TABLE OF CONTENTS

SECTION PAGE

Appendix 3C MODAL ANALYSIS OF THE TN-68 BASKET

3C.1 Introduction 3C.1-1
3C.1.1 Modal Analysis 3C.1-1
3C.1.2 Results 3C.1-2
3C.1.3 Conclusion 3C.1-4

3C.2 References 3C.2-1

List of Figures

3C.1-1	Basket Finite Element Model for Modal Analysis
3C.1-2	Boundary Condition - 0° Modal Analysis
3C.1-3	0° Modal Analysis - First Mode (204 Hz)
3C.1-4	0° Modal Analysis - Second Mode (225 Hz)
3C.1-5	0° Modal Analysis - Third Mode (237 Hz)
3C.1-6	0° Modal Analysis - Fourth Mode (242 Hz)
3C.1-7	30° Modal Analysis - First Mode (195 Hz)
3C.1-8	30° Modal Analysis - Second Mode (253 Hz)
3C.1-9	30° Modal Analysis - Third Mode (258 Hz)
3C.1-10	30° Modal Analysis - Fourth Mode (264 Hz)
3C.1-11	45° Modal Analysis - First Mode (181 Hz)
3C.1-12	45° Modal Analysis - Second Mode (232 Hz)
3C.1-13	45° Modal Analysis - Third Mode (272 Hz)
3C.1-14	45° Modal Analysis - Fourth Mode (281 Hz)
3C.1-15	Maximum Dynamic Amplification Factor for a Triangular Load

APPENDIX 3C

MODAL ANALYSIS OF TN-68 BASKET

3C.1 Introduction

This appendix presents the modal analysis of the TN-68 fuel support basket. The TN-68 basket is analyzed for an 18 in. end drop and tipover accident in Appendix 3B using equivalent static methods. The equivalent static loads for the drop evaluations of the TN-68 basket are determined by multiplying the peak rigid body accelerations (analyzed in Appendix D) by the corresponding dynamic load factor (DLF). The purpose of this analysis is to determine the fundamental frequencies of the basket which have the most significant effect on the response of the basket tipover side impact. Based on the fundamental frequencies of the basket structure at temperatures calculated for a 21.2 kW load, the dynamic amplification factor is determined from the spring mass model described in Appendix D. For the basket at temperatures associated with a 30 kW thermal load, the dynamic amplification factor is determined from Figure 3C.1-15 which is taken from NUREG/CR-3966[3].

3C.1.1 Modal Analysis

Finite Element Model

The ANSYS[1] finite element model described in Appendix 3B is used to perform the modal analysis. The supporting rails are removed from the finite element model and boundary conditions are directly applied to the panels. It is reasonable to remove the supporting rails because the coupling of rail nodes to the panel nodes would have resulted in stiffer panels and higher frequency modes. The basket finite element model is shown on Figure 3C.1-1.

Material Properties

Material properties based on a basket temperature of 500°F for 21.2 kW and 600 °F for 30 kW are input as described in Appendix 3B. Weight densities are changed to mass densities ($\rho_m = \rho_w$ /386.4).

Boundary Conditions

Boundary conditions applied to the model are as follows: restraint of the bottom half of the perimeter in the direction parallel to the drop angle vector, and restraint the direction perpendicular to the drop angle vector on the remainder of the perimeter. These boundary conditions are chosen to eliminate modes of vibration that are incompatible with the orientation of the drop. For instance, side to side modes are not important for the 0° drop, because they are restrained by the rails and cask wall and, more importantly, because they have no modal weight in the drop direction, and therefore are not activated by the drop. For 30 and 45 degree drops, boundary conditions are modified by rotating the perimeter support nodes for the drop angle and then applying the appropriate displacement boundary conditions in the rotated coordinate system. Also for 30 and 45 degree drops, the modal weight is associated with both horizontal and vertical panels of the basket. Typical boundary conditions for the 0° modal analysis are shown on Figure 3C.1-2.

3C.1.2 Results

Modes and Frequencies From ANSYS Analysis

The first six mode frequencies resulting from the different drop orientation ANSYS modal analyses are tabulated below:

ANSYS Modal Analysis Results

Mode	Frequency		
	0^o	30^o	45^o
1	204	195	181
2	225	253	232
3	237	258	272
4	242	264	281
5	246	266	282
6	247	268	292

Results From Hand Calculations

For the first mode shape of each drop, the deformed shape of the central basket panels resemble s a simple-simple supported beam.

As an order of magnitude check, the frequency of the fundamental mode of vibration for the simple-simple supported beam is calculated below and compared to the frequency of the first mode of 0^o ANSYS modal analysis result. Reference 2, page 369, case 6,"Single span, end supported, uniform load W", lists the following equation for the fundamental frequency:

$$f = 3.55 / (5WL^3/384EI)^{1/2}$$

Where:

$W = 5.1577$ lbs.
$L = 6.1875$ in.
$E = 25.8 \times 10^6$ psi
$I = 0.001462$ in.^{4}

Substituting the values given above,

$$F = 173 \text{ Hz}$$

This value is reasonably close to the solution given by ANSYS for the basket. The actual support conditions for the basket are somewhere in between simple-simple and fixed-fixed supports. A fixed-fixed beam's fundamental frequency is approximately double that of a simple-simple supported beam. Therefore, we should expect the ANSYS solution to be somewhere between these values.

<u>Basket with 30 kW Thermal Load</u>

The above fundamental frequency equation is used to ratio basket frequency between the frequency calculated from ANSYS (basket with fuel up to 21.2 kW) and basket with high burn up fuel.

$f = 3.55 / (5WL^3/384EI)^{1/2}$

f_1 = Fundamental frequency of basket (w/fuel up to 21.2 kW) calculated from ANSYS
f_2 = Fundamental frequency of basket (w/high burn up fuel)
E_1 = Modulus of elasticity of basket Plate at 500°F = 25.8×10^6 psi (w/fuel up to 21.2 kW)
E_2 = Modulus of elasticity of basket Plate at 600°F= 25.3×10^6 psi (w/fuel up to 30 kW)
W_1 = Uniform load on basket plate. This is proportional to basket plate equivalent densities calculated based on total fuel assembly weight distributed on 164 inch basket length
W_2 = Uniform load on basket plate. This is proportional to basket plate equivalent densities calculated based on total fuel assembly weight distributed on 144 inch basket length (active fuel length)

Using the above frequency equation and simplifying,

$$f_1^2 / f_2^2 = (E_1 / E_2)(W_2 / W_1)$$

$$f_2 = f_1 [(E_2/E_1)(W_1/W_2)]^{1/2}$$

The fundamental frequencies for the 30 kW load are calculated using the above relationship:

	0-degree Drop Orientation	30-degree Drop Orientation	45-degree Drop Orientation
f_1 from Section 3C.1.2	204 Hz	195 Hz	181 Hz
E_1 at 500°F	25.8×10^6 psi	25.8×10^6 psi	25.8×10^6 psi
E_2 at 600°F	25.3×10^6 psi	25.3×10^6 psi	25.3×10^6 psi
D_1	4.006 lb/in^3	3.1125 lb/in^3	2.219 lb/in^3
D_2	4.634 lb/in^3	3.579 lb/in^3	2.524 lb/in^3
Factor $[(E_2/E_1)(D_1/D_2)]^{1/2}$	0.9207	0.9235	0.9285
f_2 = Factor * f_1	187	180	168

The dynamic load factor is a function of the rise time of the applied load, the duration of the load, the shape of the load, and the natural period of the structure. DYNA computer program as described in Appendix 3D is used to predict the impact duration during the tipover analysis. Based on the results in the Appendix 3D, the impact during is 0.003 sec and the pulse shape is triangle.

From Figure 3C.1-15 (from reference 3), the dynamic load factor is calculated as follows:

t = impact duration = 0.003
T = 1/f = 1/187 = 0.005348
t/T = 0.003/0.005348 = 0.56

Therefore, the dynamic load factor is approximately 1.32. This dynamic load factor is similar to the dynamic load factor calculated from the LS-DYNA dynamic analysis described in Appendix 3D.5.2.

