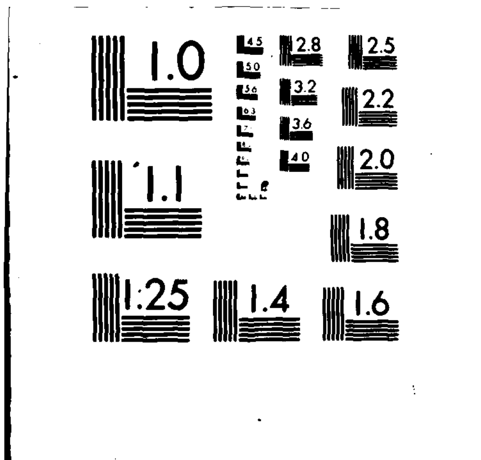
AD-A113 117 VIRGINIA UNIV CHARLOTTESVILLE SCHOOL OF ENGINEERING--ETC F/G 13/10.1
NONLINEAR TRANSIENT SHOCK RESPONSE ANALYSIS FOR SUBMERGED SHELL--ETC(U)
JUN 80 T A GIACOFCI, W D PILKEY DNA001-78-C-0105

UNCLASSIFIED SBI-AD-E300 949 NL

END
DATE
FILMED
4-82
DTIC



MICROCOPY RESOLUTION TEST CHART

DNA 5411F

NONLINEAR TRANSIENT SHOCK RESPONSE ANALYSIS FOR SUBMERGED SHELL STRUCTURES

University of Virginia
School of Engineering and Applied Sciences
P.O. Box 3366, University Station
Charlottesville, Virginia 22903

5 June 1980

Final Report for Period 1 January 1978—31 December 1979

CONTRACT No. DNA 001-78-C-0105

THIS WORK SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER RDT&E RMSS CODE B344078464 Y99QAXSF50115 H2590D.

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DNA 5411F	2. GOVT ACCESSION NO. AD-A113 117	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) NONLINEAR TRANSIENT SHOCK RESPONSE ANALYSIS FOR SUBMERGED SHELL STRUCTURES		5. TYPE OF REPORT & PERIOD COVERED Final Report for Period 1 Jan 78—31 Dec 79
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Tom A. Giacofci Walter D. Pilkey		8. CONTRACT OR GRANT NUMBER(s) DNA 001-78-C-0105
9. PERFORMING ORGANIZATION NAME AND ADDRESS Univ of Virginia, Sch of Engrg & Applied Sciences P.O. Box 3366, University Station Charlottesville, Virginia 22903		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Subtask Y99QAXSF501-15
11. CONTROLLING OFFICE NAME AND ADDRESS Director Defense Nuclear Agency Washington, D.C. 20305		12. REPORT DATE 5 June 1980
		13. NUMBER OF PAGES 30
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B344078464 Y99QAXSF50115 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Nonlinear Transient Response
Submerged Shell
Shockwave
Modal Superposition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report proposes the use of a modal superposition approach for the non-linear transient response analysis of structures. The acceleration residue flexibility procedure, which incorporates the static response at each time, is coupled to the modal superposition method. The nonlinearities are taken into account by using updated stiffness information in the static response. The effectiveness of the method is derived from the use of efficient reanalysis techniques to calculate the static solutions.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SUMMARY

This report proposes the use of a modal superposition approach for the nonlinear transient response analysis of structures. The acceleration or residue flexibility procedure, which incorporates the static response at each time, is coupled to the modal superposition method. The nonlinearities are taken into account by using updated stiffness information in the static response. The effectiveness of the method is derived from the use of efficient reanalysis techniques to calculate the static solutions.

TABLE OF CONTENTS

SECTION I INTRODUCTION

Structural damage to submerged shell structures excited by a shock wave is an inherently nonlinear phenomenon. Fundamental to the study of such phenomena is the formulation of a consistent and reliable theory to predict the nonlinear transient response of a shell structure. Naturally, a complete investigation of the problem must include the fluid-structure iteration. Here only the nonlinear structural response will be considered.

The modal superposition method has for many years been the dominant dynamic analysis method for linear systems. Recently, it has been suggested [Ref. 1,2,3] that the modal superposition method can be successfully applied to nonlinear problems. It would appear that modal superposition is competitive with direct integration for many nonlinear problems and may be better for problems involving "wide-band" governing equations.

It has also been recognized that the modal superposition method is aided when it is supplemented with a static solution calculated for the load applied at particular times. In dynamics treatises of 20 or 30 years ago, this method was referred to by a variety of names, e.g., the acceleration method. It is now sometimes called the residue flexibility method. This method was recognized as improving convergence, at least during the period for which the loading is applied. It is now believed [Ref. 4] that the use of the static response will account for the effect of higher modes.

SECTION II FORMULATION OF THE METHOD

1. DEVELOPMENT OF THE METHOD

It is proposed that a modal superposition analysis be employed for nonlinear problems. The static response at each point in time is to be used to supplement the modal summation. The nonlinearities can be incorporated using an incremental or a pseudo-force approach. For the formulatioin to be outlined here, use of the pseudo-force method is probably the most straight forward technique.

Let the p normal mode shapes for the structure at time t = 0 be

$$\{\phi_1\} \quad \{\phi_2\} \; . \; . \; . \; \{\phi_p\} \qquad (1)$$

These should be computed at the outset of the solution.

At each time t calculate the static displacements due to the load occurring at time t. Use the updated stiffness characteristics. Let $\{u_{NL}\}$ be this solution, i.e. the solution to the static problem at time t.

Let {u} be the physical degrees of freedom. Then, set

$$\{u\} = [\phi \vdots u_{NL}] \{q\} = [R]\{q\} \qquad (2)$$

where

$$[\phi] = [\{\phi_1\} \; \{\phi_2\} \; . \; . \; . \;] \qquad (3)$$

$$\{q\} = \text{modal coordinates}$$

$$[R] = [\phi \vdots u_{NL}] \qquad (4)$$

The modal equations would then be coupled

$$[R]^T[m][R]\{q\} + [R]^T[k][R]\{q\} = [R]^T\{F\} \qquad (5)$$

where

$[m]$ is the mass matrix

$[k]$ is the stiffness matrix

$\{F\}$ is the loading vector

Although Eqs. (5) are coupled, note that

$$[R]^T[m][R] \text{ and } [R]^T[k][R]$$

are of much smaller order than $[m]$ and $[k]$. In fact, for linear systems they take the special form

$$\begin{bmatrix} x & & & 0 & & x \\ & x & & & & x \\ & & x & & & x \\ & 0 & & x & & x \\ x & x & x & x & x & x \end{bmatrix}$$

For some cases, an efficient algorithm for solving Eq. (5) can probably be established.

