CHAPTER - 1

INTRODUCTION

1.1 INTRODUCTION

Man took a leaf out of the book of nature to apprise himself of the potentiality of stiffened structures. One comes across a wide variety of these natural stiffened structures in day to day life - leaves, sea shells, mushrooms, vegetables, fishes are some of the glaring examples. In the past the development of the stiffened structural form was slow due to man's limited knowledge and limited availability of known materials. Innovation and introduction of structural materials like steel, reinforced concrete, aluminium alloys and composites have brought about a revolution in structural design. It is only in the last century that a new era of stiffened structures has been started by engineers and technologists through continuous research and a zeal for exploiting the properties of these materials to their fullest extent. New materials alone are not responsible for the advancement in structural designs. Continuous efforts by engineers and researchers have paved the way for the development of new stiffened structural forms and their design procedures.

Since the beginning of the nineteenth century, stiffened structural elements have found wide applications in engineering. These stiffened plate elements through their light weights provide an efficient and effective means to cater to the requirements of the designs. Their response to the applied external forces and bending strength make them ideally suited for application in various engineering structures. Typical examples where thin plates strengthened by means of stiffeners in the form of longitudinals and beams or frames are ocean structures - ships, offshore drilling and production platforms and other similar structures. Much of the knowledge of stiffened plates has advanced with the development of bridge engineering. Various types of bridge configurations, viz. bridge slabs, box girders and cellular structures having straight, skew or horizontally curved plan forms, have posed great challenges to designers and analysts. Apart from bridges, civil engineers have also been confronted with the problem of designing composite concrete-steel beams which find wide application in floor construction. Aeronautical engineers have been moving in parallel with other engineers in contributing to the knowledge of the structural mechanics associated with stiffened plates. The development of light weight metal construction for aircraft followed the discovery that a structure built of two sets of mutually perpendicular beams covered with a thin metal sheet could safely carry loads even if the skin buckled. Further, there are various other structures where stiffened plates have found wide applications.

Looking into the stiffened plate structural problems of to-day, one can say that there are two basic types of plate structures - (i) a plate stiffened by 'open' stiffeners or 'closed' stiffeners on one side or both sides of the plate, (ii) two skin plates (unstiffened or stiffened as in (i) above) separated by webs. Depending on the requirements and the design, the plan form of the plate may be square, rectangular, skewed, horizontally curved, polygon or of any other arbitrary shape. The stiffeners can occupy positions which are parallel to the edges or inclined in an arbitrary manner to the edges. All the stiffeners may have an identical cross-section or the geometrical properties may vary from stiffener to stiffener. The stiffeners may be placed at equal spacings or they may have unequal spacings between them. In the case of a double plate structure, commonly known as cellular structure, the spacing between the two skin plates can be uniform or tapering or can have any other type of variation. Stiffened plate panels are used in the various components of the hull of a ship (namely - deck, bulkhead, side shell, bottom shell etc.), as well as in bridge decks, lock gates, helidecks, floors of buildings etc. The cellular type of structure is used in bridge, aircraft wing, dockgates, as well as in the double bottom, a wing tank or a rudder of a ship and so on. Depending on the use, a stiffened plate panel has a set of boundary and support conditions and can be subjected to a wide variety of external applied loads. Such structures pose difficulties for structural analysis owing to their complicated structural arrangements. No exact analytical procedure is available, but various approximate methods for analysis can be used. A significant amount of analytical and experimental investigations have been conducted on the problem.

Various approaches have been suggested for the analysis of stiffened plate problems. Amongst the different idealisations proposed are the orthotropic plate concept and the plated grillage concept for ships structures. In the orthotropic plate model the stiffened plate is replaced by a bare plate having orthotropic plate properties. In the grillage analysis the plate is considered as the flange of the beams. In many actual engineering structures the ribs are placed only on one side of the plate. This makes the stiffened plate problem even more difficult and it becomes necessary to include the eccentricity of the stiffener in the formulation of the differential equations for the plate-beam system.

The advent of the computer has changed the outlook in many fields of engineering, and shipbuilding is no exception. The impact of the computer can be seen clearly in the field of structural engineering. Ocean structural engineers are becoming more dependant on computational methods of structural analysis using various numerical methods to solve structural problems which were not attempted earlier owing to the tremendous computational labour involved. For the analysis of complex structures such as stiffened plates, various numerical techniques have been applied for obtaining the solution. The more important methods which have been applied for the solution of stiffened plates are the finite difference method, the dynamic relaxation method, the finite strip method and the finite element method. These methods along with their advantages and disadvantages have been discussed in detail in the next chapter.

Following the advent of the high speed computer, the finite element method has proved to be undoubtedly the most versatile of these approaches. The existing applications of the finite element method to stiffened plate problems have certain disadvantages, such as - correct representation of the stiffener in the plate element, correct evaluation of the beam and the plate stresses, fitting in of irregular boundaries of the plate, consideration of the transverse shear deformations of the plate and the stiffener in the formulation and orientation of the stiffener in the plate. The work described in this thesis is an attempt to overcome these limitations.

