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SEISMIC ANALYSIS OF NUCLEAR POWER PLANT STRUCTURES

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ABSTRACT

Primary structures for nuclear power plants are designed to resist expected earthquakes of the site. Two intensities are referred to as Operating Basis Earthquake and Design Basis Earthquake. These structures are required to accommodate these seismic loadings without loss of their functional integrity. Thus, no plastic yield is allowed.

This paper describes the application of NASTRAN in analyzing some of these seismic induced structural dynamic problems and shows that NASTRAN, with some modifications, can be used to analyze most structures that are subjected to seismic loads. A brief review of the formulation of seismic-induced structural dynamics is also presented.

Two typical structural problems were selected to illustrate the application of the various methods of seismic structural analysis by the NASTRAN system.

INTRODUCTION

This paper describes the basic formulation and the method of solution by NASTRAN for the structural responses due to seismic disturbances. Some illustration problems are also presented. The discussion is primarily aimed at nuclear power plant structures; however, it could be applied to other types of structures since the seismic requirements on nuclear power plants are more stringent than most other structures.

ANALYTICAL FORMULATION

The seismic loading is described by the ground acceleration, $A(t)$. Disregarding the soil-structure interaction effect, the structure is subjected to the ground acceleration at its foundation. Thus, the equation of motion for the structure can be expressed as

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$$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = -[M]\{\alpha\}A(t) \qquad (1)$$

where

$[M]$	mass matrix
$[C]$	damping matrix
$[K]$	stiffness matrix
$\{X\}$	displacement matrix
$\{\alpha\}$	directional cosines that relate $\{X\}$ to A(t)
A(t)	ground acceleration

Expressing equation (1) by normal mode coordinates, we reduced it to the following uncoupled equation:

$$M_i\ddot{Y}_i + 2\lambda_i M_i \omega_i \dot{Y}_i + K_i Y_i = -\Gamma_i M_i A(t) \qquad (2)$$

where

$[\phi]$	characteristic matrix
$\{X\}$	$[\phi]\{Y\}$
$\{\dot{X}\}$	$[\phi]\{\dot{Y}\}$
$\{\ddot{X}\}$	$[\phi]\{\ddot{Y}\}$
M_i	$\{\phi_i\}^T[M]\{\phi_i\}$ = Generalized mass for the i^{th} mode
λ_i	$\dfrac{\{\phi_i\}^T[C]\{\phi_i\}}{2\omega_i\{\phi_i\}^T[M]\{\phi\}}$ = Damping ratio for the i^{th} mode
Γ_i	$\dfrac{\{\phi_i\}^T[M]\{\alpha\}}{\{\phi_i\}^T[M]\{\phi_i\}}$ = Participation factor for the i^{th} mode
ω_i	Undamped circular frequency of the i^{th} mode
$\{\phi_i\}$	Mode shape matrix of the i^{th} mode
$\{\phi_i\}^T$	Transpose of ϕ_i

ω_i and $\{\phi_i\}$ are calculated from:

$$\left| [K] - \omega^2 [M] \right| = 0 \tag{3}$$

METHODS OF SOLUTION

The NASTRAN system offers the following methods of solution:

(1) Rigid Format 3; Mode Shape Analysis:

The frequencies of the structure are obtained by Rigid Format 3. From these frequencies an equivalent static load is estimated to facilitate the preliminary design and analysis. The Uniform Building Code accepts this approximate analysis without further analysis by spectrum method or transient method

(2) Rigid Format 9; Direct Transient

The degrees of freedom of the structure are condensed by Guyan reduction. The mass of the structure is distributed and input via CONM2 cards. The forcing function, $-A(t)M_i$ is input by TLOAD1 cards, where $A(t)$ is the ground acceleration history and M_i the concentrated mass specified by CONM2 cards. The time function, $A(t)$, is specified by TABLE1 cards, and the scale factors of DAREA cards are set equal to the numerical values of M_i.

