STRUCTURAL ANALYSIS OF THE GE SPENT FUEL RACKS FOR THE CG&E ZIMMER NUCLEAR POWER STATION

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1.0 INTRODUCTION

The NRC SQRT reviewed the stress analysis of the fuel racks performed by GE and in their report of December 28, 1981 expressed several concerns regarding the method of analysis. CG&E submitted their response to these concerns, based on an analysis performed by NUTECH, on April 7, 1982. The NRC expressed the following concerns on this latter analysis. (1) The mathematical model used to perform the seismic analysis of the spent fuel storage racks did not adequately represent the structural properties of the racks. The rack was considerably more flexible than modeled and the analysis results were perhaps nonconservative. (2) The stick model used did not account for any flexibility of the horizontal support divider beam which could contribute significantly to the response of the spent fuel rack. The NRC requested the licensee to perform a requalification of the racks taking into consideration the NRC comments.

The purpose of this report is to present the structural analysis of the GE spent fuel racks for SQRT requalification. The analysis determines the structural adequacy of the General Electric spent fuel racks at the CG&E Zimmer Nuclear Power Station under the dead weight and seismic loads. The stresses at several critical sections of the rack are evaluated for the specified loading and are checked against the allowable stresses.

The dynamic stress analysis of the spent fuel racks is performed by the finite element method. The STARDYNE computer code is used for this purpose. The horizontal loads are input using acceleration response spectra. The effects of the dead weight and the vertical seismic acceleration are calculated separately using a static analysis and combined with those of the horizontal seismic loads where appropriate.

2.0 SUMMARY OF RESULTS AND CONCLUSIONS

A summary of least margins calculated for the spent fuel rack sections and welds is provided in Table 1. These margins represent the ratios of the allowable stresses to the calculated stresses. A margin greater than or equal to one indicates acceptability.

All margins for the stresses in the critical components and welds in the rack are greater than one. It is, therefore, concluded that the structural design of the racks is adequate to withstand the specified seismic event.

TABLE 1 - SUMMARY OF LEAST MARGINS

Component or Weld	Calculated Stress (psi)	Allowable Stress (psi)	Margin of Safety
Vertical Columns of the Rack (Axial + Bending)	7775	15360	1.98
Welds Between Columns & Base	7824	10240	1.31
Bearing Stress on Bolt Pads	17440	19200	1.10
Compression of Base Casting	5694	19200	3.37
Welds on Diagonal Bracing	780	10240	13.13

3.0 INPUT INFORMATION

1. The structural details of the rack are taken from the drawings listed in References 1 and 2, the two GE reports listed in References 3 and 4 and the NUTECH report listed in Reference 5.

2. <u>Material Properties:</u> Material types are taken from References 1, 2 and 12.

Rack Supporting Structure: type 304 stainless steel.
Modulus of Elasticity = 28,000,000 psi (Ref. 6, Table I-6.0)
Poisson's ratio = 0.3

End channels and WF section columns: 6063-T5 Aluminum.

Modulus of Elasticity = 10,300,000 psi (Ref. 7)
Poisson's ration = 0.334
Yield Strength = 16000 psi

Base casting and Bolt Pads: B26 SG70A-TG Aluminum.

Modulus of Elasticity = 10,300,000 psi (Ref. 7)
Poisson's ratio = 0.334
Yield Strength = 20000 psi

The allowable stresses for a normal operating condition are taken as sixty percent of the yield stress for tension, compression and bearing (References 8 and 9) and as forty percent of the yield stress for shear. The loading condition considered herein includes SSE loads. Consequently, the normal allowable stresses are multiplied by a factor of 1.6 in accordance with Reference 10.

4.0 MATHEMATICAL MODELING

The structural analysis of the rack under the seismic loading is performed using the finite element method and STARDYNE computer code (Reference 3).

4.1 Rack Arrangement

The arrangement of the spent fuel racks in the spent fuel pool is shown in Figure 1. There are five rows of racks in the east-west direction. Each row of these racks is contained between two horizontal support beams, hereafter addressed as S&L beams, which run between the north and the south walls of the pool. The array with two rows is close to the west wall of the pool and the array with three rows is close to the east wall of the pool. The two arrays are independent of each other and are separated by a 3 foot gap. The two GE divider beams aa' and bb' are not continuous over the S&L beams. They are individual beams whose webs are bolted to the top flange of the S&L I-beams with a single bolt (Ref. 2d, details 71, 72 and 73). At these locations the S&L I-beams are supported by standard 6 inch pipe columns. At the other locations the GE dividers are held between guides attached to the top flanges of the S&L beams (Ref. 2c Details 66 and 67), and they are free to translate in the east-west direction. Therefore, each row of racks in the array acts structurally independently of the other rows during a seismic event. It is sufficient to model any one of the rows for the dynamic structural analysis of the racks.

