Finite Element Analysis of Ship Structures

J Ramanujam, *Member*
C G Nandakumar, *Member*

This paper presents the finite element modelling and analysis of ship structures. Various loading in the ship hull such as still water loads and wave induced loads are briefly explained. Static and dynamic analysis of ship structures are investigated.

Keywords : Ship structures; Finite element analysis; Finite element

INTRODUCTION

Finite element analysis is universally recognised as the most important technological breakthrough in the field of engineering analysis of structures. The development of computer has caused the finite element method to become one of the most popular techniques for solving engineering problems. For analysing a complicated structure like a ship hull, the finite element method is the only tool which is giving satisfactory results. This paper abounds with descriptions of applications in this field.

Hull structures of ships consist of a steel framework surrounded by steel plating. A hull module is a three-dimensional framework of beams and stiffened panels. In a hull module, most of the lateral loads act initially on the plating. Then, through the action of plate bending, the plating transmits the load to the nearby major beams, the transverse frame and longitudinal girders. Conventional structural analysis for longitudinal strength can be done by Moment Distribution Method or Clapyron's Three-Moment Theorem. However these methods never account for non-prismatic nature of beam idealisation of ship. With regard to its overall transverse dimensions, a hull module is usually non- prismatic. Non-prismatic modelling can be efficiently done by finite element method. The transverse frames also can be analysed by Moment Distribution or by strain energy method.

STRUCTURAL MODELLING

Finite Element Modelling

Only in recent years some attempt has been made to analyse the complete vessels as a three-dimensional model. Traditionally, ship structural design criteria are based on long experiences as set forth in the rules of ship classification societies. The last thirty five years have seen many departures from conventional ship design with respect to ship size and types. For example, oil tankers have increased in size from a typical 30,000 tonnes to well over 300,000 tonnes. The period saw the birth of container ships and the great increase in size of the bulk carriers. Since little or no experience has been accumulated for these vessels more rational methods of analysis have to be employed. The finite element method has been appearing as a powerful tool for the analysis of various types of structures. Parallel to developments in available elements, programs and numerical methods, improvements in computer hardware have all contributed in the advancement of this technique. The tool has been used in last two decades to analyse ship in its totality. As expected, investigations carried out on this gigantic problem of 3D analysis of ship structures are not many. In the analysis of ship, it is convenient to take advantage of the symmetry about the centre line or plane. The boundary conditions should be taken properly while considering the symmetry.

J Ramanujam is with the Department of Civil Engineering, M A College of Engineering, Kothamangalam 686 666 and C G Nandakumar is with the Department of Ship Technology, Cochin University of Science and Technology, Cochin 682 022.

This paper was presented at the Fourteenth National Convention of Marine Engineers held at Cochin during February 9-10, 2001.

The finite element method requires that the actual continuous ship structure be replaced by a mathematical model made up of discrete structural elements of known elastic and geometric properties. The objective is to develop a model which simulates the elastic behaviour of the continuous structure as closely as required. The original structure is approximated by an assemblage of a finite number of approximately shaped elements interconnected at a finite number of points, called nodal points or nodes. The basic unknowns of this model are the values of the displacement components at these nodal points. The loading on the structure is approximated by concentrated forces acting at the nodal points and in the direction of nodal displacement parameters.

Beam Finite Element Modelling

The hull module can be idealised as a simple beam under vertically applied loads. Usually engineer's beam theory is used to analyse the structure and the translational and rotational degree of freedom are incorporated in the element. Conventional beam finite element with 6 dof per node, viz, 3 translations and 3 rotations can be used for this purpose. Structural behaviour of hull girder will be conceived as a continuous beam with intermediate supports at transverse frames. Static analysis to determine deflections, bending moments and stresses as well as dynamic analysis to determine the natural frequencies, mode shapes and stresses can be performed using this model.

Torsional analysis can be performed in a similar beam model which has the additional features to account for warping. Warping will be incorporated as an additional seventh degree of freedom and hyperbolic shape functions may be used to represent the components of displacement field associated with torsion and warping.

Three-dimensional Modelling

The hull module is essentially a 3D thin-walled box girder made up of stiffened panels and the module analysis consists of the calculation of the principal responses of it.

Local Analysis of Ship Structures

Sometimes it becomes necessary to perform the stress or deflection evaluation of selected structural components at local level, viz, bulkheads, decks, etc. In such situations, 2D membrane or plate elements are used to model plating together with beam elements to model stiffener.

