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# ON IMPROVING AND EXTENDING THE DESIGN SHOCK SPECTRA USED IN DDAM

by

Frank L. DiMaggio and David Ranlet

OFFICE OF NAVAL RESEARCH

CONTRACT NO. N00014-72-C-0119

TECHNICAL NOTE

September 1976

This project is sponsored by the joint DNA/ONR/NAVSEA program in
"Advanced Submarine Shock Survivability in Underwater Nuclear Attack."

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# ABSTRACT

A method is presented which may be used to improve and extend the design shock spectra used in the Dynamic Design Analysis Method (DDAM).

## I INTRODUCTION

The Dynamic Design Analysis Method (DDAM), introduced by Belsheim and O'Hara of the Naval Research Laboratory, Ref. [1], requires design shock spectra as inputs. To date, these values have been obtained from a limited number of test results and their applicability is limited to very heavy internal components. It is the purpose of this note to indicate how this limitation can be relaxed and how the presently used spectra can be improved.

## II SUMMARY OF NORMAL MODE THEORY ON WHICH DDAM IS BASED

This section is a summary of the presentation of O'Hara and Cunniff, Ref. [2], with some changes in notation. Generalization to more than one-dimensional motion is straightforward, as demonstrated, e.g., by Cunniff and O'Hara, Ref. [3].

Consider a one-dimensional, n degree of freedom system, S, like the 2 degree of freedom system shown in Fig. 1, subjected to a base acceleration $\ddot{z}$. In what follows, the generic displacement of the i-th mass $M_i$ will be denoted by $x_i(t)$. The subscript j, like i, will refer to a mass point.

Let $\omega_a$ , $a = 1, 2, \ldots n$, denote the a-th fixed-base natural frequency of S, and let $c_{ia}$ denote the displacements of the masses $M_i$ in the a-th principal mode, as shown in Fig. 2. The relative displacement of $M_i$ with respect to the base, denoted by

$$y_i = x_i - z \tag{1}$$

may then be expressed as

$$y_i = \sum_a y_{ia} = \sum_a q_a c_{ia} \tag{2}$$

in which the $q_a$ are generalized coordinates.

For zero initial conditions,

$$q_a = - \frac{\sum_i M_i c_{ia}}{\sum_i M_i c_{ia}^2} \frac{V_a}{\omega_a^2} \tag{3}$$

in which

$$V_a(t) = \omega_a \int_0^t \ddot{z}(\tau) \sin \omega_a(t - \tau)d\tau \tag{4}$$

The generalized accelerations are

$$\ddot{q}_a = \frac{\sum_i M_i c_{ia}}{\sum_i M_i c_{ia}^2} (V_a - \ddot{z}) \tag{5}$$

The contribution to the displacement $x_i$ from the a-th mode then becomes

$$x_{ia} = \frac{c_{ia} \sum_j M_j c_{ja}}{\sum_j M_j c_{ja}^2} (z - \frac{V_a}{\omega_a^2}) \tag{6}$$

and

$$\ddot{x}_{ia} = \frac{c_{ia} \sum_j M_j c_{ja}}{\sum_j M_j c_{ja}^2} V_a \tag{7}$$

The contribution to the base reaction from the a-th mode may be obtained by considering the contribution to the motion of S of the a-th mode. If inertia is replaced by equivalent (d'Alembert) body forces, the equilibrium free body diagram of Fig. 3 permits the determination of the contribution of the a-th mode to the reaction on the base of S as

$$R_a = \sum_i M_i \ddot{x}_{ia} = \frac{[\sum_i M_i c_{ia}]^2}{\sum_i M_i c_{ia}^2} V_a \tag{8}$$

Letting

$$\frac{[\sum_i M_i c_{ia}]^2}{\sum_i M_i c_{ia}^2} \equiv M_a \tag{9}$$

denote the a-th effective modal mass, the base reaction becomes

$$R_a = M_a V_a \tag{10}$$

$M_a$ is the mass of a simple oscillator, of frequency $\omega_a$, producing the same base reaction, $R_a$, as that contributed by the a-th mode. It can be shown that

$$\sum_a M_a = \sum_i M_i \tag{11}$$

## III APPLICATION TO DDAM

The total base reaction on S can be obtained by adding the modal contributions of Eq. (10), i.e.,

$$R = \sum_a R_a = \sum_a M_a V_a \tag{12}$$

if the base motion z(t) is known and the structure S modeled such that frequencies $\omega_a$ and modal masses $M_a$ can be determined*)

DDAM provides an approximation to Eq. (12), motivated by the impossibility, at the time of its formulation, of obtaining reliable analytical or experimental values for the base motion z(t) of shells, containing internal structures, to shock loading. The best that could be done was to specify, on the basis of a limited number of tests, the maximum value of $|V_a|$ as a function of modal frequency $\omega_a$ . The plot of $|V_a|_{max}$ as a function of $\omega_a$ is referred to as a design shock spectrum. An illustrative example is shown in Fig. 4.

