Non-Linear Out of Plane Behavior of Steel Plates with Cutouts under Compressive Loads

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Abstract

In many engineering industries, especially in aircraft and ship construction, it is important to achieve higher stiffness with high strength to weight ratio. One of the commonly used structural components is stiffened steel plates. The stiffeners not only carry a portion of load but also subdivide the plate into smaller panels, thus increases considerably the critical stress at which the plate buckles. From the literature survey carried out, it is found that factors such as size of the subpanel, shape and size of stiffener and number of equally spaced stiffeners will affect the critical buckling strength of stiffened plates with longitudinal stiffeners. Cut-outs are widely used in ships and offshore structures for the purpose of access and maintenance and there will be a reduction in strength due to theses cut out. In phase-II of the project work, for the above said purpose, sandwich panel plates which are used in ship construction industry are taken for study. The plate FE models are generated, analysed and validated using software ANSYS 17.0.

Keywords: *stiffened steel plate, sandwich panel system, buckling, and cutouts.*

1. Introduction

Stiffened plates are the primary members in ship hulls, ship decks, aircraft fuselage, aircraft wing etc. High strength, light weight and durability are the important criteria in marine and aerospace structures. Stiffened composite plates with cut-out and geometric imperfections subjected to axial and lateral loading are more vulnerable to failure. Hence, the behaviour of stiffened composite plates with cut-out and geometric imperfections needs to be studied under combined axial and lateral loading. Stiffeners in a stiffened plate make it possible to sustain highly directional loads, and introduce multiple load paths which may provide protection against damage and crack growth under the compressive and tensile loads. The biggest advantage of the stiffeners is the increased bending stiffness of the structure with a minimum of additional material, which makes these structures highly desirable for loads and destabilizing compressive loads.

In this paper, stiffened plates are analysed using different materials. Also, different methods are proposed such as composite layers and sandwich panel system for restoring the lost strength of steel plate due to the presence of cut-out

2. Objectives

The main objective of the present study is to find the lost strength and stiffens of the stiffened steel plate due to presence of cutout. Analysis and study is carried out to determine methods to overcome the lost strength. This study will mainly be focused towards the nonlinear out of plane behavior of the section. . The Main objectives of the study are;

1. To Study the out of plane behavior of steel plates with various cutouts.
2. To compare the out of plane behavior of stiffened steel plates with sandwich panel system.
3. To Study the effect of various composite materials such as CFRP, GFRP BFRP…
4. To study the effect of different composite layers on plate.

3. Structural Model and Material Property

Stiffened composite plates with various cut-outs are analyzed using the software ANSYS 17.0. Here the main part of the body is composed of steel plate and GFRP stiffeners are connected to steel plate to increase its strength and stiffness. In this model the steel plate of standard size 954x954mm, having a thickness of 6.35mm is analyzed and the size of the model is kept similar to the reference model and the results are compared. In order to increase the strength four GFRP stiffeners are provided at a spacing of 270mm.In this analysis one end is kept fixed and a compressive load is provided on the opposite edge, by providing this boundary condition the maximum critical situation can be attained. In this analysis the stiffeners are connected to the steel plate by welded connection and mesh size of 10mm is provided for all the elements. Material properties are demonstrated in Table 1 and sectional drawing is shown in Fig. 1. Fig 2 shows the geometrical model of stiffened steel plate and contact between stiffeners and surface body respectively in ANSYS and Fig.3 shows the meshing and loading diagram.

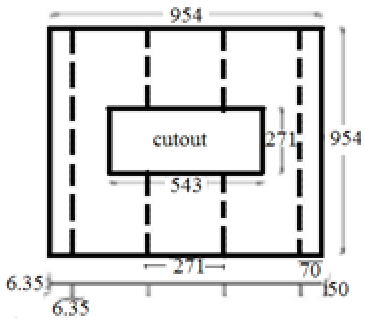

Fig.1 Sectional drawing (All dimensions are in mm)

