XN-NF-696(NP)(A)

ENC'S SOLUTION TO THE NRC SAMPLE PROBLEMS - PWR FUEL ASSEMBLIES MECHANICAL RESPONSE TO SEISMIC AND LOCA EVENTS

MAY 1986

RICHLAND, WA 99352

EXXON NUCLEAR COMPANY, INC.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

December 26, 1985

Mr. J. C. Chandler, Lead Engineer
Reload Fuel Licensing
Exxon Nuclear Company, Inc.
2101 Horn Rapids Road
Post Office Box 130
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Dear Mr. Chandler:

SUBJECT: ACCEPTANCE FOR REFERENCING OF LICENSING TOPICAL REPORT XN-NF-696, "ENC'S SOLUTION TO THE NRC SAMPLE PROBLEMS-PWR FUEL ASSEMBLIES MECHANICAL RESPONSE TO SEISMIC AND LOCA EVENTS"

We have completed our review of the subject topical report submitted by the Exxon Nuclear Company, Inc. (Exxon) by letter dated June 23, 1983. We find the report to be acceptable for referencing in license applications to the extent specified and under the limitations delineated in the report and the associated NRC evaluation, which is enclosed. The evaluation defines the basis for acceptance of the report.

We do not intend to repeat our review of the matters described in the report and found acceptable when the report appears as a reference in license applications, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to the matters described in the report.

In accordance with procedures established in NUREG-0390, it is requested that Exxon publish accepted versions of the reports, proprietary and non-proprietary, within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed evaluation between the title page and the abstract. The accepted versions shall include an -A (designating accepted) following the report identification symbol.

Should our criteria or regulations change such that our conclusions as to the acceptability of the report are invalidated, Exxon and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued effective applicability of the topical reports without revision of their respective documentation.

Sincerely,

Herbert N. Berkow

Herbert N. Berkow, Director
Standardization and Special
Projects Directorate
Division of PWR Licensing-B

Enclosures:
As stated

Enclosure

Safety Evaluation of ENC's Solutions to the NRC Sample Problem - PWR Fuel Assemblies Mechanical Response to Seismic and LOCA Events (XN-NF-696)

1. INTRODUCTION

Previously, we have approved the Exxon Nuclear Company (ENC) PWR fuel assembly mechanical response model under combined seismic and LOCA loads (XN-NF-76-47(P)(A)). The model calculations were based on the nonlinear transient dynamic analysis option of the ANSYS code. Subsequently, ENC changed the model calculations from ANSYS to the NASTRAN code. In order to demonstrate that the result of NASTRAN analysis still complied with the SRP criteria, we requested ENC to provide a new calculation of the NRC standard problems. ENC provided a new solution described in the report XN-NF-696 for review. Our contractor, Idaho National Engineering Laboratory (INEL), has performed an independent calculation using the FAMREC computer code (Ref. 1) as a check of the ENC results.

2. ANALYSIS SUMMARY

Three cases were considered depending on the core plate displacement functions. The core plate displacement determined the response of impact forces on the fuel assemblies, in particular, the grid spacers under seismic and LOCA loading conditions. INEL ran these three cases using the auditing code FAMREC and then compared the results with the ENC's results as described in the INEL technical report (Ref. 2). The comparisons showed that the ENC spacer grid maximum forces were either equal to or greater than the maximum forces calculated by INEL for the first and third cases, and the INEL maximum forces were larger than the ENC forces for second case. However, the second case had smaller core plate motions and thus smaller spacer grid forces.

Both INEL and ENC predicted that the maximum forces occurred at approximately the same times. The locations of the maximum forces appeared different for different calculations. INEL attributed the cause of these discrepancies to the different assumed shapes of the baffle plate. However, since the more important parameter, maximum impact force, was not sensitive to the shape of the baffle plate, we conclude that ENC analysis is acceptable.

3. CONCLUSIONS

Because (1) ENC's new analysis is consistent with our audit calculation, and (2) the NASTRAN and ANSYS codes are widely acceptable computer codes for structural analysis, we conclude that the report XN-NF-696 can be referenced for licensing applications for PWR seismic and LOCA loading analysis.

References

1. R. L. Grubb, "Pressurized Water Reactor Lateral Core Response Routine, FAMREC (Fuel Assembly Mechanical Response Code)", USNRC NUREG/CR-1019, September 1979.

2. B. L. Harris, "Review of Exxon Nuclear Company's Fuel Assembly LOCA-Seismic Response Reports XN-NF-81-51P and XN-NF-696", EG&G EGG-EA-6618, May 1984.

XN-NF-696 (NP) (A)

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ENC'S SOLUTION TO THE NRC SAMPLE PROBLEMS - PWR FUEL ASSEMBLIES

MECHANICAL RESPONSE TO SEISMIC AND LOCA EVENTS

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ENC'S SOLUTION TO THE NRC SAMPLE PROBLEMS - PWR FUEL ASSEMBLIES MECHANICAL RESPONSE TO SEISMIC AND LOCA EVENTS

TABLE OF CONTENTS

ENC'S SOLUTION TO THE NRC SAMPLE PROBLEMS - PWR FUEL ASSEMBLIES

MECHANICAL RESPONSE TO SEISMIC AND LOCA EVENTS

LIST OF TABLES

ENC'S SOLUTION TO THE NRC SAMPLE PROBLEMS - PWR FUEL ASSEMBLIES MECHANICAL RESPONSE TO SEISMIC AND LOCA EVENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

ENC'S SOLUTION TO THE NRC SAMPLE PROBLEMS - PWR FUEL ASSEMBLIES MECHANICAL RESPONSE TO SEISMIC AND LOCA EVENTS

1.0 INTRODUCTION

The Exxon Nuclear Company's evaluation procedure for the dynamic response of fuel assemblies subjected to seismic and LOCA events assumes that a row of fuel assemblies are excited by the lateral motions of the core plates. The effects of these displacements at the fuel assemblies boundary can be modeled using a modal simulation of the fuel assembly's dynamic characteristics. Spacer grids form an envelope around the assemblies at the spacer grid locations where assemblies may contact one another or the core barrel. The impacts of these assemblies cause interactions at these locations which are modeled with a non-linear model for the spacer grid structure. The whole modeling procedure is developed such that the dynamic behavior of the resultant structural model can be evaluated with the MSC/NASTRAN program.

This report describes how the characteristics described for the NRC's standard problem for PWR fuel assemblies subjected to seismic and LOCA events are interpreted and used to obtain predicted responses using the general theory applied to commercial PWR plants. A flow diagram depicting this procedure is shown in Figure 1.

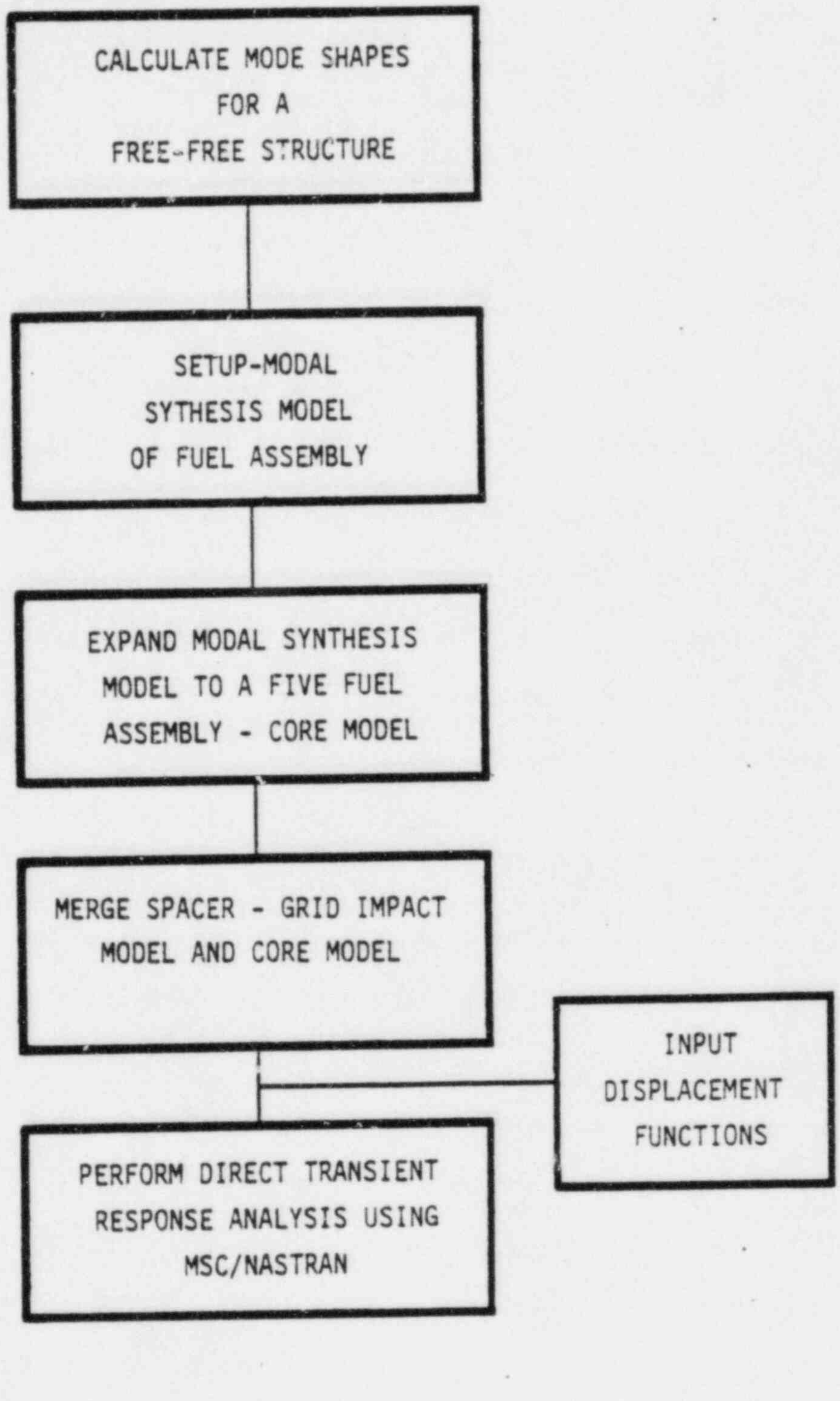

Figure 1 Flow Diagram For Dynamic Analysis of the NRC Sample Problems

2.0 THE NRC SAMPLE PROBLEMS

2.1 REACTOR CORE AND INPUT LOADS

The reactor core for the sample problem consists of thirteen (13) fuel assemblies with five (5) fuel assemblies on the largest diameter. The gaps between the peripheral fuel assemblies and the baffle or core barrel are 0.06 inches, the gaps between the fuel assemblies are 0.03 inches. Figure 2.1.1 shows the reactor core's cross section and the direction and phasing of the input displacements to the core support plates and core barrel. The assumed input displacement functions are analytically defined in Table 2.1.1. For the first case, CASE1, the displacement function is a simple sine wave with a frequency of 3 hz and an initial velocity of 9.425 in/sec which is imposed on both the upper and lower core plates. The displacement function for the second case is divided into two parts with CASE2A, the first part, having an amplitude four times less than the second part, CASE2B. The displacement function is a combined sine wave having three components with the frequency content of 3.183, 15.9 and 86 hz. A time delay of 0.006 seconds is imposed on the displacement functions applied to the upper and lower core plates. Figures 2.1.2 and 2.1.3 show the core plates input displacement functions for CASE1 and CASE2B.

