Nonlinear Buckling Analysis of Stiffened Plate: A Review

Betty Rebecca Kuriakose[1], Jinta John[2]

[1] M. Tech Student, Dept. of Civil Engineering, St. Joseph's College of Engineering and Technology, Palai, Kerala, India

[2]Assisstant Professor, Dept. of Civil Engineering, St. Joseph's College of Engineering and Technology, Palai, Kerala, India

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Abstract - Stiffened *plates are used as load bearing components in marine structures. Stiffeners are used in order to attain the economical design of plate instead of increasing the thickness of plate. They are used to avoid the usage of thick plates which produces high weight for the structures. The stiffeners are usually used in hull of a ship, deck of offshore platforms, in all main bridge beams etc. The factors which affect the behavior of stiffened plates are the geometry of plate, stiffener slenderness and its spacing and yield stress of material. The behavior of stiffened plates are also being affected by factors like initial deformation, residual stress, boundary conditions and type of loading. The failure modes of plates include plate buckling, tripping of the stiffener and Euler buckling. The stiffeners enhance the rigidity of the base structures by increasing the moment of inertia. A parametric study on ultimate strength of stiffened composite plate has not been conducted in the reviews read.*

Key Words: Stiffened plate; stiffeners; buckling; tripping; residual stress.

1.INTRODUCTION

Stiffeners are defined as the secondary plates or sections which are usually attached to web of beam or flange of beam, and they are used to stiffen the beam against the out of plane deformations. In many of the engineering structures, the stiffened plate is used as the major structural component. Stiffened plate is usually used in many engineering branches like aerospace engineering, automotive engineering, shipbuilding etc. They are used as main component in wings, truck boxes, bottom plate of ship etc. These structures are usually subjected to in-plane biaxial and shear loading. Stiffeners are economical and they have enough strength and therefore it helps to improve the strength / weight ratio and it also decreases the cost of structure. The stiffeners are positioned in such a way that it prevents the global buckling mode. The buckling strength analysis of stiffened plate subjected to in-plane loading is an important aspect in structural design and analysis. Stiffened plates are usually economical, efficient and aesthetic. The dead load can be minimized in a stiffened plate and the strength performance can be improved under various loading conditions. The stiffened members have good load carrying capacity with a small additional weight penalty. The smeared or discrete stiffener approaches can be used for the analysis of stiffened plate. The smeared approach can be used for larger stiffeners and widely spaced stiffeners. The discrete approach is used for sparsely spaced stiffeners of any size.

2. TYPES OF STIFFENED PLATE

The stiffened plate can be of two types: regular stiffened and arbitrarily stiffened. The regular stiffened plate is subjected to uniaxial stress and arbitrarily stiffened plate is subjected to the biaxial stress.

2.1 REGULAR STIFFENED PLATE

Liu and Wang [9] stated that a uniaxial stress refers to a stress which acts in one direction only. When a specimen is subjected to uniaxial loading, the force acts over the cross-sectional area and it generates a tensile stress and strain within the material. Whereas the biaxial stress refers to a two-dimensional state of stress and there only two normal stresses are present. A regular stiffened plate has its stiffeners on vertical or horizontal position. While in the case of the arbitrarily stiffened, the stiffeners are placed in inclined position. The arbitrarily stiffened plate provides a better buckling performance when compared to the regular stiffened plate as it resists the biaxial loadings. Therefore, the analytical analysis of arbitrarily stiffened plate is more complicated when compared to the regular stiffened plate.

Soares & Gordo [3] conducted several numerical studies and experiments for the performance of stiffened panels under the uniaxial compressive loadings. Throughout the design process, the probability of tripping of stiffener was also considered. They concluded that plate strength calculations must be done properly because it creates a huge impact on the strength of column. The results shows that there is a possibility of overall column type of failure. This failure usually occurs in uniaxially stiffened panels.