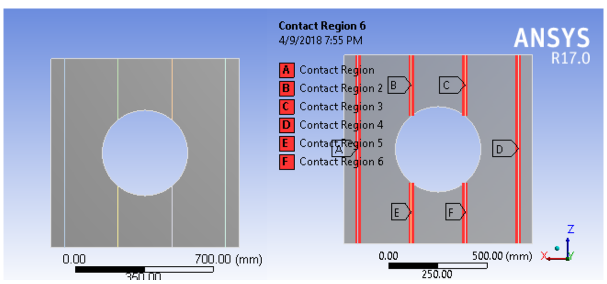

Fig.2 Geometrical modelling and contact between stiffeners and the surface body in ANSYS

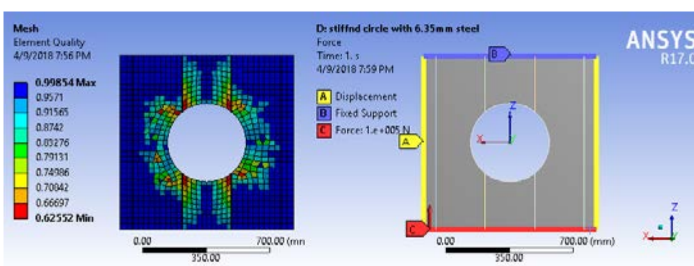

Fig.3 Meshing and loading diagram in ANSYS

Table.1 Material properties

Property	Steel	GFRP	Epoxy
Density(kg/m^3)	7850	2000	1160
Young's modulus (Pa)	2E + 11	4.5E + 10	6.134E + 10
Poisson's ratio	0.3	0.4	0.35
Tensile strength	2.5E+ 8	3.5E+ 7	3.35E+ 7

4. Results and Discussions

4.1 Study the Effect of Different Materials on Plate Sections

Today, the use of glass and carbon FRP materials for marine construction is becoming more widely accepted in practice. Most of these early applications were driven by the need to overcome corrosion problems experienced with steel or aluminum alloys or environmental degradation suffered by wood. Another reason for using composite was to reduce weight, particularly the topside weight of ships. The high acoustic transparency of composites also resulted in their use in ships and sonar domes on submarines. Various materials such as steel, GFRP, CFRP etc. are considered in the study. Ultimate load, maximum displacements and failure modes of stiffened composite plates with different material are analyzed and compared.