(3) Rigid Format 8 or 11; Direct Frequency Responses or Model Frequency and Random Response

The mass of the structure is distributed at the active DOF and input via CONM2 cards. The loading is input by RLOAD1 cards. The loading is equal to $-SA(f) * M_i$ where $SA(f)$ is the seismic spectrum, M_i is the mass at DOF i, and f are the frequencies. SA(f) is input by TABLED1 and M_i by DAREA cards as scale factors. These analyses should be performed by restarting from Rigid Format 3 run.

ILLUSTRATION PROBLEMS

(1) Heat Exchanger (Test Model)

The heat exchanger structure as shown in Figure 1 is analyzed according to Uniform Building Code, UBC. The frequencies were obtained by Rigid Format 3. An equivalent static load was computed according to UBC and static analysis was made under the combined loadings of this equivalent seismic load, thermal loads and differential air pressure. Results of this combined loading was compared with other specified combined loadings. Under this seismic analysis, this heat exchanger is only qualified as a separate test unit and not as a part of any nuclear power plant.

(2) Shielding Structures

Figures 2 and 3 show the NASTRAN model of an interim fuel element decaying shielding system. This system consists of a cover plate, a neutron shield, and a thermal shield. The transport equipment which is movable and locked on the cover when in use is considered as nonstructural mass. The cover plate, the neutron, and the thermal shield are modeled by plate elements and connecting bars by bar elements. This model has about 1200 DOF and was condensed to about 250 DOF by Guyan reduction. The difference between the fundamental frequency of the original model and of the Guyan model is less than 1%.

CONCLUSION

From the experiences based on these analyses, it is obvious that NASTRAN can be used to analyze structural dynamics under seismic loads. The NASTRAN system has no limitation on the structural model size as imposed in most other general purpose structural analysis programs. Other advantages in using the NASTRAN system in dealing with seismic analysis are:

Restart and loading combinations

Flexible I/O format

Model applicable to all computers and analysis

Complete selection of analysis methods

We did not make any cost comparison with any other programs; however, we believe the overall cost (man-hours plus computer charges) are lower than other major programs.