3C.1-3 Conclusion

The first four (4) mode shapes of the 0, 30, and 45 degree modal analyses (basket with fuel assembly up to 21.2 kW) are plotted on Figures 3C.1-3 through 3C.1-14. Except for the first mode shapes of each drop orientation, the mode shapes are neither symmetric nor have significant modal deflection in the direction of the drop angle. Therefore, the frequencies of these modes with substantial modal weight in the direction of the drop - for angles 0^o, 30^o, and 45^o are 204 Hz, 195 Hz, and 181 Hz, respectively.

3C.2 References

1. ANSYS Engineering Analysis System User's Manual, Rev. 5.2, Vol. 1 to 4, 1995.

2. Roark, R. "Formulas for Stress and Strain" Fourth Edition.

3. NUREG/CR-3966 “Methods for Impact Analysis of Shipping Containers” by T.A. Nelson and R.C. Chun

Figure 3C.1-1
Basket Finite Element Model for Modal analysis

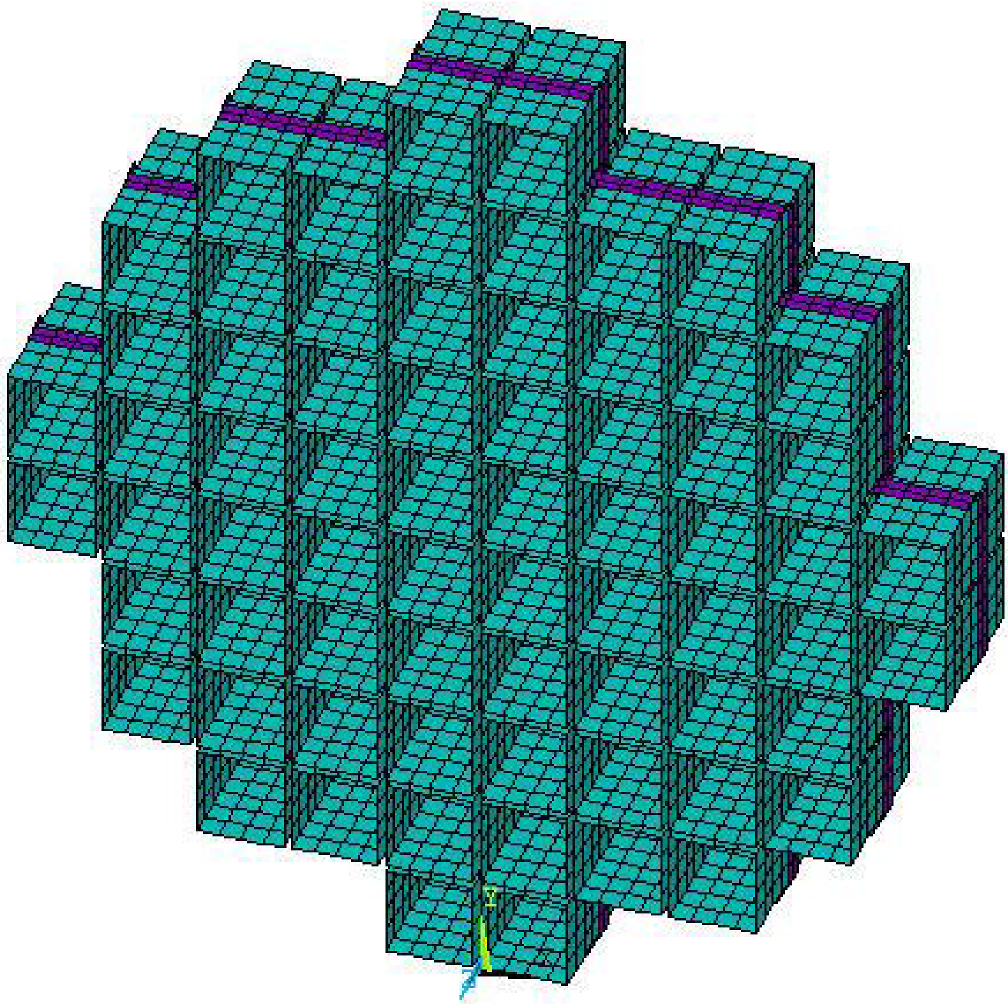

Figure 3C.1-2
Boundary Condition – 0^{o} Modal Analysis

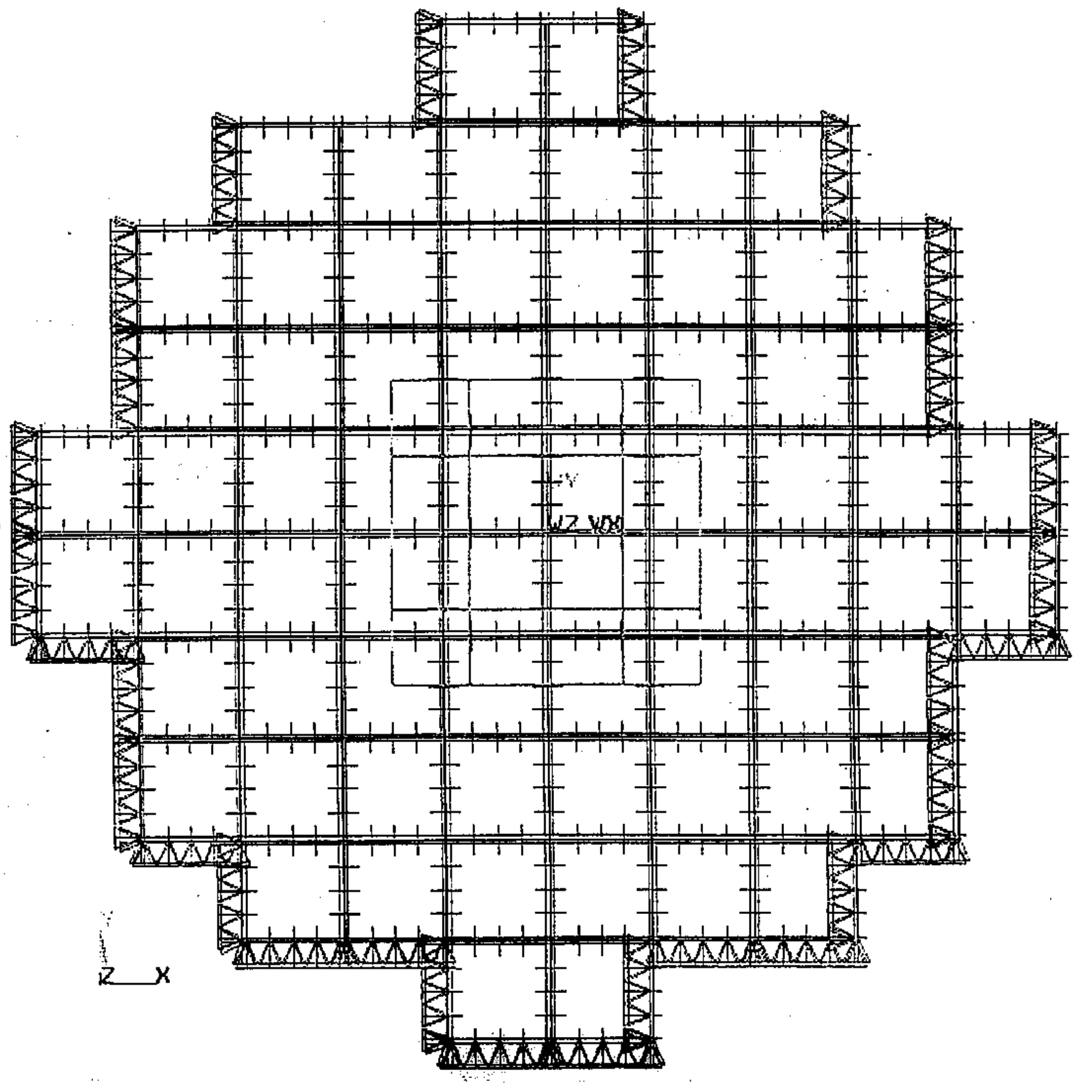

Figure 3C.1-3
0^0 Modal Analysis –First Mode (204 HZ)