If the local structure is modelled as an unstiffened membrane, the plating can be modelled using 2D finite elements, viz, constant stress traingle, linear strain triangle, constant shear rectangle, isoparametric quadrilateral family elements, triangular and rectangular plate bending elements, etc. Total analysis of ship hull happens to be the analysis of stiffened plate. Since the hull module is an assemblage of stiffened panels, it can be modelled by lumping of stiffener, orthotropic plate method, or stiffener as beam element.

LOADS

Still Water Loads

When a ship is at sea, it is subjected to forces which cause the structure to distort and the correct assessment of the magnitude of the forces is difficult. The forces may be divided into static forces and dynamic forces. Still water forces are static in nature, by considering ship to be floating in equilibrium. Still water load curve is obtained as the algebraic sum of weight curve and buoyancy curve.

Wave-induced Loads

Wave induced loads are usually classified as slowly varying loads which consist of the dynamic pressure distribution on the hull due to the combination of wave encounter and the resulting ship motion, sloshing of liquid cargo, shipping of green seas on deck, wave slap on sides and on foredecks, inertia loads, launching and berthing loads, ice breaking loads, etc.

The other classification, viz, rapidly varying loads consist of slamming, forced vibration, pressure pulses from the propeller, etc. These loads are on many occasions non-linear. Hence, for accurate structural analysis, random seastate should be considered and a spectral finite element analysis has to be carried out.

ANALYSIS

Depending upon the situation, static or dynamic, free and forced vibration analysis of ship structures have to be performed. Estimation of ultimate strength and fatigue life also happens to be essential.

Static Analysis

Structural modelling is the first step in the analysis of a structure. As explained earlier, a hull module can be modelled as a beam or 3D structure. For local level analysis, different structural components like decks, bulkheads, etc, can be modelled by using 2D membrane or plate element.

Super element technique can be effectively used for modelling ship structures which has repetitive structural components. The super element may be a combination of bar, beam, triangle and quadrilateral elements. Nodes that are wholly within the super element and are not required for attaching it to the rest of the structure may be deleted by static condensation. If such super elements occur repeatedly, this deletion provides a saving in computation.

After structural modelling the element characteristics like stiffness matrix [k] and nodal load vector [p] are calculated for each element. These [k] and [p] are transformed to global level by multiplying with transformation matrix. These element characteristics are assembled to get the stiffness matrix and load vector for the structure in the global system. The boundary conditions are introduced and the system equilibrium equation is solved by using any standard solved to get the displacements in the global axes. Once the nodal displacement parameters have been determined, the internal stress components are calculated from element equilibrium equation.

Dynamic Analysis

Free Vibration

The free vibration characteristics and corresponding mode shapes of ship structures can be investigated by modelling it as a beam. The free vibration equation is given below.

$$([K] - w^2 [M])\{\phi\} = 0 \tag{1}$$

where w^2 are the eigen values, $[K]$ and $[M]$ are global mass and stiffness matrices of the total structural system respectively, $[\phi]$ are the eigen vectors.

There are various algorithms available for the solution of eigen value problem. Out of these Householders method, Subspace iteration and Laconz's method are more popular.

Forced Vibration

At the various substructure levels vibration may be set up by the main or auxilary engines, by fluctuating hull pressure due to propellers or other sources of excitation. The dynwnic equilibrium equation for multiple degree of freedom is

$$[M]\,[\ddot{X}] + [C]\,[\dot{X}] + [K]\,[X] = \{P\,(t)\} \tag{2}$$

Where $[C]$ is the damping matrix and $P\,(t)$ is the loading vector. The equation can be solved by iterative procedure.

Ultimate Strength

The collapse of a ship structure is an extremely complex process and in the past there has been no method available that could provide a complete and accurate analysis of such a structure. Finite element method is efficiently used for this purpose nowadays. The ultimate strength analysis of selected substructures like the decks, sides of a ship or the double bottom can be performed by modelling them as a plate elements. Separate analysis of buckling and plastic hinge failure are performed. In the buckling analysis it is assumed that the collapse is purely by bifurcation buckling. This assumption converts the equili-brium equations in to an eigen value probleia for which a solution can be obtained.