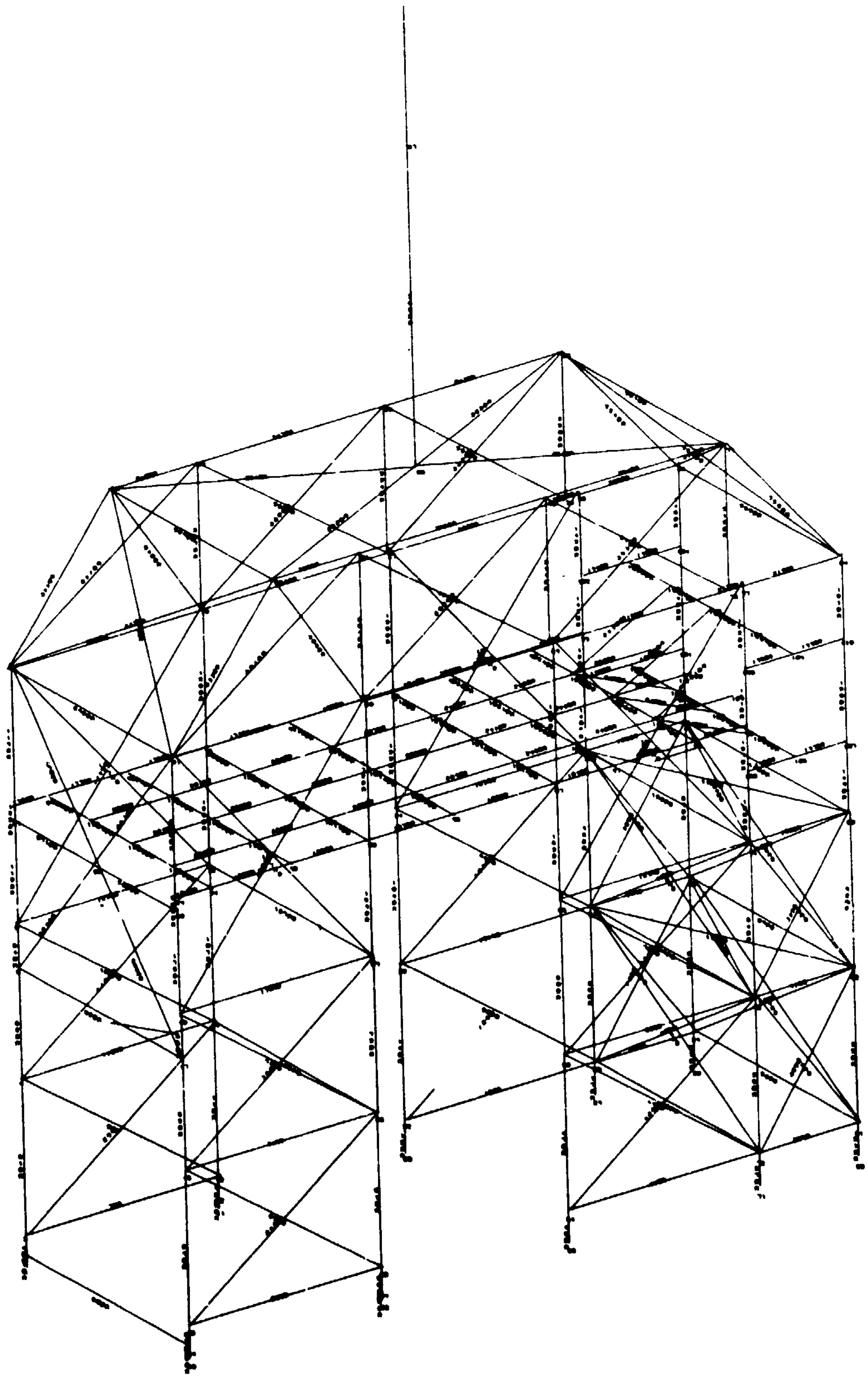

Figure 1.- Heat exchanger (test unit).