4.2 Finite Element Model

One row of racks in the north-south direction contained between two S&L beams is modeled for the structural analysis. The middle row of the three row array close to the east wall of the pool (Figure 2) is selected for this purpose. The S&L support beams, the GE divider beams and the vertical pipe columns are included in the finite element model. The model is shown in Figures 3 and 4. The top of the vertical column is rigidly connected to the bottom flange of the S&L beam using four bolts and a steel plate welded to the pipe (Ref. 2c, Detail 68). The bottom of the vertical pipe column is rigidly fixed to the pool floor (Ref. 2b Detail 59). Therefore, the pipe columns are assumed to be fixed at their bases and rigidly connected to S&L beams at their top ends. The S&L beams are

attached to embedments in the pool walls through connections made with thin plates bolted to the webs of these I-beams (Ref. 2c, Details 64, 65 and Ref. 2d, Detail 69). These S&L beams are, therefore, assumed to have pinned support since these connections are very flexible as far as bending is concerned. The S&L beams nearest to the east and west walls have horizontal restraints as shown in Figure 1. These are I-beams which are rigidly fixed to embedments in the pool walls at their one end and rigidly jointed to the S&L beams at the other end. The restraints are modeled as beams with fixed supports at the wall and rigid jointed to S&L beams. The racks are modeled as vertical beams whose stiffness properties are determined to be close to those of a detailed two-vertical beam model. Two of the racks identified as R1 and R2 in Figure 2 are modeled with a larger number of nodes than the other racks. The forces and moments in these racks are used for the analysis of critical components and welds. The GE divider beams which connect the racks to the S&L beams are modeled with stiffness properties so determined as to reflect their very rigid behavior. The pinned connections as well as guided connections are introduced by using the appropriate STARDYNE PIN codes at the ends of the GE divider beams where they are connected to the S&L beams.

The rack structure is made of two rows of fuel cells (made from aluminum channels and I-sections), each row having ten cells. These channel and I-section columns are welded at their bottom to a base casting which rests on the pool floor and are bolted to it. The channels and I-sections forming the ten rows of cells are adequately braced together such that for bending about the axis parallel to the shorter dimension of the rack, they act integrally as a single composite beam. Therefore, they are modeled as a single vertical beam whose stiffness properties are calculated on the assumption of this integral behvior. Each row of ten cells are attached to each other by the flexible GE divider beam (the 0.5 inch thick web has to transfer the moments) at a height of 118 inches above the pool floor and by another very flexible plate (0.5 inch thick) at the top. Therefore, integral composite action for bending about an axis parallel to the longer dimension of the rack is not assumed. The two stick model will, therefore, consist of two vertical beams fixed at their bases and connected by two very flexible beams one at the level of GE divider beam and the other at the top.

The single vertical beam model represents the entire twenty-cell rack structure.

It is fixed at the base and its stiffness for bending about the axis parallel to the shorter dimension of the rack will be twice the corresponding stiffness of the individual vertical beams of the two-beam model. In order to determine the stiffness for bending about the axis parallel to the longer dimension of the rack the procedure that is described here is used. The first few vibration frequencies of the two-beam model are calculated. The single-beam model stiffness is so determined that its frequencies for similar vibrating modes are close to the corresponding frequencies of the two-beam model. It is found that assuming the two rows of ten fuel cells to act individually, ignoring entirely any increase in the stiffness due to the GE divider beam, results in frequencies that are close to those calculated for the two-beam model. Therefore the stiffness properties used for the single-beam model of the rack are twice those for the individual beams of the two-beam model. The beams representing the GE divider beams are considered to be rigid jointed to the rack beams. The total masses of the rack structure included in the model are those due to the rack, fuel assemblies and the mass of water contained in the rack. These masses are uniformly distributed over the height of the vertical beams modeling the racks. The additional hydrodynamic mass due to the racks vibrating in the water is calculated using the procedures described in Reference 11. These masses which are different in the two horizontal directions are appropriately lumped at the rack nodes.

5.0 DYNAMIC STRUCTURAL ANALYSIS

A frequency analysis of the rack structure is performed using the HQR option of STARDYNE. The displacements in the two horizontal directions of the rack beams are selected as the 104 dynamic degrees of freedom. The first sixty frequencies are determined and are used for the dynamic analysis by the response spectrum method. The magnitude of the sixtieth frequency is 161 Hz and this is well in the rigid range of the horizontal response spectra (Figures 5 and 6). The total mass of the structure included in the dynamic analysis is evaluated in each direction and for the mass that is not included in the response spectrum analysis an equivalent static analysis is performed using the appropriate rigid range acceleration. The two results are added to give the final results for these dynamic analyses. The results of the two horizontal earthquakes are combined in an SRSS manner. The magnitude of the smallest vertical frequency is 230 Hz and this is well into the rigid range of the specified response spectrum (Figure 7). Therefore, the vertical seismic effects are determined from an equivalent static analysis using the appropriate rigid range acceleration. Where applicable, the results of the vertical seismic effects are absolutely added to the results of the horizontal seismic effects. The effect of the seismic load is added to the effect of the dead weight in such a way as to result in the worst load combination. The forces and moments in the rack calculated from the dynamic structural analysis are used to check the structural adequacy of the racks. The stresses at the critical sections such as the columns of the fuel cells, the welds between the columns and the base casting, bearing at the bolt pad, compression of the base casting at supports and the welds on the diagonal bracings, are checked to determine the structural adequacy of the racks.