2.2 SPACER GRID DESCRIPTION

A schematic diagram given for the sample problem showing how the load deflection characteristics are defined is shown in Figure 2.2.1 for both the in-grid and through-grid spacer load-deflection responses. The through-

Table 2.1.1 Input Displacement Functions

Case	Input Displacement Function
1	$X_U(t) = 0.5 \sin 18.85t$ $\quad \dot{X}_U(0) = 9.425$ in/sec
	$X_L(t) = X_U(t)$
2	$X_U(t) = A\,(1.0 \sin 20.0t + 0.5 \sin 100.0t$
	$-0.1296 \sin 540.0t) \quad t \geq 0$
	$X_U(t) = 0 \quad t < 0$
	$X_L(t) = X_U(t-\Delta t) \quad t = 0.006 \quad$ All t.
2A	$A = 0.05$
2B	$A = 0.20$

where: t = seconds

X = displacements

U = upper core plate

L = lower core plate

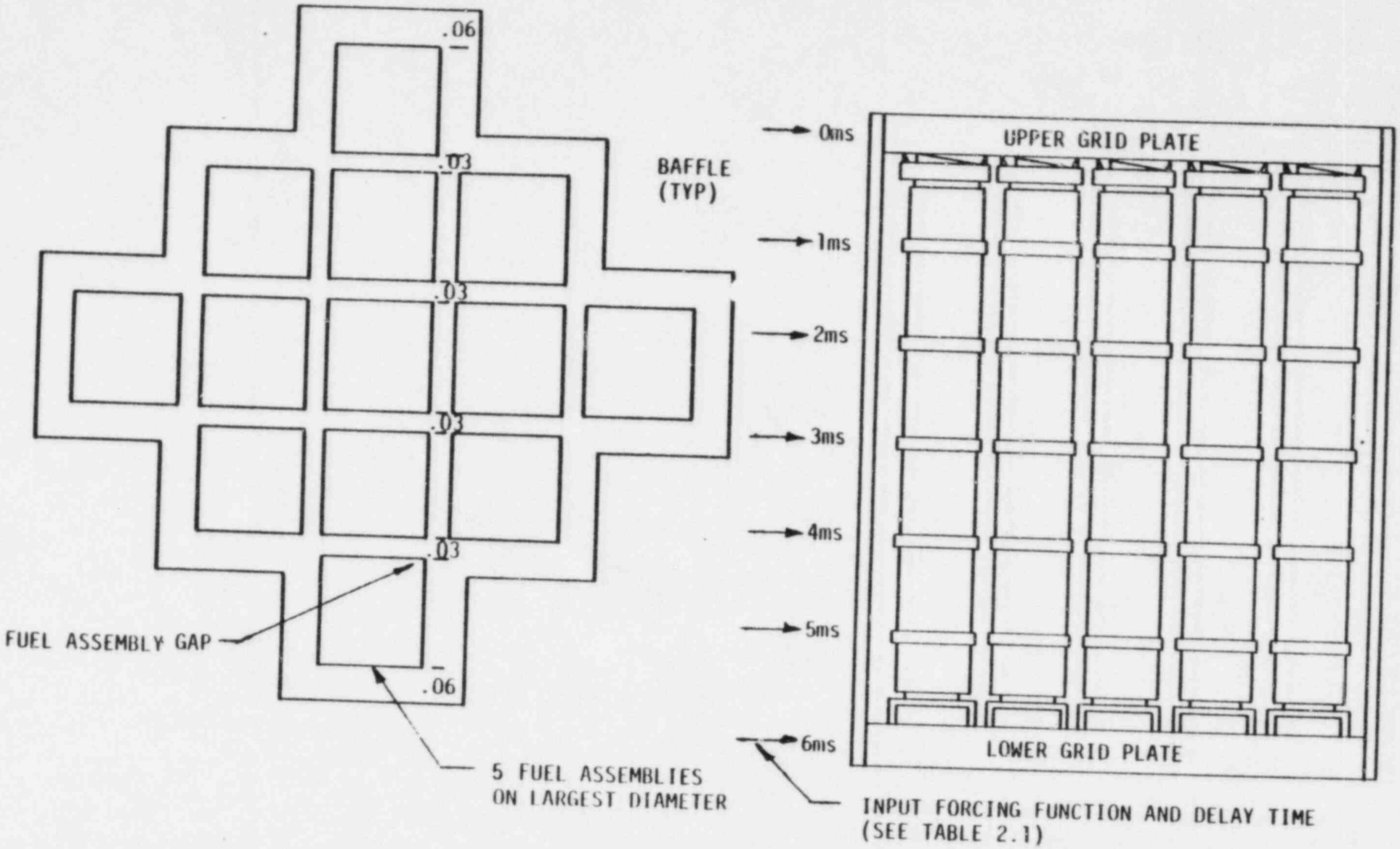

Figure 2.1.1 Reactor Core Cross Section

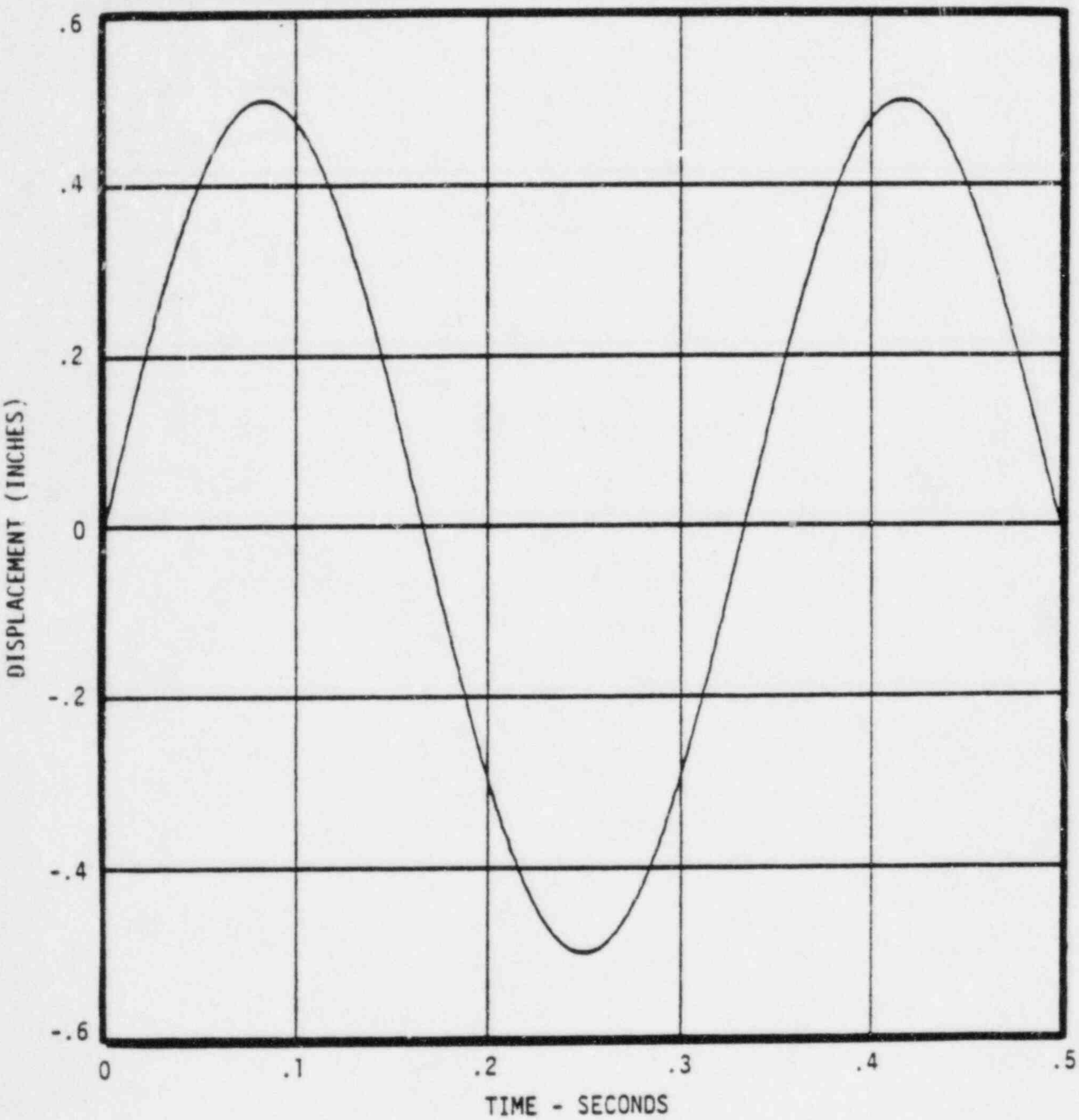

Figure 2.1.2 CASE1 Sine Input

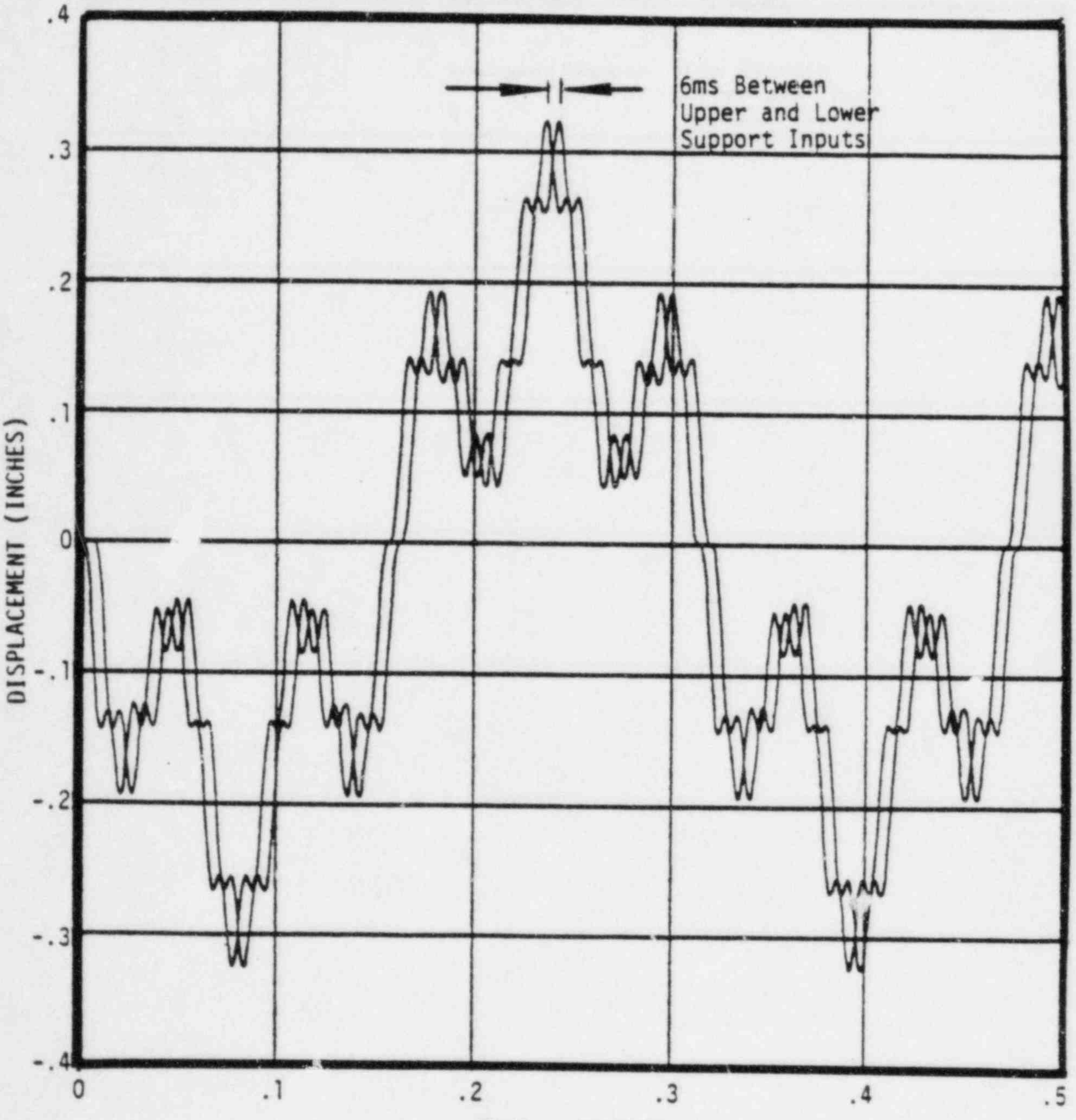

Figure 2.1.3 CASE2B Three Frequency Sine Wave Input

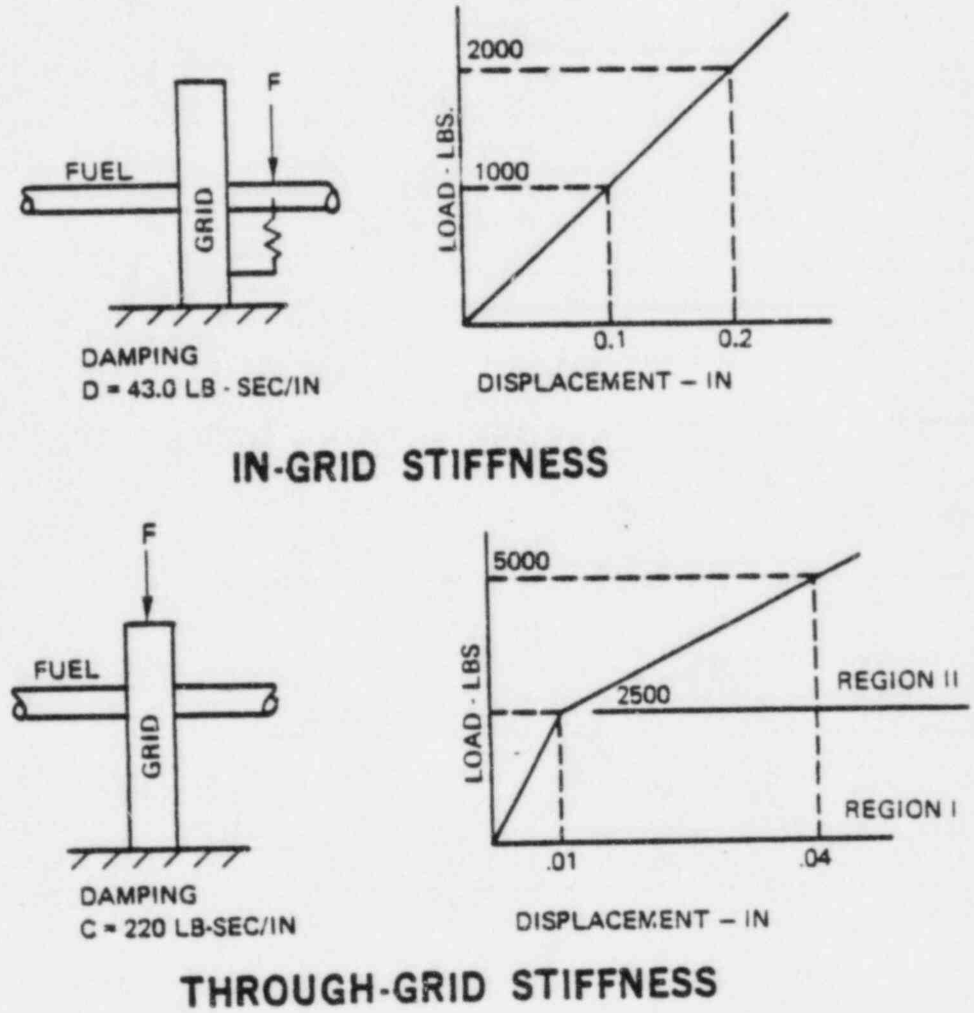

Figure 2.2.1 Spacer Mechanical Properties

grid stiffness is bi-linear which represents the possible collapse of the spacer grid. Viscous damping values are also given for the in-grid and through-grid loading conditions. The viscous damping in the through-grid response is only activated when the gaps between the spacers are closed.

2.3 FUEL ASSEMBLY DESCRIPTION

The fuel assembly's length and spacer locations are shown in Figure 2.3.1. The fuel assembly's weight is 1,855 lbs with its mass distribution given as lumped masses located at nodal locations. The cross sectional dimensions of the fuel assembly (such as cladding diameters) are not given because the sample problem is setup so that the primary deformations of the fuel assembly can be modeled with prescribed fuel assembly characteristics. Accordingly, the stiffness characteristics are defined by a load deflection curve and a frequency response, specifically:

- The bi-linear load-deflection curve shown in Figure 2.3.1 and,
- The clamped-clamped natural frequencies of 3, 5, 7, 9 & 11 hz.

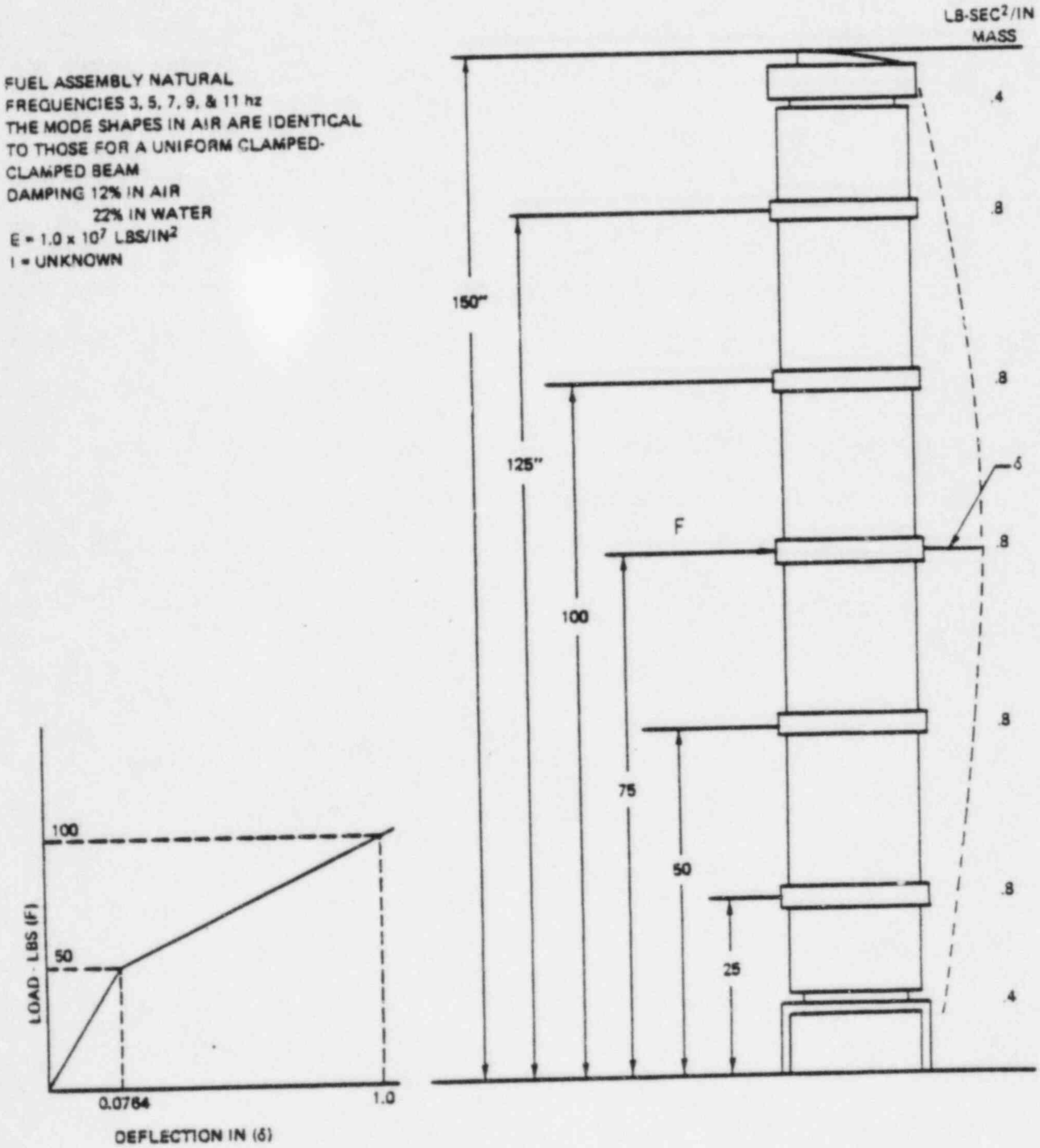