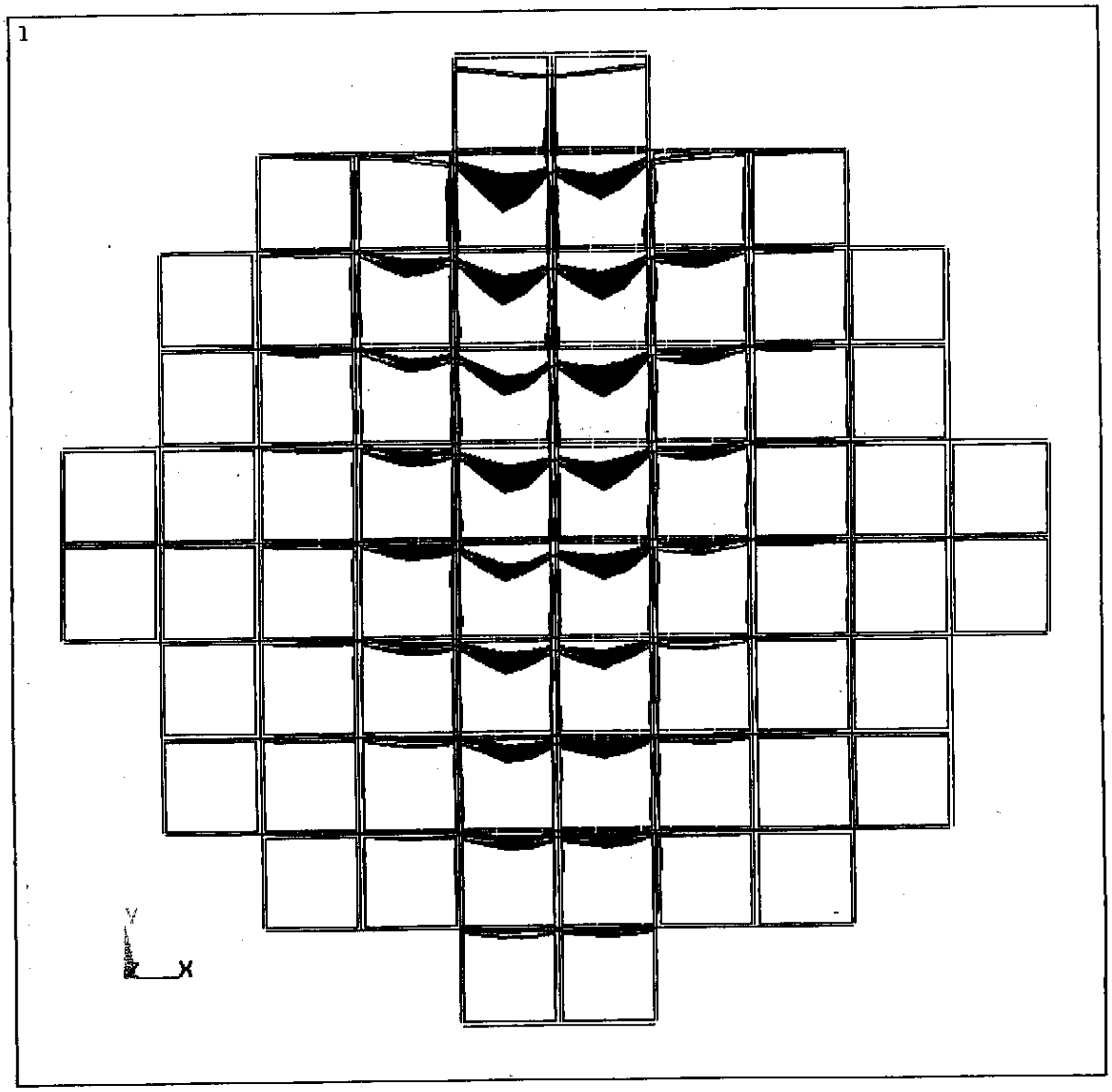

Figure 3C.1-4
0^0 Modal Analysis – Second Mode (225 HZ)

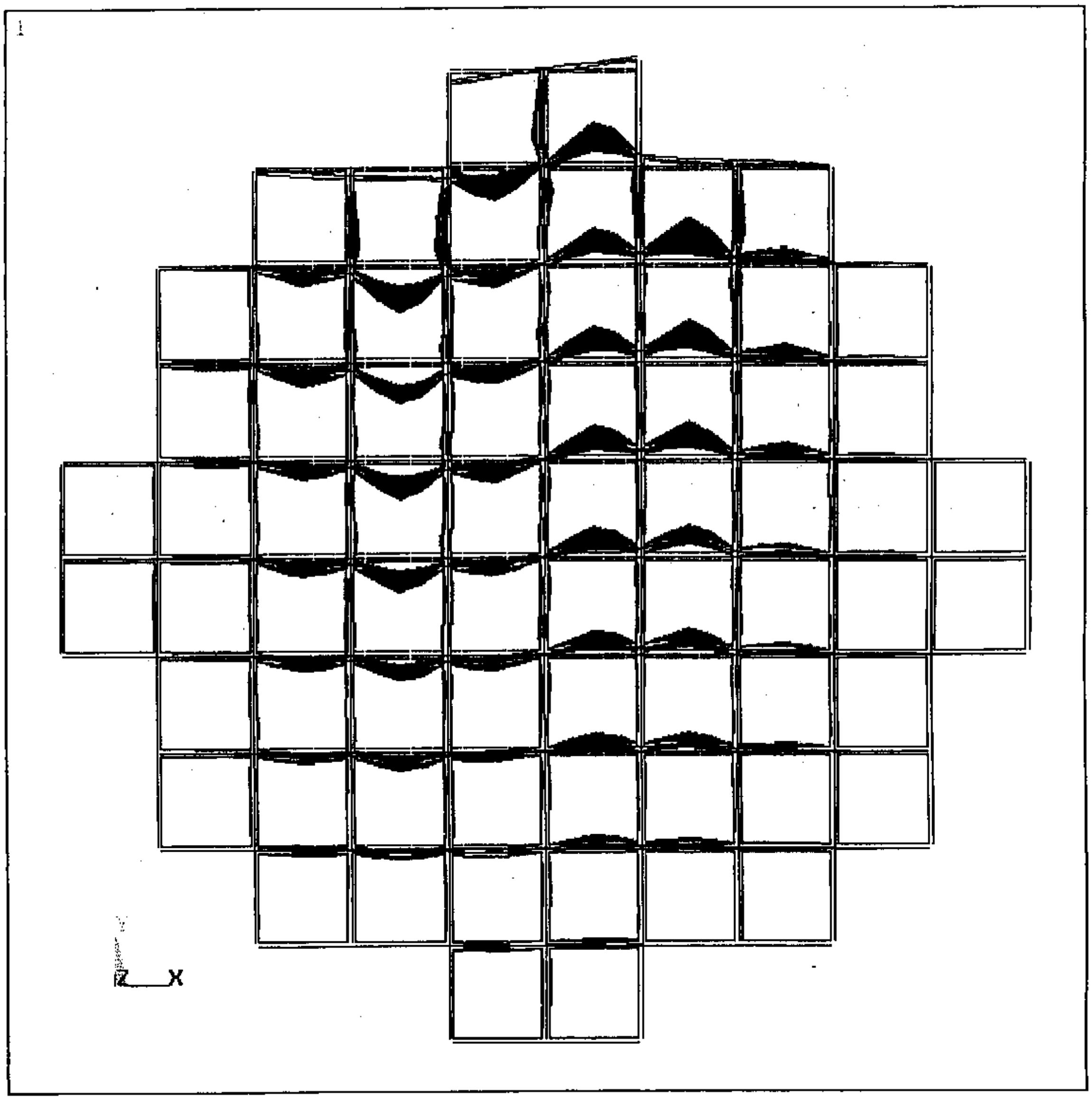

Figure 3C.1-5
0^0 Modal Analysis –Third Mode (237 HZ)

