DYNAMIC DESIGN ANALYSIS METHOD (DDAM) USING MSC/NASTRAN

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ABSTRACT

Components on naval ships are currently analyzed for shock loads due to hostile attacks using the Dynamic Design Analysis Method (DDAM). DDAM estimates the dynamic response of a component to a beam excitation resulting from the motion of the ship's hull.

This paper gives a brief description of the history and use of DDAM, presents an overview of the mathematics, and demonstrates the use of DDAM in designing a typical submarine component.

The demonstration problem uses MSC/NASTRAN for the dynamic analysis and modal summations, and shows how DDAM can be performed using MSC/NASTRAN Solution 103.

The opinions herein are that of the authors' and do not necessarily represent the opinion of Newport News Shipbuilding.

Introduction

Background

Machinery and equipment for shipboard use must be designed to operate successfully under severe conditions of shock. Equipment and its foundations must be built to withstand shock due to attacks by bombs, torpedoes, and mines. The source of shock to the equipment is the sudden, transient motion of the ship's structure caused by the sudden application of external forces to a portion of the ship's hull.

Shock produced by underwater explosions is one of the most severe design cases for a combatant ship. Shock damage can be produced by a large variety of weapons when detonated at a considerable miss distance from the ship's hull.

History

Over a period of more than 50 years, the United States Navy has developed a shock hardening program to assure that a ship or it's equipment have the capability of surviving shock loads produced by near misses in a combat environment.

The attention of the Navy was focused on the problem by experiences during the early part of World War II. Large German mines exploding not in contact with the hull, caused the disablement of ship machinery due to the shock effect.

Until the 1950s, shipboard items were designed for shock using the static "g" method. The engineers designed for the static loads equal to N times the item weight. The Naval Research Laboratory, in an effort to promote more realistic shock design, developed the Dynamic Design Analysis Method (DDAM).

DDAM Overview

Early investigations of the response of land structures to earthquakes led to the development of shock spectrum analysis. This is defined as the maximum response of each of a series of simple mechanical systems having different frequencies. The spectrum is usually expressed as the maximum acceleration plotted as a function of natural frequency.

There is an interaction between the equipment being shock loaded and its structure. This change in spectrum is often referred to as the spectrum-dip effect. This same phenomenon occurs in earthquake engineering. Free-field ground motion will have a higher spectrum, in general, than a location with a very heavy structure (referred to as soil-structure interaction analysis).

In the analyses of shipboard equipment the spectrum-dip has a pronounced effect on the shock spectrum that individual items experience. The design spectra curves used in the DDAM method vary for mounting location and orientation. The spectrum is also greatly reduced to account for the weight of the equipment.

To develop design shock spectrum curves for surface ships and submarines, the Navy has conducted many shock tests and analyzed the results at the base of equipment structures. The culmination of these tests was DDAM.

In summary, DDAM modifies the input shock spectra to account for mounting location and orientation and also the spectrum-dip phenomenon.

DDAM Procedure

The first step in the DDAM procedure is to calculate the free vibration frequencies and mode shapes for the structure. This requires solving the free vibration eigenvalue problem:

$$[K]\{\Phi\}-\omega^2[M]\{\Phi\}=0$$

Where;

$[K]=stiffness$
$\{\Phi\}=mode\ shape$
$[M]=mass$
$\omega=natural\ frequency$

For a system with n mass degrees of freedom, there will be n free vibration mode shapes. For multiple degree of freedom systems, the eigenvalue problem can be solved by rewriting the equation in the form:

$$[K]-\omega^2[M]\{\Phi\}=0$$

Since a zero mode shape is not a solution, this requires that the determinate of the left portion of the equation be zero. MSC/NASTRAN solution 103 can be used to determine the eigenvalues and eigenvectors for multi-degree of freedom models.

Once the mode shapes and frequencies have been determined, the modal mass and the participation factors can be computed.

$$M_a^x = \frac{\Sigma_i M_i X_{ia}^2}{\Sigma_i M_i (X_{ia}^2 + Y_{ia}^2 + Z_{ia}^2)}$$

$$P_a^x = \frac{\Sigma_i M_i X_{ia}}{\Sigma_i M_i (X_{ia}^2 + Y_{ia}^2 + Z_{ia}^2)}$$

The modal masses and participation factors are similarly calculated for the y and z direction where M_a and P_a are the modal mass and participation factors for the x, y, and z direction.