2.2 ARBITRARILY STIFFENED PLATE

When arbitrarily stiffened plate is compared to the regular stiffened plate, the arbitrarily stiffened plate provides better buckling performance. It provides better buckling performance by resisting the biaxial loadings. The regular stiffened plate is less complicated compared to the arbitrarily stiffened plate when the analytical analysis is done. The arbitrarily stiffened plate has stiffeners which are kept in inclined position.

3. BUCKLING OF STIFFENED PLATES

Grondin et.al [4] studied the stability of a stiffened plate having tee- shaped stiffeners using the finite element method model. Using finite strain four node shell element, the four series of stiffened plate panels were modelled. The model was validated using the full-sized stiffened plate specimens and they were used for studying various other parameters. The parameters considered are the shape of initial imperfections in the plate, the magnitude of the initial imperfections in the plate, the magnitude of residual stress and the direction of applied uniform bending. There are different failure modes of stiffened plate. They are plate buckling, tripping of the stiffener and Euler buckling. Plate buckling is the sort of buckling which happens when there is buckling of individual parts or plate elements, without the overall buckling of the member. A plate which is buckled in shear, can carry additional or extra shear because of the tensile field action. The figure1 below shows the plate buckling of a stiffened plate. Stiffener tripping is a form of lateral torsional buckling. Here, torsion takes place about the stiffener to the junction of plate. Studies show that the tripping of stiffener is more critical compared to the plate buckling or the overall buckling failure. It depends upon the torsional stiffness of the stiffener. The figure 2 below shows the tripping of the stiffener. Euler buckling is used to determine the critical buckling load of column as the stress in the column remains elastic. Euler buckling load is the compressive axial force which is required to form the lateral instability of a column, which is vertical and weightless. Euler's theory is based on the assumption which are related to point of axial load application, material of column, cross-section, limits of stress, and failure of column. This theory does not consider the effect of direct stress in the column. Figure 3 below shows the Euler buckling of a stiffened plate.

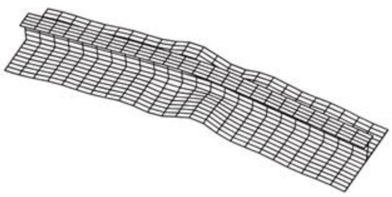

Fig -1: Plate Buckling

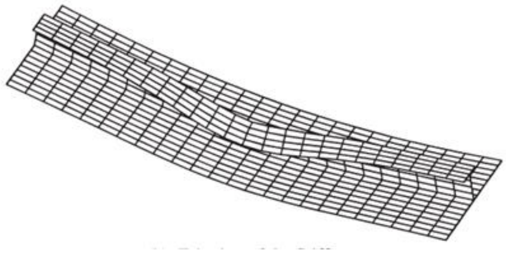

Fig -2: Tripping of Stiffener

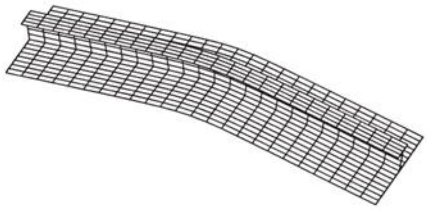

Fig -3: Euler Buckling

Ozdemir et.al [14] studied the buckling analysis of stiffened plate having curvilinear surface by using a mesh free model. They also analyzed a twisted T-shaped structure with both the web and flange as curvilinear geometry. The obtained results were compared with linear and quadratic shell elements using finite element method. The loads and critical buckling modes were obtained by using fully converged and present method.

Kumar et.al [13] conducted different analysis to study about the length to thickness ratio, aspect ratio and the effect of fiber orientation. It was found out that the buckling load increases by increasing the number of stiffeners on the stiffened plate. It was also found that T-shaped stiffened plate helps to sustain the maximum buckling load. A finite element method was conducted to find out the buckling load for the three types of composite material like the graphite, CFC and Kevlar.

