Appendix A

to

WCAP 9401/9402, "Verification Testing and Analyses of the Westinghouse 17x17 Optimized Fuel Assembly"

WEGAP VERIFICATION WITH THE USNRC SAMPLE PROBLEMS

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INTRODUCTION

Currently, two Westinghouse computer codes, namely WECAN and WEGAP, are used for obtaining the dynamic response solution of the reactor core in pressurized water reactors. The purpose of this report is to describe the general analytical features of these computer codes and to present a comparison of the results as verification of the WEGAP Code.

The WECAN computer program is a Westinghouse general purpose finite element computer program for various types of structural analyses. The mathematical formulation, computational procedures, and the verification of various types of benchmark problems have been extensively discussed in the Westinghouse topical report (reference 1). The use of WECAN to solve the suggested sample problems was submitted to USNRC as given in reference 2.

This report is devoted to the discussion of the NRC sample problem solution using the WEGAP computer program. The WEGAP program is a special computer code for obtaining core dynamic responses.

A specific Westinghouse computer code for core dynamic response analysis-WEGAP

The WEGAP computer program is a specialized finite element computer program designed to solve the dynamic responses of the reactor core in pressurized water reactors. The program treats the interactions between the fuel assemblies as applied psuedo forces in order to eliminate the traditional approach of reformulating the structural stiffness matrix at each successive time step. An iterative procedure used to check the convergence of the impact force has been incorporated into the code to assure that the dynamic response solution is properly derived. The computer program also utilizes the individual fuel assembly properties throughout the analysis to reduce the computer core storage requirements.

These improvements in the method of solution and computation procedure enable us to obtain the dynamic response solution for a reactor core subjected to asymmetric boundary conditions with very efficient numerical techniques.

The governing differential equations of motion for a reactor core are:

+(a,c)

The Newmark-Beta multistep direct integration method as described in Reference 3 is used to obtain the displacement solution at each successive time step. The required time increment which is one-fourteenth or less of the shortest period is needed to assure solution convergence. Figure 1 shows the flow diagram of the overall procedure for analyzing the postulated SSE or LOCA transients. The flow diagram of WEGAP program structure is given in Figure 1A.

Fuel assembly dynamic response for a hypothetical reactor core problem

The dynamic response solutions to these problems were initially requested by the NRC in order to qualify the nuclear fuel vendors' computer code features as well as the analytical capability. The dynamic response solutions to the sample problems using the Westinghouse general purpose finite element, WECAN,were documented in Reference 2.

Statement of Sample Problems

The suggested NRC problems are summarized in Table 1. The first problem has a prescribed initial velocity input sine wave. The second problem has a combination of three sine waves with zero initial displacement and velocity for both upper and lower core plates. The motions for the lower core plate indicate a 0.006 sec time delay in reference to the upper core plate.

The simplified reactor core cross-section is illustrated in Figure 1. The core consists of five (5) assemblies on the longest diameter. The peripheral fuel assembly to baffle gap and the internal fuel assembly gap are 0.06 in. and 0.03 in. respectively. The fuel assembly mechanical properties such as a description of the fuel assembly lateral stiffness, mass distribution, material property and dynamic characteristics are given in Figure 3. The fuel assembly spacer grid mechanical properties are presented in Figure 4.

Assumptions and Analytical Modeling

The following assumptions were employed in the processes of obtaining the dynamic response solutions of the postulated core analyses.

1. The non-linear fuel assembly stiffness characteristics as illustrated in Figure 3 were not incorporated into the fuel assembly model (Figure 5).

2. [ ]+(a,c)

+(a,c)

[ ]

3. The lumped mass-spring system was u ed to simulate the fuel assembly dynamic characteristics.

Based on these assumptions, the simplified fuel assembly model as shown in Figure 5 was constructed using the discrete mass distribution, the first five fundamental resonant frequencies together with their mode shapes, and the orthogonality relationship among normalized mode shapes. This simplified fuel assembly finite element model preserves essentially all the fuel assembly important dynamic characteristics. The listing of the finite element model corresponding to the damping assumption (A) is given in Table 2. It should be noted that the discrete mass point corresponds to the first nodal point of the defined spring-damper element.

The bilinear elastic-plastic spacer grid models are also given in Table 2.

The reactor core model was represented by five (5) fuel assemblies as schematically shown in Figure 2. The summary of the core cross-section model,and the designation of fuel assembly and spacer grid models are given in Table 3. The baffle motions at each individual grid elevation were linearly interpolated as the input for the core model between the upper core plate and lower core plate.

Analytical Results

An analytical evaluation of the core model given in Table 3 was performed using the forcing function designated as case 2 in Table 1. The results of the grid maximum force and time of mid-grid impact are summarized in Tables 4 through 6. Table 4 presents the grid maximum impact force for each grid ele ation for case 2A. The maximum response results correspond to a 0.5 sec. forcing function input. Both WEGAP and WECAN results were tabulated for the purpose of comparison. The transient responses obtained from the WEGAP core model compare extremely well with that from WECAN. The difference in peak grid force is well within 1%. The slight increase in impact force is attributed to the assumed grid weight of about 2 lbs.

The WEGAP results corresponding to the fuel assembly damping assumptions (A and B) are summarized in Table 5. The maximum impact force for each grid was screened from one second real time dynamic response results. The consideration of low damping coefficients at higher modes will slightly alter the dynamic response results.

However, the peak grid force does not show much difference for this particular example. The plots of the upper and lower core plate motions for Case 2A are shown as the dotted and solid lines respectively in Figure 6.

The dynamic response results of some selected fuel assembly positions - such as the fuel assembly relative displacements, total displacement, grid impact forces and fuel assembly support reaction forces are schematically shown in Figures 7 through 13.

A second analysis was performed using the forcing function designated as Case 2B as given in Table 1. This case was run to illustrate the non-linear feature of the WEGAP Code. The input upper and lower core plate motions are plotted as the dotted and solid curves respectively in Figure 14. The various dynamic response results are given in Figures 15 through 18. The maximum grid response results are summarized in Table 6. The grid impact force exceeding 2500 lb. would indicate that the bi-linear elastic feature of the grid model was utilized.

CONCLUSIONS

As a result of this comparison study, the following conclusions were noted:

1. The transient responses (grid impact forces, relative deflection, and support reaction force distribution) obtained from WEGAP core model compare extremely well with that from WECAN. The differences in the peak responses are well within 1%.

2. The numerical techniques used in the WEGAP Code requires mass values at all nodal point locations. Consequently, some small differences in impact force predictions between the WECAN and WEGAP Codes are inherent due to the modeling differences. However, for severe dynamic transients, the analytical responses predicted by the two codes become insignificant.

REFERENCES

1. "Benchmark Problem Solutions Employed for Verification of the WECAN Computer Program", WCAP 8929, Westinghouse, 1977.

2. Letter, T.M. Anderson to Dr. D.F. Ross, Jr., dated May 1, 1978 (NS-TMA-1772).

3. ASME Boiler and Pressure Vessel Code, Section III Division 1, Appendix N, Winter 1978 Addenda.

TABLE 1

FORCING FUNCTIONS

CASE	FORCING FUNCTION		
1.	$X_U(t) = 0.5 \sin 18.85t$		$\dot{X}_U(0) = 9.425$ IN/SEC
	$X_L(t) = X_U(t)$		
2.	$X_U(t) = A\,(1.0 \sin 20.0t + 0.5 \sin 100.0t - 0.1296 \sin 540.0t)$		$t \geq 0$
	$X_U(t) = 0$		$t < 0$
	$X_L(t) = X_U(t - \Delta t)$	$\Delta t = 0.006$	ALL t.
	(A) $A = 1/20$		
	(B) $A = 1/5$		

POOR ORIGINAL

TABLE 2 FUEL ASSEMBLY MODEL

+(a,c)

IMPACT PROPERTIES

PROPERTY SET NO. 1

IMPACT EL	GAP	STIF 1	DAMP 1	FMAX	STIF 2	DAMP 2
5	.60000E-01	.25[illegible]+06	220.00	2500.0	83300.	220.00
4	.60000E-01	.2[illegible]06	220.00	2500.0	83300.	220.00
3	.60000E-01	.2500[illegible]6	220.00	2500.0	83[illegible]0.	220.00
2	.60000E-01	.2500[illegible]	220.00	2500.0	83300.	220.00
1	.60000E-01	.2500[illegible]E+06	220.00	2500.0	83300.	220.00

PROPERTY SET NO. 2

IMPACT EL	GAP	STIF 1	DAMP 1	FMAX	STIF 2	DAMP 2
5	.30000E-01	.25000E+06	220.00	2500.0	83300.	220.00
4	.30000E-01	.25000E+06	220.00	2500.0	83300.	220.00
3	.30000E-01	.25000E+06	220.00	2500.0	83300.	220.00
2	.30000E-01	.25000E+06	220.00	2500.0	83300.	220.00
1	.30000E-01	.25000E+06	220.00	2500.0	83300.	220.00

TABLE 3 CORE MODEL

```
                    ----------------------------------
                     BAFFLE    NBRRL=1 LINEAR INTER.
                    ----------------------------------

                         IMPACT PROPERTY SET   1

                    **********************************
ASSEMBLY  1         *           MODEL 1              *
                    **********************************

                         IMPACT PROPERTY SET   2

                    **********************************
ASSEMBLY  2         *           MODEL 1              *
                    **********************************

                         IMPACT PROPERTY SET   2

                    **********************************
ASSEMBLY  3         *           MODEL 1              *
                    **********************************

                         IMPACT PROPERTY SET   2

                    **********************************
ASSEMBLY  4         *           MODEL 1              *
                    **********************************

                         IMPACT PROPERTY SET   2

                    **********************************
ASSEMBLY  5         *           MODEL 1              *
                    **********************************

                         IMPACT PROPERTY SET   1

                    ----------------------------------
                     BAFFLE
                    ----------------------------------
```