6.0 REFERENCES

1. GE Drawings:
   a. No. 762E210 Rev. 6
   b. No. 829E422 (Fuel Bundle)
   c. No. 105D4781 Rev. 2 (Spent Fuel Storage Rack)

2. Sargent and Lundy drawings:
   a. No. S-421, Rev. N, Reactor Building Pool Liner Bottom Liner Plan.
   b. No. S-428, Rev. L, Reactor Building Pool Liner Sections & Details, Sheet 7.
   c. No. S-429, Rev. L, Reactor Building Pool Liner Sections & Details, Sheet 8.
   d. No. S-439, Rev. G, Reactor Building Pool Liner Sections & Details, Sheet 9.

3. Stress Analysis - Spent Fuel Storage Rack by General Electric, File No. 33.803.0551, October 21, 1977.

4. Caorso, Assurance of Function, DRF No. 139FI6-E002-BB1, General Electric, File No. 33.803.0551, October 20, 1977.

5. NUTECH File No. 33.803.0551, Zimmer Nuclear Power Station Spent Fuel Storage Calculations.

6. ASME Boiler and Pressure Vessel Code, 1980 Edition, Section III, Division 1, Appendices.

7. Annual Book of ASTM Standards - Part 7. American Society for Testing and Materials, 1979.

8. John W. Clark, Design of Aluminum Structural Members, Section 10, Structural Engineering Handbook, McGraw Hill 1979.

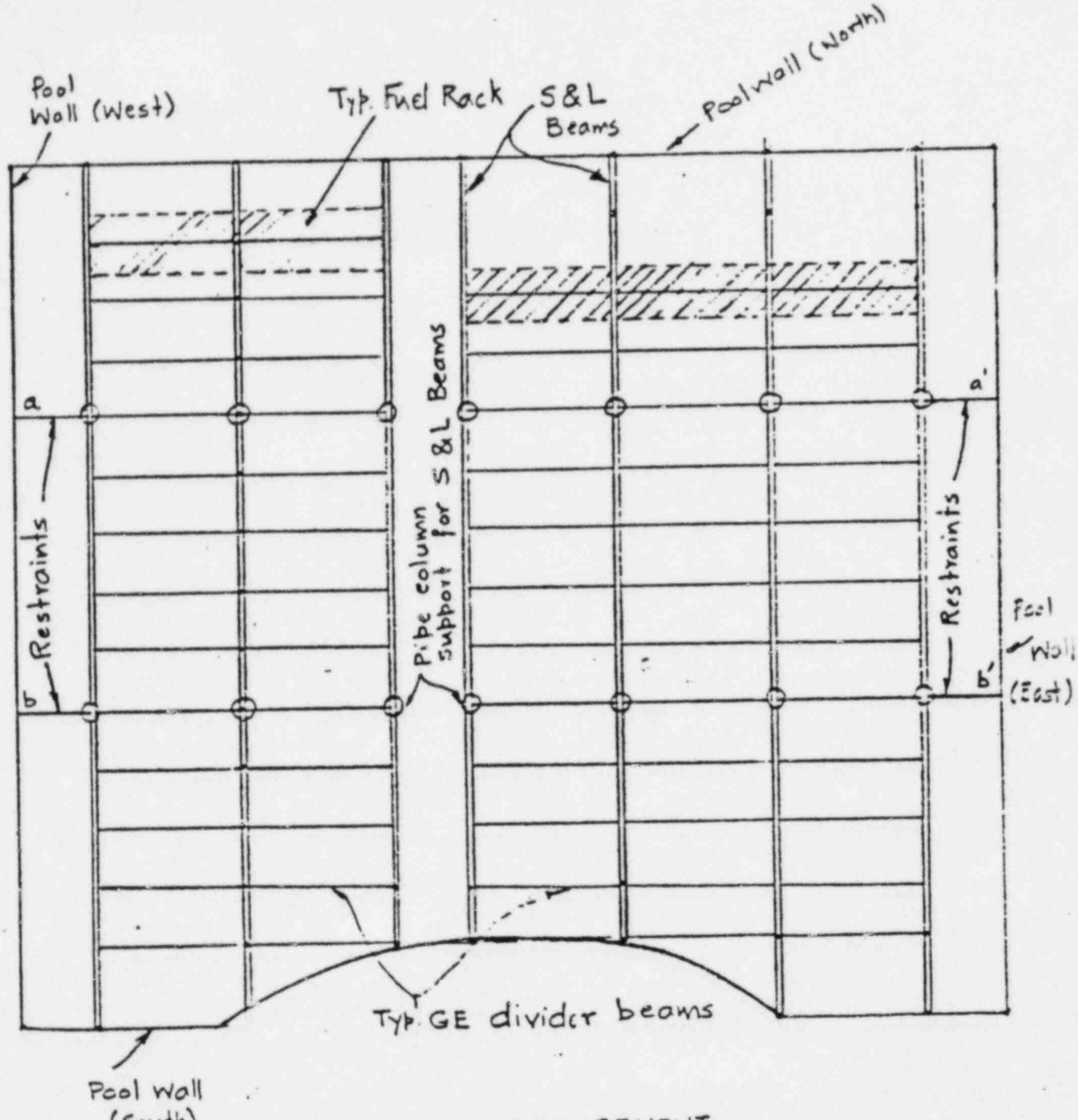
9. Commentary on specifications for Aluminum Structures, Aluminum Construction Manual, The Aluminum Association, First Edition, 1971.