In recent years the finite element method has been generalised and used for nonlinear problems involving both types of nonlinearity-geometric and material. this has been achieved by introducing incremental iteration, *ie*, by using a load- deflection approach involving successive increments of load and by performing several linear finite element analyses at each load level. Nonlinear finite element analysis can be performed for individual members or by considering hull module as a beam. Nonlinear finite element analysis is the only method that can give truly rigorous and accurate estimate of the ultimate strength of a large structure.

SOFTWARE PACKAGES FOR SHIP STRUCTURAL ANALYSIS

Several software packages are now-a-days available. NISA is a general purpose finite element package for ship structural analysis. Different types of analysis like static, dynamic and nonlinear analysis can be done by this package.

Finite element modelling using DISPLAYIII consists of two steps viz, geometric and finite element modelling. The preprocessing phase consists of mesh generation, material definition, constraint definition, load definition and model displays. In the solution phase the element matrices, displacements and stresses are calculated. In the post processing phase stress contours and displacements are displayed. A ship structure can be modelled using a 3D shell element (NKTP 20) which includes membrane, bending and shear deformation effects. The element has 6 degree of freedom per node. The stiffeners can be modelled as a 3D beam element (NKTP 12). Linear static analysis is performed to predict the response of the structure under prescribed boundary conditions and time independent applied loads.

CONCLUSION

The power of FEM resides principally in its versatility. The main advantages of FEM is that physical problems which are so far intractable and complex for any closed form solution can be analysed. It can take care of any type of boundary, material anisotrophy and any type of loading. Another attractive feature of FEM is the close physical resemblance between the actual structure and its finite element model.

For engineers interested in using software packages in analysing ship structures it is necessary to know the basics of FEM and the asswnptions on which the development is made in finite element applications this knowledge can make the difference between the good answer and bad disaster.

REFERENCES

1. J S Wu and C Sen. 'Analysis of Wave Induced Horizontal and Torsion Coupled Vibration of a Ship Hull.' *Journal of Ship Research*, vol 31, no 4, December 1987, pp 235-252.

2. J K Park, A K Thayambillil and Y E I Park. 'Local Buckling of Stiffeners in Ship Plating.' *Journal of Ship Research*, vol 42, March 1998, pp 56-67.

3. M A Daye and T G Tordis. 'Elasto Plastic Algorithms for Plates and Shell under Static and Dynamic Loads.' *Computers and Structures*, vol 39, no 12, 1991, pp 195-205.

4. C S Smith *et al*. 'Strength of Stiffened Plating under Combined Compression and Lateral Pressure.' *RINA*, 1991, pp 131-142.

5. O K Bedair and M S Troitsky. 'A Study of the Fundamental Frequency Characteristics of Eccentricity and Concentrically Simply Supported Stiffened Plates.' no 11, pp 1257-1272.

6. W Jiang *et al*. 'Finite Element Modelling of Stiffened and Unstiffened Orthotropic Plates.' *Computers and Structures*, vol 63, no 1, 1997, pp 105-117.

7. C J Chen, W Liu and S M Chern. 'Vibration Analysis of Stiffened Plates.' *Computers and Structures*, vol 50, no 4, 1994, pp 471-480.

8. A F Saleeb and T Y Chang. 'An Efficient Quadrilateral Element for Plate Bending Analysis.' *International Journal for Num Methods in Engg*, vol 24, 1987, pp 1125-1155.

9. M Mukopadhyay. 'Stiffened Plates in Bending.' *Computers and Structures*, vol 50, no 4, 1994, pp 541-548.

10. T S Koko and M D Olson. 'Nonlinear Analysis of Stiffened Plates using Super Elements.' *International Journal for Num Methods in Engg*, vol 31, 1991, pp 319-343.

11. O C Zienkiewics. 'The Finite Element Method in Engg Science.' *McGraw Hill*, New York, 1973.

12. R D Cook. 'Concepts and Applications of Finite Element Analysis.' *John Wiley and Sons, Inc*, Third Edition, 1989.

13. K J Bathe and E L Wilson. 'Numerical Methods in Finite Element Analysis.' *Prentice Hall Inc*, 1996.

14. B Irons and S A Ahamed. 'Techniques of Finite Elements.' *Eilis Horwood Ltd*, 1980.

15. O F Hughes. 'Ship Structural Design.' *John Wiley & Sons*, New York, 1983.

16. W Muckle. 'Strength of Ship's Structures.' *Edward Arnold Ltd*, London, 1967.