TABLE 4

WEGAP VERSUS WECAN GRID IMPACT FORCES - CASE 2A (0.5 sec. Response)

F/A Position	Max. Grid Load, Lbs					Time (Grid #3) Sec.
	Grid #1	Grid #2	Grid #3	Grid #4	Grid #5	
B-1	- (-)	390 (388)	563 (557)	424 (417)	- (-)	0.3195 (0.3198)
1-2	- (-)	185 (189)	381 (374)	261 (256)	- (-)	0.3200 (0.3200)
2-3	- (-)	48 (95)	174 (186)	103 (154)	- (-)	0.4262 (0.3143)
3-4	- (-)	94 (199)	172 (243)	143 (245)	- (-)	0.4260 (0.4198)
4-5	- (-)	218 (366)	375 (371)	356 (350)	- (-)	0.4250 (0.4250)
5-B	- (-)	420 (398)	582* (578)	576 (569)	41 (116)	0.4233 (0.4235)

(   ) Values in parenthesis are from WECAN Analysis

*   Maximum Grid Force

TABLE 5

WEGAP GRID IMPACT FORCE FOR F.A. DAMPING STUDY - CASE 2A (1 SEC RESPONSE)

F/A Position	Max. Grid Load, Lbs					Time (Grid #3) Sec.
	Grid #1	Grid #2	Grid #3	Grid #4	Grid #5	
B-1	61 (95)	545 (485)	569 (583)*	461 (444)	117 (146)	0.5755 (0.3195)
1-2	- (-)	243 (206)	381 (385)	261 (222)	- (-)	0.3200 (0.3200)
2-3	- (-)	82 (72)	174 (179)	103 (83)	- (-)	0.3210 (0.3210)
3-4	- (-)	94 (98)	172 (167)	143 (120)	- (-)	0.4260 (0.4260)
4-5	- (-)	218 (207)	375 (360)	356 (319)	- (-)	0.4250 (0.4250)
5-B	- (-)	449 (386)	582* (560)	576 (525)	69 (93)	0.4233 (0.4230)

F/A Damping: [ ]+ (a,c)

Value in Parenthesis: 22% damping (1st mode)
~10 High Modes

* Maxiumum Grid Force

TABLE 6

WEGAP VERSUS WECAN GRID IMPACT FORCE - CASE 2B 0.5 SEC RESPONSE

F/A Position	Max. Grid Load, Lbs.					Time (Grid #3) Sec.
	Grid #5	Grid #4	Grid #3	Grid #2	Grid #1	
B-1	2044 (2020)	2405 (2417)	1921 (1922)	2722 (2712)	2170 (2290)	0.1433 (0.1435)
1-2	1315 (950)	1693 (1720)	1402 (1399)	2163 (2150)	1561 (1550)	0.1433 (0.1435)
2-3	751 (778)	1188 (1215)	926 (922)	1499 (1484)	1024 (1022)	0.1433 (0.1110)
3-4	1033 (1030)	1713 (1703)	1475 (1467)	1728 (1720)	1022 (1446)	0.1090 (0.1090)
4-5	1682 (1680)	2493 (2481)	2101 (2084)	2320 (2316)	1587 (1586)	0.1070 (0.1075)
5-B	2414 (2407)	[illegible] (3167)	2847 (2845)	2813 (2803)	2362 (2407)	0.1053 (0.1050)

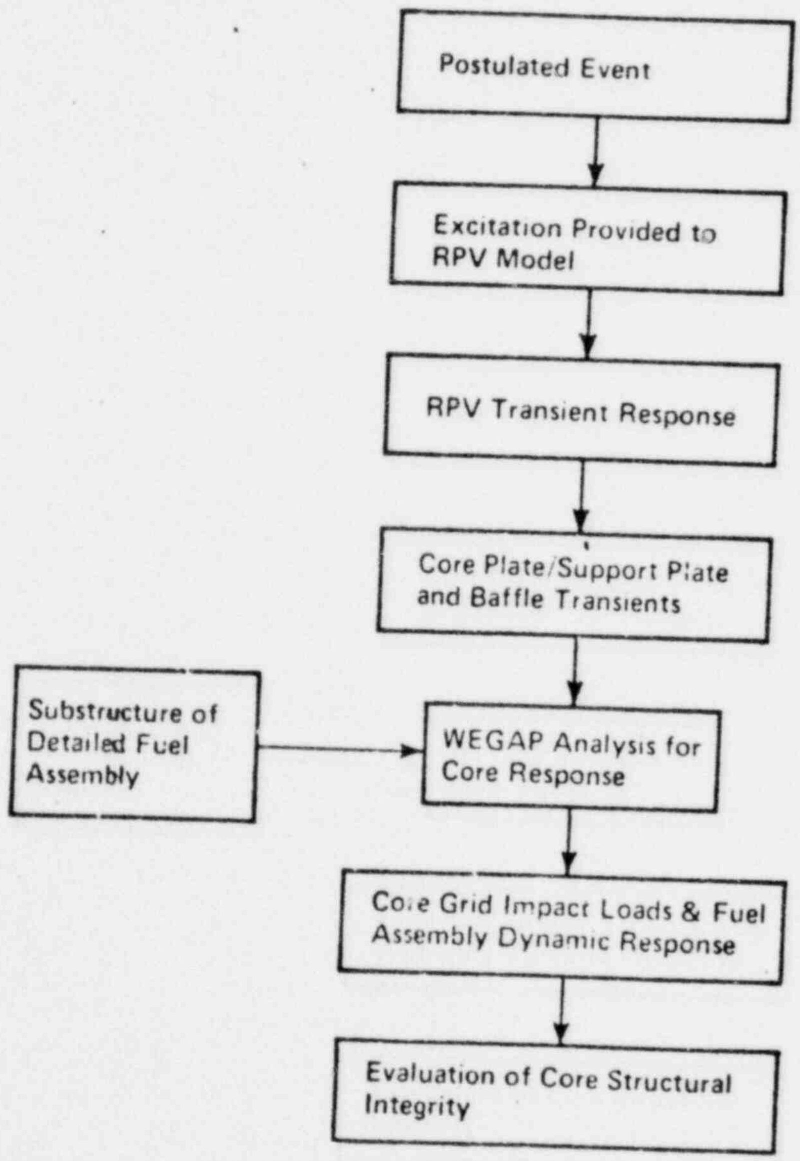
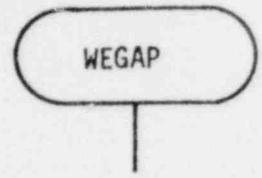
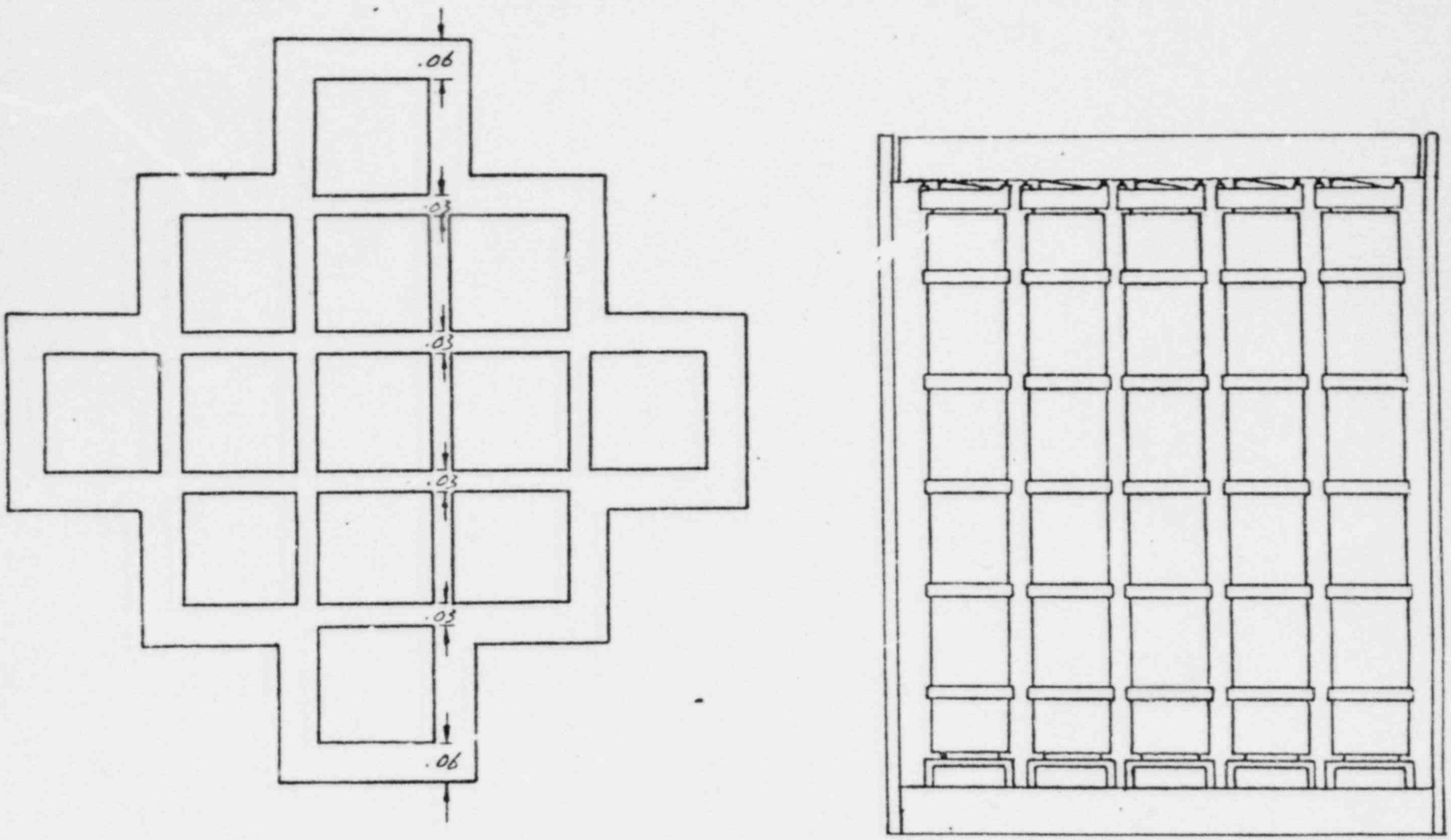