As an alternative to this procedure, the $\{u_{NL}\}$ can be transformed to a more favorable set of coordinates. Compute $\{\bar{u}_{NL}\}$ from $\{u_{NL}\}$ which is orthogonal to $\{\phi_1\}, \ldots, \{\phi_p\}$. Set

$$\{u\} = [\phi \; \vdots \; \bar{u}_{NL}]\{q\} = [\bar{R}]\{q\} \qquad (6)$$

The modal equations will be uncoupled here. However, in order to achieve the uncoupled modal equations it is necessary to calculate $\{\bar{u}_{NL}\}$ from $\{u_{NL}\}$.

2. DISCUSSION

The proposed procedure is a nonlinear version of the residual flexibility or acceleration approach for modal superposition. The advantage in this technique over the use of updated $\{\phi_i\}$ may lie in both greater efficiency and accuracy. There is some question as to the effectiveness of the use of updated mode shapes, say $\{\psi\}$, since $\{\psi\}$ will be formed of linear combinations of $\{\phi_i\}$.

To achieve the desired efficiency and accuracy, it is proposed that a novel static reanalysis procedure be employed to update the static solutions at time t. This is the key to the solution technique.

3. STATIC REANALYSIS METHODS

The success of the proposed method depends on the availability of an efficient and reliable method for the static reanalysis of a structural system. Before developing such a method we will review some of the currently available reanalysis techniques. The goal of reanalysis technology is to analyze a modified structure by taking advantage of information from the solution to the original or unmodified structure to avoid a complete analysis of the modified structure.

The methods will be grouped as approximate and exact techniques. The approximate methods can be categorized as: perturbation (Taylor series) method, iteration method, and reduced basis method. These are generally applicable to small magnitude modifications distributed over a large portion of the structural system. In constrast, the exact methods are applicable to localized modifications with arbitrary magnitudes. Application of the exact method requires that the structural configuration and the validity of the finite element model are not affected by the modification.

The underlying principles of the exact methods involve the conception of parallel elements, initial stress, and pseudo loads. Pure algebraic formulas such as the Sherman-Morrison formula (5) and its generalization, the Woodbury formula (5) can also be directly used to develop exact modification methods. In this section, a direct method based on the Woodbury formula due to Argyris and Roy (6), a successive modification method proposed by Kavlie and Powell (7) and the pseudo load method developed by the authors are discussed. The last method although similar to that of Argyris and Roy is derived by only using the system's linearity.

In addition to reanalysis the pseudo load approach provides closed (or semi-closed) form relationships between static response variables and the design parameters. This enables the design (i.e., select design parameters) for prescribed responses.

Notation

Static Reanalysis

$\underline{b}$ = a Boolean matrix which expands $\tilde{\Delta K}$ into $\underline{\Delta K}$,

$$\underline{\Delta K} = \underline{b}^T \; \tilde{\Delta K} \; \underline{b}$$

B = system bandwidth

d_i = ith design parameter

D = number of design variables

$\underline{K}$ = system stiffness matrix

$\underline{K}_i$ = modified system stiffness matrix with the 1 through ith non-zero columns of $\underline{\Delta K}$ included

$\underline{\Delta K}$ = stiffness modification matrix of system

$\underline{\tilde{\Delta K}}$ = $\underline{\Delta K}$ with all null columns removed

$\underline{\tilde{\Delta K}}_i = \underline{X}_i$ = ith non-null column of $\underline{\Delta K}$

$\underline{\tilde{\tilde{\Delta K}}}$ = $\underline{\tilde{\Delta K}}$ with all null rows removed

$\underline{L}$ = lower triangular matrix

n_c = number of non-null columns (rows) of $\underline{\Delta K}$

$\underline{P}$ = external load vector

r = number of reduced basis vectors

$\underline{R}$ = transformation matrix

$\underline{U}$ = original system solution

$\underline{\bar{U}}$ = modified system solution

$\underline{U}^{(i)}$ = ith basis vector used in the reduced basis method

$\underline{U}_i$ = modified system solution after the 1 through ith non-null columns of $\underline{\Delta K}$ are included

$\underline{W}_i^{(k)}$ = $\underline{K}_k^{-1}\underline{X}_i = \underline{K}_k^{-1}\underline{\tilde{\Delta K}}_i$

$\underline{X}_i$ = $\underline{\tilde{\Delta K}}_i$, ith column of $\underline{X}$

$\underline{Y}_i^T$ = ith row of $\underline{Y}^T$

Approximate Methods

Taylor Series Expansion (8)

The static responses can be expanded in Taylor series as functions of the design parameters, for example,

$$\bar{\underline{U}} = \underline{U} + \sum_{i=1}^{D} \frac{\partial \underline{U}}{\partial d_i} \Delta d_i + \sum_{i=1}^{D} \sum_{j=1}^{D} \frac{\partial^2 \underline{U}}{\partial d_i \partial d_j} \Delta d_i \, \Delta d_j \qquad (7)$$

+ higher order terms

The derivative terms are evaluated by differentiating the system's static equilibrium equation,

$$\underline{K}\ \underline{U} = \underline{P} \qquad (8)$$

assuming that the external load vector's, $\underline{P}$, change is negligible when a design parameter changes. The first two derivatives are expressed by,

$$\frac{\partial \underline{U}}{\partial d_i} = - \underline{K}^{-1} \frac{\partial \underline{K}}{\partial d_i} \underline{U} \qquad (9)$$

$$\frac{\partial^2 \underline{U}}{\partial d_i \partial d_j} = - \underline{K}^{-1} \left(\frac{\partial^2 \underline{K}}{\partial d_i \partial d_j} \underline{U} + \frac{\partial \underline{K}}{\partial d_i} \frac{\partial \underline{U}}{\partial d_j} + \frac{\partial \underline{K}}{\partial d_j} \frac{\partial \underline{U}}{\partial d_i} \right) \qquad (10)$$

Note that in practice $\underline{K}$ is not inverted, instead the triangularized form of $\underline{K}$ obtained from the unmodified system's solution is used to solve for the vectors in equations (9) and (10). In addition, to maximize the computational efficiency, advantage should be taken of the sparsity of the derivatives of $\underline{K}$. Ordinarily only the first order terms of equation (7) are retained.

Storaasli and Sobieszczanski (9) have applied the first order Taylor series method to a 5000 dof fuselage midsection model. Less than 16% error was observed for single element variation of -100% (i.e. element removal) to +500%, and for -50% to 50% change for multi-elements. The incorporation of second order terms would undoubtedly increase this solution accuracy, but at the expense of increased computational burden.