Using such a spectrum, a conservative design value for the base reaction of Eq. (12) may be obtained as

$$R \simeq \sum_a M_a \, |V_a|_{max} \tag{13}$$

or more refined statistical measures, e.g., root mean square values, could be used.

The limited test results available allowed design shock spectra to be constructed only for very heavy internal components.

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*) Similar series expressions for the total displacements, relative displacements and spring forces may be readily written.

## IV IMPROVING AND EXTENDING THE RANGE OF APPLICABILITY OF DDAM

In a series of reports, Refs. [4]-[6], Weidlinger Associates has proposed an analytical method, programmed for high-speed digital computers, which produces, as a part of its output, the function $z(t)$ for shock loading of finite-length shell structures with internal components. This method of analysis has been used to make excellent predictions of tests on submerged shells containing internal structure conducted in Chesapeake Bay by UERD, Ref. [7]. This program has been continued, and there is every indication that much more complex structures subjected to shock loading will soon be capable of successful analysis.

The analytical method developed by Weidlinger Associates can be used to develop improved design shock spectra, by calculating maximum values of $|V_a|$ using Eq. (4). It is suggested that results first be obtained for those combinations of input and structure for which DDAM is now considered applicable, as check points, and then to fill in the range where DDAM is presently not used.

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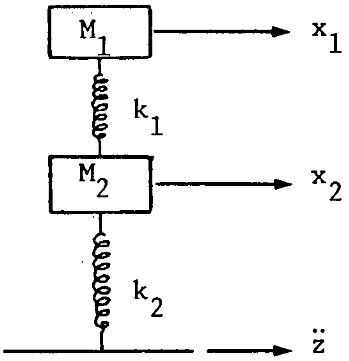


Fig. 1

System S

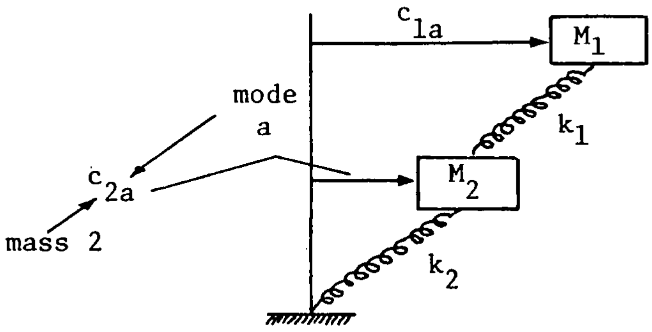
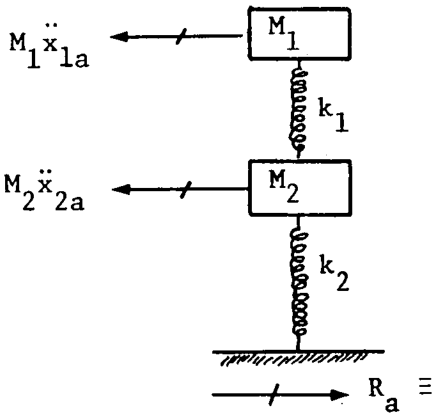


Fig. 2

a-th Principal Mode of S



Base Reaction on Component S (a-th Mode)

Fig. 3

Free Body Diagram for Determining Contribution to Base Reaction from a-th Mode

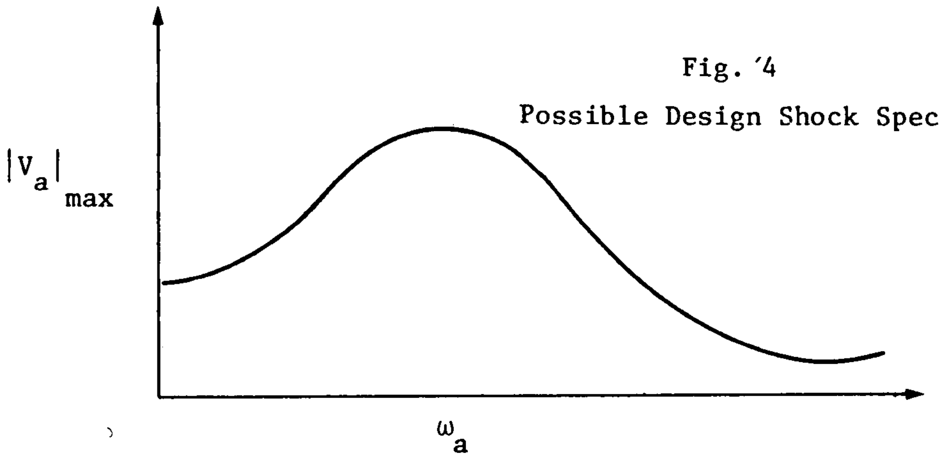


Fig. 4

Possible Design Shock Spectrum

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