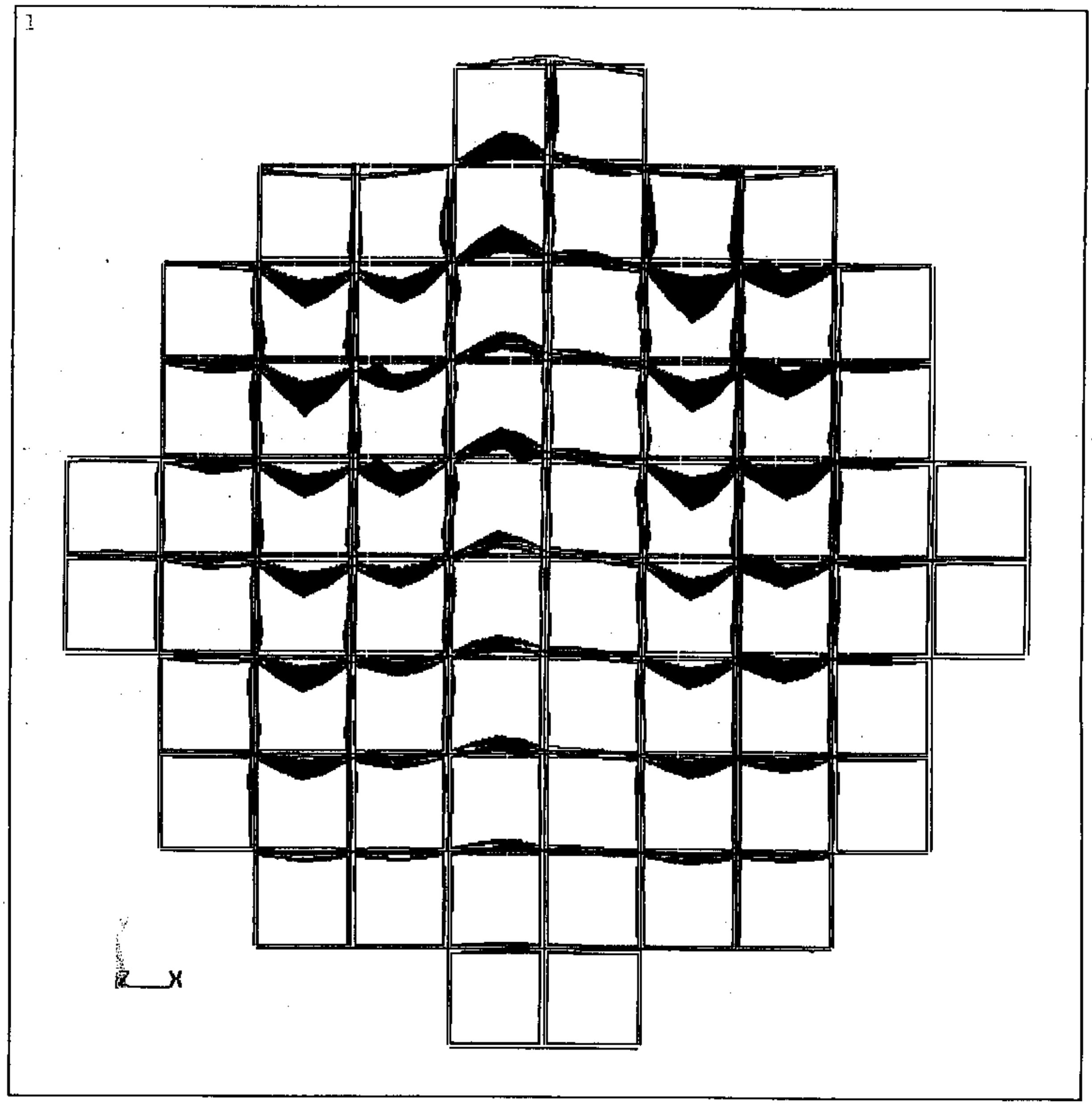

Figure 3C.1-6
0^0 Modal Analysis – Fourth Mode (242 HZ)

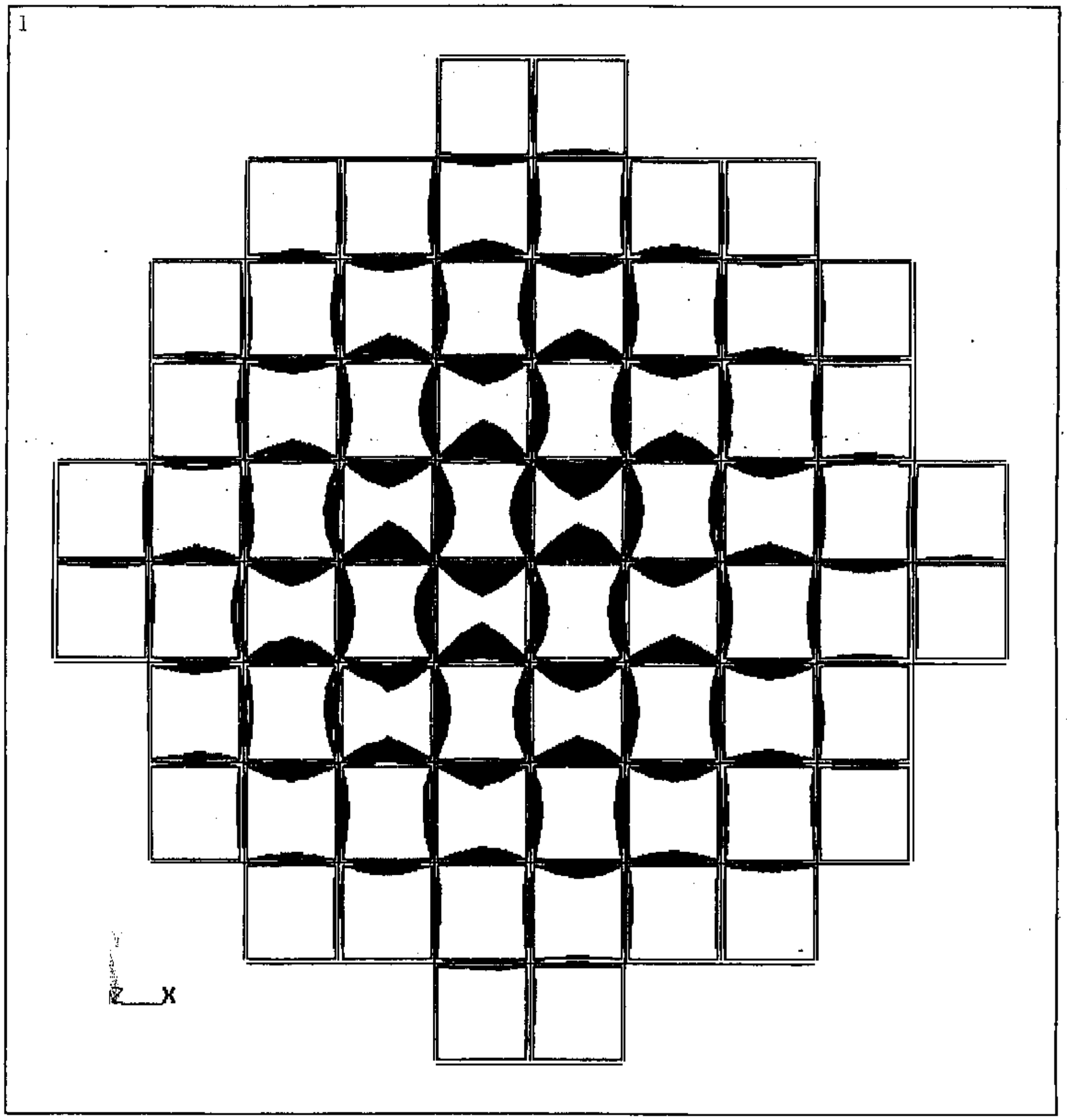

Figure 3C.1-7
30^0 Modal Analysis – First Mode (195 HZ)