Iteration Method

The equilibrium equation of the modified system may be written as,

$$\underline{K}\ \bar{\underline{U}} = \underline{P} - \underline{\Delta K}\ \bar{\underline{U}} \qquad (11)$$

From this form an iterative solution approach is derived in the following recursive form,

$$\underline{K}\ \bar{\underline{U}}^{(i+1)} = \underline{P} - \underline{\Delta K}\ \bar{\underline{U}}^{(i)} \qquad (12)$$

Back substitution is employed to solve for $\bar{\underline{U}}^{(i+1)}$, utilizing the triangularized form of $\underline{K}$ from the unmodified system's solution. The iteration is started using,

$$\bar{\underline{U}}^{(o)} = \underline{U} = \text{unmodified system response} \tag{13}$$

Noor and Lowder (7) suggested a method comprised of the Taylor series and iteration formulas. First $\bar{\underline{U}}^{(o)}$ is computed via a Taylor series method, i.e.

$$\bar{\underline{U}}^{(o)} = \underline{U} + \sum_{i=1}^{D} \frac{\partial \underline{U}}{\partial d_i} \Delta d_i \tag{14}$$

Then $\bar{\underline{U}}^{(o)}$ is used to initiate the iterative process in eq.(12), for $i>0$. Usually one or two iteration cycles are reported sufficient to obtain good results.

Reduced Basis Method

Fox and Miura (10) introduced a procedure analogous to assumed modes to reduce the dimension of the modified structure's static equilibrium problem. A set of known system deflection vectors $\underline{U}^{(1)}$, $\underline{U}^{(2)}$, ..., $U^{(r)}$ are assumed to span the solution space. Since $r \ll n$ = number of dof, this is obviously an approximation. The approximate solution of the modified system then follows as,

$$\bar{\underline{U}} = \sum_{j=1}^{r} C_j \underline{U}^{(j)}, \quad \underline{C} = [C_1\ C_2\ \ldots\ C_r]^T \tag{15}$$

$$\tilde{\underline{K}}\ \underline{C} = \tilde{\underline{P}} \qquad (r\mathrm{x}1) \tag{16}$$

$$\tilde{\underline{K}} = \underline{R}^T(\underline{K} + \underline{\Delta K})\ \underline{R} \qquad (r\mathrm{x}r) \tag{17}$$

$$\tilde{\underline{P}} = \underline{R}^T\ \underline{P} \qquad (r\mathrm{x}1),\ \underline{R} = [\underline{U}^{(1)} \mid \ \ldots\ \mid \underline{U}^{(r)}]\ (n\mathrm{x}r) \tag{18}$$

Fox and Miura indicated this is equivalent to applying the Ritz-Galerkin principle in the subspace spanned by the set of vectors $\underline{U}^{(1)} \ldots \underline{U}^{(r)}$. Although suggestions were provided, a systematic approach to calculating the basis vectors and deciding the value of r was not indicated. Noor and Lowder (8) suggested the use of the following as basis vectors,

$$\underline{U}^{(1)} = \underline{U}, \quad \underline{U}^{(i+1)} = \frac{\partial \underline{U}}{\partial d_i} \qquad i=1,2,\ldots D \tag{19}$$

where D is the number of design parameters. Excellent results were obtained.

Exact Methods

Successive Modification Methods (SMM)

This method, developed by Kavlie and Powell (7), incorporates the modification matrix, $\underline{\Delta K}$, a single non-null column at a time. The basis of this approach is the Sherman-Morrison formula (see Householder (5)) for the inverse of a modified matrix, i.e.

$$(\underline{A} + \underline{X}\,\underline{Y}^T)^{-1} = \underline{A}^{-1} - (\underline{A}^{-1}\,\underline{X})(\underline{Y}^T\,\underline{A}^{-1})/(1 + \underline{Y}^T\,\underline{A}^{-1}\,\underline{X}) \qquad (20)$$

where $\underline{X}$ and $\underline{Y}$ are column vectors representing the modification to $\underline{A}$.

The system's static equilibrium equations, before and after structural modifications are,

$$\underline{K}\,\underline{U} = \underline{P}, \quad (\underline{K} + \underline{\Delta K})\,\bar{\underline{U}} = \underline{P} \qquad (nx1) \qquad (21)$$

Consider the special case when just column j of $\underline{\Delta K}$ is non-null. Designate this column as $\underline{X} = \underline{\Delta \tilde{K}}$. Then

$$\underline{\Delta K} = \underline{X}\,\underline{Y}^T = \underline{\Delta \tilde{K}}\,\underline{Y}^T, \quad \underline{Y}^T = [0 \;\ldots\; 0 \;\underset{\uparrow \text{column } j}{1}\; 0 \;\ldots\; 0] \qquad (22)$$

and equation (20) implies

$$(\underline{K} + \underline{\Delta K})^{-1} = \underline{K}^{-1} - \underline{K}^{-1}\,\underline{X}\,\underline{Y}^T\,\underline{K}^{-1}/(1 + \underline{Y}^T\,\underline{K}^{-1}\,\underline{X}) \qquad (23)$$

To apply equation (23) directly would explicitly require $\underline{K}^{-1}$. Alternatively, post multiplying this equation by $\underline{P}$ yields

$$\bar{\underline{U}} = \underline{U} - \underline{W}\,\underline{Y}^T\,\underline{U}/(1 + \underline{Y}^T\,\underline{W}), \qquad \underline{K}\,\underline{W} = \underline{X} \qquad (24)$$

where $\underline{W}$ is calculated by back substitution using the triangularized form of $\underline{K}$ from the unmodified system's solution.

For the more general case place the n_c non-null columns of $\underline{\Delta K}$ in the columns of the nxn_c matrix $\underline{X}$. The non-null column numbers of $\underline{\Delta K}$ are designated by the set of ascending integers,

$$j_1\; j_2\; \cdots\; j_{n_c} \qquad (25)$$

With these definitions the ith row of the $n_c xn$, Boolean matrix $\underline{Y}^T$ which expands $\underline{X}$ into ΔK is null except for the number one (1) in column j_i. The stiffness modification matrix is then given by,

$$\underset{(n\times n)}{\Delta K} = \underset{(n\times n_c)}{X} \quad \underset{(n_c\times n)}{Y^T} = \tilde{\Delta K} \; Y^T \tag{26}$$

For example consider a 10 dof system with modifications to K in columns 2, 5, 7 and 9, then

$$n_c = 4,\ j_1 = 2,\ j_2 = 5,\ j_3 = 7,\ j_4 = 9$$

$$\Delta K = [0 \mid \Delta K_2 \mid 0 \mid 0 \mid \Delta K_5 \mid 0 \mid \Delta K_7 \mid 0 \mid \Delta K_9 \mid 0]$$

$$X = [\Delta K_2 \mid \Delta K_5 \mid \Delta K_7 \mid \Delta K_9] = [X_1 \mid X_2 \mid X_3 \mid X_4] = \tilde{\Delta K}$$

$$Y^T = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} Y_1^T \\ \hline Y_2^T \\ \hline Y_3^T \\ \hline Y_4^T \end{bmatrix}$$

Then if more than one column of K is modified, the successive modification method of Kavlie and Powell is employed. This assumes the following recursive form;

$$U_i = U_{i-1} - W_i^{(i-1)} Y_i^T U_{i-1}/(1 + Y_i^T W_i^{(i-1)}) \tag{27}$$

$$W_i^{(k)} = K_k^{-1} X_i \quad , \qquad U_o = U \tag{28}$$

where U_i is the system's displacement vector after the first i non-null columns of ΔK are considered. Note that $W_i^{(k)}$ is the system's displacement vector at the stage when k non-null columns of ΔK are included, with X_i as the external load vector. These vectors are calculated by the formulas

$$W_i^{(k)} = W_i^{(k-1)} - W_k^{(k-1)} Y_k^T W_i^{(k-1)}/(1 + Y_k^T W_k^{(k-1)}) \tag{29}$$

$$K\, W_i^{(o)} = X_i \quad , \qquad i = 1,2, \ldots n_c \tag{30}$$

where $W_i^{(o)}$ is calculated by back substitution using the triangularized form of K from the unmodified system's solution. Equations (27) through (30) follow directly from the version of the Sherman-Morrison formula given by equation (24). A flow diagram for the 10 dof-n_c=4 system is shown in Figure 1.