Figure 2.3.1 Fuel Assembly Mechanical Properties

3.0 ENC'S FORMULATION OF THE NRC SAMPLE PROBLEM

3.1 FORMULATION OF THE REACTOR CORE MODEL FOR EVALUATION WITH NASTRAN

The structural reactor core model for a row of fuel assemblies with core plate motion excitation and assembly-assembly or assembly-core barrel impact can be evaluated with NASTRAN. The linear scalar elements and the modal shape functions are used to represent the dynamic characteristics of the fuel assemblies. The modal dynamic characteristics of the fuel assemblies are transformed into mass, damping and stiffness matrices in terms of the physical coordinates with the multiple restraint conditions. The impact forces acting on these assemblies from the grid spacer and gap impact requires the use of non-linear scalar elements evaluated in terms of the physical coordinates. The resultant system structural model considering the excitation by the motion of the core plates can be evaluated using existing evaluation features of the MSC/NASTRAN(1) code. The five fuel assembly reactor core model is shown in Figure 3.1.

3.2 STRUCTURAL MODEL FOR THE IMPACT RESPONSE OF THE SPACER GRIDS

The fuel rods and control rod guide tubes are separated by spacer grids. The outer surfaces of these spacer grids extend beyond the bounding surfaces of the fuel rods and are laterally aligned with one another. Thus, the spacer grids are the structural components that contact one another or the core barrel when the lateral excitation of the fuel assemblies is sufficient to cause impacts. The spacers are fabricated from thin strips and contain springs and dimples which space the fuel rods. Thus, the grid spacers are

flexible structures which can deform with respect to their bounding strips, through-grid deflections, and with respect to relative spacing of the fuel rods and the bounding grid structure, in-grid deformations. The majority of the mass of the fuel assembly is situated in the fuel rods, the spacer grid impact model has low mass or inertial loads associated with its deflection.