10. USNRC Standard Review Plan, Section 3.8.4, "Other Category I Structures".

11. R.G. Dong, "Effective Mass and Damping of Submerged Structures", Report No. UCRL-52342, Lawrence Livermore Laboratory, University of California, Livermore, April 1978.

12. Document No. 22A2553, Rev. 2, General Electric, Spent Fuel Storage Rack.

13. MRI/STARDYNE Structural Analysis System, Mechanics Research Inc., Los Angeles, California, 1970.



RACK ARRANGEMENT

FIGURE 1

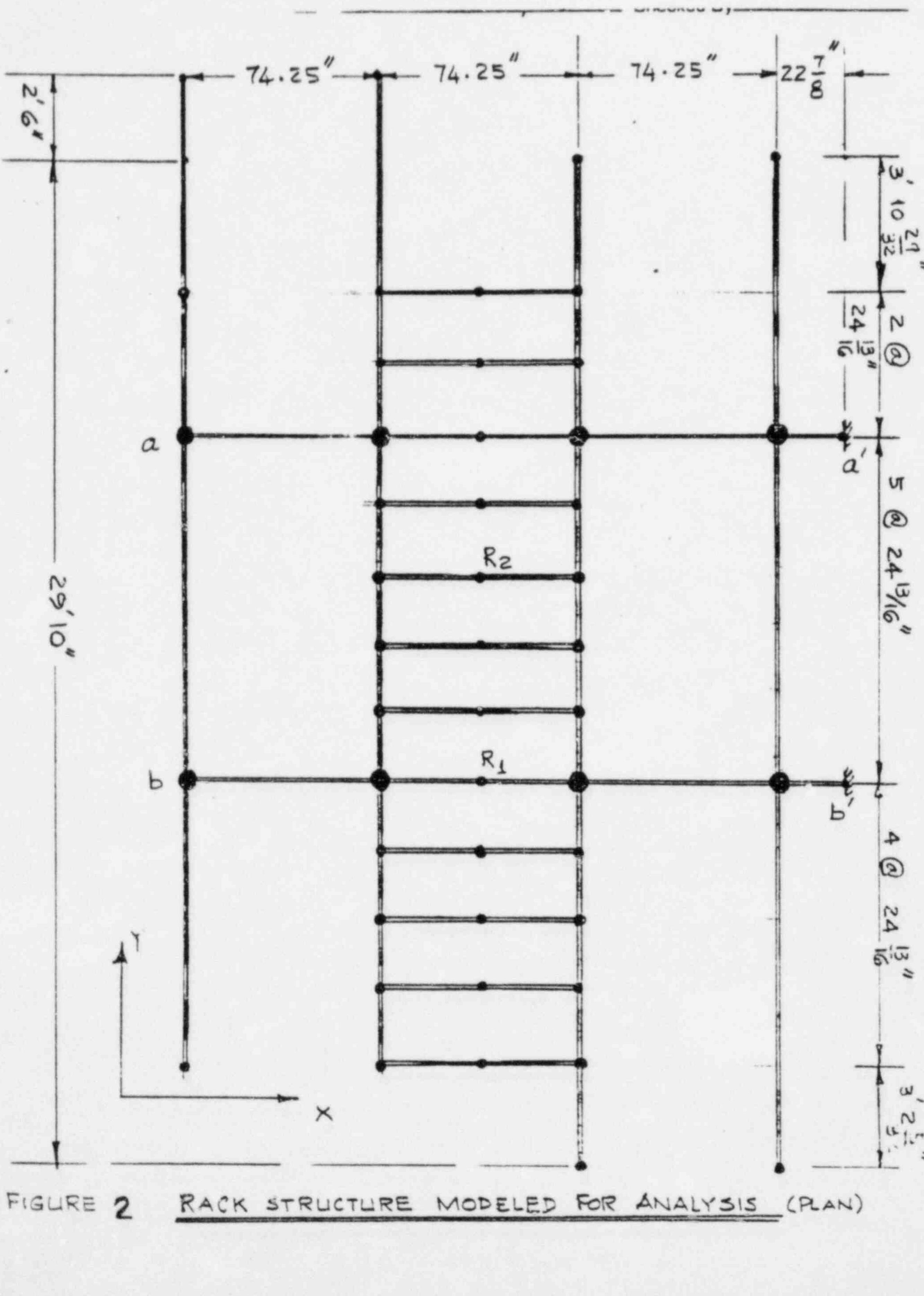


FIGURE 2 RACK STRUCTURE MODELED FOR ANALYSIS (PLAN)

