E1/E2=63.77, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum Stress without design holes =4.89E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20	3.88E+03					3.88E+03	-1.01E+03	-20.65%
0.24	0.40	1.40	4.05E+03					4.05E+03	-8.40E+02	-17.18%
0.24	0.40	1.00	4.73E+03					4.73E+03	-1.60E+02	-3.27%
0.20	0.40	1.20	3.84E+03					3.84E+03	-1.05E+03	-21.47%
0.16	0.40	1.20	3.95E+03					3.95E+03	-9.40E+02	-19.22%
0.20	0.48	1.20	3.55E+03					3.55E+03	-1.34E+03	-27.40%
0.20	0.52	1.20	3.97E+03					3.97E+03	-9.20E+02	-18.81%
0.20	0.48	1.24	3.98E+03					3.98E+03	-9.10E+02	-18.61%

Table B.39 : Four elliptical Design Hole System Material WOVEN GLASS E1/E2=1.00, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum Stress without design holes = 2.46E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.40	0.40	2.00	2.36E+03					2.36E+03	-1.00E+02	-4.07%
0.40	0.60	2.00	2.41E+03					2.41E+03	-5.00E+01	-2.03%
0.40	0.80	2.00	2.65E+03					2.65E+03	1.90E+02	7.72%
0.40	1.20	2.00	2.86E+03					2.86E+03	4.00E+02	16.26%
0.20	0.40	2.00	2.46E+03					2.46E+03	0.00E+00	0.00%
0.20	0.60	2.00	2.45E+03					2.45E+03	-1.00E+01	-0.41%
0.32	0.60	2.00	2.52E+03					2.52E+03	6.00E+01	2.44%
0.40	0.60	3.00	2.60E+03					2.60E+03	1.40E+02	5.69%
0.40	0.60	1.80	2.35E+03					2.35E+03	-1.10E+02	-4.47%
0.40	0.60	1.60	2.27E+03					2.27E+03	-1.90E+02	-7.72%
0.40	0.60	1.40	2.17E+03					2.17E+03	-2.90E+02	-11.79%
0.40	0.60	1.20	2.09E+03					2.09E+03	-3.70E+02	-15.04%
0.40	0.60	1.00	2.19E+03					2.19E+03	-2.70E+02	-10.98%
0.40	0.60	1.12	2.11E+03					2.11E+03	-3.50E+02	-14.23%
0.40	0.60	1.16	2.10E+03					2.10E+03	-3.60E+02	-14.63%
0.40	0.60	1.24	2.08E+03					2.08E+03	-3.80E+02	-15.45%
0.40	0.60	1.28	2.11E+03					2.11E+03	-3.50E+02	-14.23%
0.40	0.60	1.32	2.13E+03					2.13E+03	-3.30E+02	-13.41%

Table B.40 : Four elliptical Design Hole System Material E1/E2=15, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum Stress without design holes = 3.57E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	2.00	3.21E+03					3.21E+03	-3.60E+02	-10.08%
0.24	0.40	1.60	3.07E+03					3.07E+03	-5.00E+02	-14.01%
0.24	0.40	1.20	3.00E+03					3.00E+03	-5.70E+02	-15.97%
0.24	0.40	1.00	2.94E+03					2.94E+03	-6.30E+02	-17.65%
0.24	0.40	0.80	3.27E+03					3.27E+03	-3.00E+02	-8.40%
0.24	0.48	1.00	3.04E+03					3.04E+03	-5.30E+02	-14.85%
0.20	0.40	1.00	3.16E+03					3.16E+03	-4.10E+02	-11.48%
0.24	0.40	1.00	2.92E+03					2.92E+03	-6.50E+02	-18.21%

Table B.41 : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum Stress without design holes = 4.28E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	2.00	3.74E+03					3.74E+03	-5.40E+02	-12.62%
0.24	0.40	2.20	4.59E+03					4.59E+03	3.10E+02	7.24%
0.24	0.40	1.80	3.65E+03					3.65E+03	-6.30E+02	-14.72%
0.24	0.40	1.60	3.54E+03					3.54E+03	-7.40E+02	-17.29%
0.24	0.40	1.40	3.42E+03					3.42E+03	-8.60E+02	-20.09%
0.24	0.40	1.20	3.40E+03					3.40E+03	-8.80E+02	-20.56%
0.24	0.40	1.00	3.59E+03					3.59E+03	-6.90E+02	-16.12%

Table B.42 : Four elliptical Design Hole System Material Graghite Epoxy E1/E2=45.94, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum Stress without design holes =4.77E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.60	0.60	3.00	4.78E+03					4.78E+03	1.00E+01	0.21%
0.60	0.80	3.00	5.09E+03					5.09E+03	3.20E+02	6.71%
0.60	0.96	3.00	8.14E+03					8.14E+03	3.37E+03	70.65%
0.60	1.00	3.00	4.71E+03					4.71E+03	-6.00E+01	-1.26%
0.60	1.20	3.00	5.54E+03					5.54E+03	7.70E+02	16.14%
0.40	0.60	3.00	5.40E+03					5.40E+03	6.30E+02	13.21%
0.40	1.00	3.00	5.66E+03					5.66E+03	8.90E+02	18.66%
0.60	1.00	3.20	6.13E+03					6.13E+03	1.36E+03	28.51%
0.60	1.00	2.80	5.55E+03					5.55E+03	7.80E+02	16.35%
0.40	0.80	2.00	4.79E+03					4.79E+03	2.00E+01	0.42%
0.24	0.60	2.00	5.63E+03					5.63E+03	8.60E+02	18.03%
0.24	0.40	2.00	3.93E+03					3.93E+03	-8.40E+02	-17.61%
0.24	0.40	1.80	4.22E+03					4.22E+03	-5.50E+02	-11.53%
0.24	0.40	2.20	4.36E+03					4.36E+03	-4.10E+02	-8.60%

Table B.43 : Four elliptical Design Hole System Material Carbon Epoxy E1/E2=63.77, Fiber direction 0 ° , Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum Stress without design holes =5.26E+03

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at Φ=0°	max.stress (Pa) at Φ=30°	max.stress (Pa) at Φ=45°	max.stress (Pa) at Φ=60°	max.stress (Pa) at Φ=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.20	0.60	2.00	6.43E+03					6.43E+03	1.17E+03	22.24%
5.00	0.40	2.00	5.02E+03					5.02E+03	-2.40E+02	-4.56%
0.24	0.48	2.00	6.33E+03					6.33E+03	1.07E+03	20.34%
0.24	0.40	2.00	4.44E+03					4.44E+03	-8.20E+02	-15.59%
0.24	0.40	1.80	4.60E+03					4.60E+03	-6.60E+02	-12.55%
0.24	0.40	2.20	5.80E+03					5.80E+03	5.40E+02	10.27%

Table B.44 : Four elliptical Design Hole System Material E1/E2=1.0 Woven Glass, Fiber Direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=1.85E+3, 15°=1.85E+3, 30°=1.85E+3, 45°=1.85E+3, 60°=1.85E+3, 75°=1.85E+3, 90°=1.85E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			1.85E+03							1.85E+03	0.00E+00	0.00%
0.24	0.40	1.00	1.80E+03							1.80E+03	-5.00E+01	-2.70%
0.24	0.40	1.20	1.79E+03							1.79E+03	-6.00E+01	-3.24%
0.24	0.40	1.20	1.81E+03							1.81E+03	-4.00E+01	-2.16%
0.24	0.40	1.32	1.79E+03							1.79E+03	-6.00E+01	-3.24%
0.24	0.40	1.40	1.79E+03							1.79E+03	-6.00E+01	-3.24%
0.20	0.40	1.60	1.84E+03							1.84E+03	-1.00E+01	-0.54%
0.24	0.48	1.32	1.81E+03							1.81E+03	-4.00E+01	-2.16%
No design hole				1.85E+03						1.85E+03	0.00E+00	0.00%
No design hole					1.85E+03					1.85E+03	0.00E+00	0.00%
No design hole						1.85E+03				1.85E+03	0.00E+00	0.00%
No design hole							1.85E+03			1.85E+03	0.00E+00	0.00%
No design hole								1.85E+03		1.85E+03	0.00E+00	0.00%
No design hole									1.85E+03	1.85E+03	0.00E+00	0.00%

Table B.45 : Four elliptical Design Hole System Material E1/E2=1.0 Woven Glass, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=2.16E+3, 15°=2.16E+3, 30°=2.16E+3, 45°=2.16E+3, 60°=2.16E+3, 75°=2.16E+3, 90°=2.16E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			2.16E+03							2.16E+03	0.00E+00	0.00%
0.24	0.40	1.00	2.08E+03							2.08E+03	-8.00E+01	-3.70%
0.24	0.40	1.20	2.05E+03							2.05E+03	-1.10E+02	-5.09%
0.24	0.40	1.32	2.05E+03							2.05E+03	-1.10E+02	-5.09%
0.24	0.40	1.40	2.05E+03							2.05E+03	-1.10E+02	-5.09%
0.24	0.40	1.60	2.06E+03							2.06E+03	-1.00E+02	-4.63%
0.24	0.40	1.80	2.12E+03							2.12E+03	-4.00E+01	-1.85%
0.24	0.48	1.32	2.01E+03							2.01E+03	-1.50E+02	-6.94%
0.32	0.48	1.32	1.99E+03							1.99E+03	-1.70E+02	-7.87%
0.32	0.56	1.16	1.95E+03							1.95E+03	-2.10E+02	-9.72%
0.32	0.56	1.20	1.94E+03							1.94E+03	-2.20E+02	-10.19%
0.32	0.56	1.24	1.94E+03							1.94E+03	-2.20E+02	-10.19%
0.32	0.56	1.32	1.96E+03							1.96E+03	-2.00E+02	-9.26%
0.32	0.60	1.32	2.02E+03							2.02E+03	-1.40E+02	-6.48%
0.32	0.64	1.32	2.09E+03							2.09E+03	-7.00E+01	-3.24%
No design hole				2.16E+03						2.16E+03	0.00E+00	0.00%
No design hole					2.16E+03					2.16E+03	0.00E+00	0.00%
No design hole						2.16E+03				2.16E+03	0.00E+00	0.00%
No design hole							2.16E+03			2.16E+03	0.00E+00	0.00%
No design hole								2.16E+03		2.16E+03	0.00E+00	0.00%
No design hole									2.16E+03	2.16E+03	0.00E+00	0.00%

Table B.46 : Four elliptical Design Hole System Material E1/E2=1.0 Woven Glass, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=2.30E+3, 15°=2.30E+3, 30°=2.30E+3, 45°=2.30E+3, 60°=2.30E+3, 75°=2.30E+3, 90°=2.30E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			2.30E+03							2.30E+03	0.00E+00	0.00%
0.24	0.40	1.00	2.20E+03							2.20E+03	-1.00E+02	-4.35%
0.24	0.40	1.20	2.17E+03							2.17E+03	-1.30E+02	-5.65%
0.24	0.40	1.40	2.18E+03							2.18E+03	-1.20E+02	-5.22%
0.24	0.40	1.60	2.19E+03							2.19E+03	-1.10E+02	-4.78%
0.24	0.40	1.80	2.21E+03							2.21E+03	-9.00E+01	-3.91%
0.24	0.40	2.00	2.29E+03							2.29E+03	-1.00E+01	-0.43%
0.24	0.48	1.20	2.12E+03							2.12E+03	-1.80E+02	-7.83%
0.32	0.40	1.20	2.16E+03							2.16E+03	-1.40E+02	-6.09%
0.32	0.48	1.20	2.10E+03							2.10E+03	-2.00E+02	-8.70%
0.36	0.48	1.20	2.09E+03							2.09E+03	-2.10E+02	-9.13%
0.36	0.52	1.20	2.06E+03							2.06E+03	-2.40E+02	-10.43%
0.36	0.56	1.20	2.03E+03							2.03E+03	-2.70E+02	-11.74%
0.36	0.60	1.20	2.00E+03							2.00E+03	-3.00E+02	-13.04%
0.36	0.60	1.20	1.99E+03							1.99E+03	-3.10E+02	-13.48%
0.36	0.60	1.20	2.01E+03							2.01E+03	-2.90E+02	-12.61%
0.36	0.64	1.20	2.06E+03							2.06E+03	-2.40E+02	-10.43%
0.40	0.48	1.16	2.13E+03							2.13E+03	-1.70E+02	-7.39%

Table B.46 cont...: Four elliptical Design Hole System Material E1/E2=1.0 Woven Glass, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=2.30E+3, 15°=2.30E+3, 30°=2.30E+3, 45°=2.30E+3, 60°=2.30E+3, 75°=2.30E+3, 90°=2.30E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole				2.30E+03						2.30E+03	0.00E+00	0.00%
0.36	0.60	1.20		3.27E+03						3.27E+03	9.70E+02	42.17%
No design hole					2.30E+03					2.30E+03	0.00E+00	0.00%
No design hole						2.30E+03				2.30E+03	0.00E+00	0.00%
No design hole							2.30E+03			2.30E+03	0.00E+00	0.00%
No design hole								2.30E+03		2.30E+03	0.00E+00	0.00%
No design hole									2.30E+03	2.30E+03	0.00E+00	0.00%