4. STATIC AND DYNAMIC ANALYSIS OF STIFFENED COMPOSITE PLATE

Jiaqi et.al [21] stated that the isogrid stiffened composite plate (ISCP) is used to resist the bending and buckling loads. The bending and buckling loads of ISCP are greater when it is compared to the orthogonal stiffened composite plate and honeycomb stiffened composite plate. It was concluded that ISCP has higher bending stiffness, better mechanical properties and stronger buckling resistance compared to the orthogrid stiffened composite plate (OSCP) and honeycomb stiffened composite plate (HSCP).

Srinivasan and Thiruvenkatachari [1] stated that in their analysis, the plate was clamped on all edges. To find out the solution, integral equation technique was adopted. The integral equation technique was used to find out the solution when the plate is subjected to a uniform distributed lateral load, and also it was used for the free vibration. The integral equation technique can also be used for eccentrically stiffened skew plates. In the case of static analysis, the deflection and stresses found at the center are found out. Also, the stresses formed at the edges were also found out in this analysis. A stiffener with circumferential direction which is spaced at 1% and also in radial direction at 6° was used to do the convergence study of static analysis. The results were obtained by increasing the mesh size.

Tavakoli and Kiakojouri [11] examined the dynamic response of a steel stiffened plate which is subjected to uniform blast loading. The aim of this paper was to find out the effect to stiffener configurations. Parameters like mesh dependency, strain rate and boundary conditions were considered for this study. It was concluded placing stiffeners closer to the center gives good results compared to the stiffeners kept at even spacing under the blast loading.

Mitra et.al [8] studied about the free-vibration analysis of a stiffened plate having a large amplitude which was subjected to uniformly distributed load. The analysis was carried out for the three types of stiffened plates which were uniaxially single stiffened, uniaxially double stiffened and biaxially cross stiffened and they were subjected to uniformly distributed load. This classification was done based on the number and orientation of stiffeners.

Liu et.al [16] stated that the stiffened panels which buckle under the compressive loads will degrade the load bearing capacity of the structure. This paper deals with the mechanics of structure genome (MSG) of the stiffened composite panel. Here, the original geometrically nonlinear problem is being mathematically reduced to linear modelling of the structure. Studies show that MSG is highly accurate and efficient compared to the finite element analysis. The buckling behavior of stiffened panel under the different loading and boundary conditions were investigated in this paper.

Jeya Pratha and Santhanakrishnan [17] studied the comparative analysis of integrated stiffened panel and flat plate. The Glass Fiber Reinforced Polymer stiffened panel using the I stiffener, T stiffener and blade stiffener were fabricated by using hand layup method. Aluminum mold was used for the fabrication. Three panels for each stiffener were fabricated and twelve panels were tested for compressive strength using the computerized universal testing machine and the results obtained were compared for the best stiffener configuration. Since the critical load was higher, the plate with stiffener gives better buckling performance. So it was concluded that the I stiffened composite panel has more compressive strength compared to T and blade stiffened composite panel.

5. STATIC AND DYNAMIC ANALYSIS OF STIFFENED LAMINATED PLATES

Guo et.al [5] studied the buckling analysis of stiffened laminated plate by developing a layer wise or zigzag finite element formulation. Here, the laminated plate is divided or discretized into layers along the direction of the thickness. Each layer of the laminated plate is modelled by degenerating the shell elements and the stiffener is modelled by 3D beam elements. Advantage of this model is that it can be applicable to thin and thick laminated plates. Some assumptions were made while doing the finite element formulation that is deformation formed in each layer follow the mindlin hypothesis. It was assumed that stiffeners are of rectangular cross section and also the warping of the cross section is not considered. Here, the stiffeners are modelled as a laminated plate.

Kolli and Chandrashekhara [2] stated that in order to do the formulation, the von Karman kinematic relations of the plate and the stiffener were considered for the large deformations. The formulation may be affected by the transverse shear deformation as it affects the plate and the stiffener. This model can be used for the analysis of both the thin stiffened laminated plate and thick stiffened laminated plate. The finite element model consists of a plate which is nine-nodded isoparametric quadrilateral elements. The stiffener is represented by three nodded isoparametric beam elements. Here, the effect of stiffeners on depth, number and location of stiffeners were examined. The nonlinear behavior of an eccentrically stiffened laminated composite plate is considered here. Also, the transverse shear flexibility is being incorporated in the both beam and plate displacement fields.