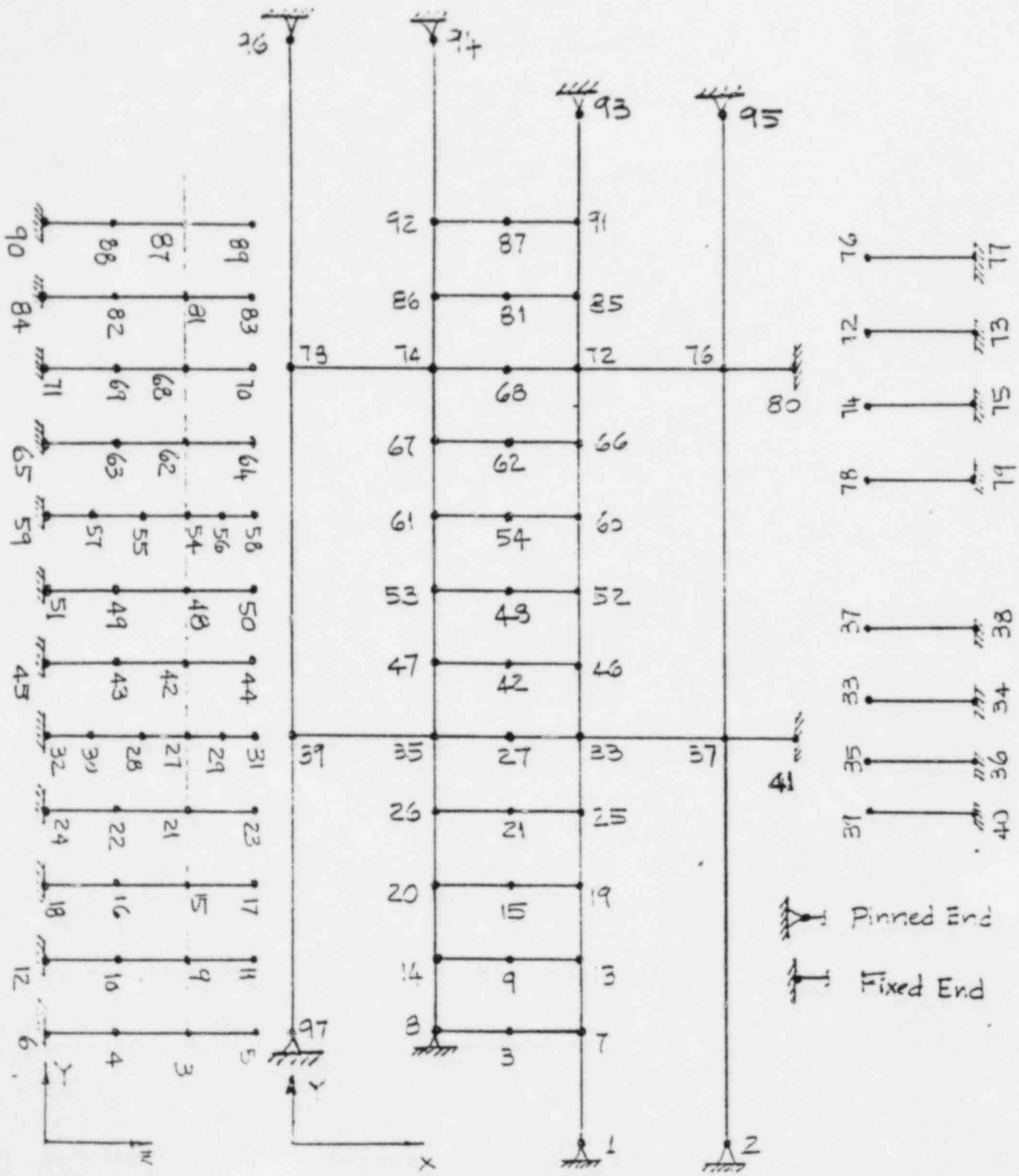


FIGURE 3 FINITE ELEMENT MODEL OF RACKS (Node Numbering)