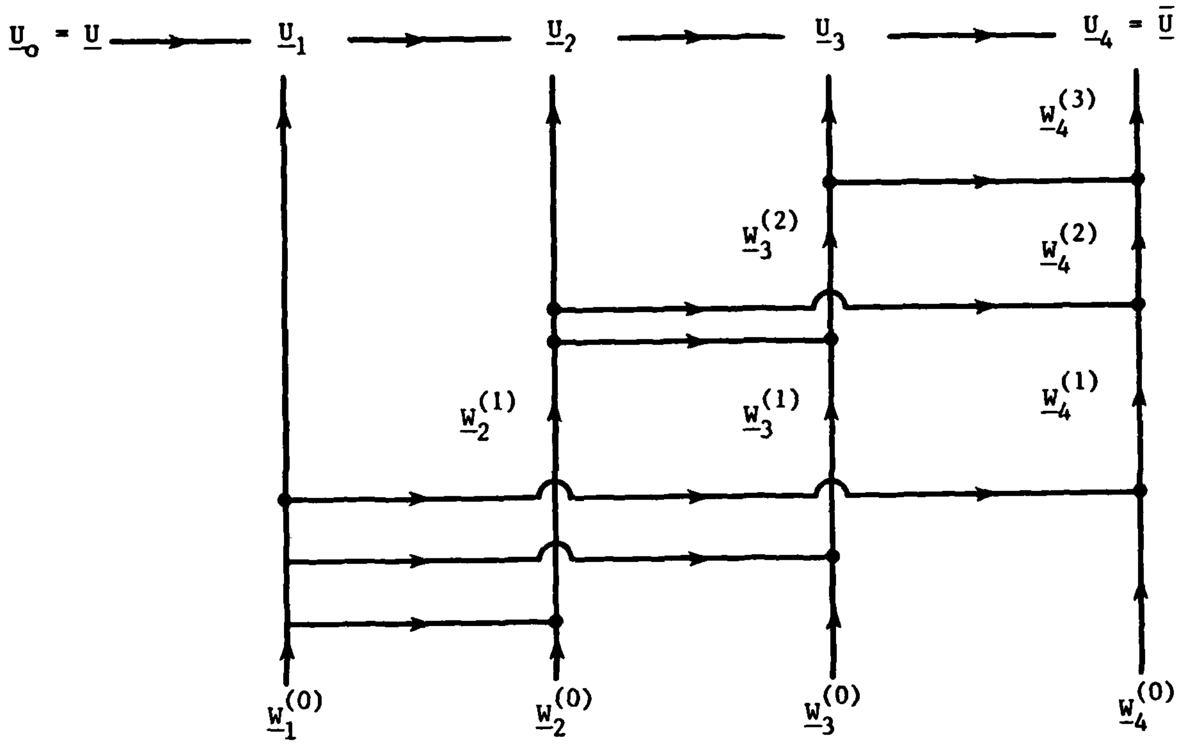


Figure 1. Flow diagram for static reanalysis (SMM), 10 dof - $n_c = 4$ system

Kavlie and Powell provide operation counts for this method, and emphasize that any reanalysis scheme should be carefully scrutinized as to when it is more efficient than complete reanalysis.

Direct Modification Method

This method was developed by Argyris, et. al. (6). The derivation is based on the Woodbury formula (ref., 5),

$$(\underline{A} + \underline{E}\ \underline{C}\ \underline{F}^T)^{-1} = \underline{A}^{-1} - \underline{A}^{-1}\ \underline{E}\ (\underline{C}^{-1} + \underline{F}^T\ \underline{A}^{-1}\ \underline{E})^{-1}\ \underline{F}^T\ \underline{A}^{-1} \tag{31}$$

however a derivation from physical arguments is also included. For reanalysis of the static equilibrium equation substitute

$$\underline{A} = \underline{K}, \quad \underline{E} = \underline{b}^T, \quad \underline{F} = \underline{b}^T, \quad \underline{C} = \tilde{\tilde{\underline{\Delta K}}} \tag{32}$$

$$\underline{\Delta K} = \underline{b}^T\ \tilde{\tilde{\underline{\Delta K}}}\ \underline{b} = \underline{E}\ \underline{C}\ \underline{F}^T \tag{33}$$

into equation (31) where $\underline{b} = \underline{Y}^T$ (see equation (26)). This yields

$$(\underline{K} + \underline{\Delta K})^{-1} = (\underline{K} + \underline{b}^T\ \tilde{\tilde{\underline{\Delta K}}}\ \underline{b})^{-1} = \underline{K}^{-1} - \underline{K}^{-1}\ \underline{b}^T\ (\tilde{\tilde{\underline{\Delta K}}}^{-1} + \underline{b}\ \underline{K}^{-1}\ \underline{b}^T)^{-1}\underline{b}\ \underline{K}^{-1} \tag{34}$$

Post multiply equation (34) by $\underline{P}$ and use equation (21). This gives

$$\underline{\Delta U} = \bar{\underline{U}} - \underline{U} = -\ (\underline{L}^T)^{-1}\ \underline{Z}\ \underline{Q}^{-1}\ (\underline{Q}^{-1} + \tilde{\tilde{\underline{\Delta K}}})^{-1}\ \tilde{\tilde{\underline{\Delta K}}}\ \underline{b}\ \underline{U} \tag{35}$$

where from the unmodified system solution the Cholesky decomposition of $\underline{K}$ is,

$$\underline{K} = \underline{L}\ \underline{L}^T \tag{36}$$

and $$\underline{L}\ \underline{Z} = \underline{b}^T \quad , \qquad \underline{Q} = \underline{Z}^T\ \underline{Z} \tag{37}$$

Computationally, the following procedure was suggested,

(1) Compute $\tilde{\underline{r}}' = \tilde{\tilde{\underline{\Delta K}}}\ \underline{b}\ \underline{U}$, (2) Evaluate $\underline{Q}$ and $\underline{Z}$,

(3) Triangularize $\underline{Q}$; $\underline{Q} = \underline{L}_Q\ \underline{L}_Q^T$ and evaluate $\underline{Q}^{-1}$,

(4) Triangularize $(\underline{Q}^{-1} + \tilde{\tilde{\underline{\Delta K}}})$; $(\underline{Q}^{-1} + \tilde{\tilde{\underline{\Delta K}}} = \underline{L}_s\ \underline{L}_s^T$,

(5) Compute $\underline{g}$ and $\tilde{\underline{r}}''$ from $\underline{L}_s\ \underline{L}_s^T\ \underline{g} = \tilde{\underline{r}}'$ and $\underline{L}_Q\ \underline{L}_Q^T\ \tilde{\underline{r}}'' = \underline{g}$,

(6) Compute $\tilde{\underline{r}}''' = \underline{Z}\ \tilde{\underline{r}}''$, finally

(7) Solve $\underline{L}^T\ (\bar{\underline{U}} - \underline{U}) = -\ \tilde{\underline{r}}'''$.