Figure 1 Overall Analysis Process



+(a,c)

FIGURE 1A WEGAP FLOW DIAGRAM



13 Assemblies in all
5 on largest diameter

FIGURE 2 REACTOR CORE CROSS SECTION

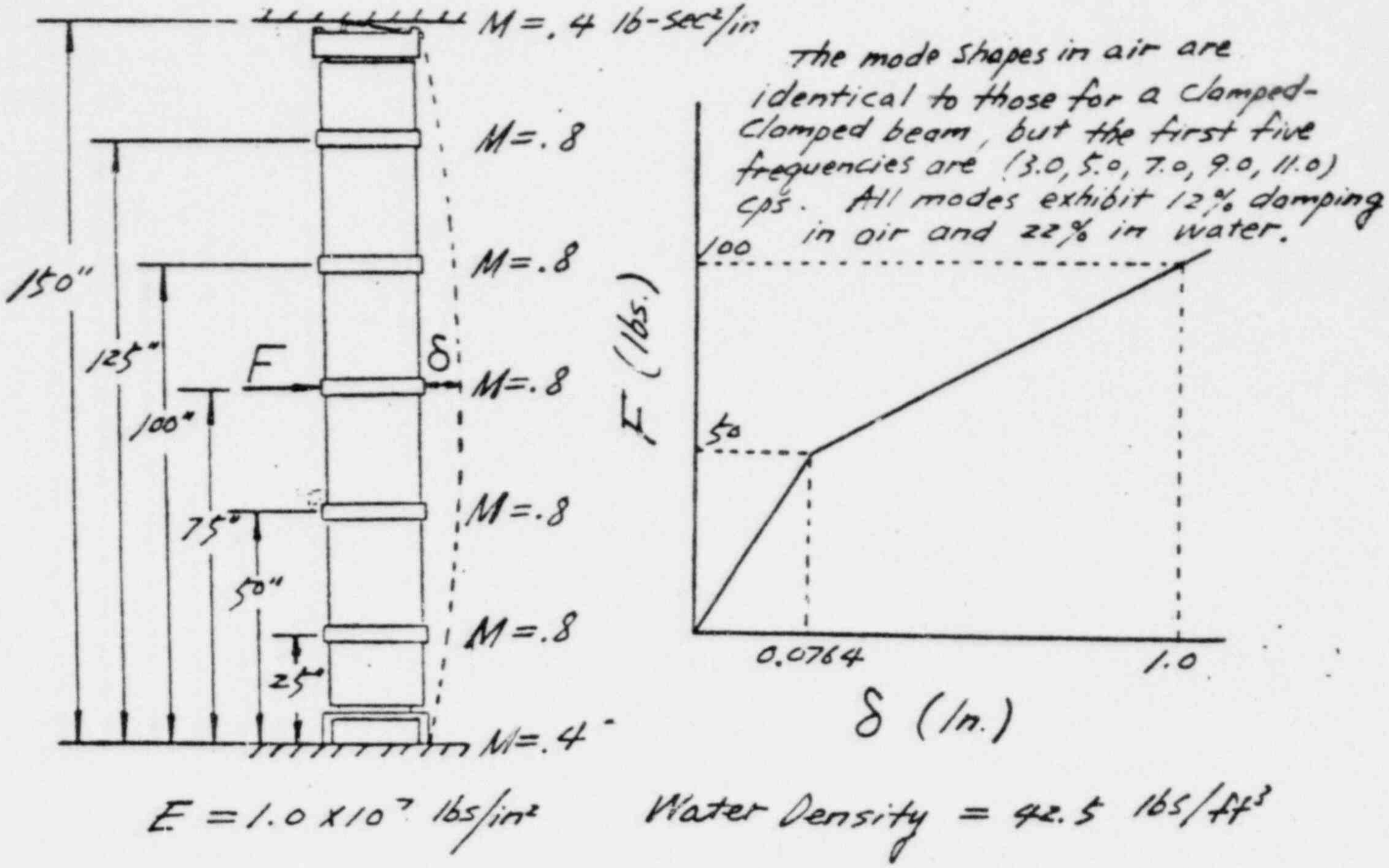


FIGURE 3 FUEL ASSEMBLY DESCRIPTION AND MECHANICAL PROPERTIES

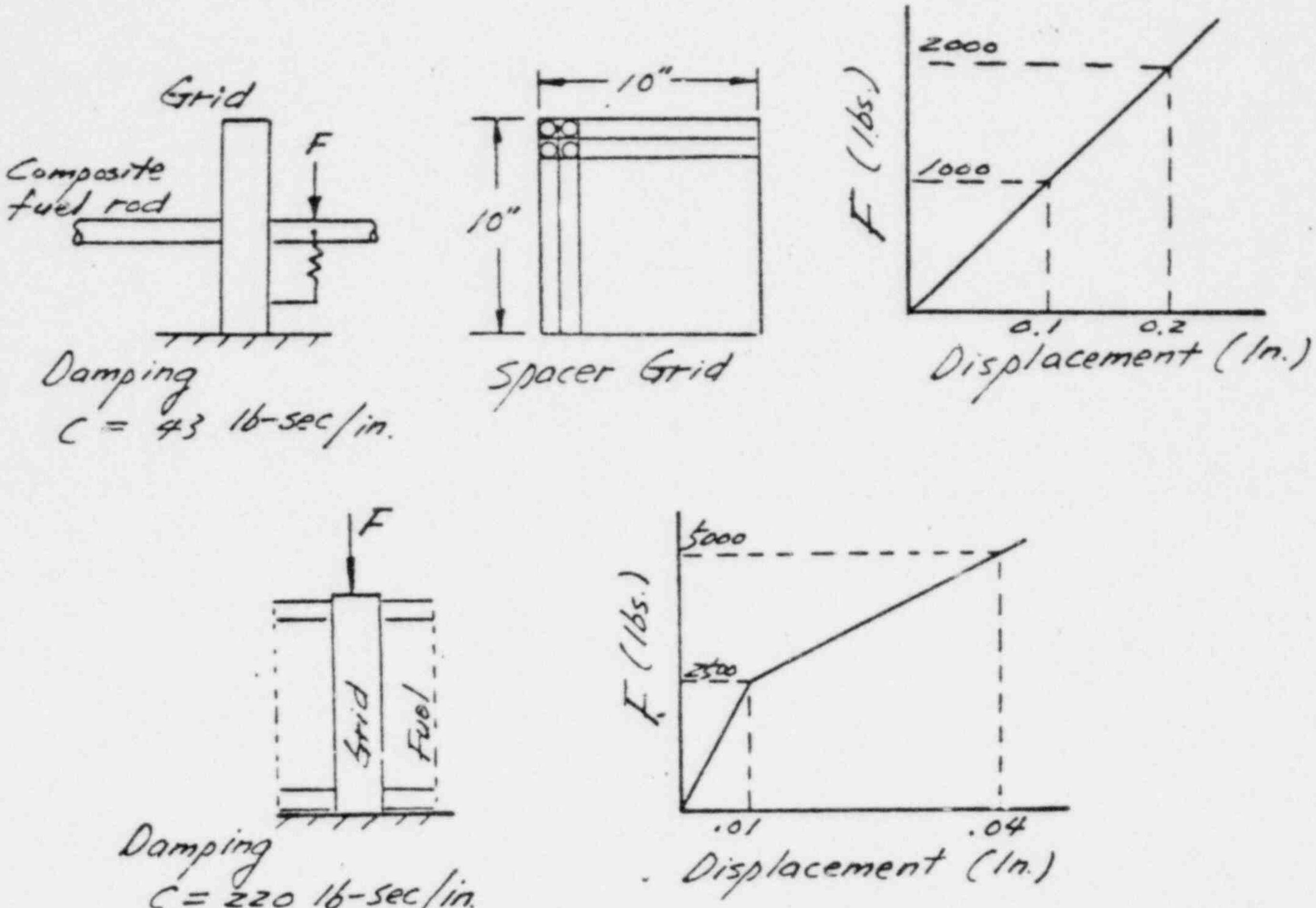


FIGURE 4 SAPCER GRID MECHANICAL PROPERTIES