1.2 OBJECT AND SCOPE OF THE WORK

The main purpose of the present work is to obtain solutions of stiffened plate structures in bending by an efficient and accurate finite element method which is readily applicable to a wide variety of ocean/marine plated structures such as bulkheads, decks, shell plating, double bottoms, wing tanks, helidecks, dock-gates, ramps and other engineering structures. Isoparametric quadratic stiffened plate bending elements with three degrees freedom per node and five degrees of freedom per node have been developed here to achieve this purpose. The main feature of the elements is that the formulation is based in a general manner without disturbing the position or the properties of the stiffeners. Even a stiffener having arbitrary orientation within an element remains undisturbed in the formulation. A similar approach was made earlier in the case of the stiffened plate plane stress problem (Mukhopadhyay, 1981). Further, as the formulation is based on the isoparametric quadratic element, irregular boundaries of the structure as also the transverse shear deformations of the plate and the stiffeners can be very conveniently taken care of.

The method is more theoretically accurate than any of the finite element approaches made so far. A comparison is made between the present method and the lumped model to study the extent of inaccuracy inherent in the latter approach. A new scheme for obtaining stiffener stresses for the lumped model is also proposed. Application has been made to a helideck on the basis of the element developed. At the inclined boundaries of the octagonal helideck, the elements are triangular. With the help of the isoparametric characteristics of the element by collapsing a couple of nodes, rectangular elements have been transformed into the triangular boundary elements.

A variety of problems such as rectangular stiffened plates, composite bridges, box girders, cellular bridges, curved stiffened bridges, skew stiffened plates, dock gates and helidecks are analysed by this method. Loadings considered are point load, uniformly distributed load, patch load and hydrostatic load, depending on the problem. Different support conditions for different problems are considered. Results obtained by the proposed method are compared with those in published literature. Also the results obtained by conducting model experiments with models made from perspex have been analysed by the proposed finite element approach.

In order to obtain the solution of the problems, two computer programs have been developed in FORTRAN-IV. One program is based on the element with three degrees of freedom per node whereas the other program is based on the element with five degrees of freedom per node. The salient features of the programs are listed below :

i) Automatic mesh generation

ii) Element stiffness matrix generation

iii) Assembly of overall stiffness matrix in half-band width

iv) Element loading matrix generation by assigning any type of load including patch loading

v) Generation of overall loading matrix

vi) Fitting in the boundary conditions of the structure

vii) Calculation of the nodal displacements

viii) Calculation of plate stress resultants

ix) Calculation of stiffener stress resultants.

The input data required for the analysis are as follows :

a) Linear plate dimensions together with the intensity of loading

b) Mesh division details, number of stiffeners in either direction, type of loading and mode of integration

c) Boundary conditions of the plate

d) Material properties of the plate and the stiffeners

e) Stiffener positions and geometrical properties.

The program was developed and run on a B6700 computer of the Regional Computer Centre, Calcutta.

1.3 NOMENCLATURE

a	plate dimension in longitudinal direction
A_s	cross-sectional area of the stiffener
b	plate dimension in transverse direction
$[B]$	strain matrix
$[B]_r$	strain matrix associated with the rth node
$[D]$	rigidity matrix
$[\bar{D}]$	modified rigidity matrix
$[D_s]$	rigidity matrix for the stiffener/cross-web
$[\bar{D}_s]$	modified rigidity matrix for the stiffener/ cross-web
E	Young's modulus
$\{f\}$	displacement field vector
G	modulus of rigidity

h	distance between the two skin plates
$[H]$	matrix connecting strain and modified strain vectors for the plate
$[H_s]$	matrix connecting strain and modified strain vectors for the stiffener/cross-web
$[I]$	identity matrix
I_x	second moment of the stiffener area about the reference plane of the structure along x-axis
I_y	second moment of the stiffener area about the reference plane of the structure along y-axis
$\|J\|$	polar moment of inertia of the stiffener
$[J]$	Jacobian matrix
$\|J\|$	Jacobian determinant
$[K]_e$	element stiffness matrix
$M_x, M_y, M_{xy}, N_x, N_y, N_{xy}$	stress - resultants
$[N]$	matrix of shape functions
$[N]_r$	matrix of shape functions of the rth node
q	uniform load intensity per unit area
Q_x, Q_y	shear forces
r	arbitrary node number
$\{R\}$	vector of reactions
s	subscript to denote stiffener/cross-web
S_i	shear area of the stiffener/cross-web
S_x, S_y	shear rigidities

t	plate thickness
T	transpose
$[T]$	transformation matrix
u, v	displacements in the plane of the plate
U, V, W	displacements of any point in the co-ordinate directions
w	lateral deflection of the plate
x, y, z	co-ordinates
x'	x co-ordinate of the centroid of the stiffener cross-section from web mid-line
y'	y co-ordinate of the centroid of the stiffener cross-section from web mid-line
α	inclination of stiffener to x-axis
δ	variational operator
$\{\delta\}$	vector of nodal displacements
$\{\delta\}_r$	vector of nodal displacements at the rth node
$\{\epsilon\}$	strain vector
$\{\bar{\epsilon}\}$	modified strain vector
$\{\sigma\}$	stress vector
$\{\bar{\sigma}\}$	stress-resultant vector
θ_x, θ_y	rotations of the middle surface normals
ϕ_x, ϕ_y	shear rotations of the middle surface normals
ξ, η	non-dimensional element coordinates
ν	Poisson's ratio