Argyris emphasized that the preceeding algorithm is more efficient than complete reanalysis only when n_c is approximately less than 0.75B. Also mentioned is that Argyris's approach is generally more efficient than Kavlie and Powell's as expressed by equation (27)-(30).

A New Method Pseudo Load Method

It is hypothesized here that the modifications actually behave as "closed-loop" deflection dependent loadings, forcing the unmodified system. Furthermore, suppose that for a localized modification, the added pseudo loading only is dependent on a small portion of the displacements. The modified system solution employs the available information from the solution of the unmodified system. This permits the modified system dispalcements to be expressed as functions of the displacements associated with only that portion of the system where modifications occur. Partitioning the modified system displacement vector and equating the modification related displacements yields a reduced set of equations. The following analytically summarizes the preceeding concepts.

Substitute equation (26) into equation (11)

$$\underline{K}\,\bar{\underline{U}} = \underline{P} - \underline{X}\,\underline{Y}^T\,\bar{\underline{U}} \qquad (n \times 1) \qquad (38)$$

$$\bar{\underline{U}} = \underline{U} - \underline{K}^{-1}\,\underline{X}\,\underline{Y}^T\,\bar{\underline{U}} \qquad (n \times 1) \qquad (39)$$

Employ the previous notation of equation (24). Equation (39) is expressed as

$$\bar{\underline{U}} = \underline{U} - \underline{W}\,\underline{Y}^T\,\bar{\underline{U}} \qquad (n \times 1) \qquad (40)$$

The Boolean matrix $\underline{Y}^T$ condenses $\bar{\underline{U}}$ to the form,

$$\hat{\bar{\underline{U}}} = \underline{Y}^T\,\bar{\underline{U}} \qquad (n_c \times 1) \qquad (41)$$

This condensed displacement vector contains only the coordinates which correspond to non-null columns of $\underline{\Delta K}$, i.e. $\bar{U}_{j_i}$, $i=1,2,\ldots n_c$. Equation (40) becomes,

$$\bar{\underline{U}} = \underline{U} - \underline{W}\,\hat{\bar{\underline{U}}} \qquad (n \times 1) \qquad (42)$$

By shifting rows (j_i, $i=1,2,\ldots,n_c$) in $\bar{\underline{U}}$, $\underline{U}$ and $\underline{W}$ to the top in equation (42), it is seen that

$$\begin{bmatrix} \hat{\bar{\underline{U}}} \\ n_c \times 1 \\ \hdashline \bar{\underline{U}}_r \\ (n-n_c) \\ \times 1 \end{bmatrix} = \begin{bmatrix} \hat{\underline{U}} \\ n_c \times 1 \\ \hdashline \underline{U}_r \\ (n-n_c) \\ \times 1 \end{bmatrix} - \begin{bmatrix} \hat{\underline{W}} \\ n_c \times n_c \\ \hdashline \underline{W}_r \\ (n-n_c) \\ \times n_c \end{bmatrix} \begin{bmatrix} \hat{\bar{\underline{U}}} \\ n_c \times 1 \end{bmatrix} \qquad (n \times 1) \qquad (43)$$

The condensed displacement vector is then calculable from

$$(\underline{I}_{n_c} + \hat{\underline{W}})\ \hat{\bar{\underline{U}}} = \hat{\underline{U}} \qquad (n_c x1) \qquad (44)$$

After which the remaining displacements are found using

$$\bar{\underline{U}}_r = \underline{U}_r - \underline{W}_r\ \hat{\bar{\underline{U}}} \qquad (n-n_c)x1 \qquad (45)$$

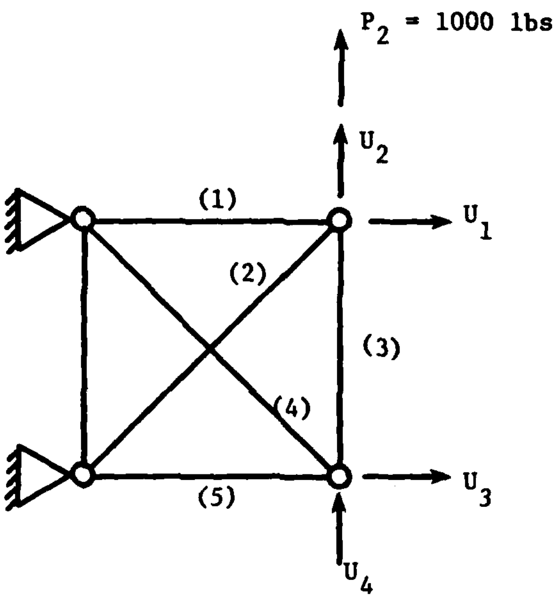
The computation of $\underline{W}$ in equation (40) proceeds by solving the separate sets of equations $\underline{K}\ \underline{W}_i = \underline{X}_i$, $i=1...n_c$. These sets are solved by back substitution utilizing the triangularized form of $\underline{K}$ from the unmodified system's solution.

The pseudo load method appears to resemble the direct modification method. Compared with the successive modification method, this method treats all modifications simultaneously. In addition, the derivation of the pseudo load method is simple and direct. The unmodified system's displacement vector and triangularized form of $\underline{K}$ may be obtained from any appropriate finite element code. A simple truss problem is included to illustrate the pseudo load method.