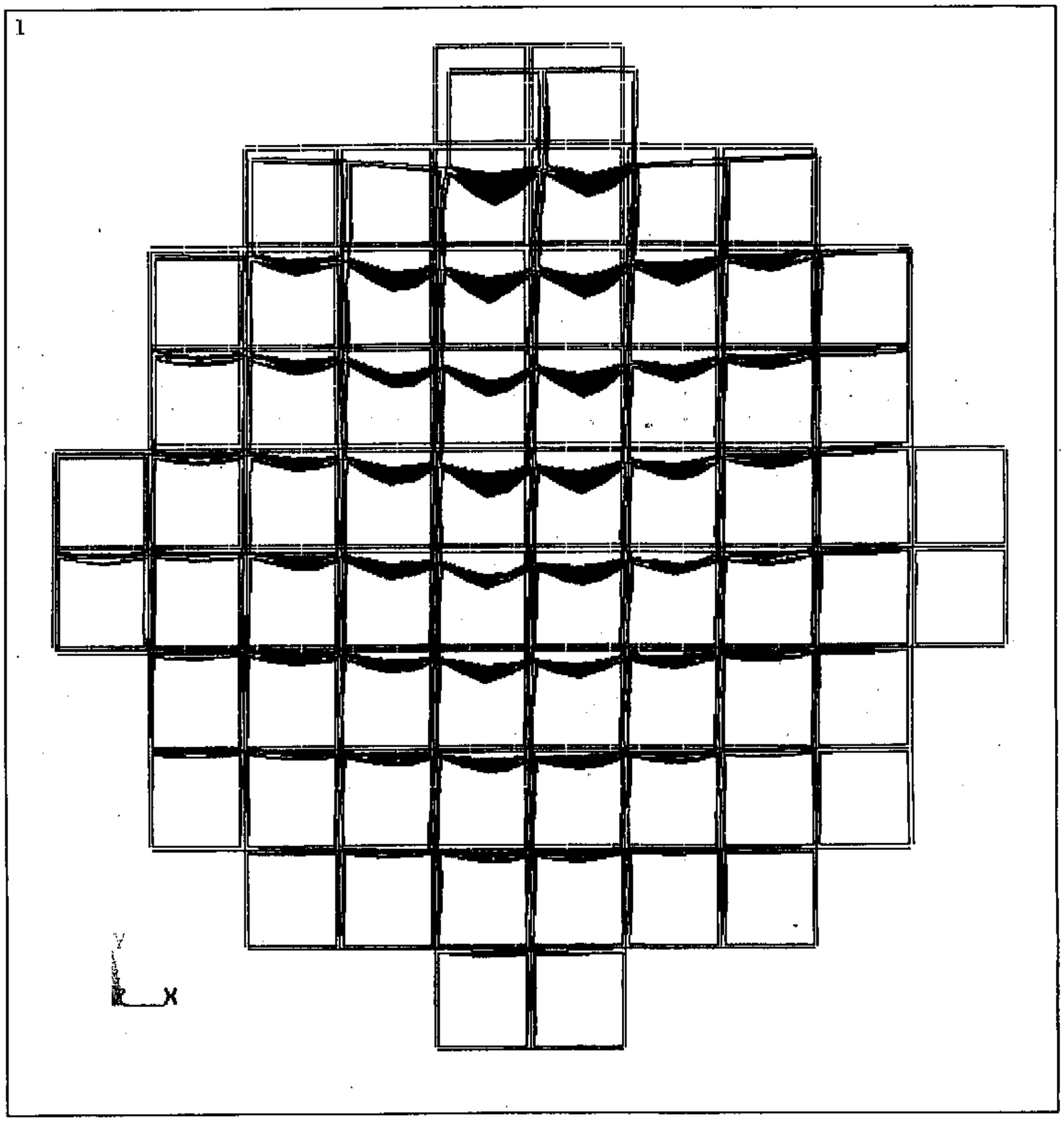

Figure 3C.1-8
30^0 Modal Analysis – Second Mode (253 HZ)

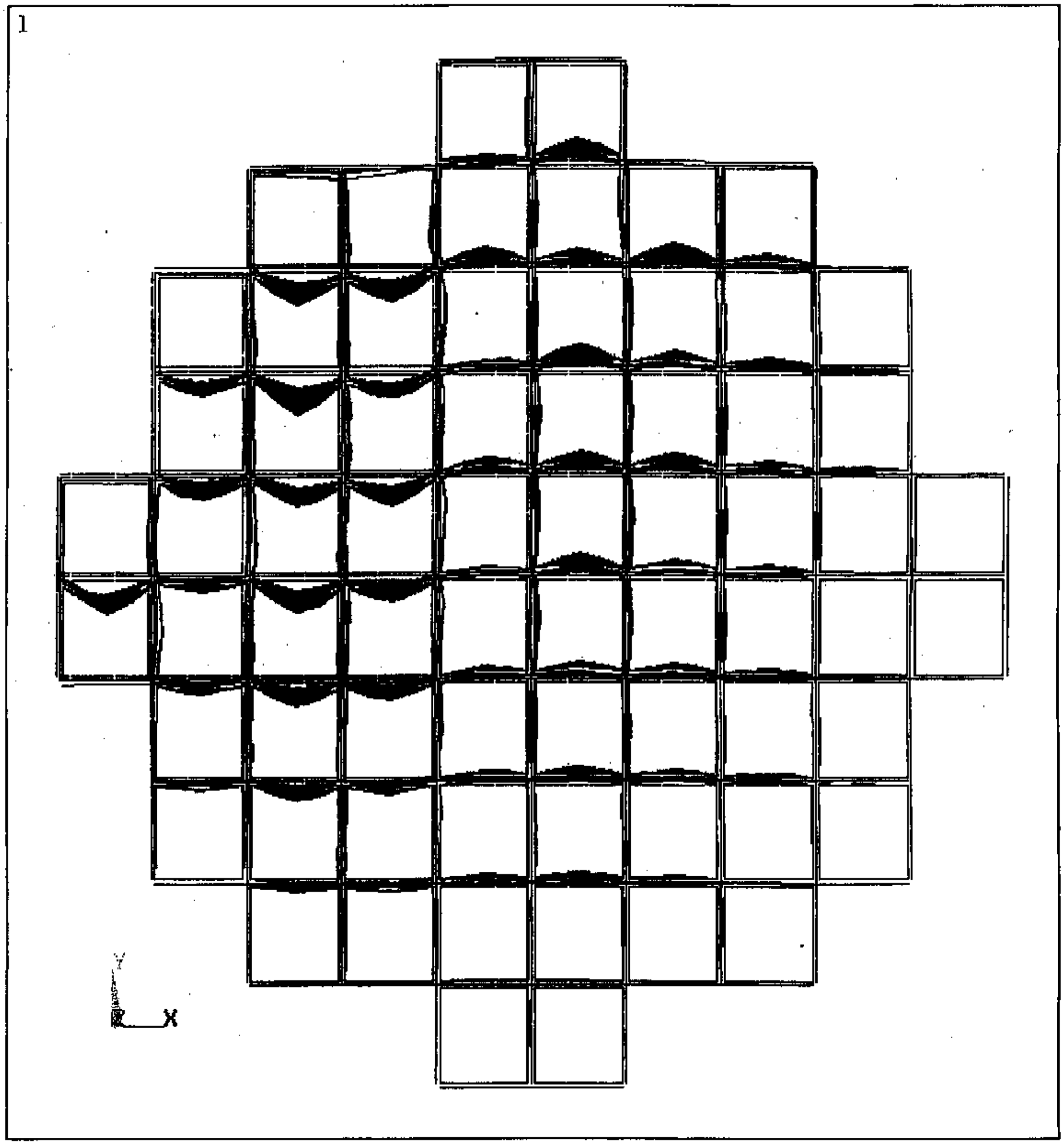

Figure 3C.1-9
30^0 Modal Analysis – Third Mode (258 HZ)