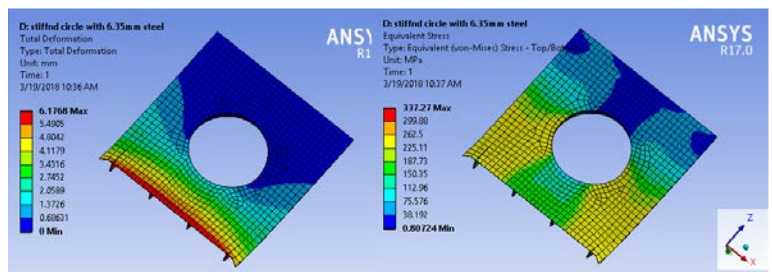

Fig.4 Deformation and stress diagram of steel plate with stiffeners

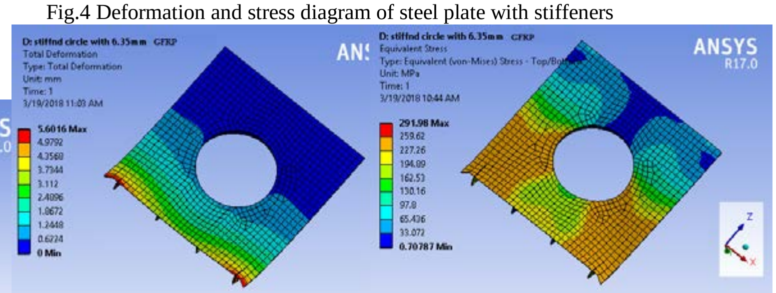

Fig.5 Deformation and stress diagram of GFRP plate with stiffeners

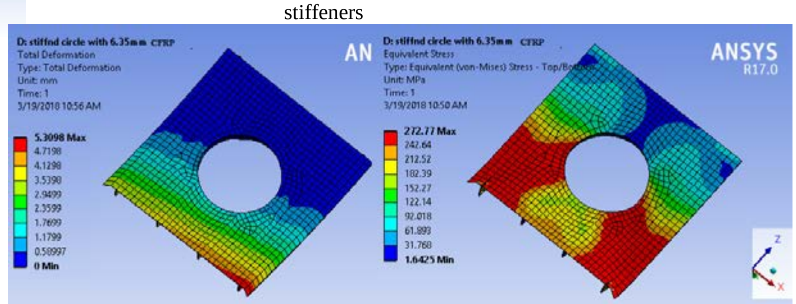

Fig.6 Deformation and stress diagram of CFRP plate with stiffeners

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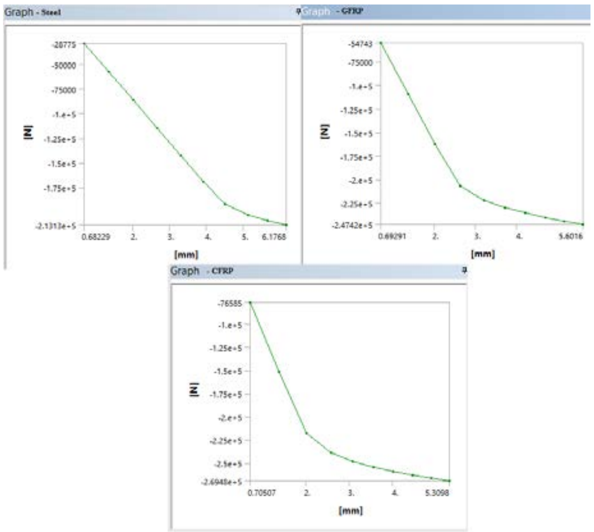

Fig.7 Load Deformation graph of steel, GFRP and CFRP sections

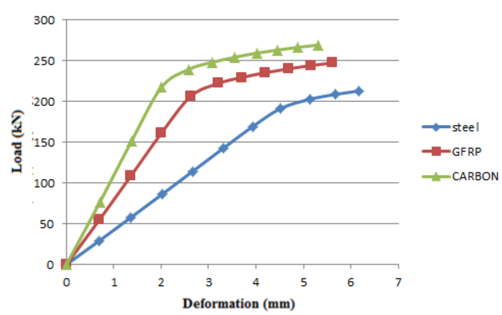

Fig.8 Comparison of Load Deformation Graph

From the analysis, we found that better result is obtained CFRP and GFRP than steel plates. From the graph the ultimate yield point for steel, GFRP, CFRP are obtained as 191.5kN, 206.48kN, 217.5kN. From this the maximum load carrying capacity is obtained for CFRP but, CFRP is not widely used because they are uneconomical. GFRP is commonly used due to its better property as compared with steel. The weight of GFRP is 75% less than steel, which is an advantage for marine and aerospace structures. GFRP has lower installation costs, less maintenance and longer product life allow for a lower lifecycle cost.

4.2 FEM Analysis of Sandwich Panel System with Cutout

Sandwich Plate System (SPS) is an alternative to conventional stiffened plate construction. Sandwich plate system is a lightweight material that consists of two metal plates separated by a core. It eliminates the need for secondary stiffeners, making the structure less complex and flush. It is roughly estimated that weight reduction possibilities of SPS over the conventional structure varies from 10 to 70%. We take the geometric model with circular cutout for the analysis. In this model we are provide steel as outer material and lighter material like resin epoxy as inner core material. The thickness of the outer core is kept as 2mm and thickness of inner core is varied to get an optimum thickness.