The geometric and material properties of the truss members are shown in Figure 2. Employing the direct stiffness method (ref. 11) with the appropriate boundary conditions provides the static equilibrium equation,

$$0.125 \times 10^6 \begin{bmatrix} 5 & 1 & 0 & 0 \\ 1 & 5 & 0 & -4 \\ 0 & 0 & 5 & -1 \\ 0 & -4 & -1 & 5 \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 1000 \\ 0 \\ 0 \end{bmatrix}, \quad \underline{K}\ \underline{U} = \underline{P} \qquad (46)$$

The Cholesky decomposition of $\underline{K}$ is $\underline{K} = \underline{L}\ \underline{L}^T$;



$L_1 = L_3 = L_5 = 20$ in.
$L_2 = L_4 = 20\sqrt{2}$ in.
$A_1 = A_3 = A_5 = 1.0$ in^2
$A_2 = A_4 = \sqrt{2}\ /\ 2$ in^2
$E = 1.0 \times 10^7$ lb/in^2

Figure 2. Truss used to illustrate the pseudo load method of static reanalysis

$$
\underline{L}\,\underline{L}^T = 0.125 \times 10^6 \begin{bmatrix} (5)^{\frac{1}{2}} & 0 & 0 & 0 \\ (5)^{-\frac{1}{2}} & (24/5)^{\frac{1}{2}} & 0 & 0 \\ 0 & 0 & (5)^{\frac{1}{2}} & 0 \\ 0 & -(10/3)^{\frac{1}{2}} & -(5)^{-\frac{1}{2}} & (22/15)^{\frac{1}{2}} \end{bmatrix} \times \begin{bmatrix} (5)^{\frac{1}{2}} & (5)^{-\frac{1}{2}} & 0 & 0 \\ 0 & (24/5)^{\frac{1}{2}} & 0 & -(10/3)^{\frac{1}{2}} \\ 0 & 0 & (5)^{\frac{1}{2}} & -(5)^{-\frac{1}{2}} \\ 0 & 0 & 0 & (22/15)^{\frac{1}{2}} \end{bmatrix}
$$

The solution for $\underline{U}$ proceeds in the standard fashion,

$$
\underline{P} = \underline{L}\,\underline{L}^T\,\underline{U} \Rightarrow \underline{P} = \underline{L}\,\underline{Y} \quad , \quad \underline{Y} = \underline{L}^T\,\underline{U}
$$

$$
\underline{U} = (2/11) \times 10^{-3}\ [-6 \quad 30 \quad 5 \quad 25] \qquad (47)
$$

Now suppose that the cross-sectional area of member 4 is changed so that $A_4 \Rightarrow A'_4 = \sqrt{2}/2\ (1 + \alpha)$. The responses of the modified system due to $\underline{P}$, as a function of α, can be calculated by the pseudo load method. The required modification matrices and indices for the problem are,

$$
\underline{\Delta K} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & e & -e \\ 0 & 0 & -e & e \end{bmatrix}, \quad \underline{X} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ e & -e \\ -e & e \end{bmatrix}, \quad \underline{Y} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix},
$$

$$
\hat{\underline{U}} = \begin{bmatrix} \bar{U}_3 \\ \bar{U}_4 \end{bmatrix}, \quad \underline{\bar{U}}_r = \begin{bmatrix} \bar{U}_1 \\ \bar{U}_2 \end{bmatrix}
$$

$$
e = 0.125 \times 10^6 \cdot \alpha \quad , \quad n_c = 2, \quad j_1 = 3, \quad j_2 = 4
$$

Using the decomposed form of $\underline{K}$, the matrix $\underline{W}$ is,

$$
\underline{W} = [\underline{W}_1 \mid \underline{W}_2] = \frac{\alpha}{11} \begin{bmatrix} 1 & -1 \\ -5 & 5 \\ 1 & -1 \\ -6 & 6 \end{bmatrix}
$$

The modified system responses are from equations (44) and (45)

$$\bar{U}_3 = ((1 + 6\alpha/11)U_3 + \alpha\, U_4/11)/(1 + 7\alpha/11) \tag{48}$$

$$\bar{U}_4 = (6\alpha U_3/11 + (1 + \alpha/11)U_4)/(1 + 7\alpha/11) \tag{49}$$

$$\bar{U}_1 = U_1 - \alpha(\bar{U}_3 - \bar{U}_4)/11 \tag{50}$$

$$\bar{U}_2 = U_2 - 5\alpha(-\bar{U}_3 + \bar{U}_4)/11 \tag{51}$$

Results like equations (48) and (49) are generally very useful since they provide (1) an efficient basis for performing a parametric study of the static response, and (2) means for prescribed static responses. The second use is illustrated by prescribing either $\bar{U}_3$ or $\bar{U}_4$ in equations (48) or (49) and then calculating the required factor α, i.e. from equation (48),

$$\alpha = 11(U_3 - \bar{U}_3)/(7\, \bar{U}_3 - 6\, U_3 - U_4) \tag{52}$$

For example if it is desired for $\bar{U}_3 = 0.9\, U_3$, then from equation (52), $\alpha = -0.234$, and from equations (48)-(51),

$$\underline{\bar{U}} = [-\,6.5 \quad 32.5 \quad 4.5 \quad 28.0] \times (2/11) \times 10^{-3}$$

If from equation (52), $\alpha < -1.0$, then the prescribed value of $\bar{U}_3$ is not realizable by only modifying member 4.

4. CONCLUSIONS AND RECOMMENDATIONS

A new method for the nonlinear transient response of structures, in particular, submerged shell structures, is formulated. This is a modal superposition technique using residue flexibility in which the static response at each time is computed using an efficient static reanalysis technique.

This preliminary development of the method appears to indicate that this approach holds promise. Some numerical tests, which are not reported here, confirm this. The method seems to deserve further development.

REFERENCES

(1) Stricklin, J.A., and Haisler, W.E., "Formulation and Solution Procedure for Nonlinear Structural Analysis," Computers & Structures, Vol. 7, 1977, pp. 125-136.

(2) Nickell, R.E., "Nonlinear Dynamics by Mode Superposition," Computer Methods in Applied Mechanics and Engineering, Vol. 7, 1976, pp. 107-129.

(3) Morris, N.F., "The Use of Modal Superposition in Nonlinear Dynamics", Computers & Structures, Vol. 7, 1977, pp. 65-72.

(4) Clough, R.W., and Wilson, E.L., "Dynamic Analysis of Large Structural Systems with Local Nonlinearities," Computer Methods in Applied Mechanics in Engineering, Vol. 17/18, 1979, pp. 107-129.

(5) Householder, A.S., "The Theory of Matrices in Numerical Analysis, 1st ed., Dover Publications, Inc., New York, 1964.

(6) Argyris, J.H., Bronlund, O.E., and Roy, J.R., "A Direct Modification Procedure for the Displacement Method," AIAA Journal, Vol. 9, No. 9, Sept. 1971, pp. 1861-1864.

(7) Kavlie, D., and Powell, G., "Efficient Reanalysis of Modified Structures," Journal of the Structural Division, ASCE, Vol. 97, No. ST1, Jan. 1971, pp. 377-392

(8) Noor, A.K., and Lowder, H.E., "Approximate Techniques of Structural Reanalysis," International Journal of Computers and Structures, Vol. 4, No. 4, 1974, pp. 801-812.

(9) Storaasli, O.O., and Sobieszczanski, J., "On the Accuracy of the Taylor Approximation for Structure Resizing," AIAA Journal, Vol. 12, No. 2, Feb. 1974, pp. 231-233.