Table B.47 : Four elliptical Design Hole System Material E1/E2=1.0 Woven Glass, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=2.46E+3, 15°=2.46E+3, 30°=2.46E+3, 45°=2.46E+3, 60°=2.46E+3, 75°=2.46E+3, 90°=2.46E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			2.46E+03							2.46E+03	0.00E+00	0.00%
5.00	10.00	50.00	2.46E+03							2.46E+03	0.00E+00	0.00%
5.00	15.00	50.00	3.46E+03							3.46E+03	1.00E+03	40.65%
6.00	10.00	50.00	2.38E+03							2.38E+03	-8.00E+01	-3.25%
8.00	15.00	50.00	2.52E+03							2.52E+03	6.00E+01	2.44%
10.00	10.00	50.00	2.36E+03							2.36E+03	-1.00E+02	-4.07%
10.00	20.00	50.00	2.65E+03							2.65E+03	1.90E+02	7.72%
10.00	30.00	50.00	2.86E+03							2.86E+03	4.00E+02	16.26%
10.00	15.00	50.00	2.41E+03							2.41E+03	-5.00E+01	-2.03%
10.00	15.00	25.00	2.19E+03							2.19E+03	-2.70E+02	-10.98%
10.00	15.00	28.00	2.11E+03							2.11E+03	-3.50E+02	-14.23%
10.00	15.00	29.00	2.10E+03							2.10E+03	-3.60E+02	-14.63%
10.00	15.00	30.00	2.09E+03							2.09E+03	-3.70E+02	-15.04%
10.00	15.00	31.00	2.08E+03							2.08E+03	-3.80E+02	-15.45%
10.00	15.00	32.00	2.11E+03							2.11E+03	-3.50E+02	-14.23%
10.00	15.00	32.00	2.11E+03							2.11E+03	-3.50E+02	-14.23%
10.00	15.00	33.00	2.13E+03							2.13E+03	-3.30E+02	-13.41%
10.00	15.00	35.00	2.17E+03							2.17E+03	-2.90E+02	-11.79%
10.00	15.00	40.00	2.27E+03							2.27E+03	-1.90E+02	-7.72%
10.00	15.00	45.00	2.35E+03							2.35E+03	-1.10E+02	-4.47%
10.00	15.00	50.00	2.41E+03							2.41E+03	-5.00E+01	-2.03%
10.00	15.00	75.00	2.60E+03							2.60E+03	1.40E+02	5.69%

Table B.47 cont... : Four elliptical Design Hole System Material E1/E2=1.0 Woven Glass, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=2.46E+3, 15°=2.46E+3, 30°=2.46E+3, 45°=2.46E+3, 60°=2.46E+3, 75°=2.46E+3, 90°=2.46E+3												
DHS a/D	**DHS b/D**	**Dist. s/D**	**max.stress (Pa) at FD=0°**	**max.stress (Pa) at FD=15°**	**max.stress (Pa) at FD=30°**	**max.stress (Pa) at FD=45°**	**max.stress (Pa) at FD=60°**	**max.stress (Pa) at FD=75°**	**max.stress (Pa) at FD=90°**	**Min.Stress Value (Pa)**	**Stress Reduction (Pa)**	**Stress Red. Ratio**
No design hole				2.46E+03						2.46E+03	0.00E+00	0.00%
6.00	10.00	25.00		2.31E+03						2.31E+03	-1.50E+02	-6.10%
6.00	10.00	30.00		2.29E+03						2.29E+03	-1.70E+02	-6.91%
6.00	10.00	35.00		2.31E+03						2.31E+03	-1.50E+02	-6.10%
6.00	10.00	31.00		2.11E+03						2.11E+03	-3.50E+02	-14.23%
No design hole					2.46E+03					2.46E+03	0.00E+00	0.00%
6.00	10.00	25.00			2.31E+03					2.31E+03	-1.50E+02	-6.10%
No design hole						2.46E+03				2.46E+03	0.00E+00	0.00%
No design hole							2.46E+03			2.46E+03	0.00E+00	0.00%
No design hole								2.46E+03		2.46E+03	0.00E+00	0.00%
No design hole									2.46E+03	2.46E+03	0.00E+00	0.00%

Table B.48 : Four elliptical Design Hole System Material E1/E2=1.0 Woven Glass, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=2.00E+3, 15°=2.00E+3, 30°=2.00E+3, 45°=2.00E+3, 60°=2.00E+3, 75°=2.00E+3, 90°=2.00E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			2.00E+03							2.00E+03	0.00E+00	0.00%
0.20	0.40	1.40	1.93E+03							1.93E+03	-7.00E+01	-3.50%
0.24	0.40	1.00	1.97E+03							1.97E+03	-3.00E+01	-1.50%
0.24	0.40	1.20	1.93E+03							1.93E+03	-7.00E+01	-3.50%
0.24	0.40	1.40	1.92E+03							1.92E+03	-8.00E+01	-4.00%
0.24	0.48	1.40	1.95E+03							1.95E+03	-5.00E+01	-2.50%
No design hole				2.00E+03						2.00E+03	0.00E+00	0.00%
No design hole					2.00E+03					2.00E+03	0.00E+00	0.00%
No design hole						2.00E+03				2.00E+03	0.00E+00	0.00%
No design hole							2.00E+03			2.00E+03	0.00E+00	0.00%
No design hole								2.00E+03		2.00E+03	0.00E+00	0.00%
No design hole									2.00E+03	2.00E+03	0.00E+00	0.00%

Table B.49 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=2.64E+3, 15°=2.37E+3, 30°=2.00E+3, 45°=1.92E+3, 60°=2.26E+3, 75°=2.57E+3, 90°=2.64E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			2.64E+03							2.64E+03	0.00E+00	0.00%
0.24	0.40	1.20	2.64E+03							2.64E+03	0.00E+00	0.00%
0.24	0.40	1.00	2.39E+03							2.39E+03	-2.50E+02	-9.47%
0.24	0.40	0.80	2.60E+03							2.60E+03	-4.00E+01	-1.52%
0.24	12.00	1.00	2.40E+03							2.40E+03	-2.40E+02	-9.09%
5.00	0.40	1.00	2.44E+03							2.44E+03	-2.00E+02	-7.58%
0.24	0.40	0.96	2.39E+03							2.39E+03	-2.50E+02	-9.47%
0.24	0.40	1.04	2.68E+03							2.68E+03	4.00E+01	1.52%
No design hole				2.37E+03						2.37E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.16E+03						2.16E+03	-2.10E+02	-8.86%
0.24	0.40	1.20		2.29E+03						2.29E+03	-8.00E+01	-3.38%
0.24	0.40	0.96		2.26E+03						2.26E+03	-1.10E+02	-4.64%
5.00	0.40	1.00		2.27E+03						2.27E+03	-1.00E+02	-4.22%
0.24	11.00	1.00		2.19E+03						2.19E+03	-1.80E+02	-7.59%
No design hole					2.00E+03					2.00E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.02E+03					2.02E+03	2.00E+01	1.00%
0.24	0.40	1.20			1.99E+03					1.99E+03	-1.00E+01	-0.50%
0.24	0.40	1.24			2.29E+03					2.29E+03	2.90E+02	14.50%
0.24	0.40	1.16			1.98E+03					1.98E+03	-2.00E+01	-1.00%
0.24	0.40	1.12			1.95E+03					1.95E+03	-5.00E+01	-2.50%
0.24	0.40	1.08			1.99E+03					1.99E+03	-1.00E+01	-0.50%
5.00	0.40	1.12			2.03E+03					2.03E+03	3.00E+01	1.50%
0.24	11.00	1.12			2.03E+03					2.03E+03	3.00E+01	1.50%

Table B.49 cont.. : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=2.64E+3, 15°=2.37E+3, 30°=2.00E+3, 45°=1.92E+3, 60°=2.26E+3, 75°=2.57E+3, 90°=2.64E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole						1.92E+03				1.92E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.05E+03				2.05E+03	1.30E+02	6.77%
0.24	0.40	1.20				1.95E+03				1.95E+03	3.00E+01	1.56%
0.24	0.40	1.24				1.92E+03				1.92E+03	0.00E+00	0.00%
0.24	0.40	1.28				1.91E+03				1.91E+03	-1.00E+01	-0.52%
No design hole							2.26E+03			2.26E+03	0.00E+00	0.00%
0.24	0.40	1.00					2.35E+03			2.35E+03	9.00E+01	3.98%
0.24	0.40	1.20					2.16E+03			2.16E+03	-1.00E+02	-4.42%
No design hole								2.57E+03		2.57E+03	0.00E+00	0.00%
0.24	10.00	1.00						2.50E+03		2.50E+03	-7.00E+01	-2.72%
0.24	10.00	1.20						2.45E+03		2.45E+03	-1.20E+02	-4.67%
No design hole									2.64E+03	2.64E+03	0.00E+00	0.00%
0.24	0.40	1.00							2.39E+03	2.39E+03	-2.50E+02	-9.47%
0.24	0.40	1.20							2.54E+03	2.54E+03	-1.00E+02	-3.79%
0.24	0.40	0.96							2.39E+03	2.39E+03	-2.50E+02	-9.47%

Table B.50 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=2.87E+3, 15°=2.56E+3, 30°=2.15E+3, 45°=2.07E+3, 60°=2.45E+3, 75°=2.79E+3, 90°=2.87E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			2.87E+03							2.87E+03	0.00E+00	0.00%
0.24	0.40	1.20	2.61E+03							2.61E+03	-2.60E+02	-9.06%
0.24	0.40	1.40	2.66E+03							2.66E+03	-2.10E+02	-7.32%
0.24	0.40	1.00	2.60E+03							2.60E+03	-2.70E+02	-9.41%
0.24	0.48	0.80	2.93E+03							2.93E+03	6.00E+01	2.09%
0.24	0.40	1.04	2.61E+03							2.61E+03	-2.60E+02	-9.06%
0.24	0.48	1.00	2.63E+03							2.63E+03	-2.40E+02	-8.36%
5.00	0.40	1.00	2.72E+03							2.72E+03	-1.50E+02	-5.23%
0.24	0.40	1/1.2	2.49E+03							2.49E+03	-3.80E+02	-13.24%
0.24	0.40	1/1.4	2.50E+03							2.50E+03	-3.70E+02	-12.89%
No design hole				2.56E+03						2.56E+03	0.00E+00	0.00%
0.24	0.40	0.96		2.43E+03						2.43E+03	-1.30E+02	-5.08%
0.24	0.40	1.00		2.24E+03						2.24E+03	-3.20E+02	-12.50%
0.24	0.40	1.00		2.29E+03						2.29E+03	-2.70E+02	-10.55%
0.24	0.40	1.00		2.35E+03						2.35E+03	-2.10E+02	-8.20%
5.00	0.40	1.20		2.28E+03						2.28E+03	-2.80E+02	-10.94%
0.24	0.44	1.24		2.27E+03						2.27E+03	-2.90E+02	-11.33%
0.24	0.40	1.16		2.48E+03						2.48E+03	-8.00E+01	-3.13%
No design hole					2.15E+03					2.15E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.10E+03					2.10E+03	-5.00E+01	-2.33%
0.24	0.40	1.20			2.07E+03					2.07E+03	-8.00E+01	-3.72%

Table B.50 cont.. : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=2.87E+3, 15°=2.56E+3, 30°=2.15E+3, 45°=2.07E+3, 60°=2.45E+3, 75°=2.79E+3, 90°=2.87E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.24			2.08E+03					2.08E+03	-7.00E+01	-3.26%
0.24	0.40	1.16			2.11E+03					2.11E+03	-4.00E+01	-1.86%
5.00	0.40	1.20			2.17E+03					2.17E+03	2.00E+01	0.93%
0.24	0.44	1.20			2.11E+03					2.11E+03	-4.00E+01	-1.86%
No design hole						2.07E+03				2.07E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.22E+03				2.22E+03	1.50E+02	7.25%
0.24	0.40	1.20				2.20E+03				2.20E+03	1.30E+02	6.28%
0.24	0.40	1.24				2.18E+03				2.18E+03	1.10E+02	5.31%
0.24	0.40	1.28				2.15E+03				2.15E+03	8.00E+01	3.86%
0.24	0.40	1.32				2.12E+03				2.12E+03	5.00E+01	2.42%
0.24	0.40	1.40				2.12E+03				2.12E+03	5.00E+01	2.42%
0.24	0.40	1.44				2.12E+03				2.12E+03	5.00E+01	2.42%
0.24	0.40	1.52				2.21E+03				2.21E+03	1.40E+02	6.76%
No design hole							2.45E+03			2.45E+03	0.00E+00	0.00%
No design hole								2.79E+03		2.79E+03	0.00E+00	0.00%
No design hole									2.87E+03	2.87E+03	0.00E+00	0.00%

Table B.51 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=3.10E+3, 15°=2.75E+3, 30°=2.31E+3, 45°=2.21E+3, 60°=2.63E+3, 75°=3.02E+3, 90°=3.10E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.10E+03							3.10E+03	0.00E+00	0.00%
0.24	0.40	1.20	2.73E+03							2.73E+03	-3.70E+02	-11.94%
0.24	0.40	1.40	2.81E+03							2.81E+03	-2.90E+02	-9.35%
0.24	0.40	1.00	2.64E+03							2.64E+03	-4.60E+02	-14.84%
0.24	0.40	0.80	3.05E+03							3.05E+03	-5.00E+01	-1.61%
0.24	0.48	1.00	2.76E+03							2.76E+03	-3.40E+02	-10.97%
0.24	0.40	1.00	2.85E+03							2.85E+03	-2.50E+02	-8.06%
0.24	0.40	1.04	2.73E+03							2.73E+03	-3.70E+02	-11.94%
0.24	0.40	0.96	2.89E+03							2.89E+03	-2.10E+02	-6.77%
No design hole				2.75E+03						2.75E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.55E+03						2.55E+03	-2.00E+02	-7.27%
0.24	0.40	1.20		2.38E+03						2.38E+03	-3.70E+02	-13.45%
0.24	0.40	1.40		2.47E+03						2.47E+03	-2.80E+02	-10.18%
0.24	0.40	1.16		2.48E+03						2.48E+03	-2.70E+02	-9.82%
0.24	0.40	0.96		2.42E+03						2.42E+03	-3.30E+02	-12.00%
5.00	0.40	1.24		2.41E+03						2.41E+03	-3.40E+02	-12.36%
0.24	0.40	1.28		2.38E+03						2.38E+03	-3.70E+02	-13.45%
No design hole					2.31E+03					2.31E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.22E+03					2.22E+03	-9.00E+01	-4.19%
0.24	0.40	1.20			2.21E+03					2.21E+03	-1.00E+02	-4.65%
0.24	0.40	1.40			2.32E+03					2.32E+03	1.00E+01	0.47%