To model the effects of the gaps, in-grid and through-grid deformations and damping requires a multi-element non-linear model for the spacer grid impact model. The application of this model requires that an additional coordinate be assigned to each spacer. The system model can be formulated for the through-grid response in terms of relative displacements of these extra coordinates. The spring in the through-grid model is active only when the gap between spacers is closed and is bi-linear to account for the collapse or buckled response. The dash pot in this model is also non-linear in that it is only activated when the gap is closed. The resultant model yields the same type of physical response as proposed by Grubb and Saffell.[3] The schematic representation of the non-linear through-grid model is presented in Figure 3.2.1. This model is an adaptation of spacer grid impact models that have been previously used.[3,4,5] The deformations of the fuel assembly are associated with the movement of the fuel rods. The fuel rods are connected to the spacer grid structure locations by the in-grid stiffness, see Figure 3.1 which accounts for the relative movement of the fuel with respect to the spacer grid.

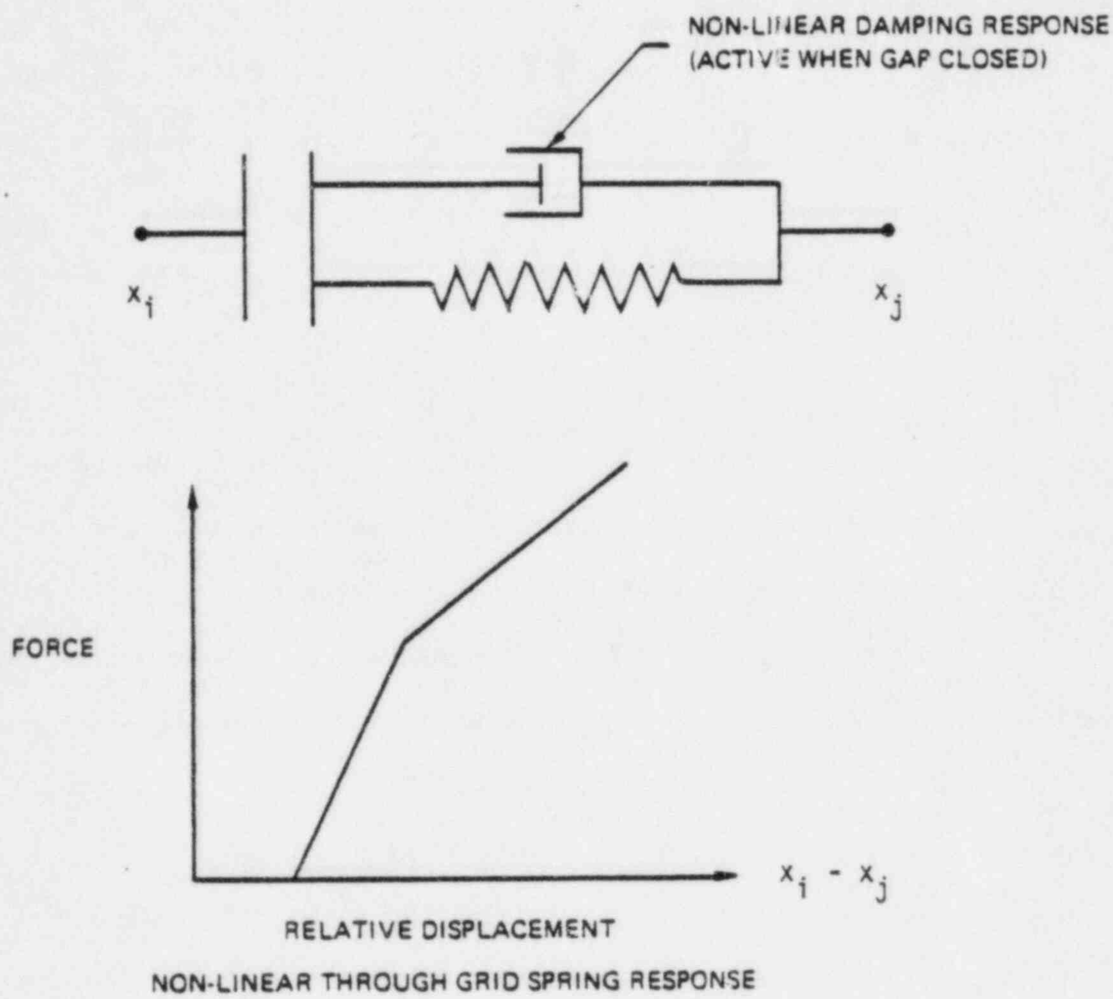

Figure 3.2.1 Application of the Through-Grid Response in the Structural Response Model

3.3 STRUCTURAL MODEL OF THE FUEL ASSEMBLY USING THE MODAL SYNTHESIS METHOD

ENC's general evaluation model uses the modal synthesis approach to develop the structural model for the fuel assembly. In the modal synthesis representation, the vibrational modal shapes and frequencies of the structure in a selected frequency range are used as the degrees of freedom. This type of structural representation permits the number of degrees of freedom of the structural or physical model to be reduced while the accuracy of the dynamic response in the selected frequency range is maintained.

Either an eigenvalue analyses or experimentally determined results that yield the natural frequencies and mode shapes can be used to form the modal representation of the structure. In the eigenvalue analysis method, the non-forced vibrations of the structure are:

$$([K]-\lambda[M])\{u\} = 0 \tag{1}$$

where:

$\{u\}$ = a set of the displacement vectors for each modal shape

λ = ω_n^2 which is the square of the natural frequencies

[K] and [M] are the free-free stiffness and mass matrices

The above displacement vectors $\{u\}$ for each mode are combined to make the modal matrix $[\phi]$.

Use of the fuel assembly represented by its vibration modes in the reactor core model requires information about the relation between the fuel assembly modal excitation and the physical motions at the core plate supports and at spacer locations. The required data for this modal modeling procedure are the natural frequencies $[\omega_n^2]$, the modal matrix or eigenvectors $[\phi]$, the modal masses of the fuel assembly and the modal damping. The displacements at connection boundaries and at spacer locations are designated by $\{X_c\}$. The displacements of these points are related to the modal coordinates $\{\xi_i\}$ of the fuel assembly by:

$$\{X_c\} = [\phi_{ci}]\{\xi_i\} \tag{2}$$

where:

ξ_i = the ith mode amplitude, modal coordinates

X_c = connection points, physical coordinates

The displacements at the grid locations are required to determine impact forces between spacers or between spacers and the core barrel.

This modeling procedure was applied for the sample problem (see Appendix A). The columns of the modal matrix $[\phi_{ci}]$ are given in Table 3.3.1. The modal masses, modal stiffnesses, modal damping and modal frequencies, are given in Table 3.3.2. Equation (2) provides the basic relations needed to formulate the modal synthesis model in terms of the physical coordinates at the connection points and spacer locations. This modal synthesis model is used for each assembly in the reactor core model (see Figure 3.1).

4.0 DIRECT TRANSIENT ANALYSIS PROCEDURE

The final set of equations of motion in physical coordinates for the five assembly model shown in Figure 3.1 which includes the spacer grid non-linear force from Figure 3.1.1 is:

$$[M]\{\ddot{x}\} + [B]\{\dot{x}\} + [K]\{x\} = \{P_1(t)\} + \{P_n\} \tag{4}$$

where:

$[M]$ = mass matrix

$\{x\}$ = a set of physical coordinates expressed as a column matrix of one term for each node point

$[B]$ = damping matrix

$[K]$ = stiffness matrix

$\{P_1(t)\}$ = is the time-dependent applied force vector*

$\{P_n\}$ = is a vector of non-linear forces which are a function of $\{x\}$ and $\{\dot{x}\}$ to model the gaps and one way impact damping

The Direct Transient Analysis capability Rigid Format No. 27 of MSC/NASTRAN was used to solve the equations of motion. MSC/NASTRAN Rigid Format No. 27 was used to evaluate the impact between fuel assemblies. The applied non-linear forces, P_n are evaluated with this option as the variations from a linear response for the spacer grid elements shown in Figure 3.1. This

* The input sine displacements time histories Table 2.1.1 are converted to forces by NASTRAN.

solution technique eliminates the traditional approach of re-formulating the stiffness matrix for each successive time step. Rigid Format No. 27 uses the Newmark-Beta(2) direct integration procedure.

A nominal time step of Δt = 0.1 ms was used for these analyses. The effect of this time step on the Newmark-Beta integration procedure was checked by making comparative runs with the time step altered by   The results from these runs were approximately identical and no convergence or stability problems were encountered.

5.0 ANALYSIS RESULTS

The response evaluation of the core structural model shown in Figure 3.1 was performed using the sine forcing functions given in Table 2.1.1. The maximum displacement, velocity and acceleration inputs for the sine forcing functions are shown in Table 5.1. The cases run are summarized below:

Run	Spacer Grid Impact Damping lb-sec/in	Fuel Assembly Damping % Critical
CASE1	220.0	22
CASE2A	220.0	22
CASE2B	220.0	22

The results of the grid impact forces are presented in Tables 5.2 through 5.4. These maximum impact forces are identified by a fuel assembly schematic with fuel assembly and row numbers noted. The forcing function fuel assembly and baffle displacements were applied for 0.5 seconds and the maximum grid impact forces were assumed to occur during this period.

Table 5.2 shows the grid impact forces for the symmetric loading of CASE1. The response is close to symmetric about Row No. 3 and there is some buildup of impact forces in direction of the input forcing function. These results for CASE1 are in agreement with those presented in Reference (5), Appendix F. The maximum grid impact forces are shown in Tables 5.3 and 5.4

Table 5.1 Maximum Inputs

Loading*	Displacement inch	Velocity in/sec	Acceleration g's
Case 1	.500	9.425	0.46
Case 2A	.0814	6.587	5.55
Case 2B	.326	26.35	22.22

* See Table 2.1.1 for sine functions.

for the asssymmetric loading conditions of cases CASE2A and CASE2B on the upper and lower core plates and baffle. The impact forces for CASE2A fall into Region I, Figure 2.2.1 and 3.1.1, and the higher impact forces for CASE2B fall into Region II for the bi-linear response of the spacer grid model. The grid impact forces exceeding 2,500 pounds indicate that the bi-linear property of the spacer grid model was exercised.

The dynamic responses of the middle spacer with impact forces between the fuel assembly and baffle, fuel assembly relative and total displacements and spacer in-grid (stiffness) element forces are shown in Figures 5.1 through 5.9. (See Figure 3.1 for assembly and grid locations given in these figures.)