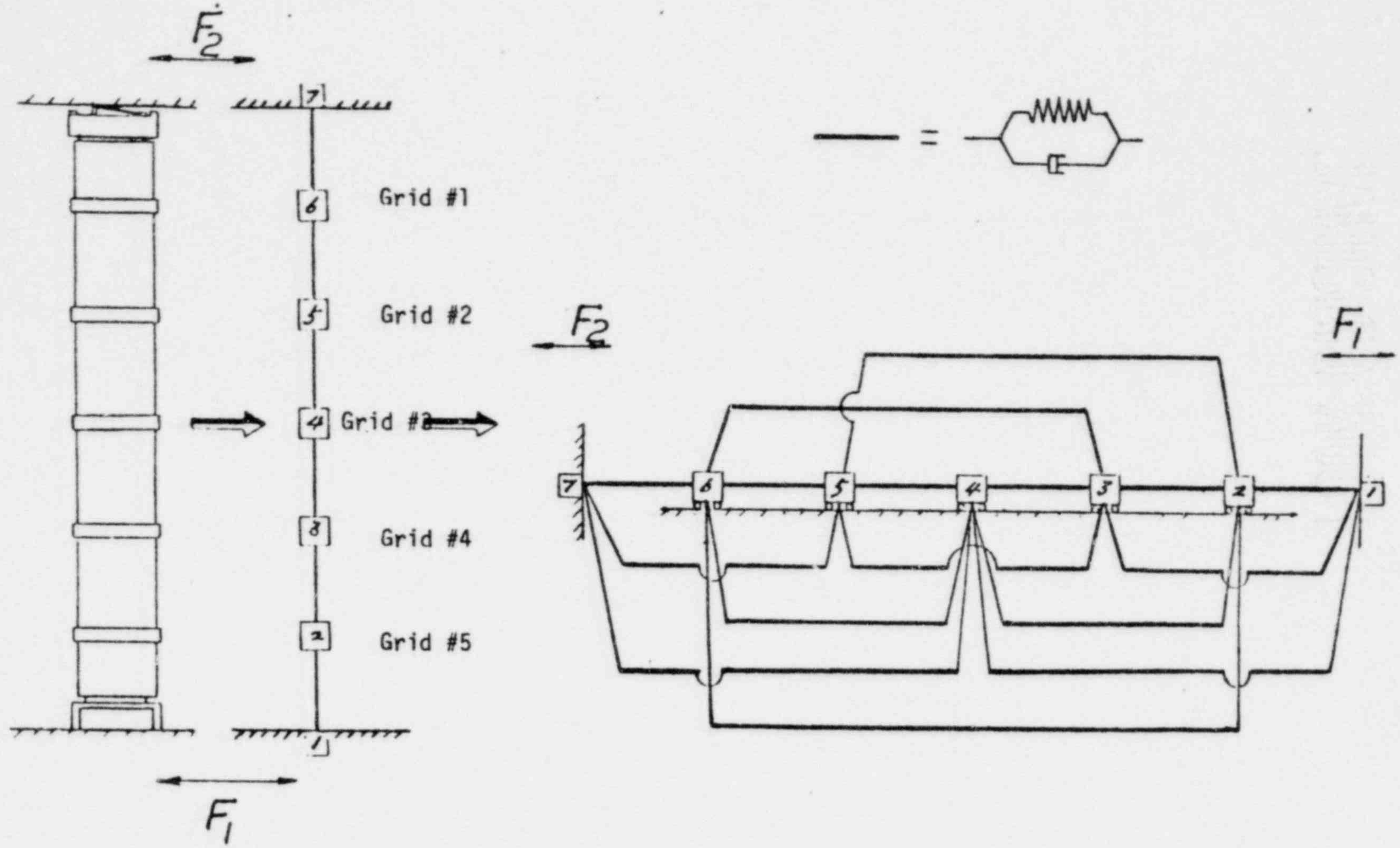


FIGURE 5 FUEL ASSEMBLY FINITE ELEMENT MODEL

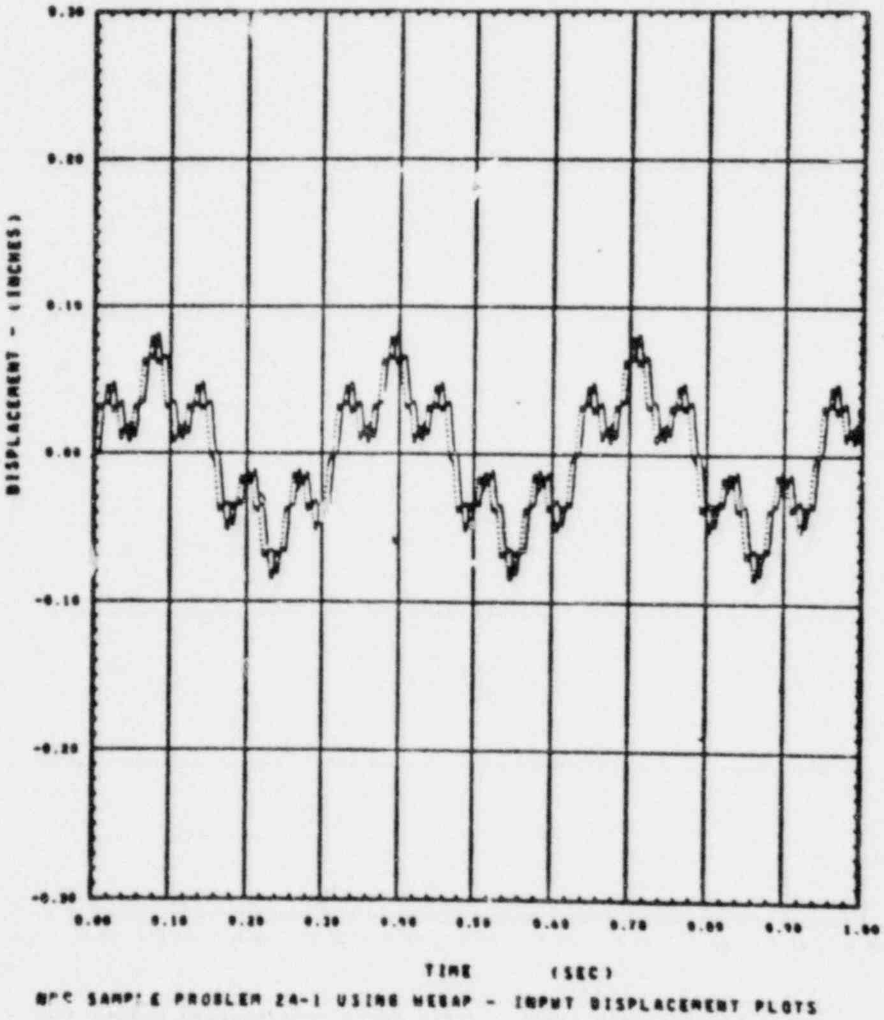


FIGURE 6 INPUT CORE PLATE DISPLACEMENT MOTIONS FOR CASE 2A

POOR ORIGINAL

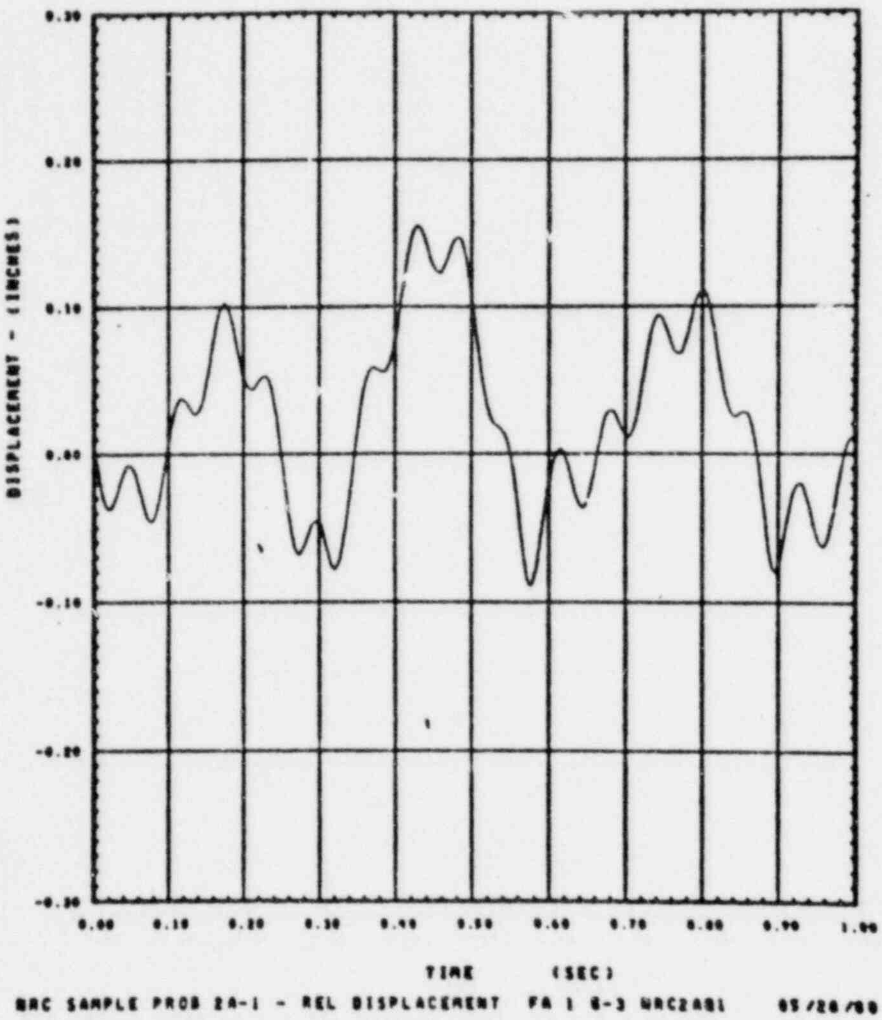


FIGURE 7 DISPLACEMENT RESPONSE OF FIRST FUEL ASSEMBLY GRID NO. 3 RELATIVE TO BAFFLE - CASE 2A

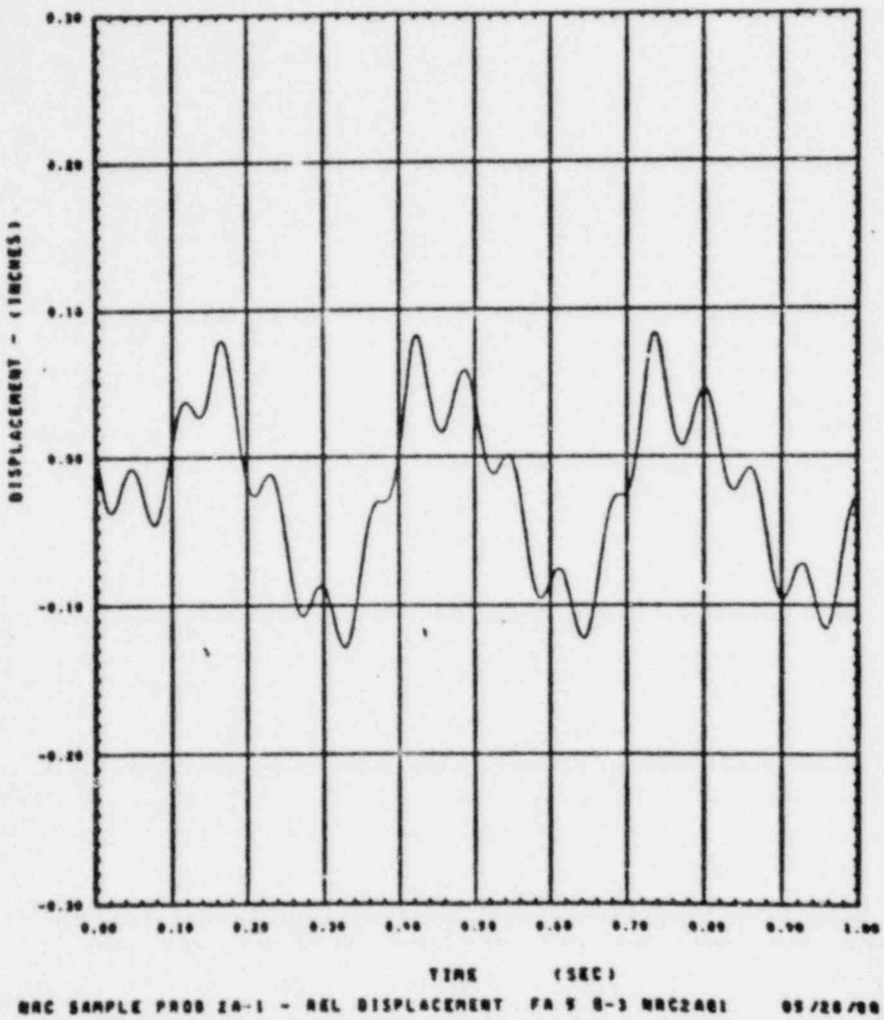