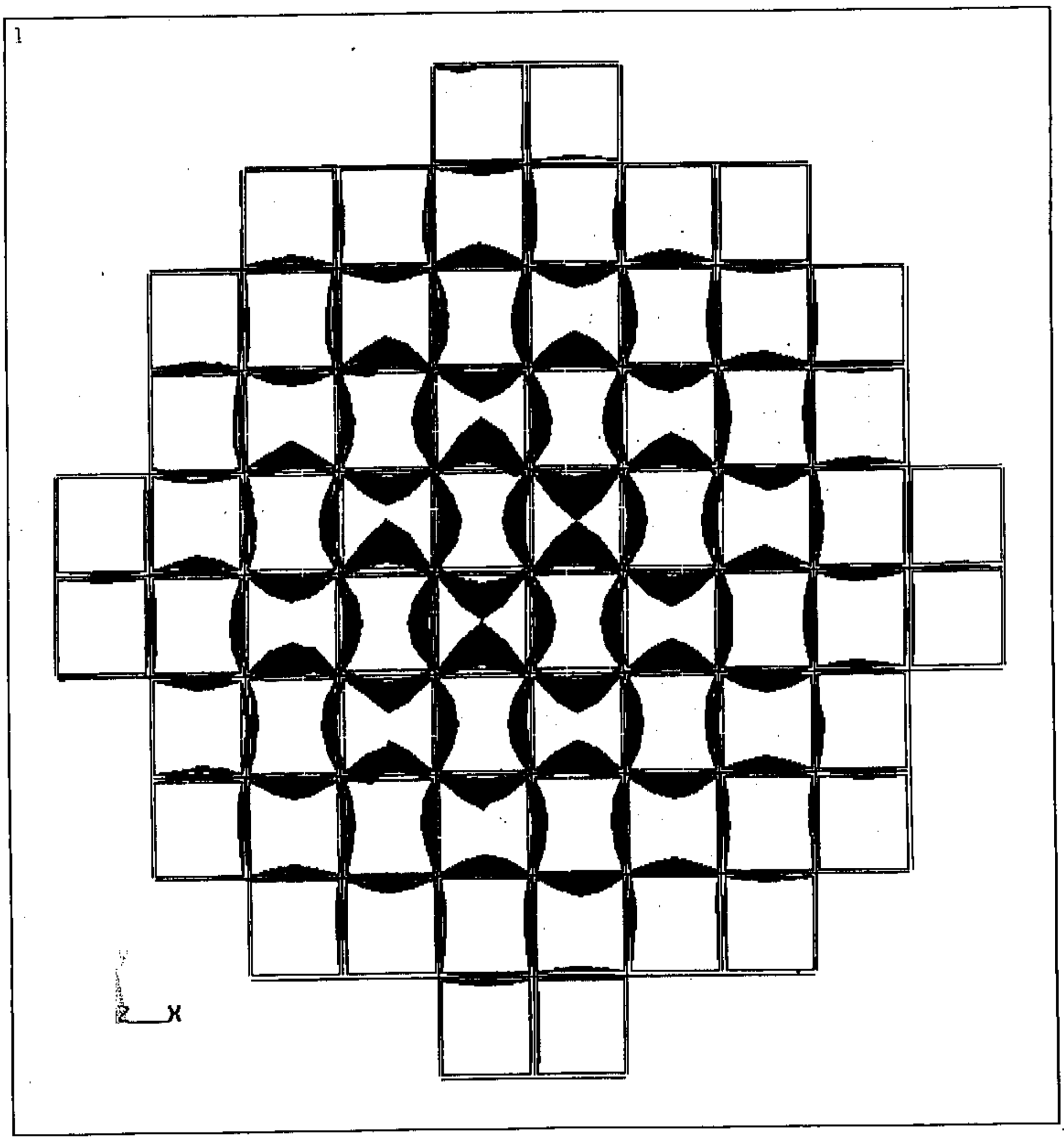

Figure 3C.1-10
30^0 Modal Analysis – Fourth Mode (264 HZ)

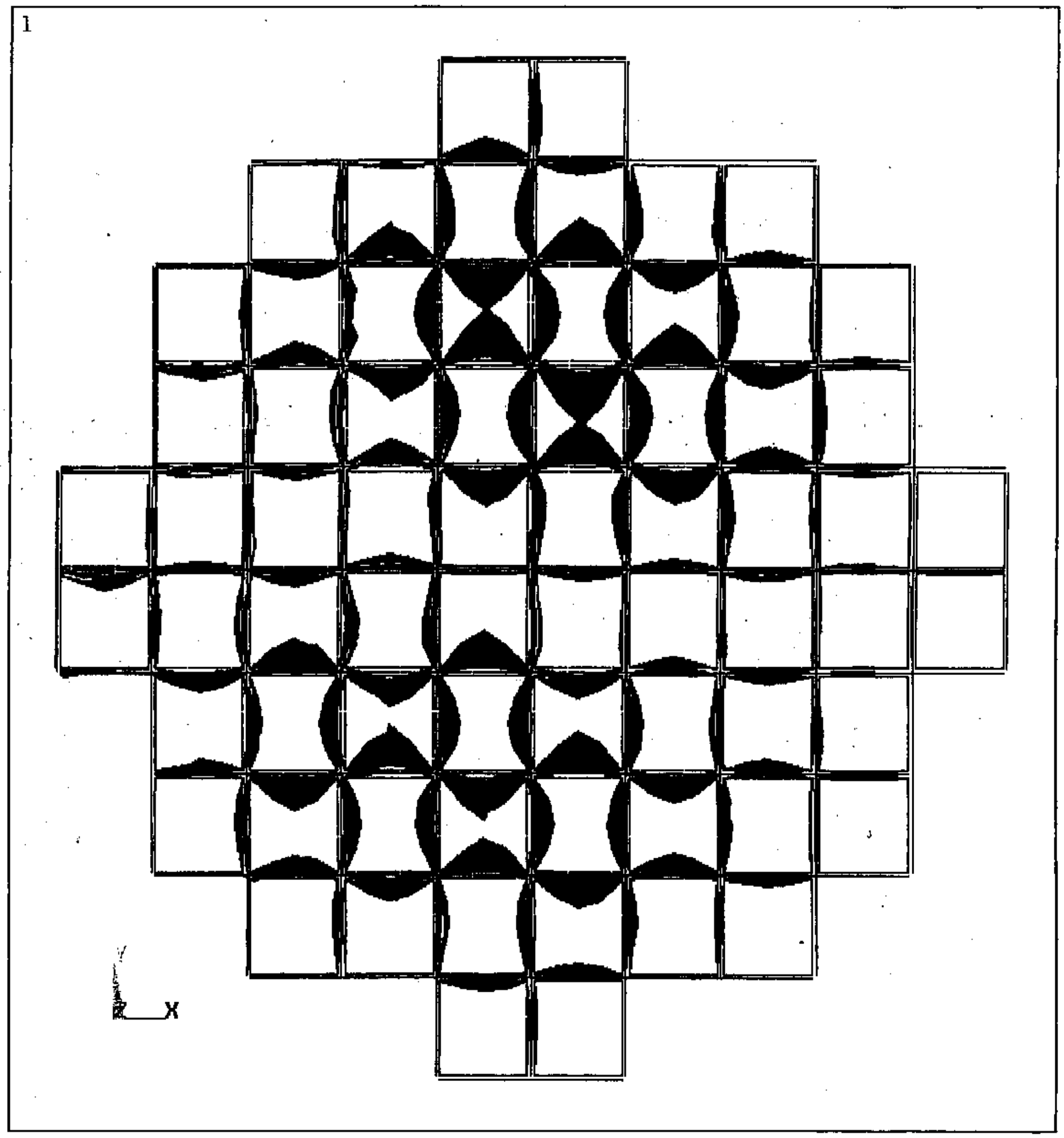

Figure 3C.1-11
45^0 Modal Analysis – First Mode (181 HZ)