Table B.51 cont..: Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=3.10E+3, 15°=2.75E+3, 30°=2.31E+3, 45°=2.21E+3, 60°=2.63E+3, 75°=3.02E+3, 90°=3.10E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.16			2.27E+03					2.27E+03	-4.00E+01	-1.86%
0.24	0.40	0.96			2.35E+03					2.35E+03	4.00E+01	1.86%
0.24	0.40	1.24			2.18E+03					2.18E+03	-1.30E+02	-6.05%
0.24	0.40	1.28			2.17E+03					2.17E+03	-1.40E+02	-6.51%
0.24	0.40	1.32			2.26E+03					2.26E+03	-5.00E+01	-2.33%
5.00	0.40	1.28			2.28E+03					2.28E+03	-3.00E+01	-1.40%
0.24	0.44	1.28			2.39E+03					2.39E+03	8.00E+01	3.72%
No design hole						2.21E+03				2.21E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.34E+03				2.34E+03	1.30E+02	5.88%
0.24	0.40	1.20				2.36E+03				2.36E+03	1.50E+02	6.79%
0.24	0.40	0.92				2.48E+03				2.48E+03	2.70E+02	12.22%
0.24	0.40	1.04				2.44E+03				2.44E+03	2.30E+02	10.41%
No design hole							2.63E+03			2.63E+03	0.00E+00	0.00%
No design hole								3.02E+03		3.02E+03	0.00E+00	0.00%
No design hole									3.10E+03	3.10E+03	0.00E+00	0.00%

Table B.52 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=3.34E+3, 15°=2.96E+3, 30°=2.46E+3, 45°=2.36E+3, 60°=2.2.82E+3, 75°=3.24E+3, 90°=3.34E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.34E+03							3.34E+03	0.00E+00	0.00%
0.24	0.40	1.20	2.86E+03							2.86E+03	-4.80E+02	-14.37%
0.24	0.40	1.40	2.97E+03							2.97E+03	-3.70E+02	-11.08%
0.24	0.40	1.00	2.92E+03							2.92E+03	-4.20E+02	-12.57%
0.24	0.48	1.20	2.73E+03							2.73E+03	-6.10E+02	-18.26%
0.24	0.56	1.20	3.05E+03							3.05E+03	-2.90E+02	-8.68%
0.24	0.52	1.20	2.83E+03							2.83E+03	-5.10E+02	-15.27%
0.20	0.48	1.20	2.75E+03							2.75E+03	-5.90E+02	-17.66%
0.24	0.48	1.16	2.75E+03							2.75E+03	-5.90E+02	-17.66%
No design hole				2.96E+03						2.96E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.67E+03						2.67E+03	-2.90E+02	-9.80%
0.24	0.40	1.20		2.46E+03						2.46E+03	-5.00E+02	-16.89%
0.24	0.40	1.40		2.55E+03						2.55E+03	-4.10E+02	-13.85%
0.24	0.40	1.16		2.61E+03						2.61E+03	-3.50E+02	-11.82%
0.24	0.40	1.24		2.54E+03						2.54E+03	-4.20E+02	-14.19%
0.20	0.40	1.20		2.54E+03						2.54E+03	-4.20E+02	-14.19%
0.24	0.44	1.20		2.50E+03						2.50E+03	-4.60E+02	-15.54%
No design hole					2.46E+03					2.46E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.34E+03					2.34E+03	-1.20E+02	-4.88%
0.24	0.40	1.20			2.34E+03					2.34E+03	-1.20E+02	-4.88%
0.24	0.40	1.40			2.41E+03					2.41E+03	-5.00E+01	-2.03%
0.24	0.40	0.96			2.48E+03					2.48E+03	2.00E+01	0.81%

Table B.52 cont... : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=3.34E+3, 15°=2.96E+3, 30°=2.46E+3, 45°=2.36E+3, 60°=2.2.82E+3, 75°=3.24E+3, 90°=3.34E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.04			2.36E+03					2.36E+03	-1.00E+02	-4.07%
0.24	0.40	1.16			2.38E+03					2.38E+03	-8.00E+01	-3.25%
0.24	0.40	1.08			2.42E+03					2.42E+03	-4.00E+01	-1.63%
0.20	0.40	1.20			2.48E+03					2.48E+03	2.00E+01	0.81%
0.24	0.44	1.20			2.38E+03					2.38E+03	-8.00E+01	-3.72%
No design hole						2.36E+03				2.36E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.49E+03				2.49E+03	1.30E+02	5.51%
0.24	0.40	1.20				2.52E+03				2.52E+03	1.60E+02	6.78%
0.24	0.40	1.40				2.43E+03				2.43E+03	7.00E+01	2.97%
0.24	0.40	1.60				2.68E+03				2.68E+03	3.20E+02	13.56%
0.24	0.40	1.44				2.43E+03				2.43E+03	7.00E+01	2.97%
No design hole							2.82E+03			2.82E+03	0.00E+00	0.00%
0.24	0.40	1.00					2.99E+03			2.99E+03	1.70E+02	6.03%
0.24	0.40	1.20					2.89E+03			2.89E+03	7.00E+01	2.48%
0.24	0.40	1.40					2.89E+03			2.89E+03	7.00E+01	2.48%
0.24	0.40	1.16					2.85E+03			2.85E+03	3.00E+01	1.06%
0.24	0.40	1.24					2.90E+03			2.90E+03	8.00E+01	2.84%
0.24	0.40	1.12					2.96E+03			2.96E+03	1.40E+02	4.96%
0.24	0.40	1.08					2.94E+03			2.94E+03	1.20E+02	4.26%
0.20	0.40	1.16					2.89E+03			2.89E+03	7.00E+01	2.48%
0.24	0.44	1.16					2.89E+03			2.89E+03	7.00E+01	2.48%

Table B.52 cont...: Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=3.34E+3, 15°=2.96E+3, 30°=2.46E+3, 45°=2.36E+3, 60°=2.2.82E+3, 75°=3.24E+3, 90°=3.34E+3												
DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.00						3.09E+03		3.09E+03	-1.50E+02	-4.63%
0.24	0.40	1.20						3.08E+03		3.08E+03	-1.60E+02	-4.94%
0.24	0.40	1.40						3.13E+03		3.13E+03	-1.10E+02	-3.40%
0.24	0.40	1.16						3.05E+03		3.05E+03	-1.90E+02	-5.86%
0.24	0.40	1.24						3.11E+03		3.11E+03	-1.30E+02	-4.01%
0.24	0.40	1.20						3.08E+03		3.08E+03	-1.60E+02	-4.94%
0.24	0.40	1.16						3.05E+03		3.05E+03	-1.90E+02	-5.86%
0.24	0.40	1.12						3.00E+03		3.00E+03	-2.40E+02	-7.41%
0.24	0.40	1.08						3.00E+03		3.00E+03	-2.40E+02	-7.41%
0.24	0.40	1.04						3.01E+03		3.01E+03	-2.30E+02	-7.10%
0.20	0.40	1.08						2.81E+03		2.81E+03	-4.30E+02	-13.27%
0.16	0.40	1.08						2.84E+03		2.84E+03	-4.00E+02	-12.35%
0.20	0.44	1.08						2.87E+03		2.87E+03	-3.70E+02	-11.42%
0.20	0.36	1.08						3.02E+03		3.02E+03	-2.20E+02	-6.79%
No design hole									3.34E+03	3.34E+03	0.00E+00	0.00%
0.24	0.40	1.00							2.92E+03	2.92E+03	-4.20E+02	-12.57%
0.24	0.40	1.20							2.89E+03	2.89E+03	-4.50E+02	-13.47%
0.24	0.40	1.40							2.97E+03	2.97E+03	-3.70E+02	-11.08%
0.24	0.48	1.20							2.73E+03	2.73E+03	-6.10E+02	-18.26%

Table B.53 : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=3.57E+3, 15°=3.14E+3, 30°=2.62E+3, 45°=2.51E+3, 60°=3.00E+3, 75°=3.46E+3, 90°=3.57E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.57E+03							3.57E+03	0.00E+00	0.00%
0.24	0.40	2.00	3.21E+03							3.21E+03	-3.60E+02	-10.08%
0.24	0.40	1.60	3.07E+03							3.07E+03	-5.00E+02	-14.01%
0.24	0.40	1.20	3.00E+03							3.00E+03	-5.70E+02	-15.97%
0.24	0.40	1.00	2.94E+03							2.94E+03	-6.30E+02	-17.65%
0.24	0.40	0.80	3.27E+03							3.27E+03	-3.00E+02	-8.40%
0.24	0.48	1.00	3.04E+03							3.04E+03	-5.30E+02	-14.85%
0.20	0.40	1.00	3.16E+03							3.16E+03	-4.10E+02	-11.48%
0.24	0.40	1.00	2.92E+03							2.92E+03	-6.50E+02	-18.21%
No design hole				3.14E+03						3.14E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.79E+03						2.79E+03	-3.50E+02	-11.15%
0.24	0.40	1.20		2.57E+03						2.57E+03	-5.70E+02	-18.15%
0.24	0.40	1.40		2.63E+03						2.63E+03	-5.10E+02	-16.24%
0.24	0.40	1.24		2.66E+03						2.66E+03	-4.80E+02	-15.29%
0.24	0.40	1.16		2.74E+03						2.74E+03	-4.00E+02	-12.74%
0.24	0.40	1.44		2.64E+03						2.64E+03	-5.00E+02	-15.92%
0.20	0.40	1.20		2.64E+03						2.64E+03	-5.00E+02	-15.92%
0.24	0.44	1.20		2.65E+03						2.65E+03	-4.90E+02	-15.61%
No design hole					2.62E+03					2.62E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.46E+03					2.46E+03	-1.60E+02	-6.11%
0.24	0.40	1.20			2.49E+03					2.49E+03	-1.30E+02	-4.96%

Table B.53 cont... : Four elliptical Design Hole System Material E1/E2=15.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=3.57E+3, 15°=3.14E+3, 30°=2.62E+3, 45°=2.51E+3, 60°=3.00E+3, 75°=3.46E+3, 90°=3.57E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	0.96			2.61E+03					2.61E+03	-1.00E+01	-0.38%
0.24	0.40	1.04			2.49E+03					2.49E+03	-1.30E+02	-4.96%
0.20	0.40	1.00			2.72E+03					2.72E+03	1.00E+02	3.82%
0.24	0.44	1.00			2.63E+03					2.63E+03	1.00E+01	0.47%
No design hole						2.51E+03				2.51E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.63E+03				2.63E+03	1.20E+02	4.78%
0.24	0.40	1.20				2.68E+03				2.68E+03	1.70E+02	6.77%
0.24	0.40	0.96				2.80E+03				2.80E+03	2.90E+02	11.55%
0.20	0.40	1.00				2.69E+03				2.69E+03	1.80E+02	7.17%
No design hole							3.00E+03			3.00E+03	0.00E+00	0.00%
No design hole								2.46E+03		2.46E+03	0.00E+00	0.00%
No design hole									3.57E+03	3.57E+03	0.00E+00	0.00%

Table B.54 : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=3.15E+3, 15°=2.64E+3, 30°=2.06E+3, 45°=1.95E+3, 60°=2.46E+3, 75°=2.97E+3, 90°=3.15E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.15E+03							3.15E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.01E+03							3.01E+03	-1.40E+02	-4.44%
0.24	0.40	1.00	2.67E+03							2.67E+03	-4.80E+02	-15.24%
0.24	0.40	0.80	3.07E+03							3.07E+03	-8.00E+01	-2.54%
0.24	0.40	1.00	2.92E+03							2.92E+03	-2.30E+02	-7.30%
0.24	0.48	1.00	2.74E+03							2.74E+03	-4.10E+02	-13.02%
0.20	0.40	1.00	2.65E+03							2.65E+03	-5.00E+02	-15.87%
0.16	0.40	1.00	2.69E+03							2.69E+03	-4.60E+02	-14.60%
No design hole				2.64E+03						2.64E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.28E+03						2.28E+03	-3.60E+02	-13.64%
0.24	0.40	1.20		2.54E+03						2.54E+03	-1.00E+02	-3.79%
0.24	0.40	1.40		2.48E+03						2.48E+03	-1.60E+02	-6.06%
0.24	0.40	0.92		2.31E+03						2.31E+03	-3.30E+02	-12.50%
0.24	0.40	0.96		2.47E+03						2.47E+03	-1.70E+02	-6.44%
0.24	0.40	1.04		2.48E+03						2.48E+03	-1.60E+02	-6.06%
0.20	0.40	1.00		2.49E+03						2.49E+03	-1.50E+02	-5.68%
0.24	0.44	1.00		2.35E+03						2.35E+03	-2.90E+02	-10.98%
No design hole					2.06E+03					2.06E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.14E+03					2.14E+03	8.00E+01	3.88%
0.24	0.40	1.20			2.09E+03					2.09E+03	3.00E+01	1.46%