(10) Fox, R.L., and Miura, H., "An Approximate Analysis Technique for Design Calculations," AIAA Journal, Vol. 9, No. 1, Jan. 1971, pp. 177-179.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Assistant to the Secretary of Defense
Atomic Energy
ATTN: Executive Assistant

Defense Intelligence Agency
ATTN: DT-1C
ATTN: RDS-2A
ATTN: DT-2
ATTN: DB-4C
ATTN: DB-4C2
ATTN: DB-4C2, C. Wiehle
ATTN: DB-4C3
ATTN: DB-4C1

Defense Nuclear Agency
ATTN: STSP
2 cy ATTN: SPSS
2 cy ATTN: SPAS
4 cy ATTN: TITL

Defense Tech Info Center
12 cy ATTN: DD

Field Command
Defense Nuclear Agency
ATTN: FCT
ATTN: FCTXE
ATTN: FCPR, J. T. McDaniel

Field Command
Defense Nuclear Agency
Livermore Br
ATTN: FCPRL

Test Construction Division
Defense Nuclear Agency
ATTN: FCTC

Interservice Nuclear Weapons School
ATTN: TTV

Joint Strat Tgt Planning Staff
ATTN: JLTW-2
ATTN: JLTW, Carpenter
ATTN: JLA
ATTN: NRI-STINFO, Lib
ATTN: DOXT
ATTN: XPFS

NATO School, SHAPE
ATTN: U.S. Documents Officer

Under Secretary of Defense for Rsch & Engrg
ATTN: Strategic & Space Sys (OS)

DEPARTMENT OF THE ARMY

BMD Advanced Tech Center
Department of the Army
ATTN: ATC-T
ATTN: ICRDABH-X

Construction Engineering Rsch Lab
Department of the Army
ATTN: CERL-SOI-L

DEPARTMENT OF THE ARMY (Continued)

Chief of Engineers
Department of the Army
ATTN: DAEN-MCE-D
ATTN: DAEN-RDL

Deputy Chief of Staff for Ops & Plans
Department of the Army
ATTN: DAMO-NC

Deputy Chief of Staff for Rsch Dev & Acq
Department of the Army
ATTN: DAMA

Engineer Studies Center
Department of the Army
ATTN: DAEN-FES, LTC Hatch

Harry Diamond Laboratories
Department of the Army
ATTN: DELHD-NW-P
ATTN: DELHD-TA-L

U.S. Army Concepts Analysis Agency
ATTN: CSSA-ADL

U.S. Army Engineer Center
ATTN: ATZA

U.S. Army Engineer School
ATTN: ATZA-CDC
ATTN: ATZA-DTE-ADM

U.S. Army Engr Waterways Exper Station
ATTN: WESSE, L. Ingram
ATTN: J. Zelasko
ATTN: WESSD, J. Jackson
ATTN: J. Strange
ATTN: F. Brown
ATTN: Lib
ATTN: WESSA, W. Flathau
ATTN: WESSS, J. Ballard
ATTN: R. Whalin

U.S. Army Foreign Science & Tech Ctr
ATTN: DRXST-SD

U.S. Army Mat Cmd Proj Mngr for Nuc Munitions
ATTN: DRCPM-NUC

U.S. Army Material & Mechanics Rsch Ctr
ATTN: DRXMR, J. Mescall
ATTN: Tech Lib

U.S. Army Materiel Dev & Readiness Cmd
ATTN: DRCDE-D, L. Flynn
ATTN: DRXAM-TL

U.S. Army Missile Command
ATTN: RSIC
ATTN: DRSMI-RH

U.S. Army Nuclear & Chemical Agency
ATTN: Lib

DEPARTMENT OF THE ARMY (Continued)

U.S. Army War College
ATTN: Lib

U.S. Military Academy
Department of the Army
ATTN: Document Lib

DEPARTMENT OF THE NAVY

David Taylor Naval Ship R&D Ctr
ATTN: Code 177, E. Palmer
ATTN: Code 1740.5
ATTN: Code 1740.1
ATTN: Code 172
ATTN: Code 1740.4
ATTN: Code L42-3
ATTN: Code 173
ATTN: Code 11
ATTN: Code 1700, W. Murray
ATTN: Code 1740.6
ATTN: Code 1770.1
ATTN: Code 2740
ATTN: Code 1740, R. Short
ATTN: Code 174
ATTN: Code 1844

Marine Corps
Department of the Navy
ATTN: POM

Marine Corp Dev & Education Command
Department of the Navy
ATTN: D091, J. Hartneady

Naval Civil Engineering Lab
ATTN: Code L08A
ATTN: Code L51, J. Crawford

Naval Coastal Systems Lab
ATTN: Code 741

Naval Electronic Systems Command
ATTN: PME 117-21

Naval Electronics Systems Command
ATTN: Commander

Naval Explosive Ord Disposal Fac
ATTN: Code 504, J. Petrousky

Naval Facilities Engineering Command
ATTN: Code 04B

Naval Material Command
ATTN: MAT 08T-22

Naval Ocean Systems Ctr
ATTN: Code 4471
ATTN: Code 013, E. Cooper

Naval Postgraduate School
ATTN: Code 1424, Lib
ATTN: Code 69NE

Naval Surface Weapons Ctr
ATTN: W. Wishard
ATTN: Tech Lib & Info Svcs Br

DEPARTMENT OF THE NAVY (Continued)

Naval Research Lab
ATTN: Code 8440, G. O'Hara
ATTN: Code 8301
ATTN: Code 8100
ATTN: Code 8445
ATTN: Code 8403, R. Belsham
ATTN: Code 6380
ATTN: Code 8406
ATTN: Code 2627
ATTN: Code 8404, H. Pusey

Naval Sea Systems Command
ATTN: SEA-3221
ATTN: SEA-09G53
ATTN: SEA-0351
ATTN: SEA-06J, R. Lane
ATTN: SEA-323
ATTN: SEA-033
ATTN: SEA-08
ATTN: SEA-9931G

Naval Surface Weapons Ctr
ATTN: Code R13
ATTN: Code U401, M. Kleinerman
ATTN: Code R10
ATTN: Code R14
ATTN: Code R15
ATTN: Code F34
ATTN: Code F31

Naval War College
ATTN: Code E-11, Tech Service

Naval Weapons Ctr
ATTN: Code 3263, J. Bowen
ATTN: Code 233
ATTN: Code 266, C. Austin

Naval Weapons Evaluation Facility
ATTN: G. Binns
ATTN: R. Hughes
ATTN: Code 10
ATTN: Code 210

Naval Weapons Support Ctr
ATTN: Code 70553, D. Moore

New London Laboratory
Naval Underwater Systems Ctr
ATTN: Code 4492, J. Kalinowski
ATTN: Code 4494, J. Patel

Newport Laboratory
Naval Underwater Systems Ctr
ATTN: Code EM
ATTN: Code 363, P. Paranzino