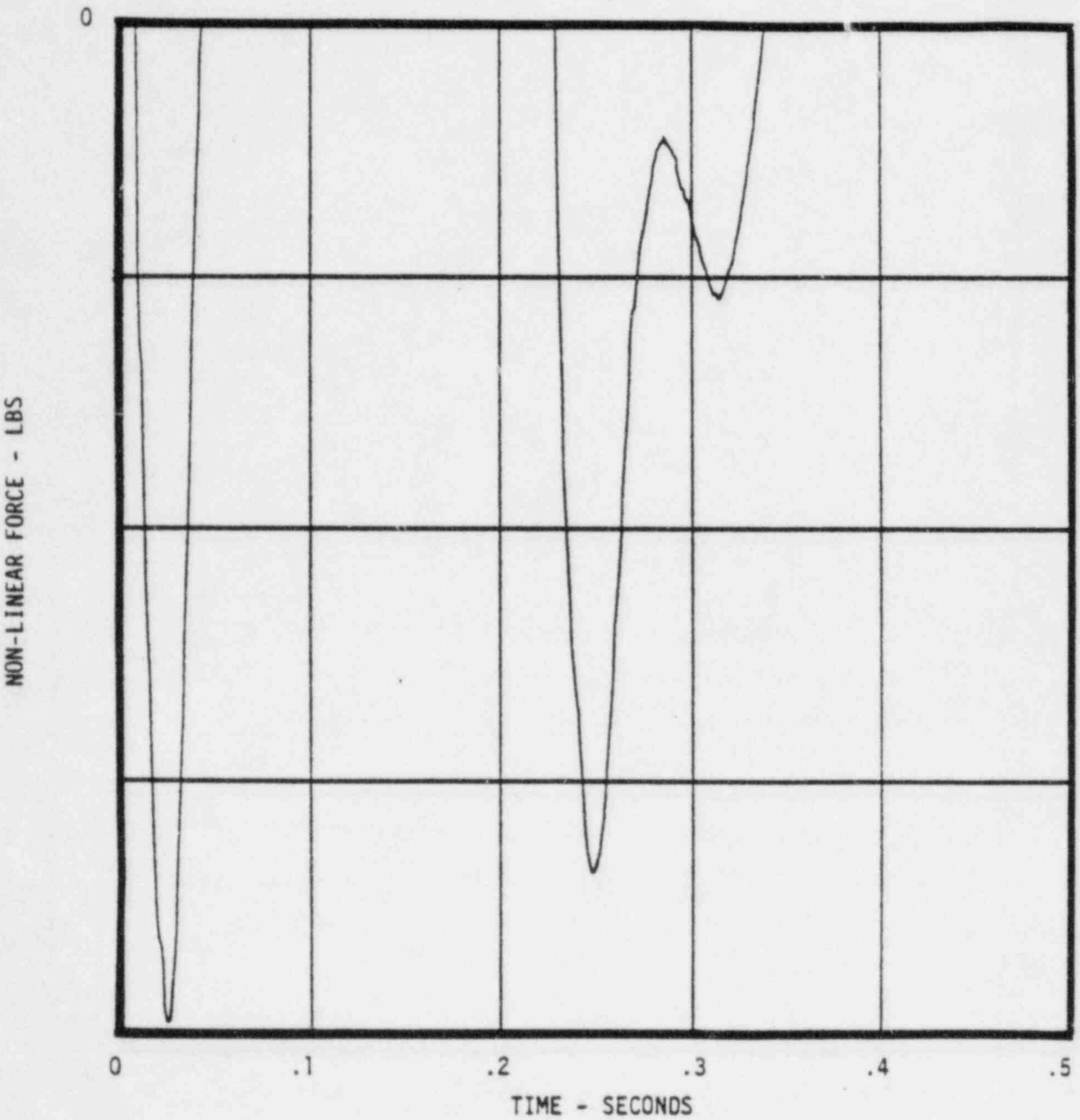

Figure 5.1 Impact Force Between Fuel Assembly No. 11 and Baffle at Row No. 3 - CASE1

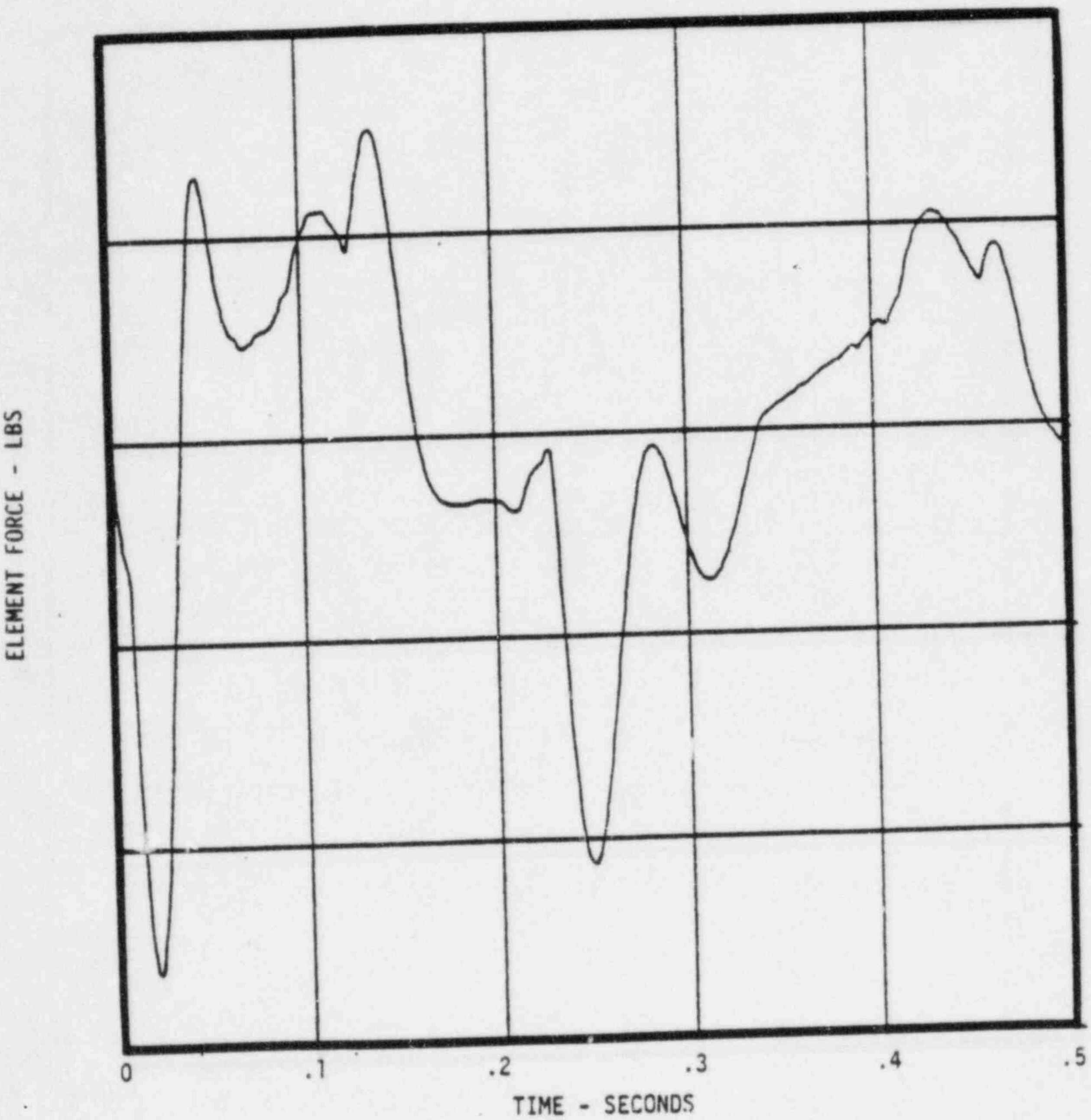

Figure 5.2 Element Force Due To In-Grid Stiffness
Fuel Assembly No. 11 At Row No. 3 - CASE1

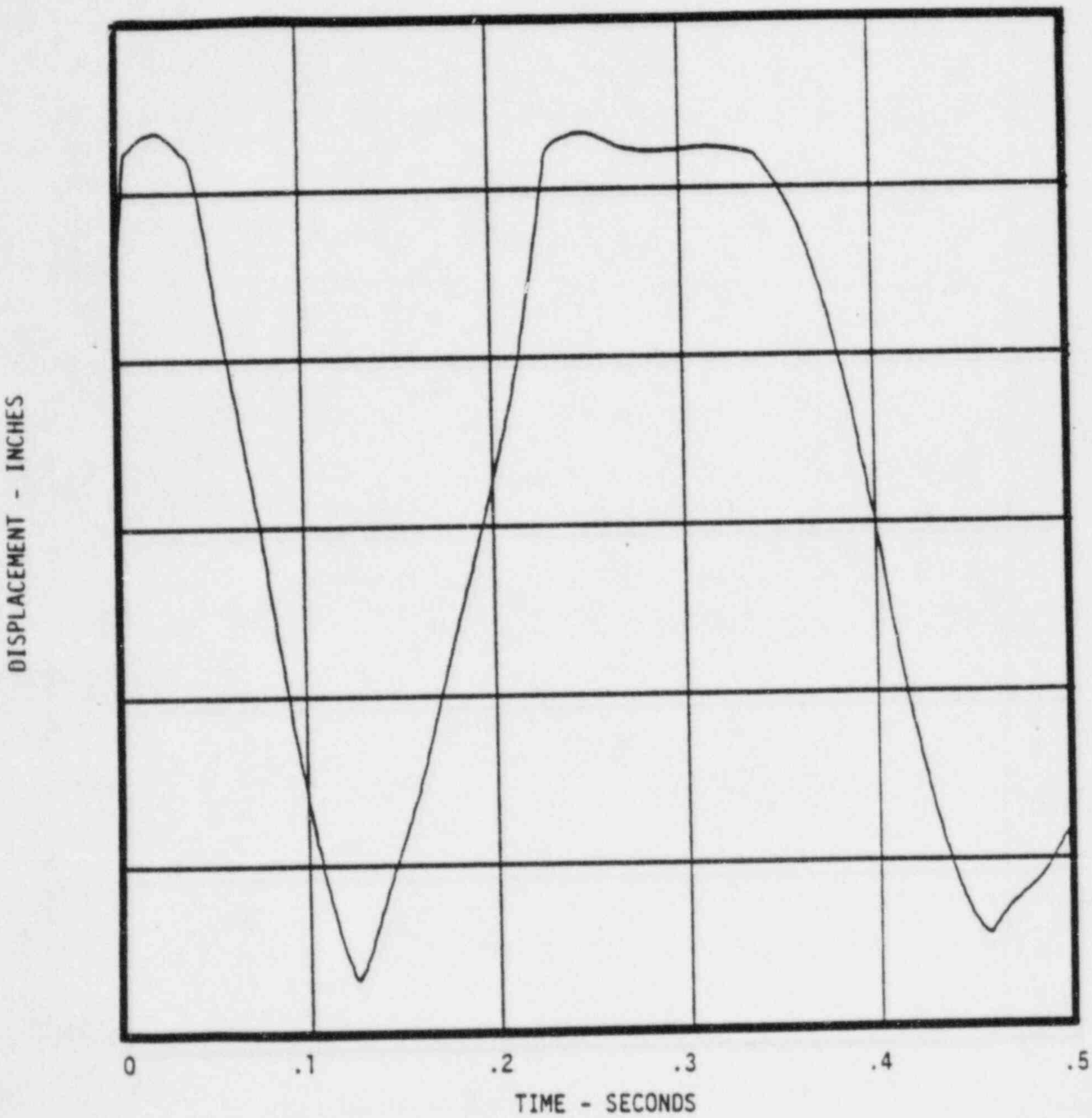

Figure 5.3 Displacement of Fuel Assembly No. 11 Relative To Baffle At Row No. 3 - CASE1