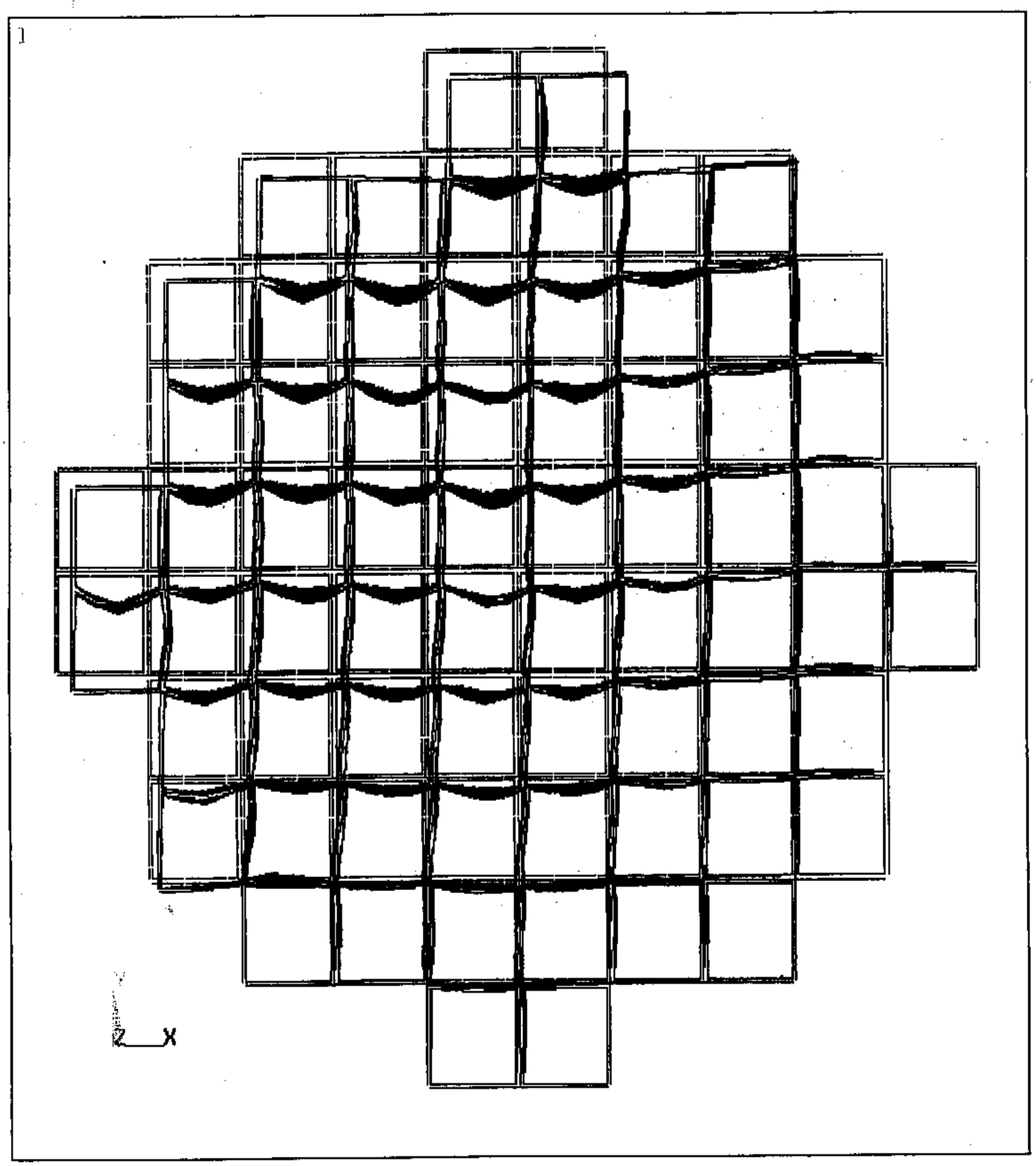

Figure 3C.1-12
45^0 Modal Analysis – Second Mode (232 HZ)

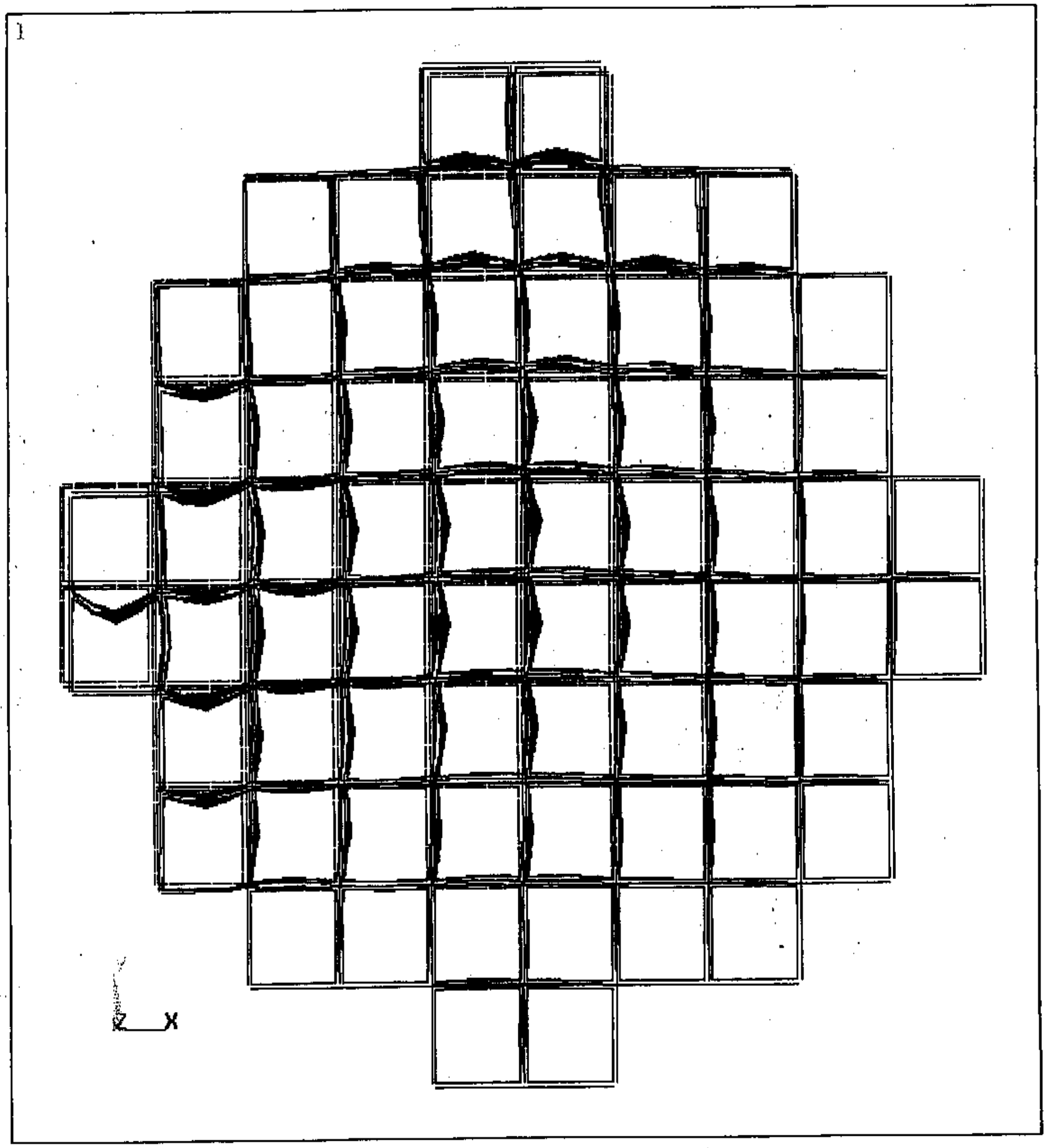

Figure 3C.1-13
45^0 Modal Analysis – Third Mode (272 HZ)