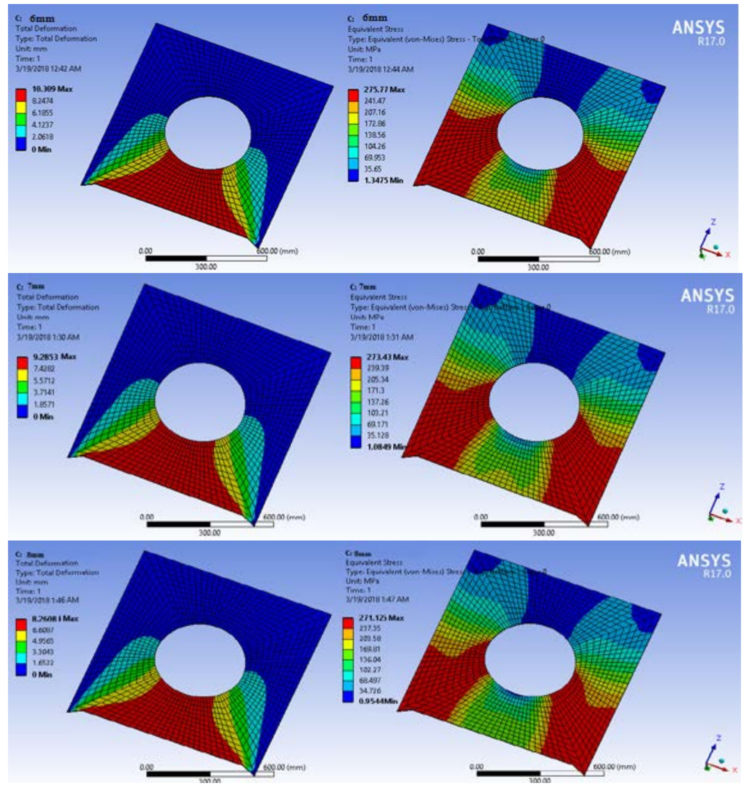

Fig.9 .Deformation and stress diagram of SPS with 6, 7mm and 8mm thick inner core

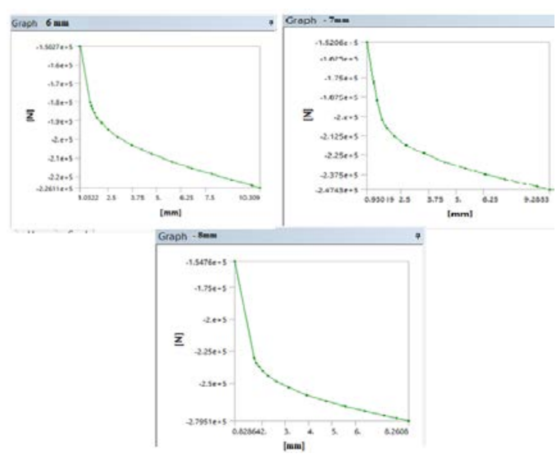

Fig.10 Load Deformation graph of SPS with various thicknesses from ANSYS software

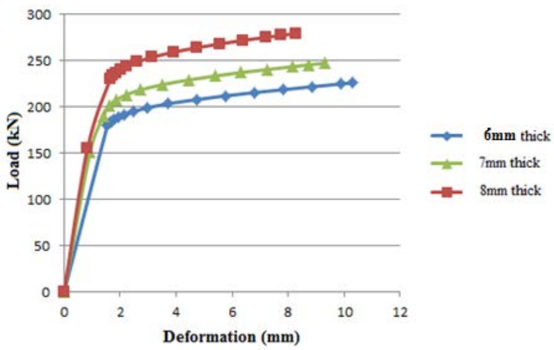

Fig.11 Comparison of Load Deformation Graph

In this analysis, the thickness of the outer core is kept constant as 2mm and thickness of the inner core is varied. From this study we can see that as the thickness of the inner core increases the load carrying capacity also increases. Also by using this SPS we can reduce the weight of the structure and the complication due to strengthening stiffeners can also be avoided. The ultimate load obtained using stiffened steel plates with and without cutout are 164kN and 192kN. From these results it is clear that by using SPS system a greater strength can be achieved as compared to steel stiffeners.

Conclusions

Stiffened steel plates with cutouts are provided in marine and aerospace structures. Due to the presence of these cutouts the strength gets reduced and here we discussed different methods in order to reduce the strength loss to a minimum value. From the study we found that by providing composite stiffeners to the steel plate a greater strength is achieved as compared to steel stiffeners. Also, from these results we found out that the sandwich plate system can be used as an alternative instead of steel plate with stiffeners. From the analysis the ultimate strength of sandwich plate system is similar to that of steel plate with stiffeners also the mass can be reduced used by using this system. Sandwich plate system eliminates the need for secondary stiffeners, making the structure less complex and flush. Considering the high strength to weight ratio, ease of construction, blast and ballistic properties of the material, availability of a flush surface etc., SPS has been widely used in building bridges, ships, stadiums, floors, blast walls etc. converting them conventional steel to sandwich plates.

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