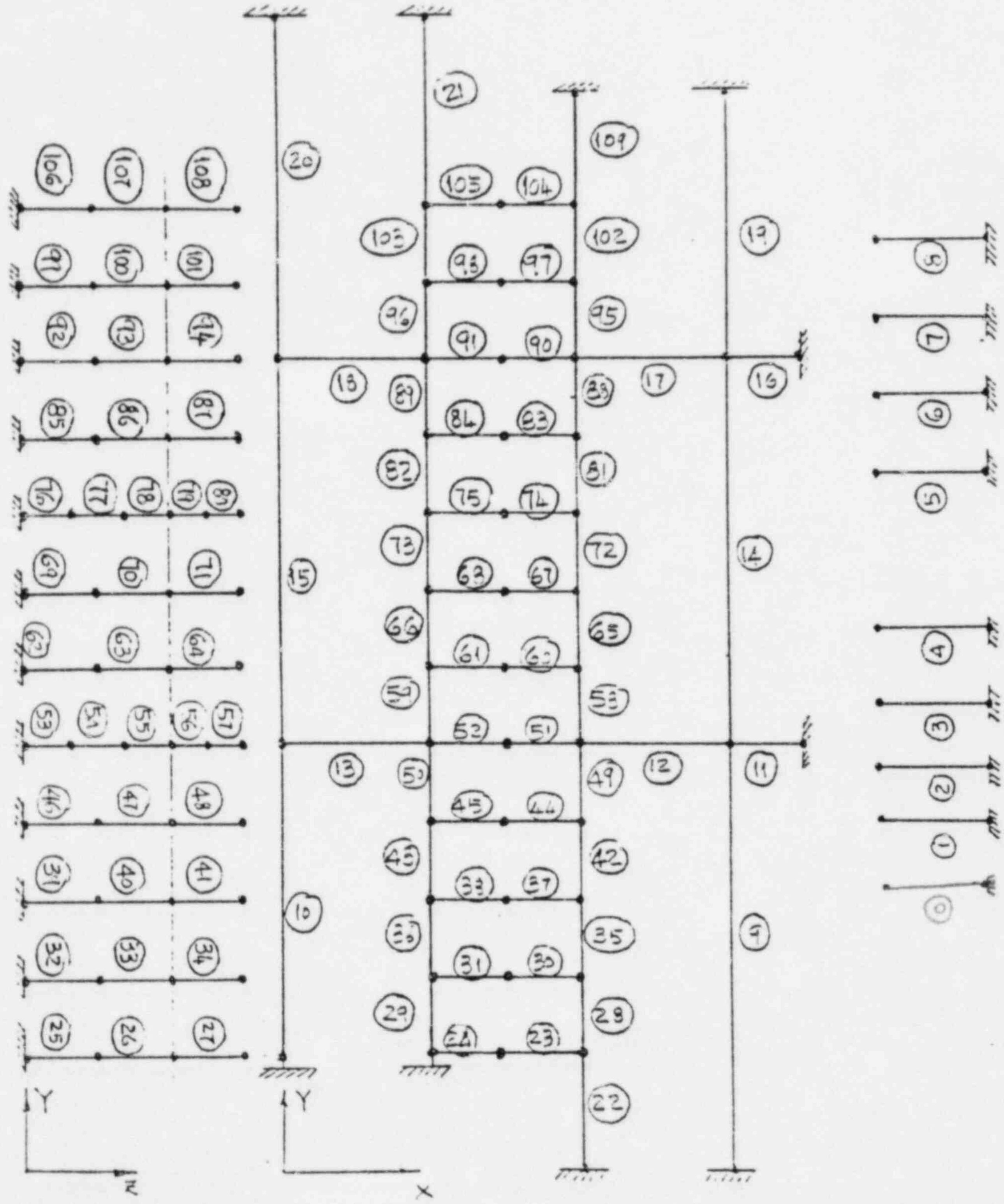
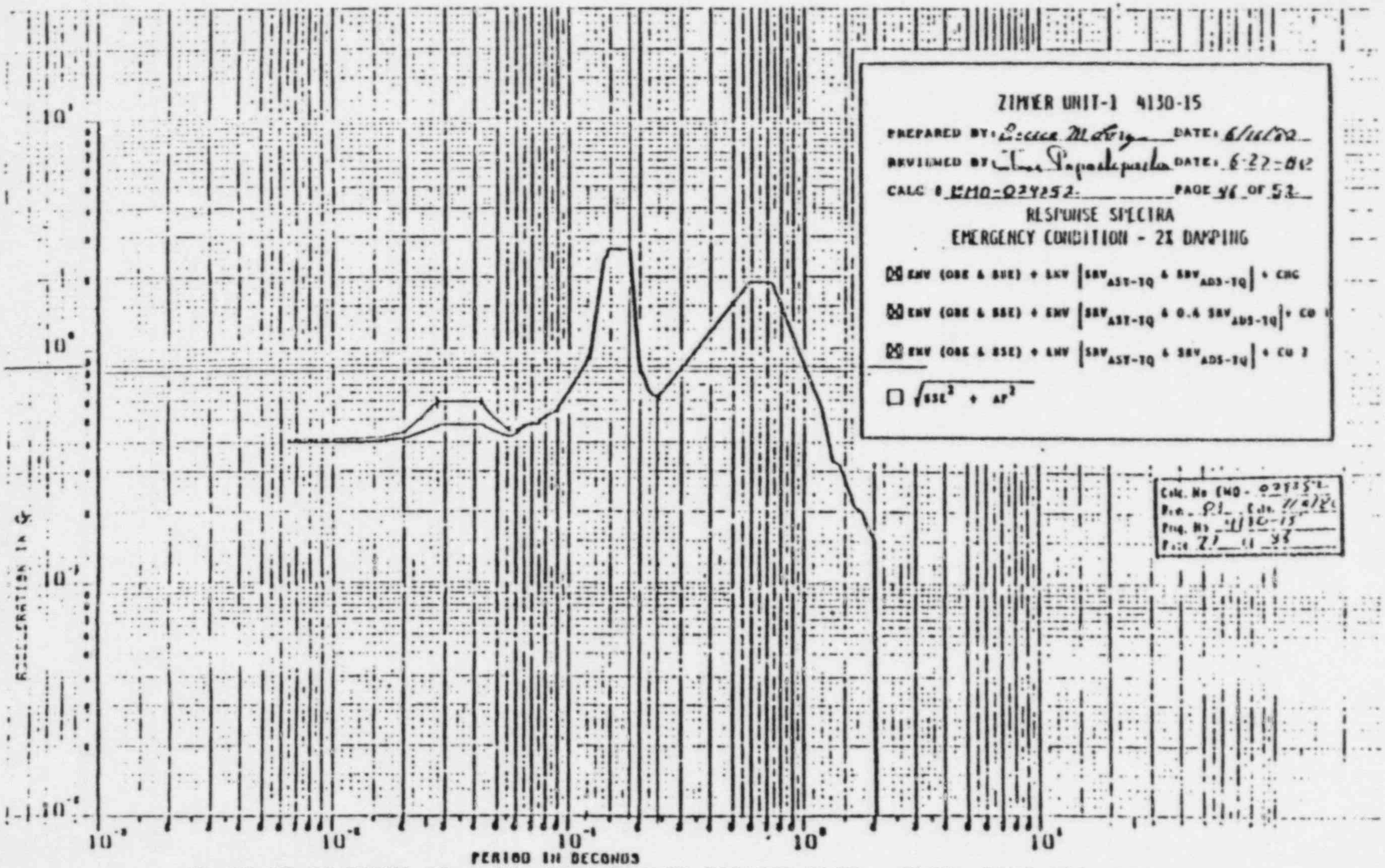