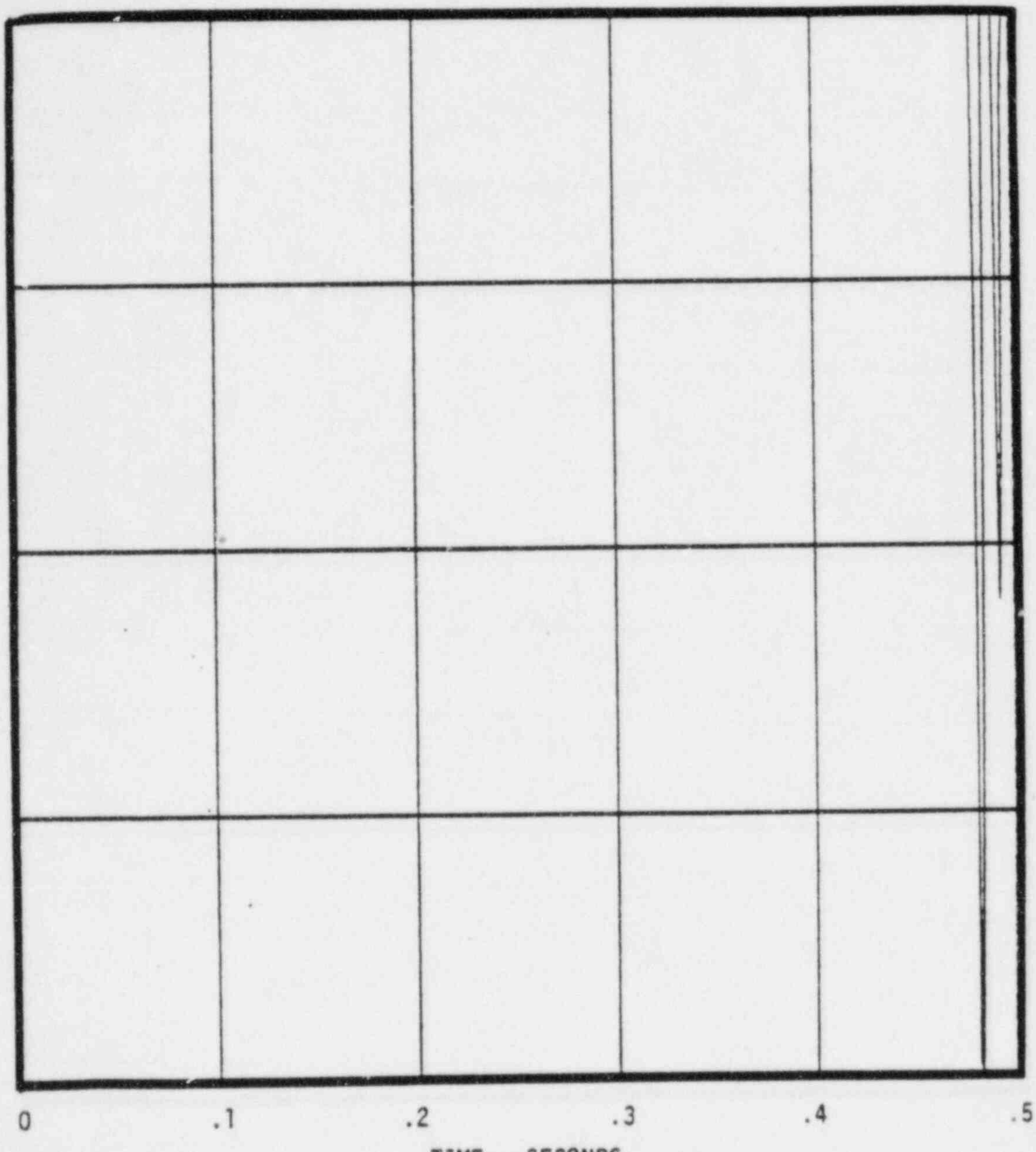

Figure 5.4 Impact Force Between Fuel Assembly No. 11 and Baffle at Row No. 3 - CASE2A

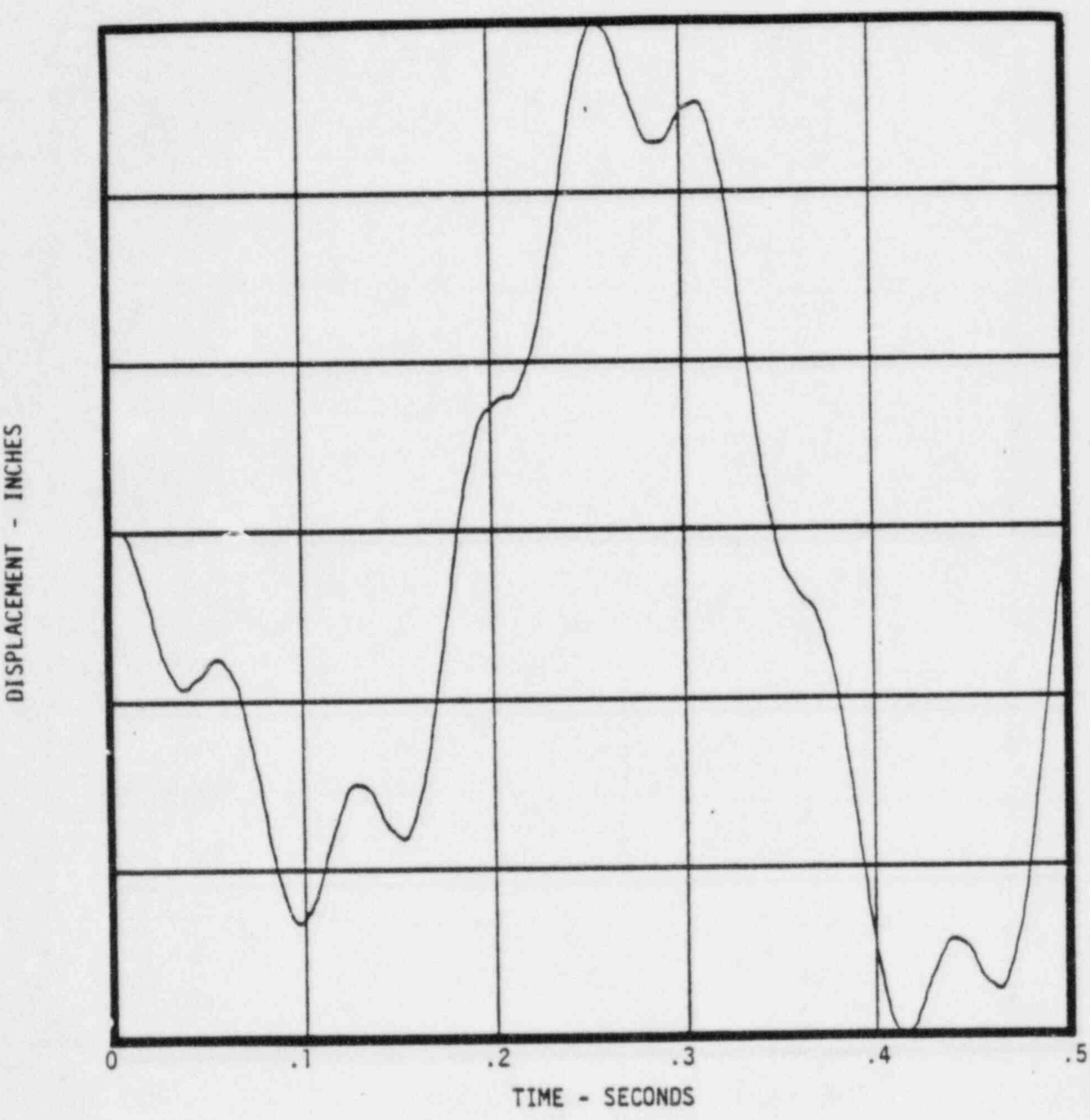

Figure 5.5 Total Displacement - Fuel Assembly No. 11 At Row No. 3 - CASE2A

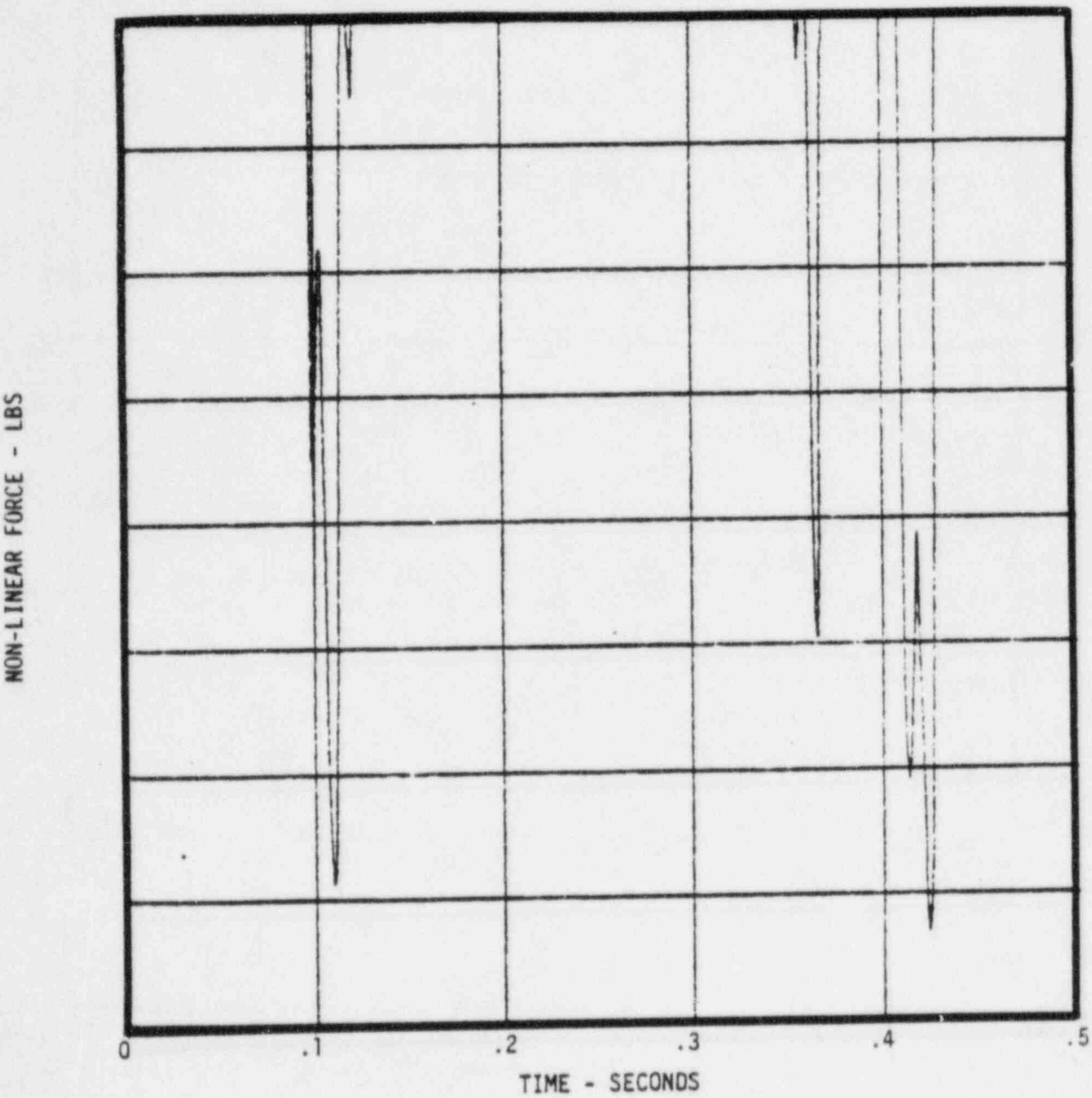

Figure 5.6 Impact Force Between Fuel Assembly No. 11
and Baffle at Row No. 3 - CASE2B