FIGURE 8 DISPLACEMENT RESPONSE OF FIFTH FUEL ASSEMBLY GRID NO. 3 RELATIVE TO BAFFLE - CASE 2A

POOR ORIGINAL

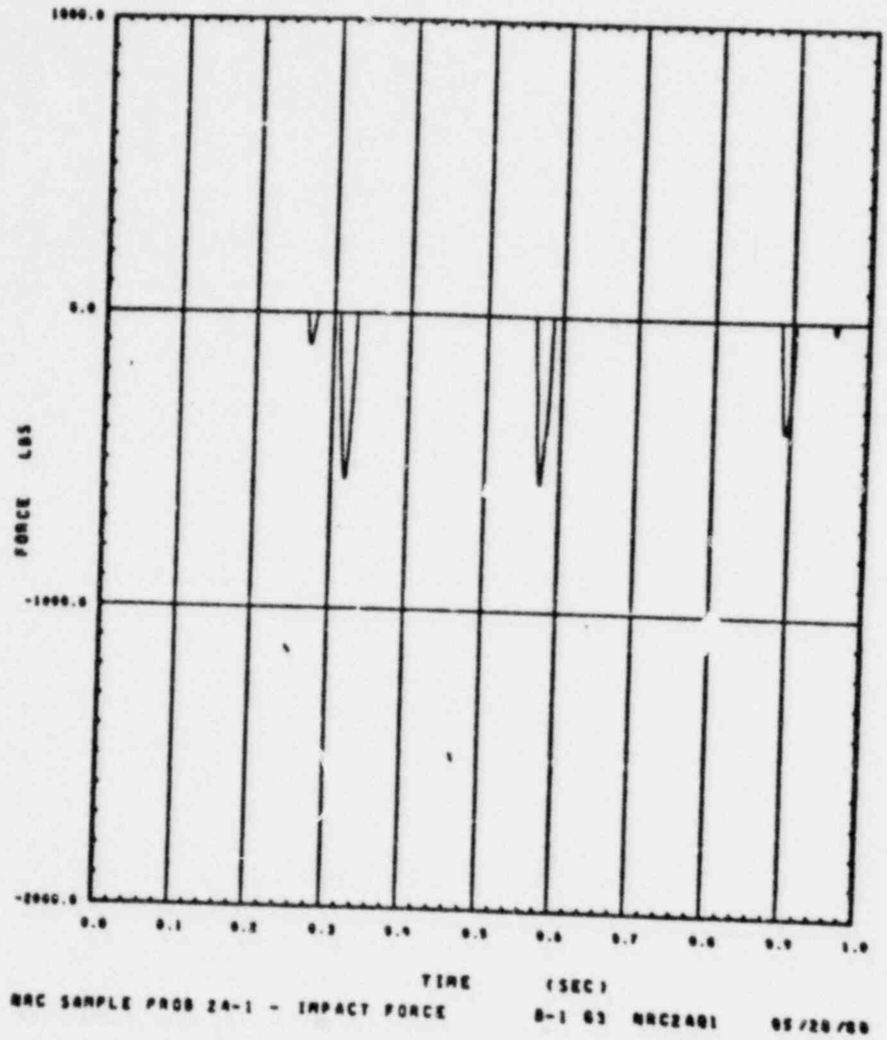


FIGURE 9 IMPACT FORCE RESPONSE BETWEEN BAFFLE AND FIRST FUEL ASSEMBLY AT GRID NO. 3 - CASE 2A

POOR ORIGINAL

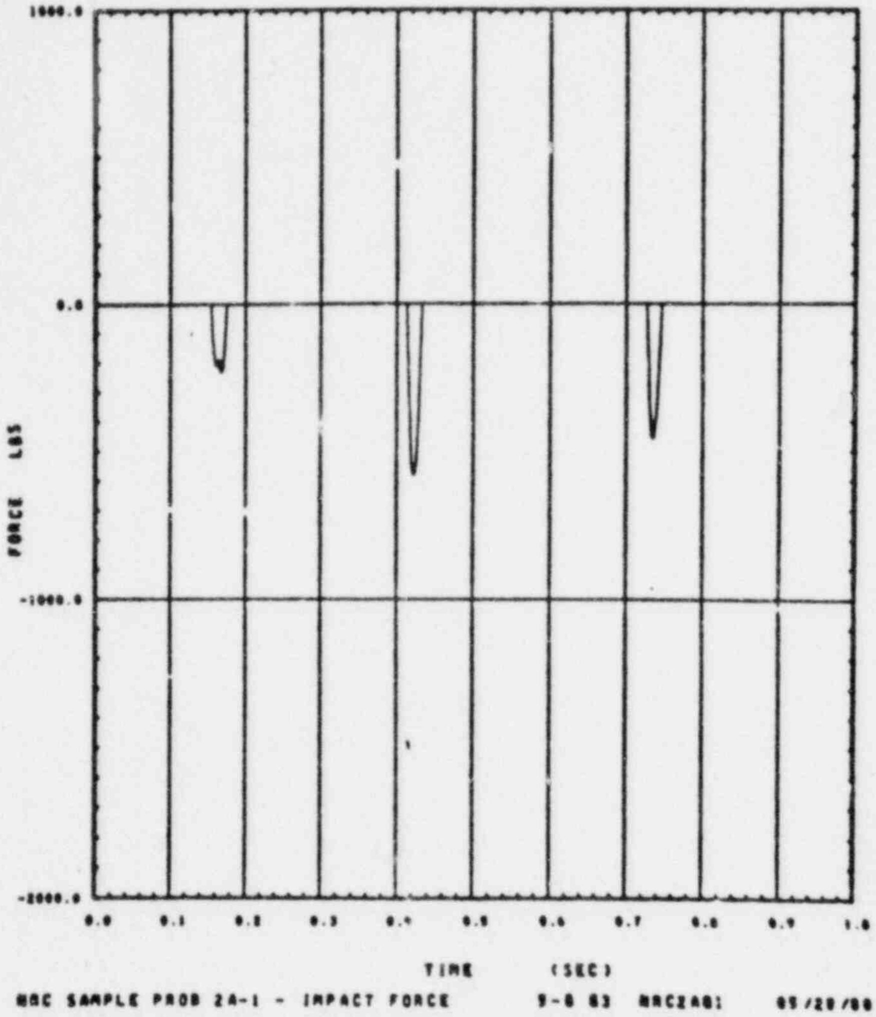