Office of Naval Research
ATTN: Code 474, N. Perrone

Strategic Systems Project Office
Department of the Navy
ATTN: NSP-273
ATTN: NSP-272
ATTN: NSP-43

DEPARTMENT OF THE NAVY (Continued)

Office of the Chief of Naval Operations
ATTN: OP 37
ATTN: OP 957E
ATTN: OP 223
ATTN: OP 225
ATTN: OP 605D5
ATTN: OP 953
ATTN: OP 654C3, R. Piacesi
ATTN: OP 03EG
ATTN: OP 951
ATTN: OP 982
ATTN: OP 982E, M. Lenzini
ATTN: OP 981N1
ATTN: OP 098T8
ATTN: OP 21
ATTN: OP 65
ATTN: OP 981
ATTN: OP 987

DEPARTMENT OF THE AIR FORCE

Air Force Institute of Technology
ATTN: Lib
ATTN: Commander

Air Force Office of Scientific Rsch
ATTN: NA, B. Wolfson

Air Force Systems Command
ATTN: DLW
ATTN: R. Cross

Air Force Weapons Lab
Air Force Systems Command
ATTN: NTED
ATTN: NTE, M. Plamondon
ATTN: NTES-C, R. Henny
ATTN: SUL
ATTN: NTES-G, S. Melzer

Assistant Chief of Staff
Intelligence
Department of the Air Force
ATTN: IN

Ballistic Missile Office
Air Force Systems Command
ATTN: DEB

Deputy Chief of Staff
Research, Development, & Acq
Department of the Air Force
ATTN: R. Steere
ATTN: AFRDQI

Deputy Chief of Staff
Logistics & Engineering
Department of the Air Force
ATTN: LEEE

Foreign Technology Div
Air Force Systems Command
ATTN: SDBG
ATTN: SDBF, S. Spring
ATTN: TQTD
ATTN: NIIS, Lib

United States Air Force Academy
ATTN: DFCEM, W. Fluhr

DEPARTMENT OF THE AIR FORCE (Continued)

Rome Air Development Ctr
Air Force Systems Command
ATTN: Commander
ATTN: TSLD
ATTN: RBES, R. Mair

Strategic Air Command
Department of the Air Force
ATTN: NRI-STINFO, Lib

DEPARTMENT OF ENERGY

Department of Energy
Albuquerque Operations Office
ATTN: CTID

Department of Energy
ATTN: OMA/RD&T

Department of Energy
Nevada Operations Office
ATTN: Doc Con for Tech Lib

OTHER GOVERNMENT AGENCIES

Central Intelligence Agency
ATTN: OSR/SE/F
ATTN: OSWR/NED

Department of the Interior
ATTN: D. Roddy

Federal Emergency Management Agency
ATTN: W. Chipman
ATTN: Rsch Div

NASA
Ames Research Ctr
ATTN: R. Jackson
ATTN: F. Nichols

U.S. Nuclear Regulatory Commission
ATTN: R. Whipp for Div Sec, L. Shao

DEPARTMENT OF ENERGY CONTRACTORS

Lawrence Livermore National Lab
ATTN: S. Erickson

Los Alamos National Lab
ATTN: M/S634, T. Dowler
ATTN: MS 670, J. Hopkins
ATTN: R. Whitaker
ATTN: R. Sanford
ATTN: A. Davis
ATTN: Reports Lib
ATTN: G. Spillman

Oak Ridge National Laboratory
ATTN: Civil Def Res Proj
ATTN: Central Rsch Lib

Sandia National Lab
Livermore Lab
ATTN: Library & Security Classification Div

Sandia National Lab
ATTN: 3141
ATTN: L. Vortman

DEPARTMENT OF DEFENSE CONTRACTORS

BDM Corp
ATTN: T. Neighbors
ATTN: A. Lavagnino
ATTN: Corporate Lib

Bell Telephone Labs
ATTN: J. White

California Institute of Technology
ATTN: T. Ahrens

California Research & Tchnology, Inc
ATTN: Lib
ATTN: K. Kreyenhagen
ATTN: S. Schuster
ATTN: M. Rosenblatt

Columbia University
ATTN: F. DiMaggio
ATTN: H. Bleich

University of Denver
ATTN: Sec Officer for J. Wisotski

Electric Power Research Institute
ATTN: G. Sliter

General Dynamics Corp
ATTN: J. Mador
ATTN: M. Pakstys
ATTN: J. Miller

Kaman AviDyne
ATTN: N. Hobbs
ATTN: Lib
ATTN: G. Zartarian
ATTN: R. Ruetenik

Kaman Sciences Corp
ATTN: F. Shelton
ATTN: Lib

Kaman Sciences Corp
ATTN: D. Sachs

Kaman Tempo
ATTN: DASIAC

Karagozian and Case
ATTN: J. Karagozian

Lockheed Missiles & Space Co, Inc
ATTN: T. Geers
ATTN: B. Almroth
ATTN: Tech Info Ctr

Lockheed Missiles & Space Co, Inc
ATTN: TIC-Library

M & T Company
ATTN: D. McNaight

Management Science Associates
ATTN: K. Kaplan

McDonnell Douglas Corp
ATTN: R. Halprin

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

NKF Engineering Associates, Inc
ATTN: R. Belsheim

Pacific-Sierra Research Corp
ATTN: H. Brode

Pacifica Technology
ATTN: R. Bjork
ATTN: G. Kent

Physics Applications, Inc
ATTN: C. Vincent

Physics International Co
ATTN: J. Thomsen
ATTN: F. Sauer
ATTN: L. Behrmann
ATTN: E. Moore
ATTN: Tech Lib

University of Pittsburgh
ATTN: M. Williams, Jr

Science Applications, Inc
ATTN: Tech Lib

Southwest Research Institute
ATTN: W. Baker
ATTN: A. Wenzel

SRI International
ATTN: G. Abrahamson
ATTN: W. Wilkinson
ATTN: A. Florence

Systems, Science and Software, Inc
ATTN: K. Pyatt
ATTN: R. Sedgewick
ATTN: Lib
ATTN: D. Grine
ATTN: T. Riney
ATTN: T. Cherry
ATTN: T. McKinley

Teledyne Brown Engineering
ATTN: J. Ravenscraft

Tetra Tech, Inc
ATTN: L. Hwang

TRW Defense & Space Sys Group
ATTN: Tech Info Ctr
ATTN: W. Lipner
ATTN: D. Jortner
ATTN: B. Sussholtz
ATTN: A. Narevsky
ATTN: A. Feldman
ATTN: P. Bhutta

TRW Defense & Space Sys Group
ATTN: P. Dai
ATTN: F. Pieper
ATTN: E. Wong
ATTN: G. Hulcher

Weidlinger Assoc, Consulting Engrg
ATTN: J. Isenberg

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

University of Virginia
4 cy ATTN: T. Giacofci
4 cy ATTN: W. Pilkey

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Weidlinger Assoc, Consulting Engrg
ATTN: J. McCormick
ATTN: M. Baron