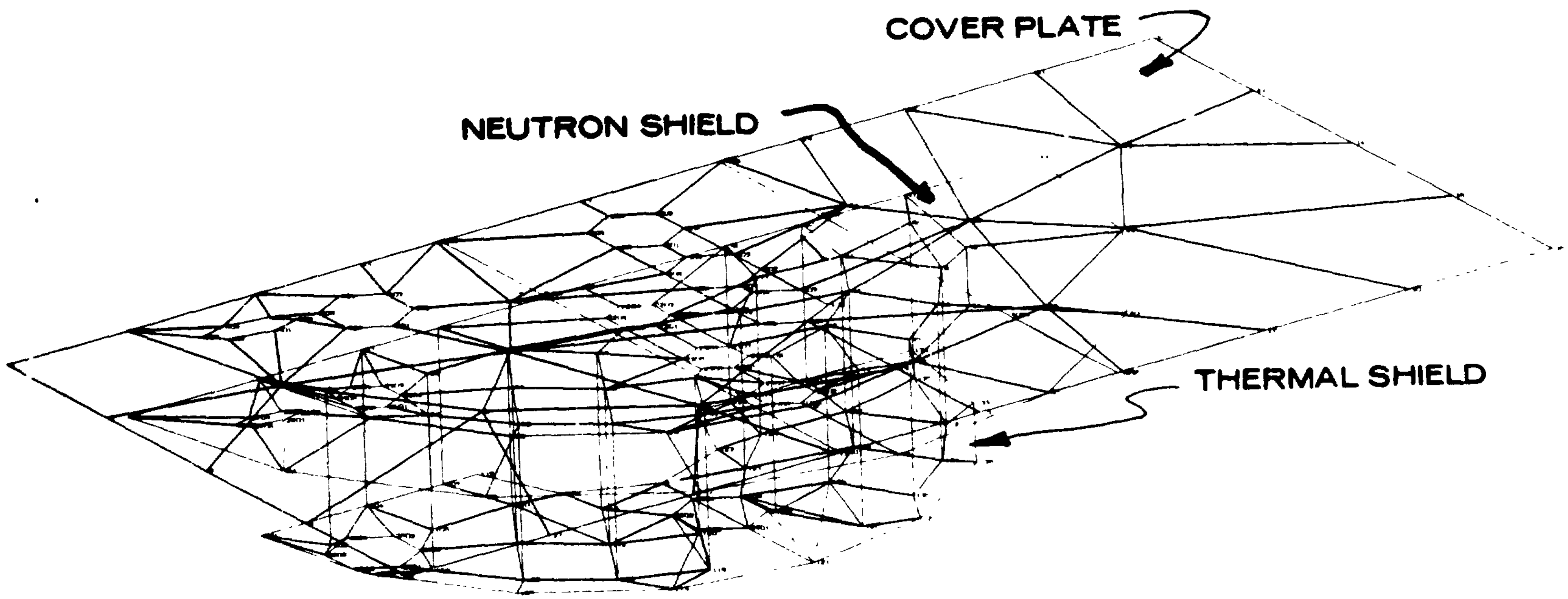

Figure 2.- Undeformed structural model.

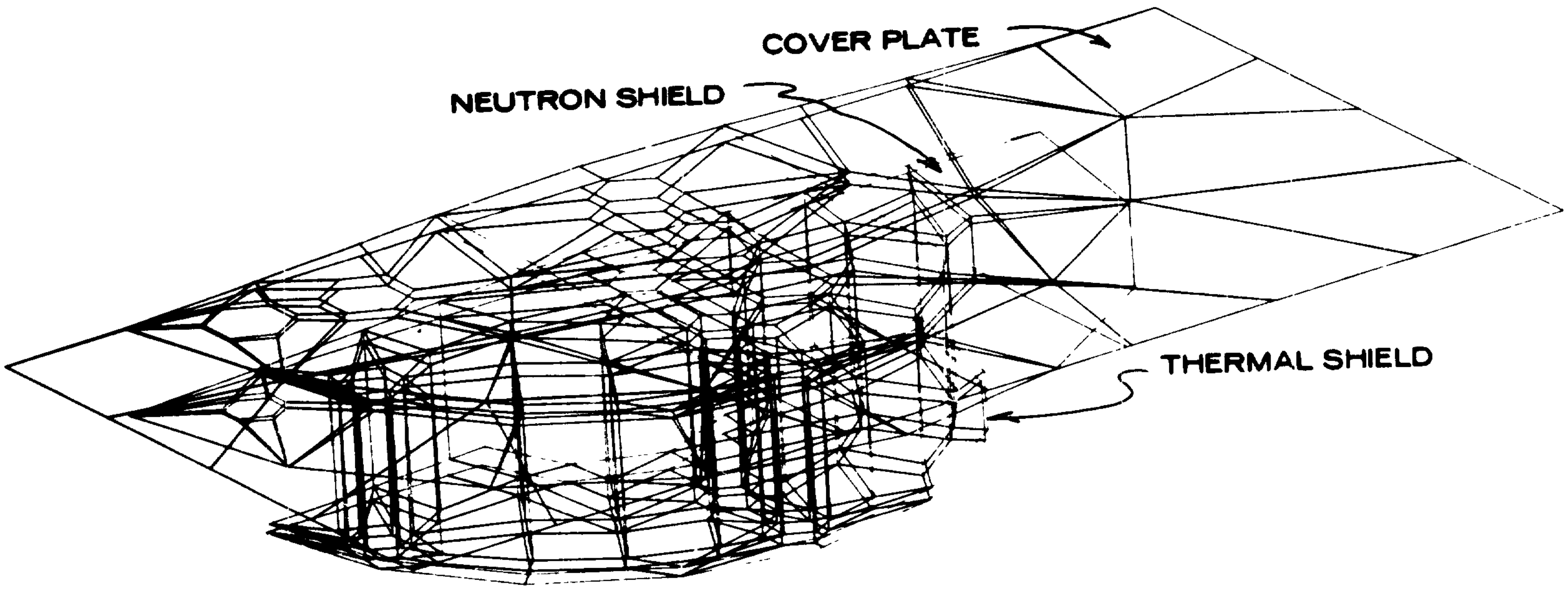

Figure 3.- Mode shape.