FIGURE 10 IMPACT FORCE RESPONSE BETWEEN FIFTH FUEL ASSEMBLY AND BAFFLE AT GRID NO. 3 - CASE 2A

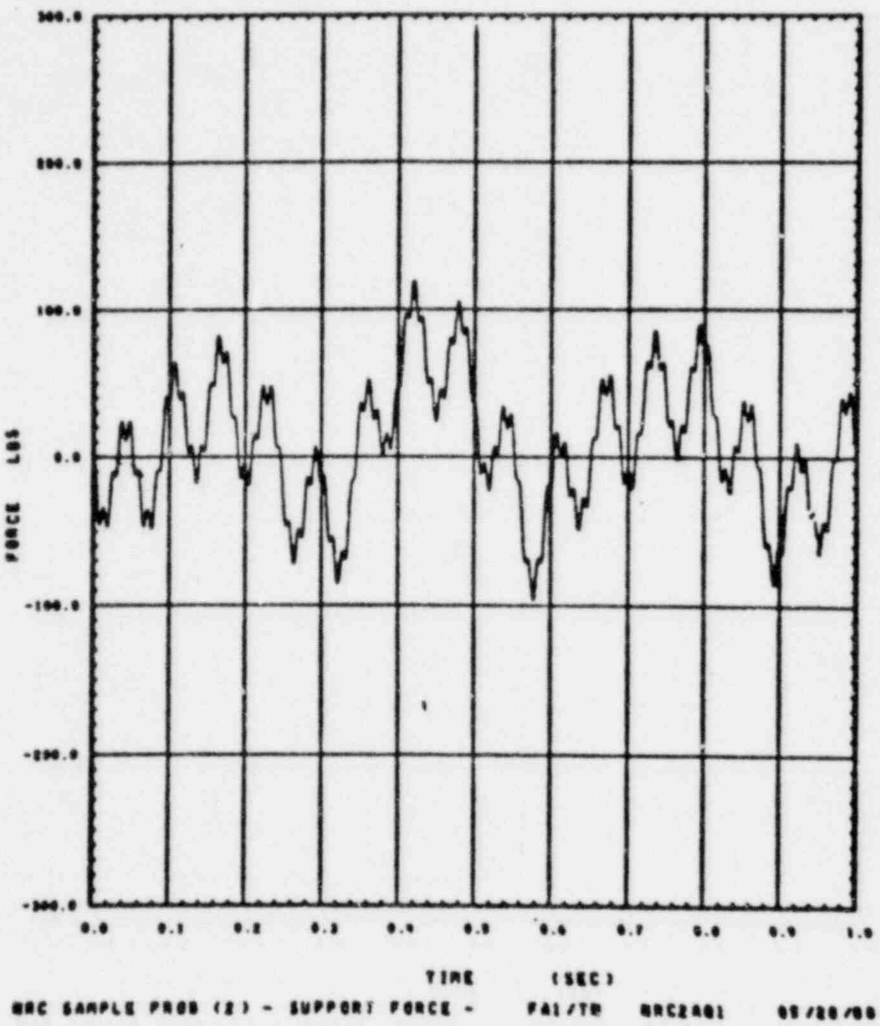


FIGURE 11 UPPER SUPPORT FORCE RESPONSE OF FIRST FUEL ASSEMBLY - CASE 2A

POOR ORIGINAL

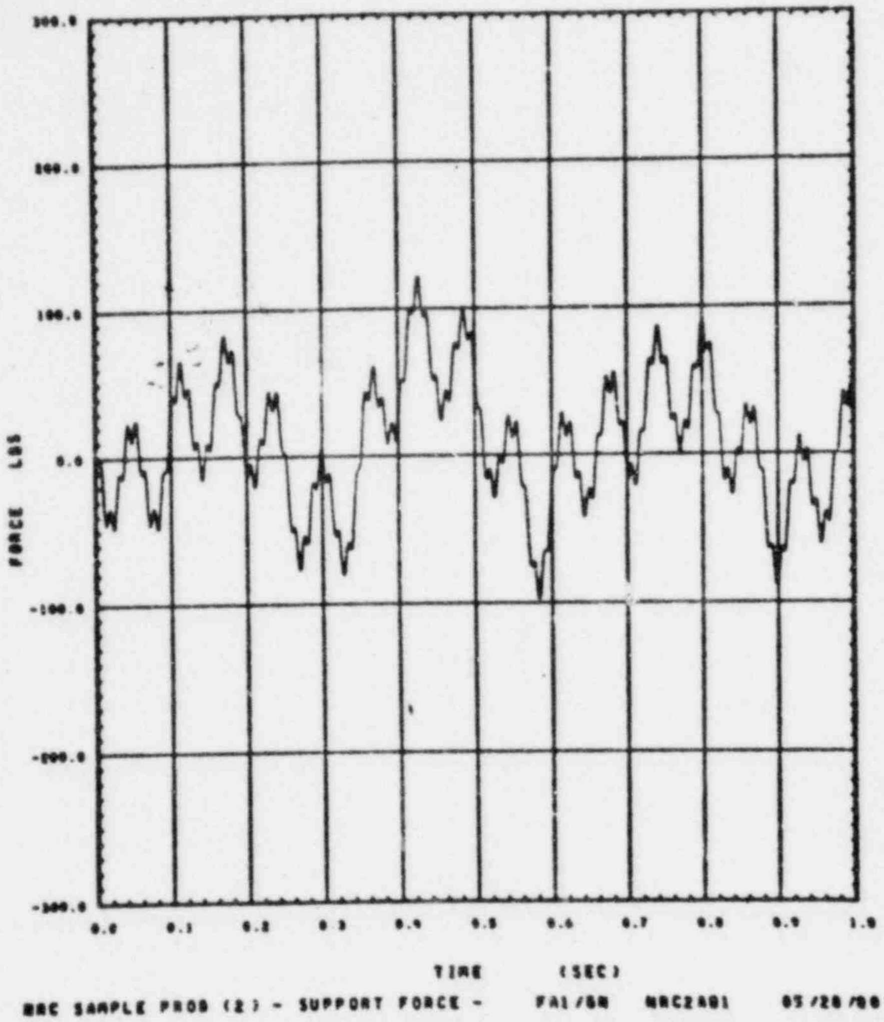


FIGURE 12 LOWER SUPPORT FORCE RESONSE OF FIRST FUEL ASSEMBLY - CASE 2A

POOR ORIGINAL

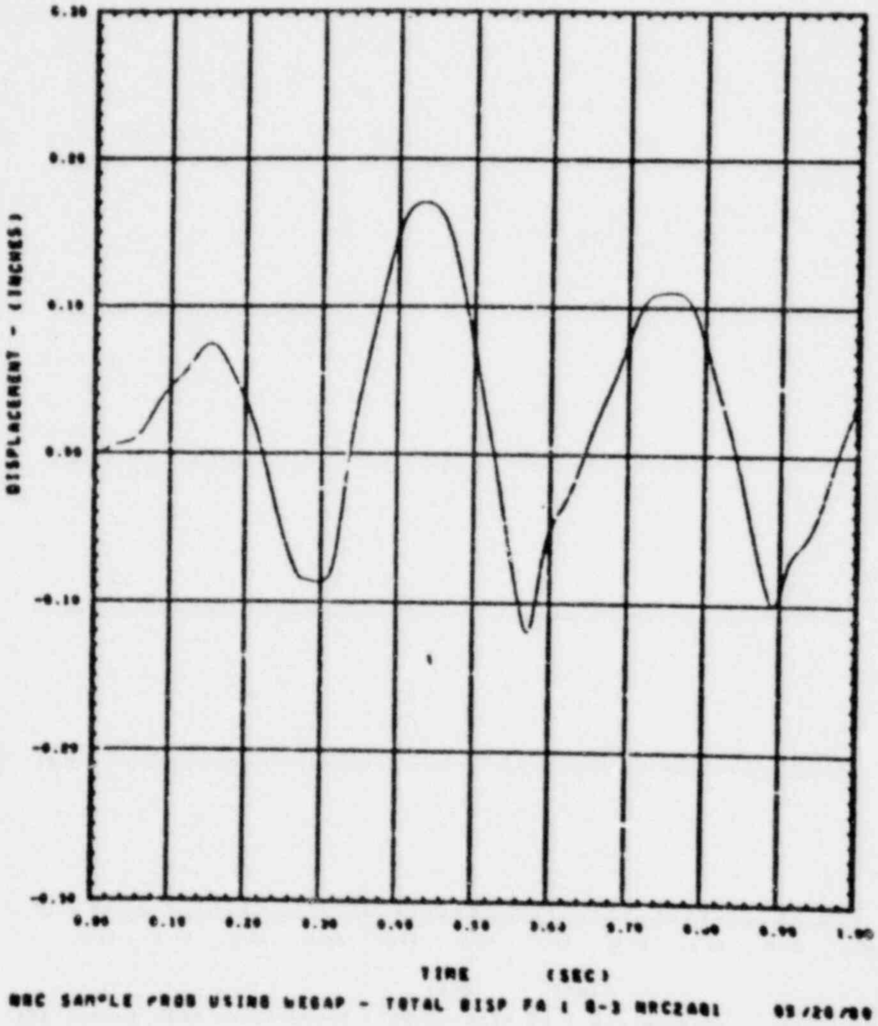