Once the mass and frequency are known for each mode, the shock spectrum acceleration can be calculated, accounting for the spectrum-dip effect, mounting location, and orientation. At Newport News Shipbuilding, the modal mass, participation factor, and spectrum calculation have been incorporated into solution 103 using DMAP alters and external programs.

The shock response for each mode is computed as follows:

$$\Gamma_{ia} = \S_{ia} P_a \frac{A_a}{\bar{\omega}_a^2}$$

Where;

$\bar{\omega}_a$ = *Natural frequency for a* th *mode*

P_a = *Participation factor*

A_a = *Shock spectrum acceleration*

$\S_{ia}$ = i^{th} *response for a* th *mode*

Γ_{ia} = *Scaled response (stress, force, displacement)*

The scaled model responses are summed using the Navy Research Lab summation. The NRL summation is a statistical estimate of the maximum response created by taking the response for the mode that exhibits the largest response and adding the root-sum-square (RSS) response of other modes. The assumption is that the peak modal responses are not in phase:

$$\Gamma_{iNRL} = | \Gamma_{iMAX} | + \sqrt{\Gamma^2_{iRSS} - \Gamma^2_{iMAX}}$$

Where:

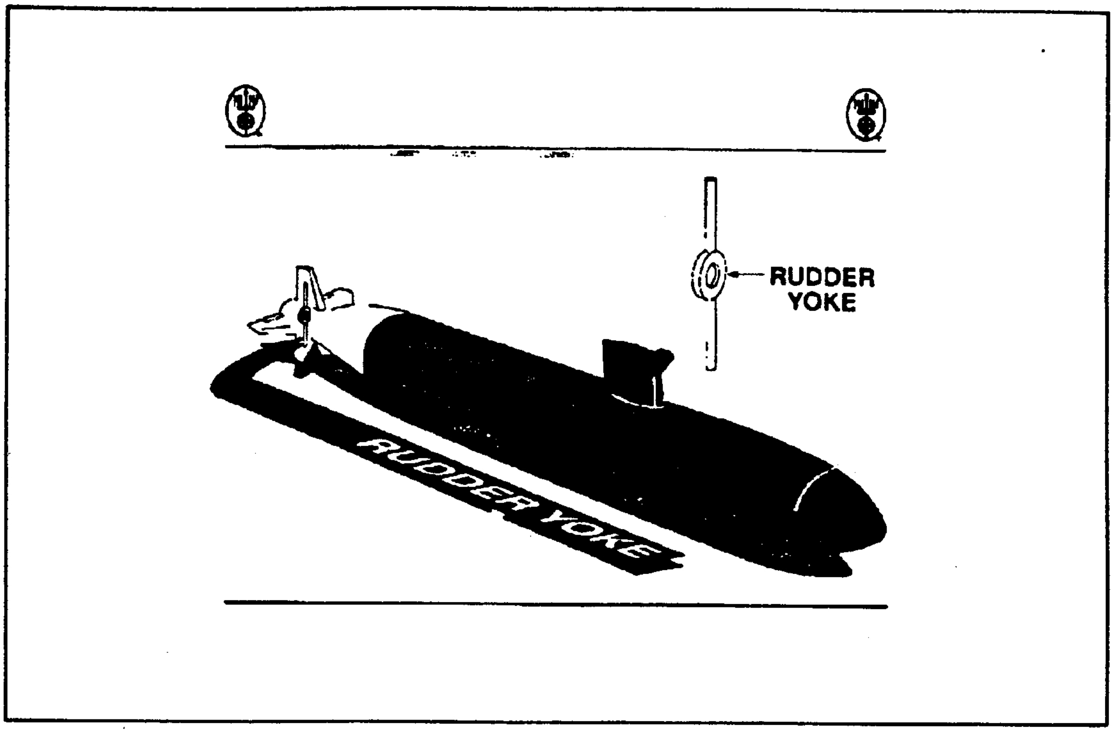
$$\Gamma_{iRSS} = \sqrt{\Sigma_a \Gamma_{ia}^2}$$
$$\Gamma_{iMAX} = \text{Maximum of } \Gamma_{ia}$$
$$\Gamma_{ia} = i^{th} \text{ scaled shock response } a^{th} \text{ mode}$$

Note that in the above equations the calculated response could be displacement, stress, force, or any other response of interest.

At Newport News Shipbuilding MSC/NASTRAN and in-house programming support the DDAM procedure. MSC/NASTRAN is used to calculate the mode shapes, model masses, and through alters the participation factors. In-house programs, which are passed the participation factors, calculated the shock spectra and write table input cards for a MSC/NASTRAN response spectra analysis.