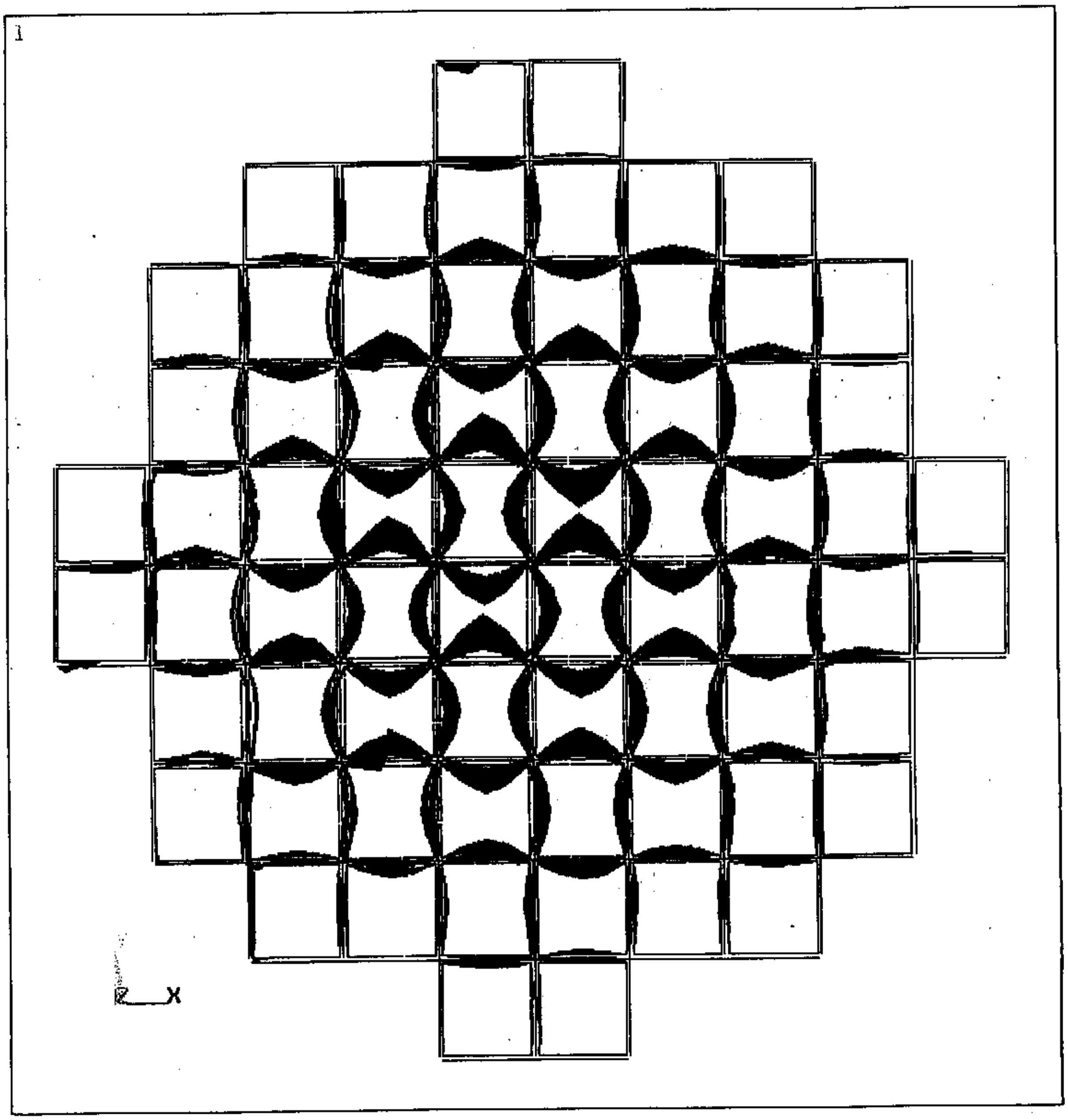

Figure 3C.1-14
45^0 Modal Analysis – Fourth Mode (281 HZ)

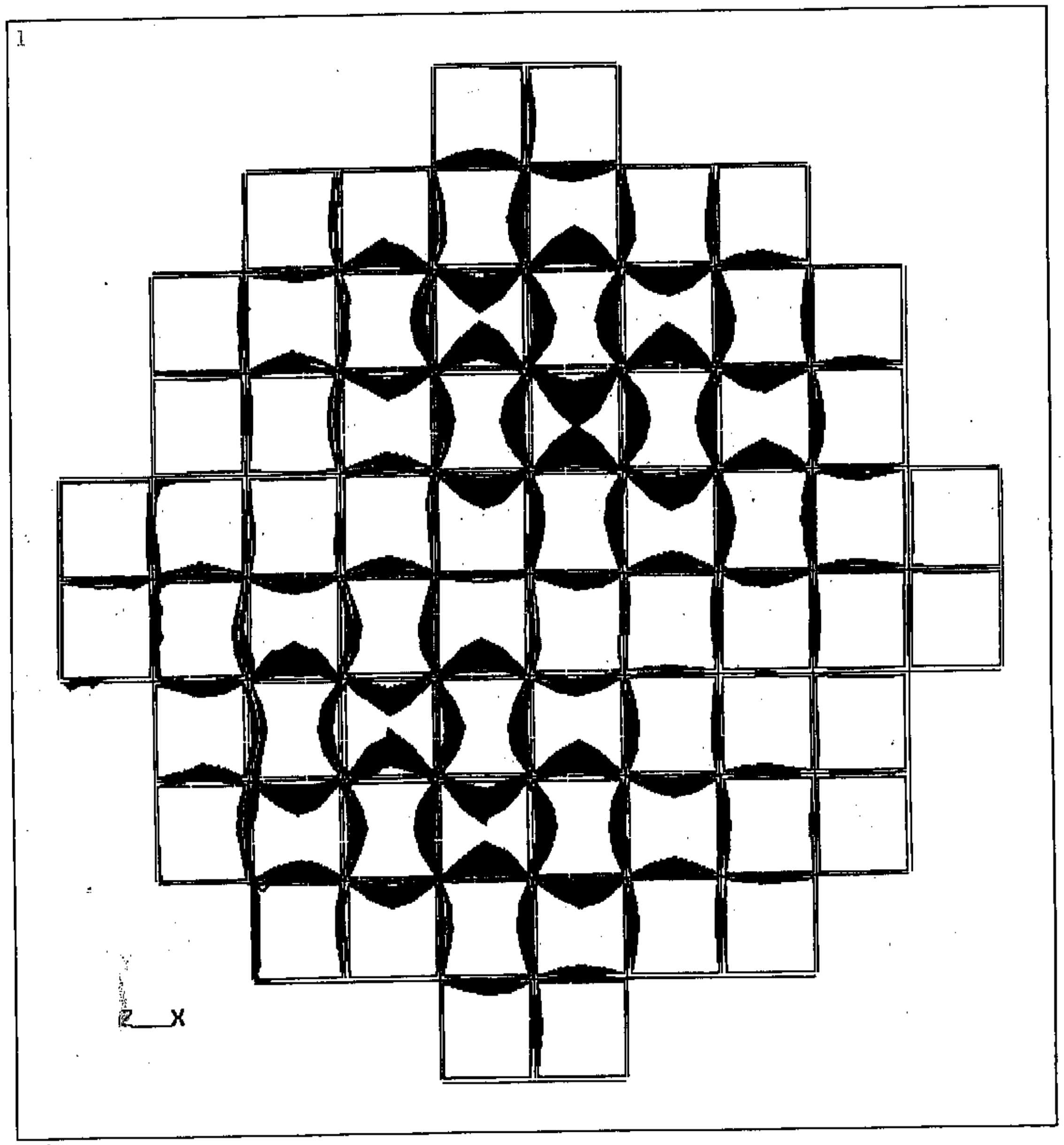

Figure 3C.1-15
Maximum Dynamic Amplification Factor for a Triangular Load