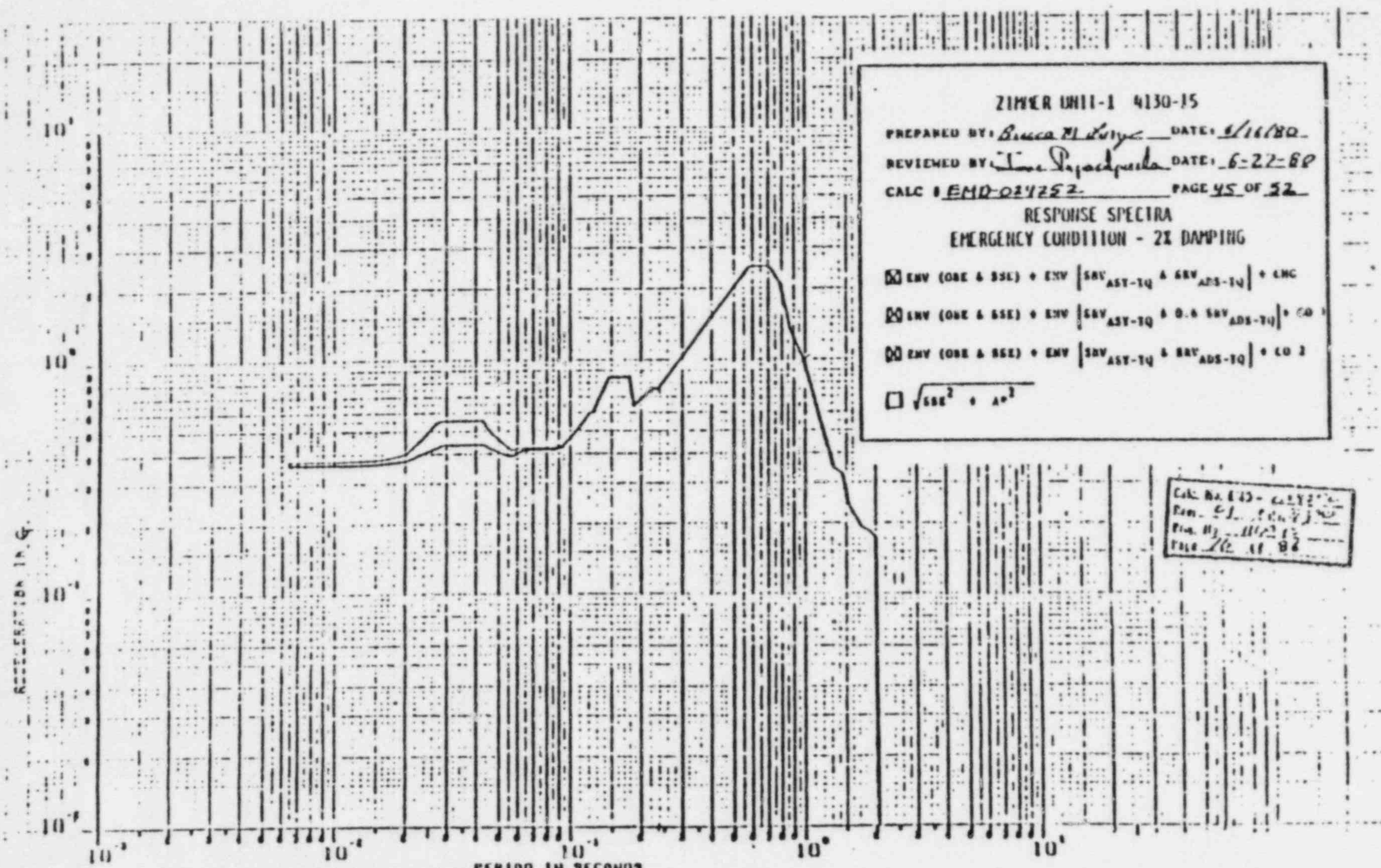
FIGURE 4 FINITE ELEMENT MODEL OF RACKS (Element Numbering)