Example

The rudder yoke of the SSN688 submarine was analyzed for shock loading.

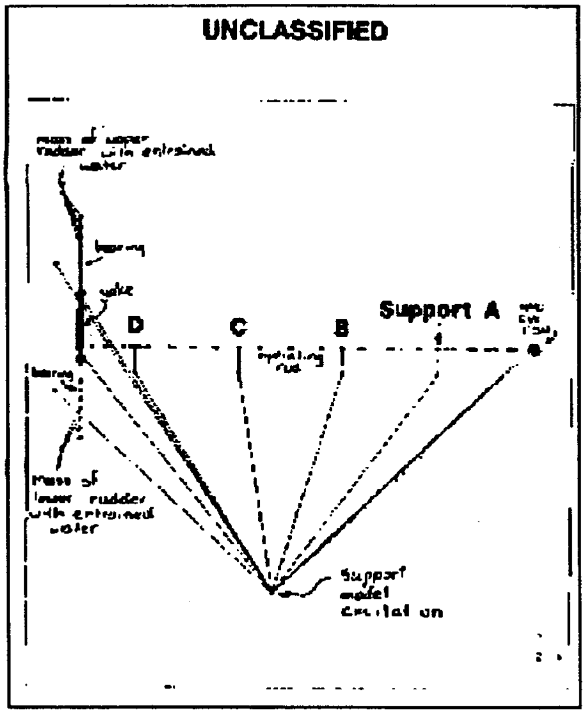


The mechanical operating system originates with a hydraulic cylinder mounted on top of the aft trim tank which moves an operating rod aligned approximately parallel to the ship centerline. Vertical and athwartship support of the operating rod is provided by the hydraulic cylinder body, a bearing mounted in the aft elliptical bulkhead, delrin bearings at the transverse bulkheads, and a guide cylinder. This guide cylinder also controls a sliding piston which connects the operating rod to the connecting rod. Axial displacement of the connecting rod forces the yoke tiller arm and yoke to rotate about the stocks' centerline resulting in rotation of the stocks and rudders, thus controlling the course of the ship.

The ships specifications impose three restrictions on the dynamic analysis mode selection, they are as follows:

(1) The number of modes considered shall be not less than half of the number of degrees of freedom for the given direction of input motion.
(2) All modes contributing a modal mass in excess of 10 percent of the total weight of the system analyzed shall be included in the selection.
(3) The total modal weight considered will be not less than 80 percent of the total system weight.

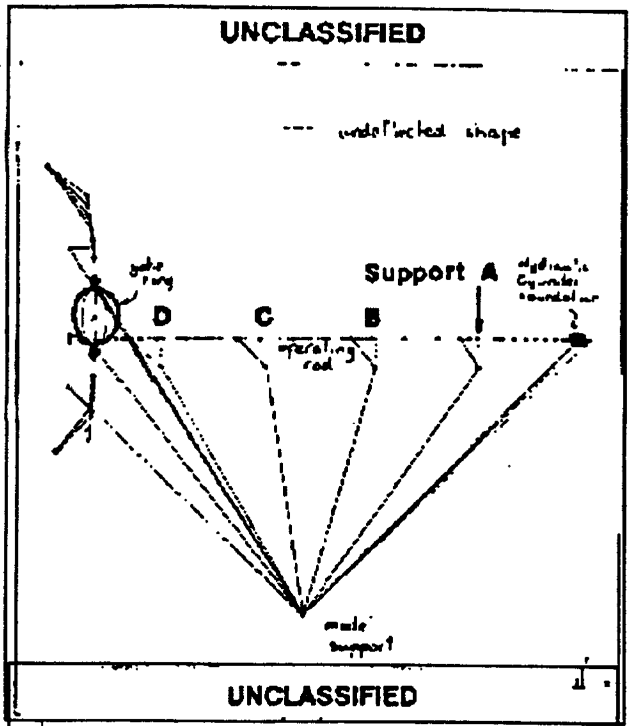
MSC/NASTRAN and I-DEAS V4.0 (SDRC) were used to perform a dynamic analysis of the 201 beam and 21 mass system.