FIGURE 13 TOTAL DISPLACEMENT RESPONSE AT FIRST FUEL ASSEMBLY AT GRID NO. 3 - CASE 2A

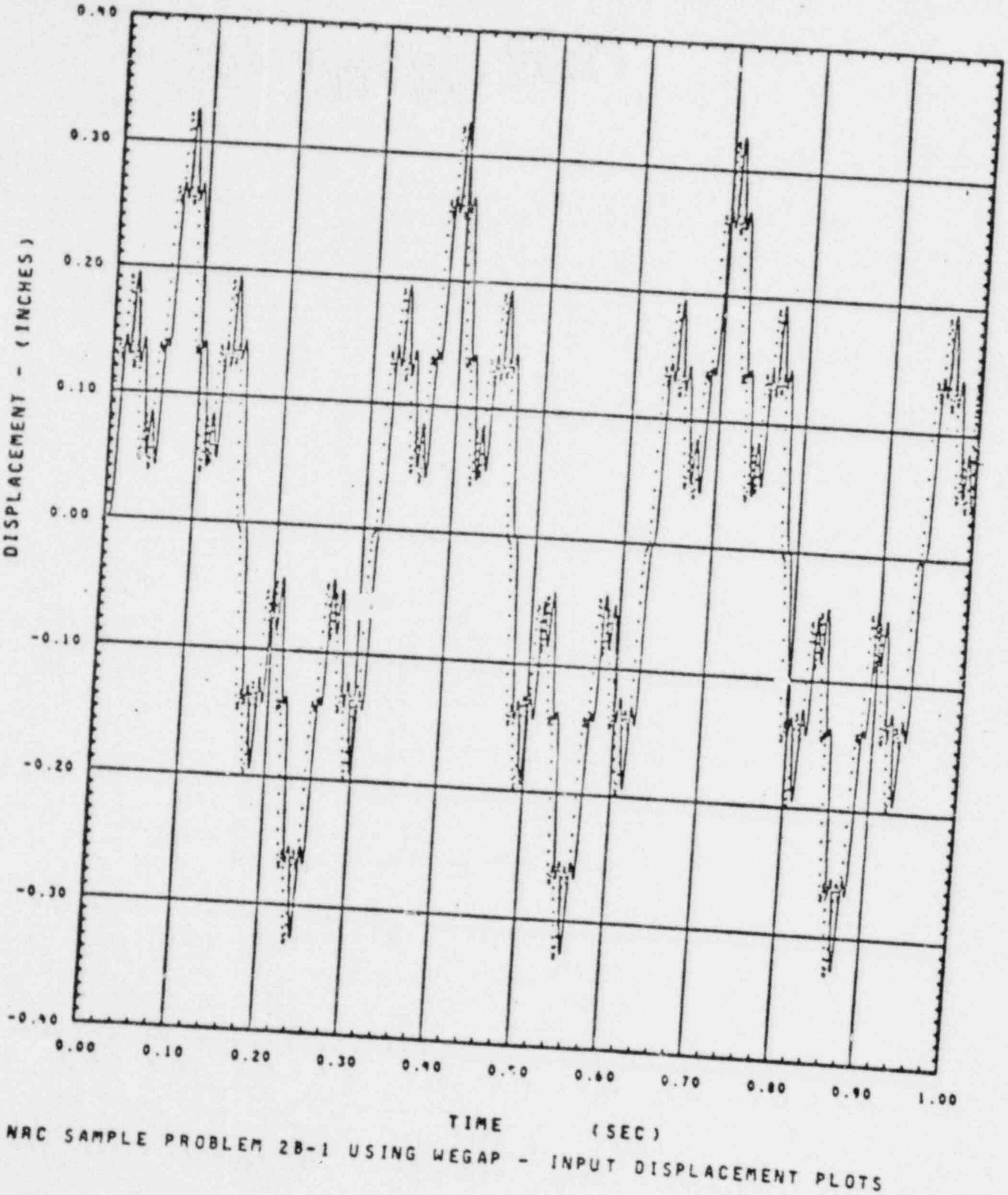


Figure 14

INPUT CORE PLATE DISPLACEMENT MOTIONS FOR CASE 2B

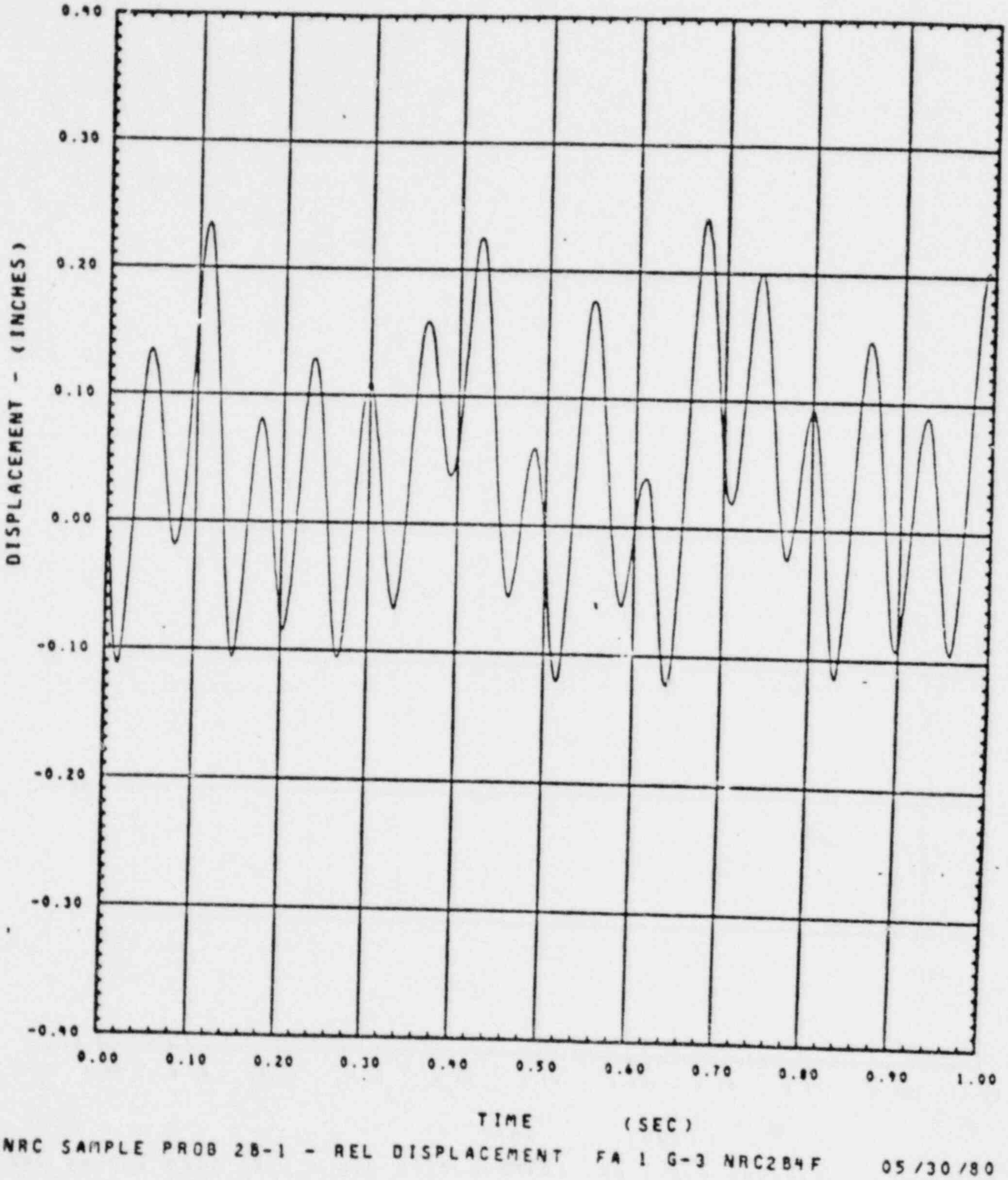


Figure 15

DISPLACEMENT RESPONSE OF FIRST FUEL ASSEMBLY GRID NO. 3
RELATIVE TO BAFFLE - CASE 2B

POOR ORIGINAL

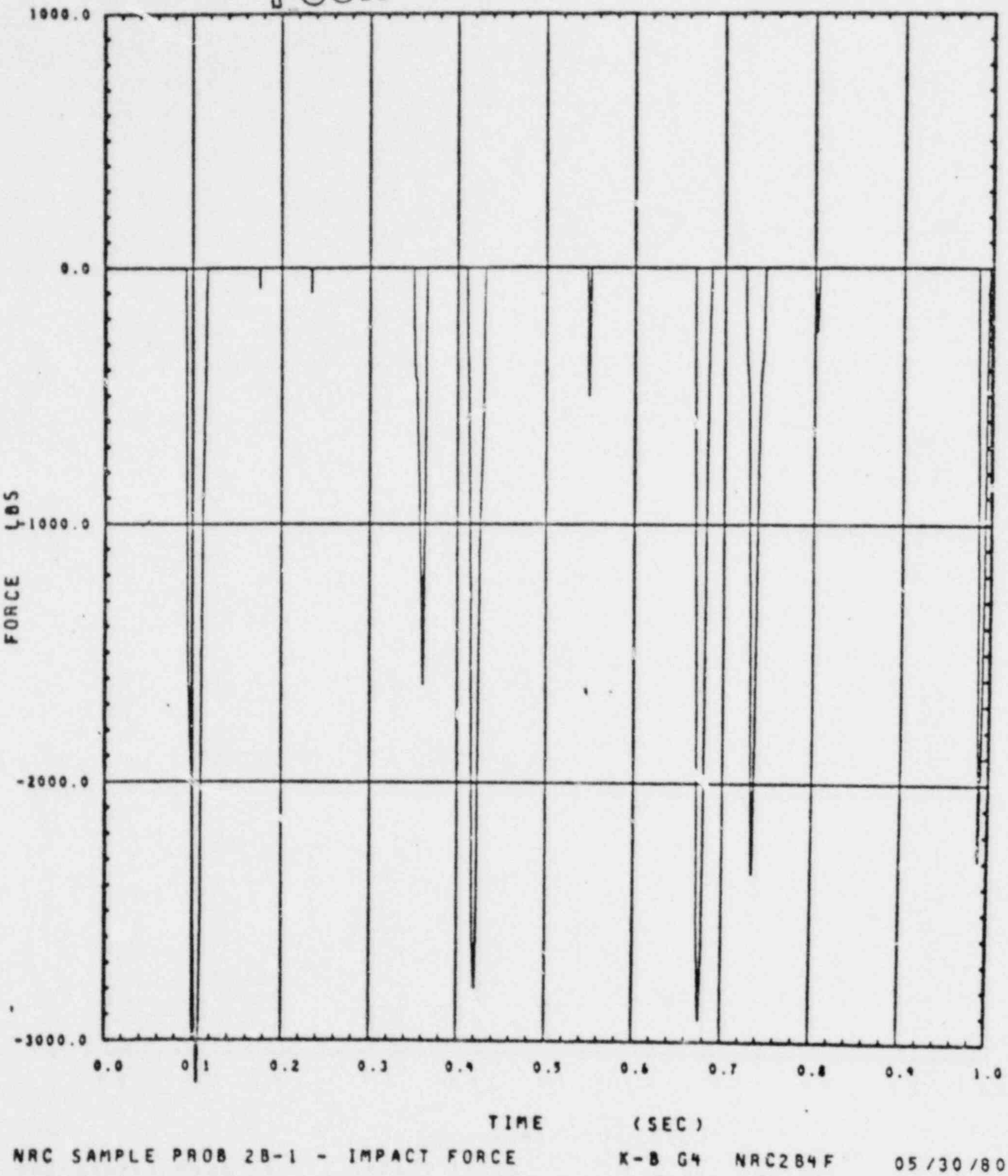