HO-EW DF-2% ABSV(C2 + C3 + C4) ZIMMER REACTOR BLDG. ELEV. 593'-0" REV. 01

Run I.D. DML 6/16/80

FIGURE 5 East-West Response Spectra for Pool Floor



HG-NS DF-2% ABSV(C2 + C3 +C4) ZIMMER REACTOR BLDG. ELEV. 593'-8" REV. 01

Run I.D. BML 6/16/80

FIGURE 6 North-South Response Spectra for Pool Floor

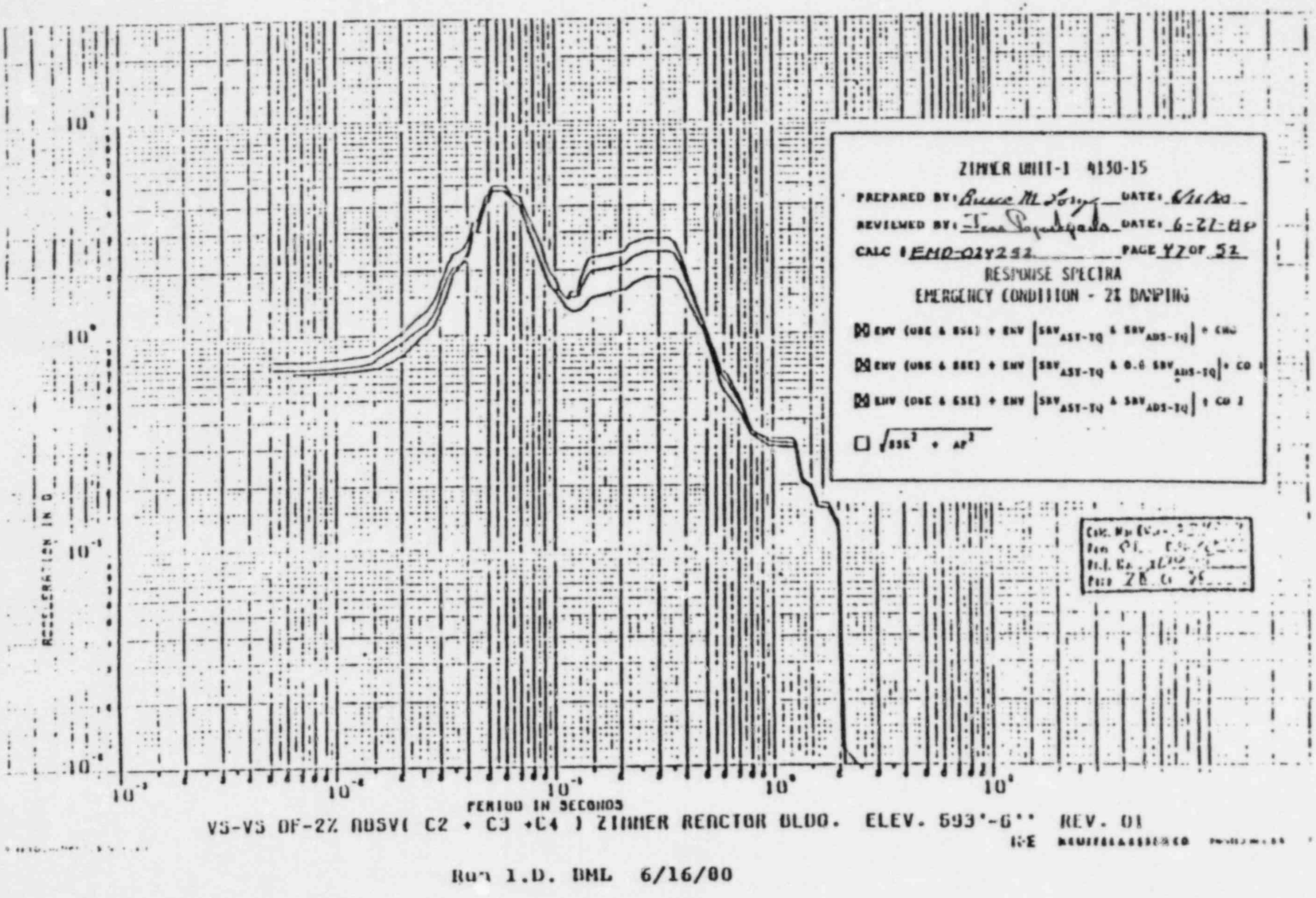


FIGURE 7 Vertical Response Spectra for Pool Floor