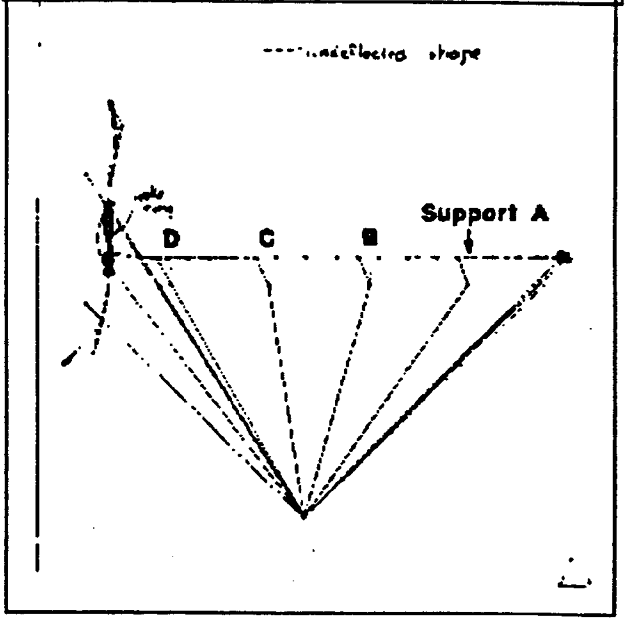


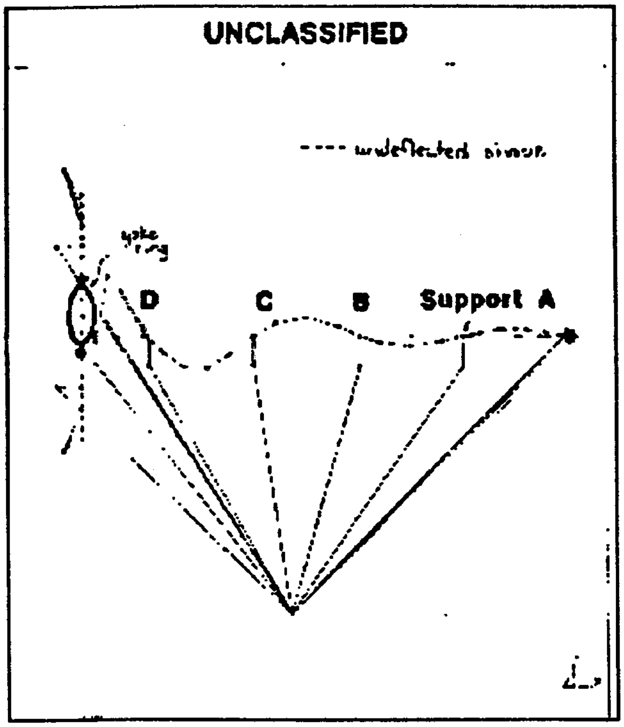
Three independent shock load cases were applied as follows:
(1) Vertical (Y - direction)
(2) Athwartship (Z - direction)
(3) Fore and Aft (X - direction)

Results

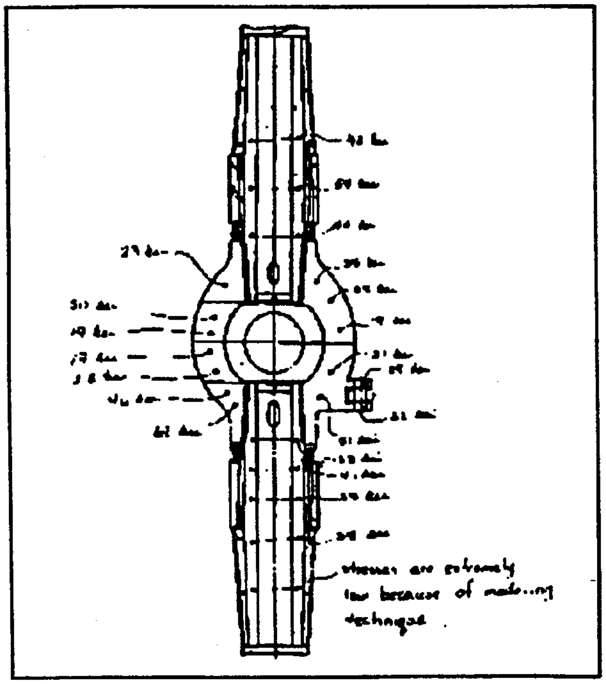
Twenty-Eight different displaced shapes were produced from the Eigen Value extraction.







The athwartship loading direction produced the maximum stresses.



Conclusion

All of the materials were found to be in an acceptable allowable range for stress criteria. The stresses that were recovered from the beams were maximum combined axial and bending at the outer fibers. The design of the rudder yoke is technically acceptable.

Bibliography

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(b) R. O. Belsheim and G. J. O'Hara, "Shock Design of Shipboard Equipment", Naval Ship Systems Command, Dept. of the Navy, Washington D.C., Report № 250-423-30, May 1961.

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