Table B.54 cont...: Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=3.15E+3, 15°=2.64E+3, 30°=2.06E+3, 45°=1.95E+3, 60°=2.46E+3, 75°=2.97E+3, 90°=3.15E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.40			2.27E+03					2.27E+03	2.10E+02	10.19%
0.24	0.40	1.24			2.09E+03					2.09E+03	3.00E+01	1.46%
0.24	0.40	1.32			2.17E+03					2.17E+03	1.10E+02	5.34%
0.24	0.40	1.16			2.06E+03					2.06E+03	0.00E+00	0.00%
0.24	0.40	1.12			2.00E+03					2.00E+03	-6.00E+01	-2.91%
0.24	0.40	1.08			2.07E+03					2.07E+03	1.00E+01	0.49%
0.20	0.40	1.12			2.14E+03					2.14E+03	8.00E+01	3.88%
0.24	0.44	1.12			2.16E+03					2.16E+03	1.00E+02	4.85%
No design hole						1.95E+03				1.95E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.21E+03				2.21E+03	2.60E+02	13.33%
0.24	0.40	1.20				2.06E+03				2.06E+03	1.10E+02	5.64%
0.24	0.40	1.40				2.32E+03				2.32E+03	3.70E+02	18.97%
0.24	0.40	1.24				2.05E+03				2.05E+03	1.00E+02	5.13%
0.24	0.40	1.16				1.96E+03				1.96E+03	1.00E+01	0.51%
0.24	0.40	1.12				2.02E+03				2.02E+03	7.00E+01	3.59%
0.24	0.40	1.28				2.08E+03				2.08E+03	1.30E+02	6.67%
0.20	0.40	1.16				2.25E+03				2.25E+03	3.00E+02	15.38%
0.24	0.44	1.16				2.19E+03				2.19E+03	2.40E+02	12.31%
No design hole							2.46E+03			2.46E+03	0.00E+00	0.00%
0.24	0.40	1.00					2.65E+03			2.65E+03	1.90E+02	7.72%
0.24	0.40	1.20					2.32E+03			2.32E+03	-1.40E+02	-5.69%

Table B.54 cont...: Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=3.15E+3, 15°=2.64E+3, 30°=2.06E+3, 45°=1.95E+3, 60°=2.46E+3, 75°=2.97E+3, 90°=3.15E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.40					2.49E+03			2.49E+03	3.00E+01	1.22%
0.24	0.40	1.24					2.33E+03			2.33E+03	-1.30E+02	-5.28%
0.24	0.40	1.16					2.29E+03			2.29E+03	-1.70E+02	-6.91%
0.24	0.40	1.12					2.24E+03			2.24E+03	-2.21E+02	-8.98%
0.20	0.40	1.16					2.33E+03			2.33E+03	-1.30E+02	-5.28%
0.24	0.44	1.16					2.39E+03			2.39E+03	-7.00E+01	-2.85%
No design hole								2.97E+03		2.97E+03	0.00E+00	0.00%
0.24	0.40	1.00						2.90E+03		2.90E+03	-7.00E+01	-2.36%
0.24	0.40	1.20						2.83E+03		2.83E+03	-1.40E+02	-4.71%
0.24	0.40	1.40						2.90E+03		2.90E+03	-7.00E+01	-2.36%
0.24	0.40	1.24						2.84E+03		2.84E+03	-1.30E+02	-4.38%
0.24	0.40	1.16						2.86E+03		2.86E+03	-1.10E+02	-3.70%
0.20	0.40	1.20						2.70E+03		2.70E+03	-2.70E+02	-9.09%
0.16	0.40	1.20						2.87E+03		2.87E+03	-1.00E+02	-3.37%
0.20	0.44	1.20						2.78E+03		2.78E+03	-1.90E+02	-6.40%
No design hole									3.15E+03	3.15E+03	0.00E+00	0.00%
0.24	0.40	1.00							2.67E+03	2.67E+03	-4.80E+02	-15.24%
0.24	0.40	1.20							3.01E+03	3.01E+03	-1.40E+02	-4.44%
0.24	0.40	1.40							3.02E+03	3.02E+03	-1.30E+02	-4.13%

Table B.55 : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=3.44E+3, 15°=2.86E+3, 30°=2.22E+3, 45°=2.09E+3, 60°=2.66E+3, 75°=3.23E+3, 90°=3.44E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.44E+03							3.44E+03	0.00E+00	0.00%
0.24	0.40	1.40	3.09E+03							3.09E+03	-3.50E+02	-10.17%
0.24	0.40	1.20	3.02E+03							3.02E+03	-4.20E+02	-12.21%
0.24	0.40	1.00	3.05E+03							3.05E+03	-3.90E+02	-11.34%
0.24	0.40	1.20	3.00E+03							3.00E+03	-4.40E+02	-12.79%
0.24	0.40	1/1.2	2.70E+03							2.70E+03	-7.40E+02	-21.51%
0.24	0.40	1/1.4	2.96E+03							2.96E+03	-4.80E+02	-13.95%
0.20	0.40	1/1.2	2.73E+03							2.73E+03	-7.10E+02	-20.64%
0.24	0.48	1/1.2	2.98E+03							2.98E+03	-4.60E+02	-14.60%
No design hole				2.86E+03						2.86E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.65E+03						2.65E+03	-2.10E+02	-7.34%
0.24	0.40	1.20		2.38E+03						2.38E+03	-4.80E+02	-16.78%
0.24	0.40	1.24		2.51E+03						2.51E+03	-3.50E+02	-12.24%
0.24	0.40	1.16		2.68E+03						2.68E+03	-1.80E+02	-6.29%
5.00	0.40	1.20		2.43E+03						2.43E+03	-4.30E+02	-15.03%
0.24	0.44	1.20		2.40E+03						2.40E+03	-4.60E+02	-16.08%
No design hole					2.22E+03					2.22E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.29E+03					2.29E+03	7.00E+01	3.15%
0.24	0.40	1.20			2.26E+03					2.26E+03	4.00E+01	1.80%
0.24	0.40	1.24			2.21E+03					2.21E+03	-1.00E+01	-0.45%
0.24	0.40	1.28			2.28E+03					2.28E+03	6.00E+01	2.70%

Table B.55 cont...: Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=3.44E+3, 15°=2.86E+3, 30°=2.22E+3, 45°=2.09E+3, 60°=2.66E+3, 75°=3.23E+3, 90°=3.44E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
5.00	0.40	1.24			2.37E+03					2.37E+03	1.50E+02	6.76%
0.24	0.44	1.24			2.28E+03					2.28E+03	6.00E+01	2.70%
0.24	0.40	1.24/1			2.39E+03					2.39E+03	1.70E+02	7.66%
No design hole						2.09E+03				2.09E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.35E+03				2.35E+03	2.60E+02	12.44%
0.24	0.40	1.20				2.42E+03				2.42E+03	3.30E+02	15.79%
0.24	0.40	0.96				2.33E+03				2.33E+03	2.40E+02	11.48%
0.24	0.40	0.92				2.53E+03				2.53E+03	4.40E+02	21.05%
No design hole							2.66E+03			2.66E+03	0.00E+00	0.00%
No design hole								3.23E+03		3.23E+03	0.00E+00	0.00%
No design hole									3.44E+03	3.44E+03	0.00E+00	0.00%

Table B.56 : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=3.72E+3, 15°=3.07E+3, 30°=2.51E+3, 45°=2.23E+3, 60°=2.86E+3, 75°=3.49E+3, 90°=3.72E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.72E+03							3.72E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.16E+03							3.16E+03	-5.60E+02	-15.05%
0.24	0.40	1.40	3.02E+03							3.02E+03	-7.00E+02	-18.82%
0.24	0.40	1.00	3.17E+03							3.17E+03	-5.50E+02	-14.78%
0.24	0.40	1.60	3.19E+03							3.19E+03	-5.30E+02	-14.25%
0.24	0.48	1.40	3.25E+03							3.25E+03	-4.70E+02	-12.63%
0.20	0.40	1.40	2.98E+03							2.98E+03	-7.40E+02	-19.89%
0.16	0.40	1.40	3.24E+03							3.24E+03	-4.80E+02	-12.90%
0.20	0.40	1.44	2.89E+03							2.89E+03	-8.30E+02	-22.31%
0.20	0.40	1.48	3.12E+03							3.12E+03	-6.00E+02	-16.13%
No design hole				3.07E+03						3.07E+03	0.00E+00	0.00%
0.24	0.40	1.20		2.65E+03						2.65E+03	-4.20E+02	-13.68%
0.24	0.40	1.00		2.77E+03						2.77E+03	-3.00E+02	-9.77%
0.24	0.40	1.40		2.74E+03						2.74E+03	-3.30E+02	-10.75%
0.24	0.40	0.80		3.60E+03						3.60E+03	5.30E+02	17.26%
0.20	0.40	1.20		2.57E+03						2.57E+03	-5.00E+02	-16.29%
0.16	0.40	1.20		2.89E+03						2.89E+03	-1.80E+02	-5.86%
0.20	0.44	1.20		2.84E+03						2.84E+03	-2.30E+02	-7.49%
0.20	0.40	1.24		2.58E+03						2.58E+03	-4.90E+02	-15.96%
No design hole					2.51E+03					2.51E+03	0.00E+00	0.00%
0.24	0.40	1.20			2.56E+03					2.56E+03	5.00E+01	1.99%

Table B.56 cont...: Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=3.72E+3, 15°=3.07E+3, 30°=2.51E+3, 45°=2.23E+3, 60°=2.86E+3, 75°=3.49E+3, 90°=3.72E+3												
DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.00			2.59E+03					2.59E+03	8.00E+01	3.19%
0.24	0.40	1.40			2.58E+03					2.58E+03	7.00E+01	2.79%
0.24	0.40	0.80			2.57E+03					2.57E+03	6.00E+01	2.39%
0.24	0.40	1.24			2.49E+03					2.49E+03	-2.00E+01	-0.80%
0.24	0.40	1.28			2.58E+03					2.58E+03	7.00E+01	2.79%
0.24	0.40	1.16			2.61E+03					2.61E+03	1.00E+02	3.98%
0.20	0.40	1.24			2.39E+03					2.39E+03	-1.20E+02	-4.78%
0.20	0.44	1.24			2.46E+03					2.46E+03	-5.00E+01	-1.99%
0.16	0.40	1.24			2.53E+03					2.53E+03	2.00E+01	0.80%
0.20	0.44	1.24			2.46E+03					2.46E+03	-5.00E+01	-1.99%
0.20	0.44	1.24/1.4			2.67E+03					2.67E+03	1.60E+02	6.37%
No design hole						2.23E+03				2.23E+03	0.00E+00	0.00%
0.24	0.40	1.20				2.60E+03				2.60E+03	3.70E+02	16.59%
0.24	0.40	1.00				2.61E+03				2.61E+03	3.80E+02	17.04%
0.24	0.40	1.40				2.46E+03				2.46E+03	2.30E+02	10.31%
0.24	0.40	1.44				2.46E+03				2.46E+03	2.30E+02	10.31%
0.24	0.40	1.32				2.46E+03				2.46E+03	2.30E+02	10.31%
0.20	0.40	1.32				2.74E+03				2.74E+03	5.10E+02	22.87%
No design hole							2.86E+03			2.86E+03	0.00E+00	0.00%
0.24	0.40	1.20					3.08E+03			3.08E+03	2.20E+02	7.69%
0.24	0.40	1.00					3.27E+03			3.27E+03	4.10E+02	14.34%

Table B.56 cont... : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=3.72E+3, 15°=3.07E+3, 30°=2.51E+3, 45°=2.23E+3, 60°=2.86E+3, 75°=3.49E+3, 90°=3.72E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.40					3.07E+03			3.07E+03	2.10E+02	7.34%
0.24	0.40	0.80					3.42E+03			3.42E+03	5.60E+02	19.58%
0.24	0.40	1.36					3.03E+03			3.03E+03	1.70E+02	5.94%
0.24	0.40	1.32					2.98E+03			2.98E+03	1.20E+02	4.20%
0.20	0.40	1.28					3.00E+03			3.00E+03	1.40E+02	4.90%
0.20	0.40	1.32					3.02E+03			3.02E+03	1.60E+02	5.59%
0.24	0.36	1.32					3.20E+03			3.20E+03	3.40E+02	11.89%
0.24	0.44	1.32					3.17E+03			3.17E+03	3.10E+02	10.84%
0.24	0.40	1.32/1.4					3.03E+03			3.03E+03	1.70E+02	5.94%
No design hole								3.49E+03		3.49E+03	0.00E+00	0.00%
0.24	0.40	1.20						3.42E+03		3.42E+03	-7.00E+01	-2.01%
0.24	0.40	1.00						3.38E+03		3.38E+03	-1.10E+02	-3.15%
0.24	0.40	1.40						3.45E+03		3.45E+03	-4.00E+01	-1.15%
0.24	0.40	1.04						3.30E+03		3.30E+03	-1.90E+02	-5.44%
0.24	0.40	0.96						3.48E+03		3.48E+03	-1.00E+01	-0.29%
0.24	0.40	1.08						3.26E+03		3.26E+03	-2.30E+02	-6.59%
0.24	0.40	1.12						3.09E+03		3.09E+03	-4.00E+02	-11.46%
0.20	0.40	1.08						2.92E+03		2.92E+03	-5.70E+02	-16.33%
0.16	0.40	1.08						2.97E+03		2.97E+03	-5.20E+02	-14.90%
0.20	0.44	1.08						3.10E+03		3.10E+03	-3.90E+02	-11.17%