Figure 16

IMPACT FORCE RESPONSE BETWEEN BAFFLE AND FIFTH FUEL ASSEMBLY
AT GRID NO. 4 - CASE 2B

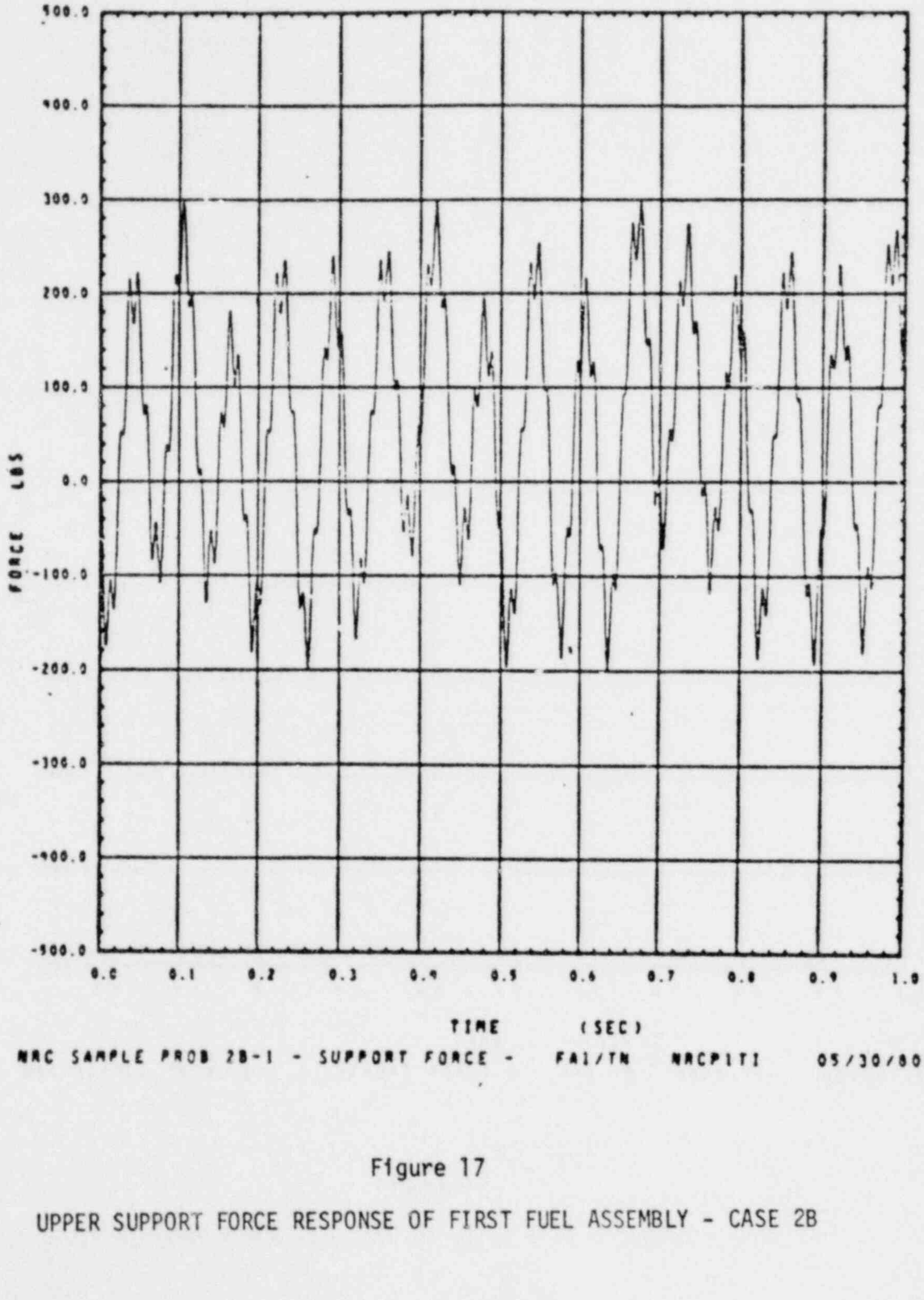


Figure 17

UPPER SUPPORT FORCE RESPONSE OF FIRST FUEL ASSEMBLY - CASE 2B

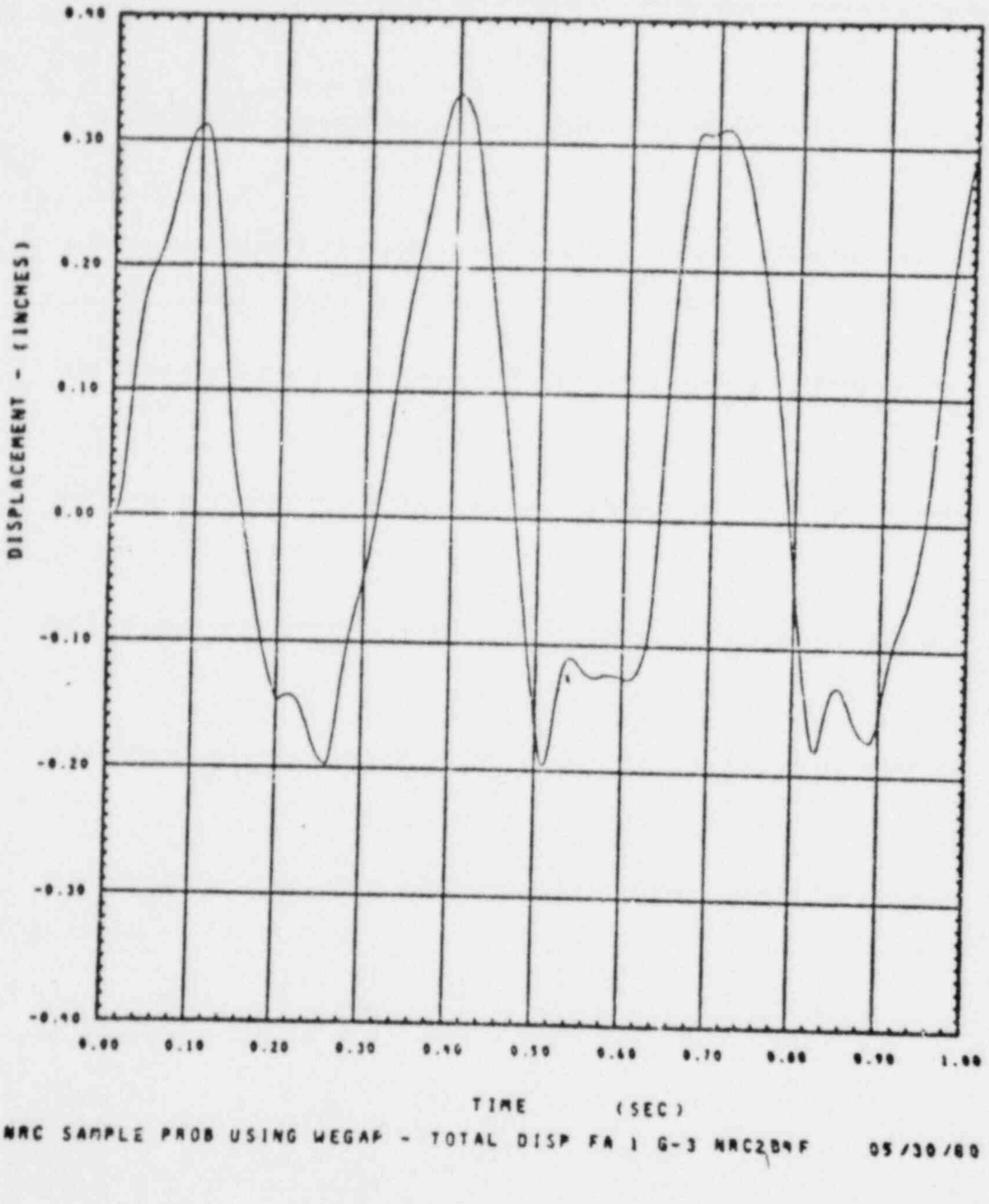


Figure 18

TOTAL DISPLACEMENT RESPONSE OF FIRST FUEL ASSEMBLY
AT GRID NO. 3 - CASE 2B