6. COMPRESSIVE STRENGTH OF STIFFENED PANELS

A.Aruljothi [20] found that factors like size and shape of stiffener, size of the subpanel, number of equi-spaced stiffeners affects the critical buckling strength of stiffened plates with longitudinal stiffeners. So in this paper, buckling strength of stiffened plate under uniform edge compression was considered. Here, FENON-linear buckling analysis was used to find out the buckling strength of stiffened plate. It was concluded that as the plate thickness increases, the buckling strength increases. Also, it was found that if the stiffener thickness increases, the buckling strength will also increase.

Gunay et.al [10] studied the analysis of thin rectangular steel plates with stiffeners which were subjected to compressive loading. By performing finite element buckling analysis, stiffened and unstiffened thin steel plates under the compression were analyzed. Semi-analytical and computational results were compared using the graphs obtained. It was found that as the stiffeners were added one by one, the value of critical buckling stress increases. Also, the stiffeners were arranged in such way that they localize both the normal and shear stresses. Steel plates were analyzed under different loading conditions.

Ozdemir et.al [15] proposed a new method to find out the ultimate strength of stiffened plate using the collapse mechanism of stiffened panel. This method is based on the Elastic Large Deflection Analysis (ELDA). The ultimate strength is found out by examining the yield at several critical points. Then the results were calculated by comparing the results with the nonlinear FEA.

Amaral et.al [19] proposed a new computational method for modelling the structural behavior of stiffened plates with symmetrical boundary conditions. They used two-dimensional finite element to decrease the computational time without losing the accuracy. Their aim was to decrease the stresses and strains by geometrical changes. The results shows that it is possible to find a proper geometrical transformation from the reference plate to stiffeners, which allows important improvements in the mechanical behavior.

Alsos and Amdahl [7] dealt with the study of the damage of hull in ships which is subjected to the grounding actions. Here, the ship is assumed to vertically settle on a rock. The aim of this paper was to study the mechanism of structural failure in a ship which was subjected to stranding. It was assumed that stiffeners which were subjected to severe in-plane bending fails in the top of flange because of over straining. It was concluded that if the stiffness of the panel increases, then the ductility of the structure decreases.

Piculin et.al [18] conducted the experiments on curved plate having different geometry and steel grade. The aim of this paper was to analyze the behavior of curved panel and their longitudinal and transverse stiffeners which were subjected to compression. In this paper, axial compression tests of curved stiffened plate were studied. Axial compressive force, strains and displacements were measured during the tests. Test results shows that failure was associated to the combination of buckling and yielding of material.

Ghavamia and Khedmati [6] stated that their aim of the paper was to find out the axil compression load of a stiffened plate. They studied the analysis by modelling the plate and stiffeners by using the SHELL 43 element. The SHELL 43 element is also called the plastic large strain element and they fall under the group of four-nodded quadrilateral elements.

Shi et.al [12] studied the collapse mechanism and ultimate strength of a crack damaged stiffened plate by conducting a test on stiffened plate having an initial crack. Stiffened plates with cracks were subjected to in-plane compression, until they gain their ultimate strength. In order to find out the influence of the crack on the ultimate strength, length, angle between the crack and position of crack were changed accordingly. It was found that crack damage decreases the ultimate strength. The initial deformations also cause the ultimate strength to get reduced.

7. CONCLUSION

Stiffened plates are used for attaining economical design of plate. It is dependent upon several factors like geometry of plate, slenderness of stiffener, initial deformation, loadings etc. It was concluded that in order to increase the buckling strength, we need to increase the thickness of plate. The arbitrarily stiffened plate provides better buckling performance when it is compared to regular stiffened plate. Then buckling load can be increased by increasing the number of stiffeners. Stiffeners are usually used in hull of ship, deck, submarines etc.

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