Table B.56 cont... : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=3.72E+3, 15°=3.07E+3, 30°=2.51E+3, 45°=2.23E+3, 60°=2.86E+3, 75°=3.49E+3, 90°=3.72E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole									3.72E+03	3.72E+03	0.00E+00	0.00%
0.24	0.40	1.20							3.16E+03	3.16E+03	-5.60E+02	-15.05%
0.24	0.40	1.00							3.28E+03	3.28E+03	-4.40E+02	-11.83%
0.24	0.40	1.40							3.26E+03	3.26E+03	-4.60E+02	-12.37%
0.24	0.40	1.24							2.96E+03	2.96E+03	-7.60E+02	-20.43%
0.24	0.40	1.32							2.97E+03	2.97E+03	-7.50E+02	-20.16%
0.24	0.40	1.28							3.23E+03	3.23E+03	-4.90E+02	-13.17%
0.20	0.40	1.24							2.86E+03	2.86E+03	-8.60E+02	-23.12%
0.16	0.40	1.24							3.03E+03	3.03E+03	-6.90E+02	-18.55%
0.20	0.44	1.24							3.16E+03	3.16E+03	-5.60E+02	-15.05%
0.20	0.40	1.32							2.95E+03	2.95E+03	-7.70E+02	-20.70%

Table B.57 : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=4.00E+3, 15°=3.28E+3, 30°=2.80E+3, 45°=2.38E+3, 60°=3.06E+3, 75°=3.75E+3, 90°=4.00E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			4.00E+03							4.00E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.31E+03							3.31E+03	-6.90E+02	-17.25%
0.24	0.40	1.40	3.17E+03							3.17E+03	-8.30E+02	-20.75%
0.24	0.40	1.60	3.34E+03							3.34E+03	-6.60E+02	-16.50%
0.24	0.40	1.44	3.48E+03							3.48E+03	-5.20E+02	-13.00%
0.24	0.40	1.36	3.39E+03							3.39E+03	-6.10E+02	-15.25%
0.24	0.48	1.40	3.37E+03							3.37E+03	-6.30E+02	-15.75%
5.00	0.40	1.40	3.25E+03							3.25E+03	-7.50E+02	-18.75%
No design hole				3.28E+03						3.28E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.82E+03						2.82E+03	-4.60E+02	-14.02%
0.24	0.40	1.20		2.97E+03						2.97E+03	-3.10E+02	-9.45%
0.24	0.40	0.96		3.00E+03						3.00E+03	-2.80E+02	-8.54%
0.24	0.40	1.04		3.00E+03						3.00E+03	-2.80E+02	-8.54%
5.00	0.40	1.00		3.19E+03						3.19E+03	-9.00E+01	-2.74%
0.24	0.44	1.00		2.73E+03						2.73E+03	-5.50E+02	-16.77%
0.24	0.48	1.00		3.31E+03						3.31E+03	3.00E+01	0.91%
No design hole					2.80E+03					2.80E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.79E+03					2.79E+03	-1.00E+01	-0.36%
0.24	0.40	1.20			2.86E+03					2.86E+03	6.00E+01	2.14%
0.24	0.40	0.96			2.89E+03					2.89E+03	9.00E+01	3.21%
0.24	0.40	1.04			2.90E+03					2.90E+03	1.00E+02	3.57%

Table B.57 cont.. : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=4.00E+3, 15°=3.28E+3, 30°=2.80E+3, 45°=2.38E+3, 60°=3.06E+3, 75°=3.75E+3, 90°=4.00E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
5.00	0.40	1.00			2.98E+03					2.98E+03	1.80E+02	6.43%
0.24	0.44	1.00			2.81E+03					2.81E+03	1.00E+01	0.36%
No design hole						2.38E+03				2.38E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.74E+03				2.74E+03	3.60E+02	15.13%
0.24	0.40	1.20				2.79E+03				2.79E+03	4.10E+02	17.23%
0.24	0.40	0.96				2.93E+03				2.93E+03	5.50E+02	23.11%
0.24	0.40	1.04				2.92E+03				2.92E+03	5.40E+02	22.69%
No design hole							3.06E+03			3.06E+03	0.00E+00	0.00%
0.24	0.40	1.00					3.35E+03			3.35E+03	2.90E+02	9.48%
0.24	0.40	1.20					3.29E+03			3.29E+03	2.30E+02	7.52%
No design hole								3.75E+03		3.75E+03	0.00E+00	0.00%
0.24	0.40	1.00						3.28E+03		3.28E+03	-4.70E+02	-12.53%
0.24	0.40	1.20						3.63E+03		3.63E+03	-1.20E+02	-3.20%
No design hole									4.00E+03	4.00E+03	0.00E+00	0.00%
0.24	0.40	1.00							3.38E+03	3.38E+03	-6.20E+02	-15.50%
0.24	0.40	1.20							3.31E+03	3.31E+03	-6.90E+02	-17.25%

Table B.58 : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=4.28E+3, 15°=3.49E+3, 30°=3.09E+3, 45°=2.52E+3, 60°=3.26E+3, 75°=3.49E+3, 90°=4.28E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			4.28E+03							4.28E+03	0.00E+00	0.00%
0.24	0.40	2.00	3.74E+03							3.74E+03	-5.40E+02	-12.62%
0.24	0.40	2.20	4.59E+03							4.59E+03	3.10E+02	7.24%
0.24	0.40	1.80	3.65E+03							3.65E+03	-6.30E+02	-14.72%
0.24	0.40	1.60	3.54E+03							3.54E+03	-7.40E+02	-17.29%
0.24	0.40	1.40	3.42E+03							3.42E+03	-8.60E+02	-20.09%
0.24	0.40	1.20	3.40E+03							3.40E+03	-8.80E+02	-20.56%
0.24	0.40	1.00	3.59E+03							3.59E+03	-6.90E+02	-16.12%
No design hole				3.49E+03						3.49E+03	0.00E+00	0.00%
0.24	0.40	1.40		3.28E+03						3.28E+03	-2.10E+02	-6.02%
0.24	0.40	1.20		3.29E+03						3.29E+03	-2.00E+02	-5.73%
0.24	0.40	1.00		3.00E+03						3.00E+03	-4.90E+02	-14.04%
0.24	0.40	0.80		3.90E+03						3.90E+03	4.10E+02	11.75%
0.24	0.48	1.00		3.27E+03						3.27E+03	-2.20E+02	-6.30%
0.20	0.40	0.96		3.31E+03						3.31E+03	-1.80E+02	-5.16%
No design hole					3.09E+03					3.09E+03	0.00E+00	0.00%
0.24	0.40	1.40			2.98E+03					2.98E+03	-1.10E+02	-3.56%
0.24	0.40	1.20			3.16E+03					3.16E+03	7.00E+01	2.27%
0.24	0.40	1.00			3.20E+03					3.20E+03	1.10E+02	3.56%
0.24	0.40	1.60			3.01E+03					3.01E+03	-8.00E+01	-2.59%
0.24	0.40	1.40			3.04E+03					3.04E+03	-5.00E+01	-1.62%
0.20	0.44	1.44			3.05E+03					3.05E+03	-4.00E+01	-1.29%

Table B.58 cont : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=4.28E+3, 15°=3.49E+3, 30°=3.09E+3, 45°=2.52E+3, 60°=3.26E+3, 75°=3.49E+3, 90°=4.28E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole						2.52E+03				2.52E+03	0.00E+00	0.00%
0.24	0.40	1.40				2.83E+03				2.83E+03	3.10E+02	12.30%
0.24	0.40	1.20				2.99E+03				2.99E+03	4.70E+02	18.65%
0.24	0.40	1.00				2.85E+03				2.85E+03	3.30E+02	13.10%
0.32	0.40	1.32				2.95E+03				2.95E+03	4.30E+02	17.06%
0.24	0.40	1.32				2.81E+03				2.81E+03	2.90E+02	11.51%
0.20	0.48	1.40				3.49E+03				3.49E+03	9.70E+02	38.49%
0.20	0.40	1.32				3.36E+03				3.36E+03	8.40E+02	33.33%
No design hole							3.26E+03			3.26E+03	0.00E+00	0.00%
0.24	0.40	1.40					3.52E+03			3.52E+03	2.60E+02	7.98%
0.24	0.40	1.20					3.46E+03			3.46E+03	2.00E+02	6.13%
0.24	0.40	1.00					3.73E+03			3.73E+03	4.70E+02	14.42%
0.24	0.40	1.24					3.61E+03			3.61E+03	3.50E+02	10.74%
0.32	0.40	1.20					3.17E+03			3.17E+03	-9.00E+01	-2.76%
0.32	0.40	1.24					3.52E+03			3.52E+03	2.60E+02	7.98%
0.32	0.40	1.16					3.09E+03			3.09E+03	-1.70E+02	-5.21%
No design hole								3.49E+03		3.49E+03	0.00E+00	0.00%
0.24	0.40	1.40						3.90E+03		3.90E+03	4.10E+02	11.75%
0.24	0.40	1.20						3.74E+03		3.74E+03	2.50E+02	7.16%
0.24	0.40	1.00						3.73E+03		3.73E+03	2.40E+02	6.88%

Table B.58 cont : Four elliptical Design Hole System Material E1/E2=30.0, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=4.28E+3, 15°=3.49E+3, 30°=3.09E+3, 45°=2.52E+3, 60°=3.26E+3, 75°=3.49E+3, 90°=4.28E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	0.80						3.77E+03		3.77E+03	2.80E+02	8.02%
0.24	0.48	0.80						3.83E+03		3.83E+03	3.40E+02	9.74%
0.28	0.40	0.80						5.09E+03		5.09E+03	1.60E+03	45.85%
0.24	0.40	0.72						5.07E+03		5.07E+03	1.58E+03	45.27%
0.32	0.40	1.00						3.40E+03		3.40E+03	-9.00E+01	-2.58%
0.32	0.40	1.20						3.17E+03		3.17E+03	-3.20E+02	-9.17%
0.32	0.40	1.04						3.47E+03		3.47E+03	-2.00E+01	-0.57%
No design hole									4.28E+03	4.28E+03	0.00E+00	0.00%
0.24	0.40	1.40							3.61E+03	3.61E+03	-6.70E+02	-15.65%
0.24	0.40	1.20							3.40E+03	3.40E+03	-8.80E+02	-20.56%
0.24	0.40	1.00							3.76E+03	3.76E+03	-5.20E+02	-12.15%

Table B.59 : Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=3.49E+3, 15°=2.80+3, 30°=2.49E+3, 45°=1.97E+3, 60°=2.65E+3, 75°=3.20E+3, 90°=3.49E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.49E+03							3.49E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.31E+03							3.31E+03	-1.80E+02	-5.16%
0.24	0.40	1.40	3.33E+03							3.33E+03	-1.60E+02	-4.58%
0.24	0.40	1.00	2.83E+03							2.83E+03	-6.60E+02	-18.91%
0.24	0.40	0.80	3.35E+03							3.35E+03	-1.40E+02	-4.01%
0.24	0.40	0.96	2.81E+03							2.81E+03	-6.80E+02	-19.48%
0.24	0.40	0.92	2.92E+03							2.92E+03	-5.70E+02	-16.33%
0.20	0.40	0.96	2.88E+03							2.88E+03	-6.10E+02	-17.48%
0.24	0.48	0.96	2.93E+03							2.93E+03	-5.60E+02	-16.05%
No design hole				2.80E+03						2.80E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.34E+03						2.34E+03	-4.60E+02	-16.43%
0.24	0.40	1.20		3.08E+03						3.08E+03	2.80E+02	10.00%
0.24	0.40	1.40		2.61E+03						2.61E+03	-1.90E+02	-6.79%
0.24	0.40	1.44		2.68E+03						2.68E+03	-1.20E+02	-4.29%
0.24	0.40	0.96		2.68E+03						2.68E+03	-1.20E+02	-4.29%
0.20	0.40	1.00		2.60E+03						2.60E+03	-2.00E+02	-7.14%
0.24	0.44	1.00		2.41E+03						2.41E+03	-3.90E+02	-13.93%
0.24	0.48	1.00		2.71E+03						2.71E+03	-9.00E+01	-3.21%
No design hole					2.49E+03					2.49E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.44E+03					2.44E+03	-5.00E+01	-2.01%

Table B.59 cont... : Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=3.49E+3, 15°=2.80+3, 30°=2.49E+3, 45°=1.97E+3, 60°=2.65E+3, 75°=3.20E+3, 90°=3.49E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20			2.67E+03					2.67E+03	1.80E+02	7.23%
0.24	0.40	1.40			2.41E+03					2.41E+03	-8.00E+01	-3.21%
0.24	0.40	1.44			2.53E+03					2.53E+03	4.00E+01	1.61%
0.24	0.40	1.36			2.51E+03					2.51E+03	2.00E+01	0.80%
0.20	0.40	1.40			2.78E+03					2.78E+03	2.90E+02	11.65%
0.24	0.44	1.40			2.76E+03					2.76E+03	2.70E+02	10.84%
0.20	0.40	1.00			2.36E+03					2.36E+03	-1.30E+02	-5.22%
0.20	0.44	1.00			2.44E+03					2.44E+03	-5.00E+01	-2.01%
No design hole						1.97E+03				1.97E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.32E+03				2.32E+03	3.50E+02	17.77%
0.24	0.40	1.20				2.17E+03				2.17E+03	2.00E+02	10.15%
0.24	0.40	1.40				2.52E+03				2.52E+03	5.50E+02	27.92%
0.24	0.40	1.24				2.20E+03				2.20E+03	2.30E+02	11.68%
0.20	0.40	1.20				2.59E+03				2.59E+03	6.20E+02	31.47%
No design hole							2.65E+03			2.65E+03	0.00E+00	0.00%
No design hole								3.20E+03		3.20E+03	0.00E+00	0.00%
No design hole									3.49E+03	3.49E+03	0.00E+00	0.00%