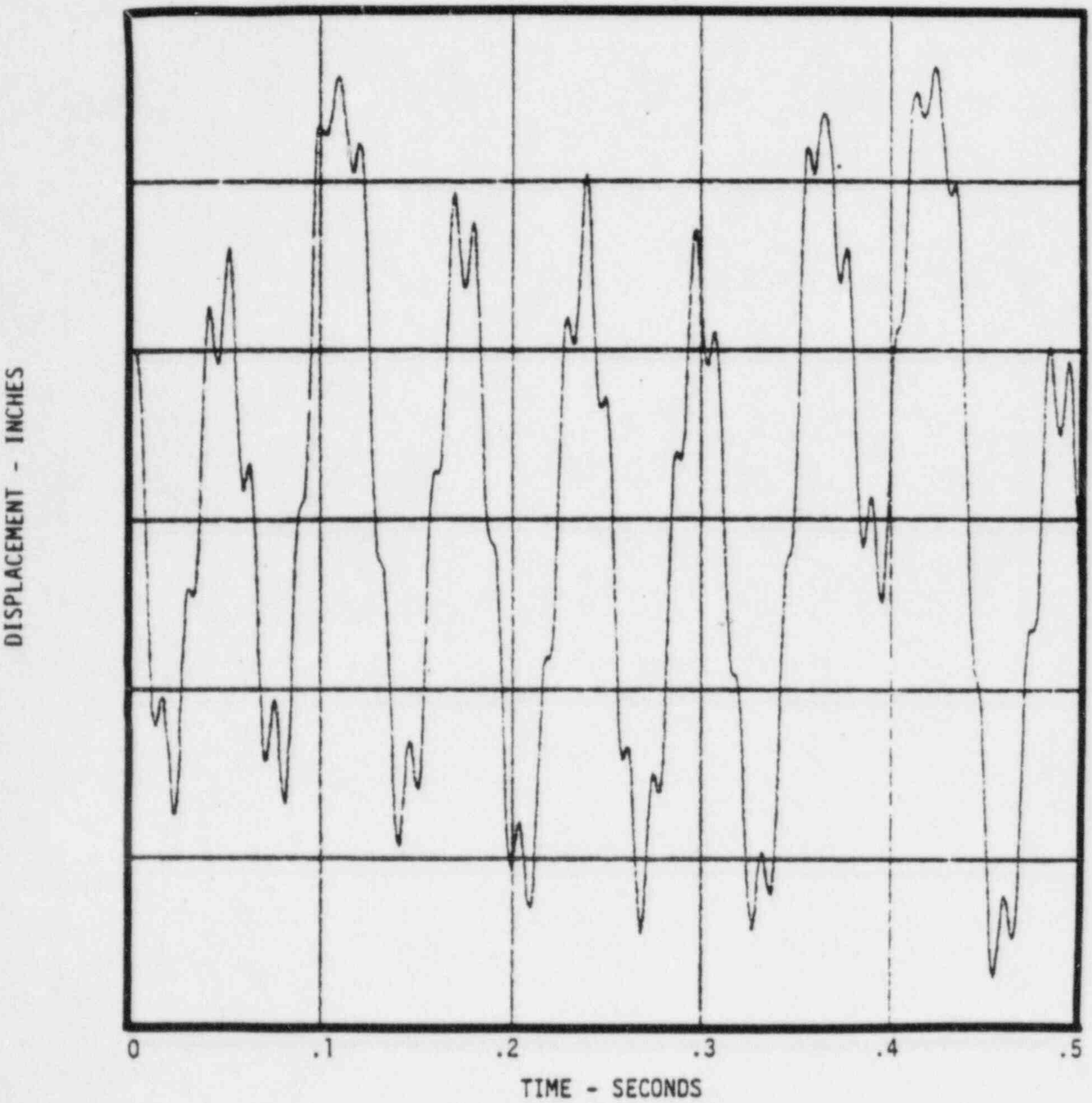

Figure 5.7 Displacement of Fuel Assembly No. 11 Relative to Baffle at Row No. 3 - CASE2B

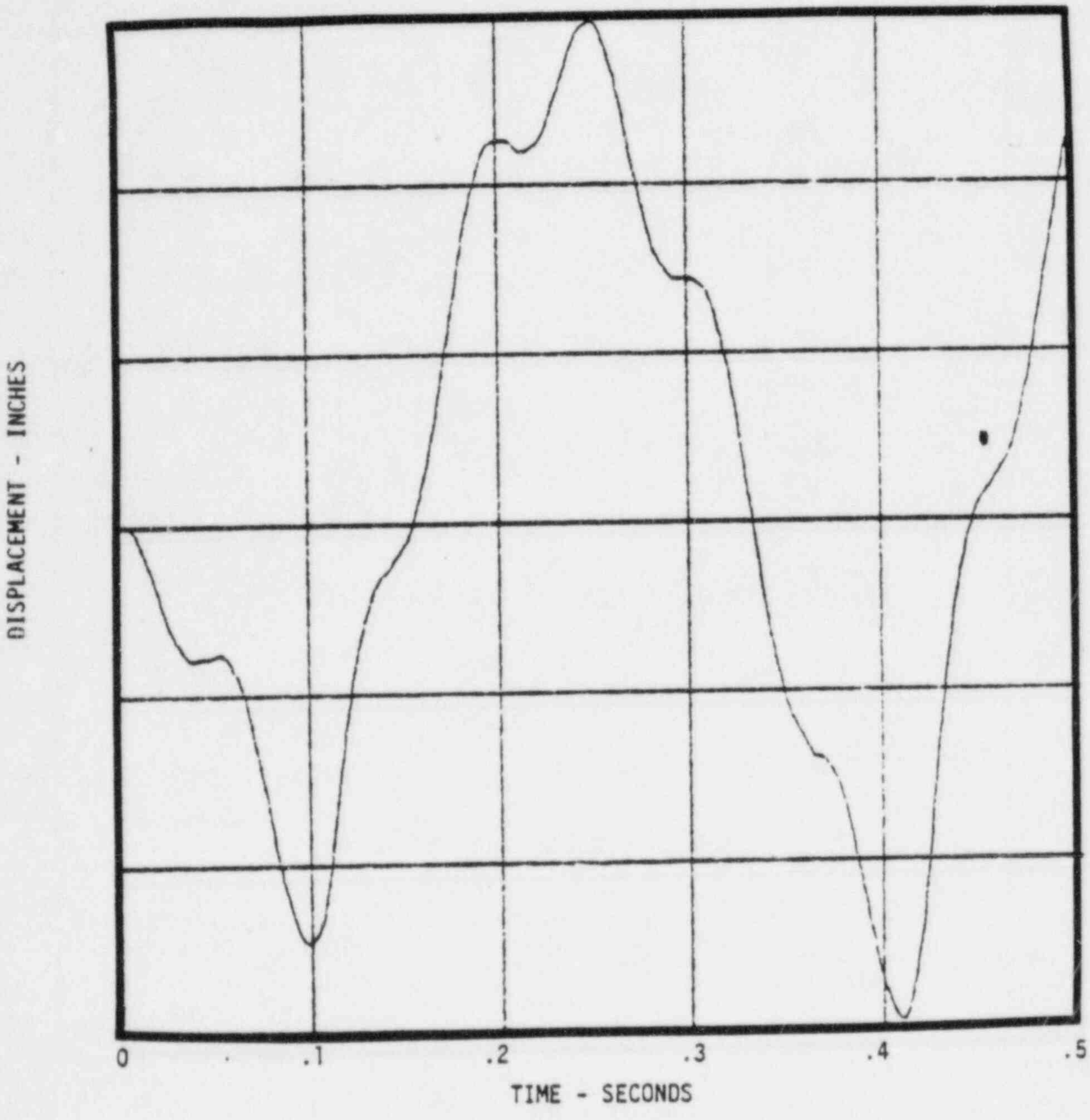

Figure 5.8 Total Displacement Fuel Assembly No. 11 at Row No. 3 - CASE2B

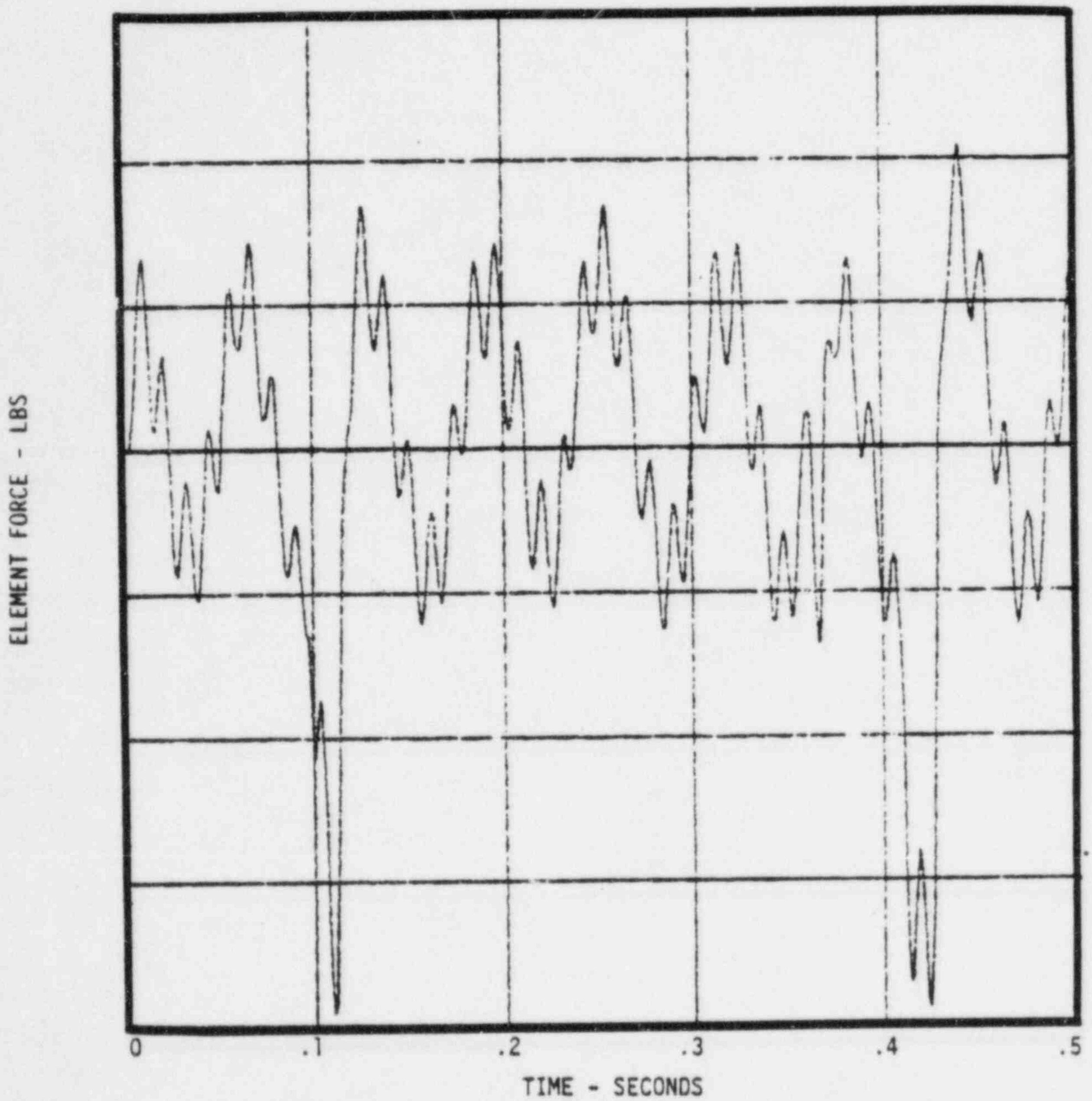

Figure 5.9 Element Force Due To In-Grid Stiffness
Fuel Assembly No. 11 at Row No. 3 - CASE2B

6.0 CONCLUSIONS

A modal synthesis substructure model of the fuel assembly has been described. This modal formulation method has application in developing the fuel assembly substructure model from experimental results.