Table B.60 : Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=3.81E+3, 15°=3.02E+3, 30°=2.89E+3, 45°=2.11E+3, 60°=2.77E+3, 75°=3.48E+3, 90°=3.81E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.81E+03							3.81E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.27E+03							3.27E+03	-5.40E+02	-14.17%
0.24	0.40	1.40	3.37E+03							3.37E+03	-4.40E+02	-11.55%
0.24	0.40	1.00	3.49E+03							3.49E+03	-3.20E+02	-8.40%
0.24	0.40	0.86	3.09E+03							3.09E+03	-7.20E+02	-18.90%
0.24	0.40	1.16/1.44	3.18E+03							3.18E+03	-6.30E+02	-16.54%
0.24	0.48	1.2/1.4	3.14E+03							3.14E+03	-6.70E+02	-17.59%
0.20	0.40	1.2/1.4	2.96E+03							2.96E+03	-8.50E+02	-22.31%
0.16	0.40	1.2/1.4	2.84E+03							2.84E+03	-9.70E+02	-25.46%
0.12	0.40	1.2/1.4	3.69E+03							3.69E+03	-1.20E+02	-3.15%
No design hole				3.02E+03						3.02E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.76E+03						2.76E+03	-2.60E+02	-8.61%
0.24	0.40	1.20		3.01E+03						3.01E+03	-1.00E+01	-0.33%
0.24	0.40	0.96		2.86E+03						2.86E+03	-1.60E+02	-5.30%
0.24	0.40	1.04		3.04E+03						3.04E+03	2.00E+01	0.66%
0.20	0.40	1.00		3.17E+03						3.17E+03	1.50E+02	4.97%
0.24	0.44	1.00		2.71E+03						2.71E+03	-3.10E+02	-10.26%
0.24	0.48	1.00		3.35E+03						3.35E+03	3.30E+02	10.93%
No design hole					2.89E+03					2.89E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.98E+03					2.98E+03	9.00E+01	3.11%

Table B.60 cont... : Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=3.81E+3, 15°=3.02E+3, 30°=2.89E+3, 45°=2.11E+3, 60°=2.77E+3, 75°=3.48E+3, 90°=3.81E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.20			2.96E+03					2.96E+03	7.00E+01	2.42%
0.24	0.40	1.40			2.77E+03					2.77E+03	-1.20E+02	-4.15%
0.24	0.40	1.60			2.80E+03					2.80E+03	-9.00E+01	-3.11%
0.24	0.40	1.48			2.85E+03					2.85E+03	-4.00E+01	-1.38%
0.24	0.40	1.44			2.82E+03					2.82E+03	-7.00E+01	-2.42%
0.24	0.40	1.36			2.86E+03					2.86E+03	-3.00E+01	-1.04%
0.20	0.40	1.40			2.73E+03					2.73E+03	-1.60E+02	-5.54%
0.16	0.40	1.40			3.16E+03					3.16E+03	2.70E+02	9.34%
0.20	0.44	1.40			2.86E+03					2.86E+03	-3.00E+01	-1.04%
No design hole						2.11E+03				2.11E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.44E+03				2.44E+03	3.30E+02	15.64%
0.24	0.40	1.20				2.57E+03				2.57E+03	4.60E+02	21.80%
0.24	0.40	0.96				2.66E+03				2.66E+03	5.50E+02	26.07%
No design hole							2.77E+03			2.77E+03	0.00E+00	0.00%
No design hole								3.48E+03		3.48E+03	0.00E+00	0.00%
No design hole									3.81E+03	3.81E+03	0.00E+00	0.00%

Table B.61 : Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=4.13E+3, 15°=3.28E+3, 30°=3.24E+3, 45°=2.25E+3, 60°=2.98E+3, 75°=3.76E+3, 90°=4.01E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			4.13E+03							4.13E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.42E+03							3.42E+03	-7.10E+02	-17.19%
0.24	0.40	1.40	3.55E+03							3.55E+03	-5.80E+02	-14.04%
0.24	0.40	1.00	3.64E+03							3.64E+03	-4.90E+02	-11.86%
0.24	0.48	1.20	3.25E+03							3.25E+03	-8.80E+02	-21.31%
0.24	0.56	1.20	3.92E+03							3.92E+03	-2.10E+02	-5.08%
0.24	0.52	1.20	3.72E+03							3.72E+03	-4.10E+02	-9.93%
0.20	0.48	1.20	3.14E+03							3.14E+03	-9.90E+02	-23.97%
0.20	0.40	1.20	2.93E+03							2.93E+03	-1.20E+03	-29.06%
0.16	0.48	1.20	3.15E+03							3.15E+03	-9.80E+02	-23.73%
0.20	0.48	1.24	3.31E+03							3.31E+03	-8.20E+02	-19.85%
No design hole				3.28E+03						3.28E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.90E+03						2.90E+03	-3.80E+02	-11.59%
0.24	0.40	1.20		3.44E+03						3.44E+03	1.60E+02	4.88%
0.24	0.40	0.96		3.19E+03						3.19E+03	-9.00E+01	-2.74%
0.24	0.40	1.04		3.18E+03						3.18E+03	-1.00E+02	-3.05%
0.20	0.40	1.00		3.63E+03						3.63E+03	3.50E+02	10.67%
0.24	0.44	1.00		3.08E+03						3.08E+03	-2.00E+02	-6.10%

Table B.61 cont...: Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=4.13E+3, 15°=3.28E+3, 30°=3.24E+3, 45°=2.25E+3, 60°=2.98E+3, 75°=3.76E+3, 90°=4.01E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole					3.24E+03					3.24E+03	0.00E+00	0.00%
0.24	0.40	1.00			3.40E+03					3.40E+03	1.60E+02	4.94%
0.24	0.40	1.20			3.37E+03					3.37E+03	1.30E+02	4.01%
0.24	0.40	1.24			3.27E+03					3.27E+03	3.00E+01	0.93%
0.24	0.40	1.28			3.40E+03					3.40E+03	1.60E+02	4.94%
0.20	0.40	1.24			3.08E+03					3.08E+03	-1.60E+02	-4.94%
0.16	0.40	1.24			3.19E+03					3.19E+03	-5.00E+01	-1.54%
0.20	0.44	1.24			3.21E+03					3.21E+03	-3.00E+01	-0.93%
0.20	0.40	1.20			3.17E+03					3.17E+03	-7.00E+01	-2.16%
No design hole						2.25E+03				2.25E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.62E+03				2.62E+03	3.70E+02	16.44%
0.24	0.40	1.20				2.78E+03				2.78E+03	5.30E+02	23.56%
0.24	0.40	0.80				4.73E+03				4.73E+03	2.48E+03	110.22%
0.24	0.40	0.96				2.89E+03				2.89E+03	6.40E+02	28.44%
0.20	0.40	1.00				2.51E+03				2.51E+03	2.60E+02	11.56%
0.16	0.44	1.00				3.04E+03				3.04E+03	7.90E+02	35.11%
No design hole							2.98E+03			2.98E+03	0.00E+00	0.00%
0.24	0.40	1.00					3.55E+03			3.55E+03	5.70E+02	19.13%
0.24	0.40	1.20					3.29E+03			3.29E+03	3.10E+02	10.40%
0.24	0.40	1.40					3.28E+03			3.28E+03	3.00E+02	10.07%

Table B.61 cont...: Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=4.13E+3, 15°=3.28E+3, 30°=3.24E+3, 45°=2.25E+3, 60°=2.98E+3, 75°=3.76E+3, 90°=4.01E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.44					3.25E+03			3.25E+03	2.70E+02	9.06%
0.24	0.40	1.48					3.23E+03			3.23E+03	2.50E+02	8.39%
0.24	0.40	1.52					3.27E+03			3.27E+03	2.90E+02	9.73%
0.24	0.40	1.52					3.27E+03			3.27E+03	2.90E+02	9.73%
0.20	0.40	1.48					3.71E+03			3.71E+03	7.30E+02	24.50%
0.24	0.44	1.48					3.40E+03			3.40E+03	4.20E+02	14.09%
0.20	0.40	1.20					3.20E+03			3.20E+03	2.20E+02	7.38%
No design hole								3.76E+03		3.76E+03	0.00E+00	0.00%
0.24	0.40	1.00						3.62E+03		3.62E+03	-1.40E+02	-3.72%
0.24	0.40	1.20						3.73E+03		3.73E+03	-3.00E+01	-0.80%
0.24	0.40	1.40						3.75E+03		3.75E+03	-1.00E+01	-0.27%
0.24	0.40	0.96						3.81E+03		3.81E+03	5.00E+01	1.33%
0.24	0.40	1.04						3.56E+03		3.56E+03	-2.00E+02	-5.32%
0.24	0.40	1.08						3.48E+03		3.48E+03	-2.80E+02	-7.45%
0.24	0.40	1.12						3.58E+03		3.58E+03	-1.80E+02	-4.79%
0.20	0.40	1.08						3.03E+03		3.03E+03	-7.30E+02	-19.41%
0.16	0.40	1.08						3.13E+03		3.13E+03	-6.30E+02	-16.76%
0.20	0.44	1.08						3.28E+03		3.28E+03	-4.80E+02	-12.77%

Table B.61 cont...: Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=4.13E+3, 15°=3.28E+3, 30°=3.24E+3, 45°=2.25E+3, 60°=2.98E+3, 75°=3.76E+3, 90°=4.01E+3													
DHS a/D	**DHS b/D**	**Dist. s/D**	**max.stress (Pa) at FD=0°**	**max.stress (Pa) at FD=15°**	**max.stress (Pa) at FD=30°**	**max.stress (Pa) at FD=45°**	**max.stress (Pa) at FD=60°**	**max.stress (Pa) at FD=75°**	**max.stress (Pa) at FD=90°**	**Min.Stress Value (Pa)**	**Stress Reduction (Pa)**	**Stress Red. Ratio**
No design hole									4.13E+03	4.13E+03	0.00E+00	0.00%
0.24	0.40	1.00							3.77E+03	3.77E+03	-3.60E+02	-8.72%
0.24	0.40	1.20							3.42E+03	3.42E+03	-7.10E+02	-17.19%
0.24	0.40	1.40							3.55E+03	3.55E+03	-5.80E+02	-14.04%
0.24	0.40	1.24							3.47E+03	3.47E+03	-6.60E+02	-15.98%
0.24	0.40	1.16							3.46E+03	3.46E+03	-6.70E+02	-16.22%
0.20	0.40	1.20							2.93E+03	2.93E+03	-1.20E+03	-29.06%
0.16	0.40	1.20							3.61E+03	3.61E+03	-5.20E+02	-12.59%
0.20	0.44	1.20							3.44E+03	3.44E+03	-6.90E+02	-16.71%
0.20	0.48	1.20							3.14E+03	3.14E+03	-9.90E+02	-23.97%

Table B.62 : Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=4.45E+3, 15°=3.67E+3, 30°=3.58E+3, 45°=2.39E+3, 60°=3.19E+3, 75°=4.03E+3, 90°=4.45E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			4.45E+03							4.45E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.51E+03							3.51E+03	-9.40E+02	-21.12%
0.24	0.40	1.60	3.62E+03							3.62E+03	-8.30E+02	-18.65%
0.24	0.40	1.00	4.05E+03							4.05E+03	-4.00E+02	-8.99%
0.24	0.40	1.40	3.60E+03							3.60E+03	-8.50E+02	-19.10%
0.24	0.48	1.40	3.66E+03							3.66E+03	-7.90E+02	-17.75%
0.20	0.40	1.20	3.04E+03							3.04E+03	-1.41E+03	-31.69%
0.20	0.48	1.20	3.04E+03							3.04E+03	-1.41E+03	-31.69%
No design hole				3.67E+03						3.67E+03	0.00E+00	0.00%
0.24	0.40	1.00		3.24E+03						3.24E+03	-4.30E+02	-11.72%
0.24	0.40	1.20		3.87E+03						3.87E+03	2.00E+02	5.45%
0.24	0.40	0.96		3.68E+03						3.68E+03	1.00E+01	0.27%
0.24	0.40	1.04		3.91E+03						3.91E+03	2.40E+02	6.54%
0.20	0.40	1.00		4.09E+03						4.09E+03	4.20E+02	11.44%
0.24	0.44	1.00		3.45E+03						3.45E+03	-2.20E+02	-5.99%
No design hole					3.58E+03					3.58E+03	0.00E+00	0.00%
0.24	0.40	1.00			3.80E+03					3.80E+03	2.20E+02	6.15%
0.24	0.40	1.20			3.79E+03					3.79E+03	2.10E+02	5.87%
0.24	0.40	1.40			3.63E+03					3.63E+03	5.00E+01	1.40%
0.24	0.40	1.48			3.63E+03					3.63E+03	5.00E+01	1.40%
0.24	0.40	1.52			3.52E+03					3.52E+03	-6.00E+01	-1.68%

Table B.62 : Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=4.45E+3, 15°=3.67E+3, 30°=3.58E+3, 45°=2.39E+3, 60°=3.19E+3, 75°=4.03E+3, 90°=4.45E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.40	1.60			3.57E+03					3.57E+03	-1.00E+01	-0.28%
0.24	0.40	1.56			3.60E+03					3.60E+03	2.00E+01	0.56%
0.20	0.40	1.52			3.49E+03					3.49E+03	-9.00E+01	-2.51%
0.16	0.40	1.52			3.57E+03					3.57E+03	-1.00E+01	-0.28%
0.20	0.44	1.52			3.50E+03					3.50E+03	-8.00E+01	-2.23%
No design hole						2.39E+03				2.39E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.49E+03				2.49E+03	1.00E+02	4.18%
0.24	0.40	1.20				2.52E+03				2.52E+03	1.30E+02	5.44%
No design hole							3.19E+03			3.19E+03	0.00E+00	0.00%
No design hole								4.03E+03		4.03E+03	0.00E+00	0.00%
No design hole									4.45E+03	4.45E+03	0.00E+00	0.00%