The grid impact forces have been calculated with MSC/NASTRAN using the program's non-linear elements.

The results of CASE1 are in agreement with the FAMREC results, Reference (5), Appendix F.

7.0 REFERENCES

1. C.W. McCormick, MSC/NASTRAN Basic Training Manual, MSR-46, July 1977, with

   NASTRAN Theoretical Manual
   MSC/NASTRAN User's Manual
   MSC/NASTRAN Programmer's Manual
   MSC/NASTRAN Application Manual

2. R.W. Clough and J. Penzien, Dynamics of Structures, McGraw Hill, 1975.

3. R.L. Grubb and B.F. Saffell, Jr., Non-Linear Lateral Mechanical Response of Pressurized Water Reactor Fuel Assemblies, 77-WA/DE-18, August 1977.

4. H. Numo, M. Mizata and N. Tsumura, Development of Advanced Method For Fuel Seismic Analysis, D416, SMiRT-4, San Francisco 1977.

5. R.L. Grubb, Pressurized Water Reactor Lateral Core Response Routine, FAMREC (Fuel Assembly Mechanical Response Code), NUREG/CR-1019, September 1979.

APPENDIX A

THE MODAL MATRIX [ϕ]

A modal matrix [ϕ] was constructed using a free-free uniform beam with modal shape functions that define seven nodal displacements and two rotations in terms of the modal degrees of freedom. Uniform beam segments with lumped masses and rotational inertias were used in the model for the mass inertial properties. This resultant modal matrix may be used to represent the frequency response for a clamped-clamped uniform beam since the non-zero natural frequencies for the two sets of boundary conditions are identical*. In the ENC analysis procedure, the boundary coordinates are not fixed as they are for the clamped-clamped boundary condition but must be free to use the general ENC evaluation procedure to satisfy input displacement conditions at the core plates. The rotational coordinates however are fixed for the reactor structural model application and are fixed in the solution procedure by restraint equations. Because of the need to subsequently prescribe the boundary conditions, the modal model of the free-free fuel assembly is modeled in the sample problem with two free body modes and seven modal frequencies which are related to the seven translation and two rotational coordinates. The end translation

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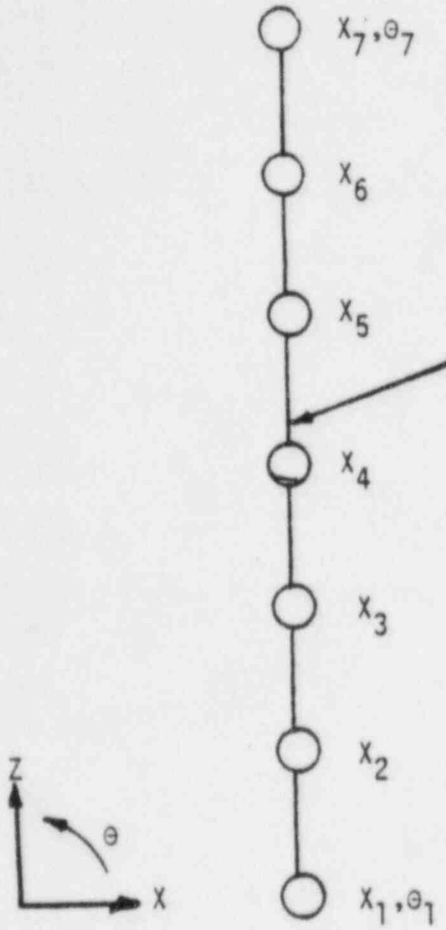
* W.T. Thomson, Mechanical Vibrations, Prentice-Hall, 1958, pp. 217.

and end rotation coordinates are explicitly included to allow for the satisfaction of boundary conditions. Table 3.2.1 shows the modal matrix [ϕ] which was calculated with the MSC/NASTRAN code. This matrix was taken from the eigenvalue analysis (natural frequency) of a uniform beam representing the NRC sample problem, see Figure A.1.



BOUNDARY CONDITIONS ARE FREE-FREE

ASSUMED STRUCTURAL MODEL TO DETERMINE MODAL MATRIX $[\phi_{ci}]$

BOUNDARY DISPLACEMENTS X_1, X_7

BOUNDARY ROTATIONS Θ_1, Θ_7

SPACER NODES X_2 THROUGH X_6

Figure A.1 Free-Free NASTRAN Structural Model

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May 24, 1984
JCC:083:84

Dr. Cecil O. Thomas, Chief
Standardization and Special Projects Branch
Division of Licensing
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

SUBJECT: XN-NF-696(P), "ENC's Solution to the NRC Sample Problems - PWR Fuel Assemblies Mechanical Response to Seismic and LOCA Events;" Response to Request for Additional Information

Ref.: Letter, R.A. Copeland (ENC) to C.O. Thomas (NRC), dated June 23, 1983; RAC:025:83.

Dear Dr. Thomas:

Enclosed for your use are twenty-two copies of ENC's response to your consultant's question regarding the subject ENC topical report. This response provides clarification of the methods used by ENC in the structural analysis of PWR fuel.

Exxon Nuclear considers information contained in the enclosure to be proprietary. In accordance with the Commission's Regulation 10 CFR 2.790(b), the Affidavit enclosed with the reference letter covering the initial issue of the subject report provides the necessary information to support the withholding of these responses from public disclosure.

If you have any questions regarding this submission, please feel free to contact me, telephone (509) 375-8639.

Sincerely,

J.C. Chandler

J.C. Chandler, Lead Engineer
Reload Fuel Licensing

cc: Mr. B. L. Harris (EG&G Idaho)
Mr. David Moran (NRC)

Response to NRC Questions

Following are the EG&G questions, and the ENC responses, pertaining to XN-NF-696, "ENC's Solution to the NRC Sample Problems - PWR Fuel Assemblies Mechanical Response to Seismic and LOCA Events."

1. The EG&G analysis showed much higher spacer grid forces than the ENC analysis at locations away from the points of maximum contact force, etc.

   Response

   The standard problem presented by the NRC is open to several interpretations or possible solutions. Any of these solutions may be correct depending on the initial assumptions made in developing the mathematical problem.

   Exxon Nuclear has viewed the problem as a fuel assembly with mode shapes consistent with those of a uniform beam and stiffness properties yielding frequencies of 3.0, 5.0, 7.0, 9.0 and 11.0 CPS. Using the procedure developed at Exxon for modeling fuel assemblies, a 60 degree-of-freedom model was generated and reduced to a 9 degree-of-freedom model. The resulting free-free mode shapes are presented in Table 3.3.1 of Reference 1, and are consistent with uniform beam theory. These mode shapes when constrained for the clamped-clamped condition are consistent with the problem definition. These mode shapes along with the above mentioned frequencies (these frequencies are inconsistent with an actual uniform beam) were input directly into the NASTRAN computer code. The grid impact model was merged with the beam model. The rotational coordinates at each end were constrained to zero and displacement time histories were prescribed at the end translational coordinates. Appropriate convergence studies were performed to insure correctness and stability of the solution.

   EG&G has also viewed the problem (Reference 2) as a beam with clamped-clamped uniform beam mode shapes and frequencies in this condition of 3.0, 5.0, 7.0, 9.0 and 11.0 CPS. EG&G has prescribed relative accelerations instead of displacements and performs all calculations in relative coordinates.

   Several basic differences exist between the two approaches. Two of the important differences in the analysis methods are, how the assumed baffle deflection is accounted for and how the error bounds of the impact force calculations are treated, by the calculational procedures. The calculational procedure used in FAMREC to apply the input forcing functions assumes that the core baffle maintains the static deflected shape of the fuel assemblies. The calculational procedure used in NASTRAN makes no assumption concerning the shape of the core baffle, it is considered a rigid body. The error tolerance for impact load computation is user controlled in FAMREC. The Newmark Beta method of integration, which is unconditionally stable with respect to the calculated impact loads, is used in NASTRAN. A summary of effects of these differences is presented below:

Analysis Differences

Item	Exxon	EG&G	Estimated Difference
Baffle Deflection	No effect	Ref. 2, Page 6	~10-20% on load near baffle
*Error Tolerance	No effect	(2)(227273)(.0008) = 364 lbs	14% on peak load

* Error tolerance calculated from Reference 2, Page 33, Equation 20 and information from Reference 2, Appendix F.

The differences discussed are by no means the only ones existing between the two approaches; however, they are reviewed as potentially the most significant differences.

Exxon feels that the answers presented in Reference 1 are sufficiently close to those calculated by EG&G to validate the methods used by Exxon. The large number of differences between the Exxon and EG&G model is easily sufficient to explain any variance in the answers. Exxon recognizes that large differences exist for some of the smaller calculated impact loads. This is not uncommon in non-linear analysis of this type. This is not viewed as a significant problem since the maximum impact load is used to assess the structural integrity of all the spacer grids in the core.

REFERENCES

(1) R.G. Hill, "ENC's Solution to the NRC Sample Problems - PWR Fuel Assemblies Mechanical Response to Seismic and LOCA Events," Exxon Nuclear Report XN-NF-696, April 1983.

(2) R.L. Grubb, "Pressurized Water Reactor Lateral Core Response Routine, FAMREC (Fuel Assembly Mechanical REsponse Code)," Idaho National Engineering Laboratory, NUREG/CR-1019, September 1979.

(3) B.L. Harris, "Review of Exxon Nuclear Company's Fuel Assembly LOCA-Seismic Response Reports XN-NF-81-51(P) and XN-NF-696," EG&G Idaho Report, Informal.

XN-NF-696(NP)(A)

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ENC's SOLUTION TO THE NRC SAMPLE PROBLEMS -

PWR FUEL ASSEMBLIES

MECHANICAL RESPONSE TO SEISMIC AND LOCA EVENTS

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