Table B.63 : Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=4.77E+3, 15°=4.05E+3, 30°=3.96E+3, 45°=2.53E+3, 60°=3.40E+3, 75°=4.31E+3, 90°=4.77E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			4.77E+03							4.77E+03	0.00E+00	0.00%
0.60	0.60	3.00	4.78E+03							4.78E+03	1.00E+01	0.21%
0.60	0.80	3.00	5.09E+03							5.09E+03	3.20E+02	6.71%
0.60	0.96	3.00	8.14E+03							8.14E+03	3.37E+03	70.65%
0.60	1.00	3.00	4.71E+03							4.71E+03	-6.00E+01	-1.26%
0.60	1.20	3.00	5.54E+03							5.54E+03	7.70E+02	16.14%
0.40	0.60	3.00	5.40E+03							5.40E+03	6.30E+02	13.21%
0.40	1.00	3.00	5.66E+03							5.66E+03	8.90E+02	18.66%
0.60	1.00	3.20	6.13E+03							6.13E+03	1.36E+03	28.51%
0.60	1.00	2.80	5.55E+03							5.55E+03	7.80E+02	16.35%
0.40	0.80	2.00	4.79E+03							4.79E+03	2.00E+01	0.42%
0.24	0.60	2.00	5.63E+03							5.63E+03	8.60E+02	18.03%
0.24	0.40	2.00	3.93E+03							3.93E+03	-8.40E+02	-17.61%
0.24	0.40	1.80	4.22E+03							4.22E+03	-5.50E+02	-11.53%
0.24	0.40	2.20	4.36E+03							4.36E+03	-4.10E+02	-8.60%
No design hole				4.05E+03						4.05E+03	0.00E+00	0.00%
0.24	0.40	1.00		3.68E+03						3.68E+03	-3.70E+02	-9.14%
0.24	0.40	1.20		4.31E+03						4.31E+03	2.60E+02	6.42%
0.24	0.40	0.92		3.99E+03						3.99E+03	-6.00E+01	-1.48%
0.24	0.40	1.04		4.35E+03						4.35E+03	3.00E+02	7.41%
0.24	0.40	0.96		4.18E+03						4.18E+03	1.30E+02	3.21%
0.20	0.48	1.00		4.55E+03						4.55E+03	5.00E+02	12.35%
0.24	0.44	1.00		3.82E+03						3.82E+03	-2.30E+02	-5.68%

Table B.63 cont...: Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=4.77E+3, 15°=4.05E+3, 30°=3.96E+3, 45°=2.53E+3, 60°=3.40E+3, 75°=4.31E+3, 90°=4.77E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole					3.96E+03					3.96E+03	0.00E+00	0.00%
0.24	0.40	1.00			4.09E+03					4.09E+03	1.30E+02	3.28%
0.24	0.40	1.20			4.20E+03					4.20E+03	2.40E+02	6.06%
0.24	0.40	0.96			4.25E+03					4.25E+03	2.90E+02	7.32%
0.24	0.40	1.04			4.30E+03					4.30E+03	3.40E+02	8.59%
0.24	0.40	1.16			4.30E+03					4.30E+03	3.40E+02	8.59%
0.24	0.40	1.24			4.06E+03					4.06E+03	1.00E+02	2.53%
0.24	0.44	1.00			4.23E+03					4.23E+03	2.70E+02	6.82%
0.24	0.40	1.28			4.25E+03					4.25E+03	2.90E+02	7.32%
0.20	0.40	1.24			4.02E+03					4.02E+03	6.00E+01	1.52%
0.16	0.40	1.24			3.96E+03					3.96E+03	0.00E+00	0.00%
0.12	0.40	1.24			4.01E+03					4.01E+03	5.00E+01	1.26%
0.16	0.44	1.24			4.12E+03					4.12E+03	1.60E+02	4.04%
0.16	0.36	1.24			3.99E+03					3.99E+03	3.00E+01	0.76%
No design hole						2.53E+03				2.53E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.98E+03				2.98E+03	4.50E+02	17.79%
0.24	0.40	1.00				3.43E+03				3.43E+03	9.00E+02	35.57%
0.24	0.40	1.20				3.25E+03				3.25E+03	7.20E+02	28.46%
0.24	0.40	1.40				3.00E+03				3.00E+03	4.70E+02	18.58%
0.24	0.40	1.44				2.99E+03				2.99E+03	4.60E+02	18.18%
0.24	0.40	1.48				3.33E+03				3.33E+03	8.00E+02	31.62%

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
Table B.63 cont...: Four elliptical Design Hole System Material E1/E2=45.94 Graghite Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=4.77E+3, 15°=4.05E+3, 30°=3.96E+3, 45°=2.53E+3, 60°=3.40E+3, 75°=4.31E+3, 90°=4.77E+3												
0.24	0.40	0.96				3.35E+03				3.35E+03	8.20E+02	32.41%
0.24	0.40	1.04				3.38E+03				3.38E+03	8.50E+02	33.60%
0.20	0.40	1.00				3.63E+03				3.63E+03	1.10E+03	43.48%
0.24	0.44	1.00				3.60E+03				3.60E+03	1.07E+03	42.29%
No design hole							3.40E+03			3.40E+03	0.00E+00	0.00%
No design hole								4.31E+03		4.31E+03	0.00E+00	0.00%
No design hole									4.77E+03	4.77E+03	0.00E+00	0.00%

Table B.64 : Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=3.81E+3, 15°=3.27E+3, 30°=3.12E+3, 45°=1.89E+3, 60°=2.56E+3, 75°=2.81E+3, 90°=3.81E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			3.81E+03							3.81E+03	0.00E+00	0.00%
0.24	0.40	1.00	3.86E+03							3.86E+03	5.00E+01	1.31%
0.24	0.40	0.96	3.80E+03							3.80E+03	-1.00E+01	-0.26%
0.24	0.40	1.04	3.66E+03							3.66E+03	-1.50E+02	-3.94%
0.24	0.40	0.92	3.00E+03							3.00E+03	-8.10E+02	-21.26%
No design hole				3.27E+03						3.27E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.95E+03						2.95E+03	-3.20E+02	-9.79%
0.24	0.40	1.20		3.43E+03						3.43E+03	1.60E+02	4.89%
0.24	0.40	1.40		3.35E+03						3.35E+03	8.00E+01	2.45%
0.24	0.40	0.96		3.16E+03						3.16E+03	-1.10E+02	-3.36%
0.24	0.40	1.04		3.34E+03						3.34E+03	7.00E+01	2.14%
0.20	0.40	1.00		3.06E+03						3.06E+03	-2.10E+02	-6.42%
0.24	0.44	1.00		3.08E+03						3.08E+03	-1.90E+02	-5.81%
No design hole					3.12E+03					3.12E+03	0.00E+00	0.00%
0.24	0.40	1.00			3.12E+03					3.12E+03	0.00E+00	0.00%
0.24	0.40	1.20			3.40E+03					3.40E+03	2.80E+02	8.97%
0.24	0.40	1.40			3.14E+03					3.14E+03	2.00E+01	0.64%
0.24	0.40	1.44			3.35E+03					3.35E+03	2.30E+02	7.37%
0.24	0.40	0.96			3.19E+03					3.19E+03	7.00E+01	2.24%
0.24	0.40	1.04			3.39E+03					3.39E+03	2.70E+02	8.65%
0.20	0.40	1.00			3.04E+03					3.04E+03	-8.00E+01	-2.56%

Table B.64 cont...: Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 0.0 N, Load ratio=0.0, Maximum stress without DHS at 0°=3.81E+3, 15°=3.27E+3, 30°=3.12E+3, 45°=1.89E+3, 60°=2.56E+3, 75°=2.81E+3, 90°=3.81E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.16	0.40	1.00			3.27E+03					3.27E+03	1.50E+02	4.81%
0.20	0.44	1.12			3.03E+03					3.03E+03	-9.00E+01	-2.88%
0.20	0.48	1.12			3.19E+03					3.19E+03	7.00E+01	2.24%
No design hole						1.89E+03				1.89E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.67E+03				2.67E+03	7.80E+02	41.27%
0.24	0.40	1.20				2.25E+03				2.25E+03	3.60E+02	19.05%
0.24	0.40	1.40				2.70E+03				2.70E+03	8.10E+02	42.86%
No design hole							2.56E+03			2.56E+03	0.00E+00	0.00%
0.24	0.40	1.00					2.85E+03			2.85E+03	2.90E+02	11.33%
0.24	0.40	1.20					2.40E+03			2.40E+03	-1.60E+02	-6.25%
0.24	0.40	1.40					2.84E+03			2.84E+03	2.80E+02	10.94%
No design hole								2.81E+03		2.81E+03	0.00E+00	0.00%
0.24	0.40	1.00						3.22E+03		3.22E+03	4.10E+02	14.59%
0.24	0.40	1.20						3.19E+03		3.19E+03	3.80E+02	13.52%
0.24	0.40	1.40						3.25E+03		3.25E+03	4.40E+02	15.66%
No design hole									3.81E+03	3.81E+03	0.00E+00	0.00%
0.24	0.40	1.00							2.86E+03	2.86E+03	-9.50E+02	-24.93%
0.24	0.40	1.20							3.58E+03	3.58E+03	-2.30E+02	-6.04%
0.24	0.40	1.40							3.58E+03	3.58E+03	-2.30E+02	-6.04%

Table B.65 : Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=4.17E+3, 15°=3.84E+3, 30°=3.66E+3, 45°=2.02E+3, 60°=2.77E+3, 75°=3.58E+3, 90°=4.17E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			4.17E+03							4.17E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.84E+03							3.84E+03	-3.30E+02	-7.91%
0.16	0.40	1.2/1.4	3.30E+03							3.30E+03	-8.70E+02	-20.86%
0.20	0.44	1.2/1.4	3.35E+03							3.35E+03	-8.20E+02	-19.66%
No design hole				3.84E+03						3.84E+03	0.00E+00	0.00%
0.24	0.40	1.00		3.27E+03						3.27E+03	-5.70E+02	-14.84%
0.24	0.40	1.20		4.04E+03						4.04E+03	2.00E+02	5.21%
0.24	0.40	0.96		3.66E+03						3.66E+03	-1.80E+02	-4.69%
0.20	0.40	1.00		4.24E+03						4.24E+03	4.00E+02	10.42%
0.24	0.44	1.00		3.66E+03						3.66E+03	-1.80E+02	-4.69%
No design hole					3.66E+03					3.66E+03	0.00E+00	0.00%
0.24	0.40	1.00			3.93E+03					3.93E+03	2.70E+02	7.38%
0.24	0.40	1.20			3.97E+03					3.97E+03	3.10E+02	8.47%
0.24	0.40	0.96			4.03E+03					4.03E+03	3.70E+02	10.11%
0.24	0.40	1.04			4.03E+03					4.03E+03	3.70E+02	10.11%
0.20	0.40	1.00			4.19E+03					4.19E+03	5.30E+02	14.48%
0.24	0.44	1.00			3.38E+03					3.38E+03	-2.80E+02	-7.65%
0.24	0.48	1.00			4.10E+03					4.10E+03	4.40E+02	12.02%
No design hole						2.02E+03				2.02E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.57E+03				2.57E+03	5.50E+02	27.23%
0.24	0.40	1.20				3.05E+03				3.05E+03	1.03E+03	50.99%
0.24	0.40	0.96				2.73E+03				2.73E+03	7.10E+02	35.15%

Table B.65 cont...: Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=4.17E+3, 15°=3.84E+3, 30°=3.66E+3, 45°=2.02E+3, 60°=2.77E+3, 75°=3.58E+3, 90°=4.17E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole							2.77E+03			2.77E+03	0.00E+00	0.00%
0.24	0.40	1.00					3.47E+03			3.47E+03	7.00E+02	25.27%
0.24	0.40	1.20					3.13E+03			3.13E+03	3.60E+02	13.00%
0.24	0.40	1.40					3.19E+03			3.19E+03	4.20E+02	15.16%
0.24	0.40	1.24					3.12E+03			3.12E+03	3.50E+02	12.64%
0.24	0.40	1.28					3.04E+03			3.04E+03	2.70E+02	9.75%
0.24	0.40	1.32					2.98E+03			2.98E+03	2.10E+02	7.58%
0.24	0.40	1.36					3.02E+03			3.02E+03	2.50E+02	9.03%
0.20	0.40	1.32					3.38E+03			3.38E+03	6.10E+02	22.02%
0.24	0.44	1.32					3.29E+03			3.29E+03	5.20E+02	18.77%
0.24	0.40	1.32/1.4					3.06E+03			3.06E+03	2.90E+02	10.47%
No design hole								3.58E+03		3.58E+03	0.00E+00	0.00%
0.24	0.40	1.00						3.58E+03		3.58E+03	0.00E+00	0.00%
0.24	0.40	1.20						3.68E+03		3.68E+03	1.00E+02	2.79%
0.24	0.40	1.40						3.68E+03		3.68E+03	1.00E+02	2.79%
0.24	0.40	0.96						3.76E+03		3.76E+03	1.80E+02	5.03%
0.24	0.40	1.04						3.60E+03		3.60E+03	2.00E+01	0.56%
0.24	0.40	1.00						3.58E+03		3.58E+03	0.00E+00	0.00%
0.20	0.40	1.00						3.08E+03		3.08E+03	-5.00E+02	-13.97%
0.16	0.40	1.00						3.10E+03		3.10E+03	-4.80E+02	-13.41%
0.20	0.44	1.00						3.86E+03		3.86E+03	2.80E+02	7.82%
0.20	0.48	1.00						3.36E+03		3.36E+03	-2.20E+02	-6.15%

Table B.65 cont...: Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 250 N, Load ratio=0.25, Maximum stress without DHS at 0°=4.17E+3, 15°=3.84E+3, 30°=3.66E+3, 45°=2.02E+3, 60°=2.77E+3, 75°=3.58E+3, 90°=4.17E+3													
DHS a/D	**DHS b/D**	**Dist. s/D**	**max.stress (Pa) at FD=0°**	**max.stress (Pa) at FD=15°**	**max.stress (Pa) at FD=30°**	**max.stress (Pa) at FD=45°**	**max.stress (Pa) at FD=60°**	**max.stress (Pa) at FD=75°**	**max.stress (Pa) at FD=90°**	**Min.Stress Value (Pa)**	**Stress Reduction (Pa)**	**Stress Red. Ratio**
No design hole									4.17E+03	4.17E+03	0.00E+00	0.00%
0.24	0.40	1.00							4.03E+03	4.03E+03	-1.40E+02	-3.36%
0.24	0.40	1.20							3.48E+03	3.48E+03	-6.90E+02	-16.55%
0.16	0.40	1.40							4.07E+03	4.07E+03	-1.00E+02	-2.40%
0.24	0.40	1.16							3.67E+03	3.67E+03	-5.00E+02	-11.99%
0.24	0.40	1.24							3.53E+03	3.53E+03	-6.40E+02	-15.35%
0.20	0.40	1.20							3.90E+03	3.90E+03	-2.70E+02	-6.47%
0.16	0.40	1.20							3.69E+03	3.69E+03	-4.80E+02	-11.51%
0.20	0.44	1.20							3.54E+03	3.54E+03	-6.30E+02	-15.11%

Table B.66 : Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=4.53E+3, 15°=4.41E+3, 30°=4.20E+3, 45°=2.21E+3, 60°=3.11E+3, 75°=3.85E+3, 90°=4.53E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			4.53E+03							4.53E+03	0.00E+00	0.00%
6	10	30	3.63E+03							3.63E+03	-9.00E+02	-19.87%
6	10	25	4.38E+03							4.38E+03	-1.50E+02	-3.31%
6	10	35	3.86E+03							3.86E+03	-6.70E+02	-14.79%
5	10	30	3.85E+03							3.85E+03	-6.80E+02	-15.01%
5	12	30	4.23E+03							4.23E+03	-3.00E+02	-6.62%
5	13	30	3.84E+03							3.84E+03	-6.90E+02	-15.23%
5	12	30/35	3.88E+03							3.88E+03	-6.50E+02	-14.35%
No design hole				4.41E+03						4.41E+03	0.00E+00	0.00%
6	10	25		3.73E+03						3.73E+03	-6.80E+02	-15.42%
6	10	30		4.66E+03						4.66E+03	2.50E+02	5.67%
6	10	24		4.21E+03						4.21E+03	-2.00E+02	-4.54%
5	10	25		3.95E+03						3.95E+03	-4.60E+02	-10.43%
6	11	25		4.09E+03						4.09E+03	-3.20E+02	-7.26%
No design hole					4.20E+03					4.20E+03	0.00E+00	0.00%
6	10	25			4.51E+03					4.51E+03	3.10E+02	7.38%
6	10	30			4.57E+03					4.57E+03	3.70E+02	8.81%
6	10	35			4.19E+03					4.19E+03	-1.00E+01	-0.24%
6	10	36			4.29E+03					4.29E+03	9.00E+01	2.14%
6	10	34			4.37E+03					4.37E+03	1.70E+02	4.05%
5	10	35			4.10E+03					4.10E+03	-1.00E+02	-2.38%

Table B.66 cont... : Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 500 N, Load ratio=0.5, Maximum stress without DHS at 0°=4.53E+3, 15°=4.41E+3, 30°=4.20E+3, 45°=2.21E+3, 60°=3.11E+3, 75°=3.85E+3, 90°=4.53E+3												
DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
4	10	35			4.49E+03					4.49E+03	2.90E+02	6.90%
5	11	35			4.36E+03					4.36E+03	1.60E+02	3.81%
No design hole						2.21E+03				2.21E+03	0.00E+00	0.00%
6	10	25				3.69E+03				3.69E+03	1.48E+03	66.97%
6	10	30				3.13E+03				3.13E+03	9.20E+02	41.63%
6	10	35				2.76E+03				2.76E+03	5.50E+02	24.89%
6	10	37				3.22E+03				3.22E+03	1.01E+03	45.70%
6	10	34				2.76E+03				2.76E+03	5.50E+02	24.89%
5	10	34				3.48E+03				3.48E+03	1.27E+03	57.47%
No design hole							3.11E+03			3.11E+03	0.00E+00	0.00%
No design hole								3.85E+03		3.85E+03	0.00E+00	0.00%
No design hole									4.53E+03	4.53E+03	0.00E+00	0.00%

Table B.67 : Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=4.89E+3, 15°=4.75E+3, 30°=3.47E+3, 45°=2.46E+3, 60°=3.47E+3, 75°=4.13E+3, 90°=4.89E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			4.89E+03							4.89E+03	0.00E+00	0.00%
0.24	0.40	1.20	3.88E+03							3.88E+03	-1.01E+03	-20.65%
0.24	0.40	1.40	4.05E+03							4.05E+03	-8.40E+02	-17.18%
0.24	0.40	1.00	4.73E+03							4.73E+03	-1.60E+02	-3.27%
0.20	0.40	1.20	4.34E+03							4.34E+03	-5.50E+02	-11.25%
0.16	0.40	1.20	3.95E+03							3.95E+03	-9.40E+02	-19.22%
0.20	0.48	1.20	3.55E+03							3.55E+03	-1.34E+03	-27.40%
0.20	0.52	1.20	4.47E+03							4.47E+03	-4.20E+02	-8.59%
0.20	0.48	1.24	4.48E+03							4.48E+03	-4.10E+02	-8.38%
No design hole				4.75E+03						4.75E+03	0.00E+00	0.00%
0.24	0.40	1.00		4.20E+03						4.20E+03	-5.50E+02	-11.58%
0.24	0.40	1.20		5.28E+03						5.28E+03	5.30E+02	11.16%
0.24	0.40	0.96		4.75E+03						4.75E+03	0.00E+00	0.00%
0.20	0.40	1.00		5.56E+03						5.56E+03	8.10E+02	17.05%
0.24	0.44	1.00		4.61E+03						4.61E+03	-1.40E+02	-2.95%
No design hole					3.47E+03					3.47E+03	0.00E+00	0.00%
0.24	0.40	1.00			5.10E+03					5.10E+03	1.63E+03	46.97%
0.24	0.40	1.20			5.17E+03					5.17E+03	1.70E+03	48.99%
0.24	0.40	0.96			5.16E+03					5.16E+03	1.69E+03	48.70%
0.24	0.40	1.04			5.25E+03					5.25E+03	1.78E+03	51.30%
0.20	0.40	1.00			5.48E+03					5.48E+03	2.01E+03	57.93%

Table B.67 : Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 750 N, Load ratio=0.75, Maximum stress without DHS at 0°=4.89E+3, 15°=4.75E+3, 30°=3.47E+3, 45°=2.46E+3, 60°=3.47E+3, 75°=4.13E+3, 90°=4.89E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
0.24	0.44	1.00			4.33E+03					4.33E+03	8.60E+02	24.78%
0.24	0.48	1.00			5.36E+03					5.36E+03	1.89E+03	54.47%
No design hole						2.46E+03				2.46E+03	0.00E+00	0.00%
0.24	0.40	1.00				2.92E+03				2.92E+03	4.60E+02	18.70%
0.24	0.40	1.20				3.73E+03				3.73E+03	1.27E+03	51.63%
0.24	0.40	0.96				3.25E+03				3.25E+03	7.90E+02	32.11%
No design hole							3.47E+03			3.47E+03	0.00E+00	0.00%
No design hole								4.13E+03		4.13E+03	0.00E+00	0.00%
No design hole									4.89E+03	4.89E+03	0.00E+00	0.00%

Table B.68 : Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=5.26E+3, 15°=3.14E+3, 30°=2.62E+3, 45°=2.51E+3, 60°=3.00E+3, 75°=3.46E+3, 90°=5.26E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole			5.26E+03							5.26E+03	0.00E+00	0.00%
0.20	0.60	2.00	6.43E+03							6.43E+03	1.17E+03	22.24%
0.20	0.40	2.00	5.02E+03							5.02E+03	-2.40E+02	-4.56%
0.24	0.48	2.00	6.33E+03							6.33E+03	1.07E+03	20.34%
0.24	0.40	2.00	4.44E+03							4.44E+03	-8.20E+02	-15.59%
0.24	0.40	1.80	4.60E+03							4.60E+03	-6.60E+02	-12.55%
0.24	0.40	2.20	5.80E+03							5.80E+03	5.40E+02	10.27%
No design hole				3.14E+03						3.14E+03	0.00E+00	0.00%
0.24	0.40	1.00		2.66E+03						2.66E+03	-4.80E+02	-15.29%
0.24	0.40	1.20		3.91E+03						3.91E+03	7.70E+02	24.52%
0.24	0.40	0.96		3.30E+03						3.30E+03	1.60E+02	5.10%
0.24	0.40	1.04		3.95E+03						3.95E+03	8.10E+02	25.80%
0.20	0.40	1.00		4.22E+03						4.22E+03	1.08E+03	34.39%
0.24	0.44	1.00		3.14E+03						3.14E+03	0.00E+00	0.00%
No design hole					2.62E+03					2.62E+03	0.00E+00	0.00%
0.24	0.40	1.00			2.68E+03					2.68E+03	6.00E+01	2.29%
0.24	0.40	1.20			2.77E+03					2.77E+03	1.50E+02	5.73%
0.24	0.40	1.40			2.26E+03					2.26E+03	-3.60E+02	-13.74%
0.24	0.40	1.44			2.39E+03					2.39E+03	-2.30E+02	-8.78%
0.24	0.40	1.36			2.50E+03					2.50E+03	-1.20E+02	-4.58%
0.20	0.40	1.40			2.43E+03					2.43E+03	-1.90E+02	-7.25%
0.24	0.44	1.40			2.68E+03					2.68E+03	6.00E+01	2.29%

Table B.68 : Four elliptical Design Hole System Material E1/E2=63.77 Carbon Epoxy, Fiber direction FD= 0°, 15°, 30°, 45°, 60°, 75°, 90°, Laminates stacking sequence (0-90-90-0), Tension 1000 N, Compression 1000 N, Load ratio=1.0, Maximum stress without DHS at 0°=5.26E+3, 15°=3.14E+3, 30°=2.62E+3, 45°=2.51E+3, 60°=3.00E+3, 75°=3.46E+3, 90°=5.26E+3

DHS a/D	DHS b/D	Dist. s/D	max.stress (Pa) at FD=0°	max.stress (Pa) at FD=15°	max.stress (Pa) at FD=30°	max.stress (Pa) at FD=45°	max.stress (Pa) at FD=60°	max.stress (Pa) at FD=75°	max.stress (Pa) at FD=90°	Min.Stress Value (Pa)	Stress Reduction (Pa)	Stress Red. Ratio
No design hole						2.51E+03				2.51E+03	0.00E+00	0.00%
0.24	0.40	1.00				3.10E+03				3.10E+03	5.90E+02	23.51%
0.24	0.40	1.20				3.07E+03				3.07E+03	5.60E+02	22.31%
0.24	0.40	0.96				3.55E+03				3.55E+03	1.04E+03	41.43%
0.20	0.40	1.00				3.62E+03				3.62E+03	1.11E+03	44.22%
0.24	0.44	1.00				3.85E+03				3.85E+03	1.34E+03	53.39%
No design hole							3.00E+03			3.00E+03	0.00E+00	0.00%
No design hole								3.46E+03		3.46E+03	0.00E+00	0.00%
No design hole									5.26E+03	5.26E+03	0.00E+00	0.00%

تصميم وأمثلة نظام تخفيض الإجهاد للصفائح المركبة

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ملخص

في هذا البحث, تم تقديم فتحات دفاعية ذات إشكال دائرية وبيضاوية في جوار الفتحة الدائرية الرئيسية التي تتوسط صفيحة مركبة لا نهائية الأبعاد. توضع هذه الفتحات صغيرة الحجم في المناطق ضعيفة الإجهاد بحيث تسحب الجهد العالي على حدود الفتحة الرئيسية مما يودي إلى تخفيف الجهد وانسيابه بشكل ملموس الأمر الذي يؤدى إلى تخفيض عامل تركيز الإجهاد.

إن الهدف من هذه العملية هو إن نصمم ونحصل على شكل وحجم وموقع هذه الفتحات الدفاعية المساعدة المثلى في صفيحة بحفرة ممركزة واحدة وهذا ينطبق في صناعات هياكل الطائرات والسفن البحرية وغيرها.

تمت الدراسة لتنزيل الإجهاد في الصفيحة في ثلاث اتجاهات أولها تحت حمل القص الصافي وثانيها تحت حمل مركب بين شد وكبس وثالثهما تحت حمل شد صافي كما أخذت اتجاهات الخيوط الفايبر بعين الاعتبار في الدراسة.

استخدمت طريقة العنصر المحدود لإيجاد الحلول العددية باستخدام برنامج (I-DEAS) وكانت طريقة إدخال نظام الدفاع الاهليجي قد أنجز نسبة تخفيض الإجهاد بمقدار يتراوح بين ٢٠.٥٦% و٣١.٦٩% كما تم مقارنة النتائج ببعض الدراسات السابقة مثل دراسة وكالة إدارة الفضاء الأمريكية ووجدت مطابقة تماما.

وأجريت تجارب عملية على بعض العينات بواسطة جهازين تم تصنيعهما محليا جهاز المرونة الضوئية وجهاز لشد العينات ووجدت النتائج المخبرية موافقة للنتائج النظرية.

إن نظام الدفاع الاهليجي الذي تم تقديمه يؤدي إلى عدة فوائد وميزات أهمها تخفيض عامل تركيز الإجهاد كما يخفض من وزن العنصر الميكانيكي.