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July 26, 1984

United States Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: Mr. George W. Knighton, Chief
Licensing Branch 3
Office of Nuclear Reactor Regulation

SUBJECT: Beaver Valley Power Station - Unit No. 2
Docket No. 50-412
Responses to NRC Structural Engineering Section Requests for Additional Information

Gentlemen:

Attached are the responses to the NRC Structural Engineering Section's Questions 220.13 and 220.14, which are related to NRC Structural Design Audit Action Item 25.

Please forward these responses to the Structural Engineering Section for review.

If you have any questions on this matter, please contact J. D. O'Neil at (412) 787-5141.

DUQUESNE LIGHT COMPANY

By E. J. Woolever
E. J. Woolever
Vice President

JDO/wjs
Attachments

cc: Ms. M. Ley, Project Manager (w/a)
Mr. E. A. Licitra, Project Manager (w/a)
Mr. G. Walton, NRC Resident Inspector (w/a)

SUBSCRIBED AND SWORN TO BEFORE ME THIS 26th DAY OF July, 1984.

Anita Elaine Reiter
Notary Public

ANITA ELAINE REITER, NOTARY PUBLIC
ROBINSON TOWNSHIP, ALLEGHENY COUNTY
MY COMMISSION EXPIRES OCTOBER 20, 1986

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COMMONWEALTH OF PENNSYLVANIA)
) SS:
COUNTY OF ALLEGHENY)

On this 26th day of July, 1984, before me, a Notary Public in and for said Commonwealth and County, personally appeared E. J. Woolever, who being duly sworn, deposed and said that (1) he is Vice President of Duquesne Light, (2) he is duly authorized to execute and file the foregoing Submittal on behalf of said Company, and (3) the statements set forth in the Submittal are true and correct to the best of his knowledge.

Anita Elaine Reiter
Notary Public

ANITA ELAINE REITER, NOTARY PUBLIC
ROBINSON TOWNSHIP, ALLEGHENY COUNTY
MY COMMISSION EXPIRES OCTOBER 20, 1986

NRC Letter: September 15, 1983

Question 220.13 (Section 3.8.4.1.4, SRP 3.8.4.II)

Provide the load combination, analysis procedures, and acceptance criteria used in the design of fuel pool liner and slab. Indicate how the leak-tight integrity of the fuel pool liner and structural integrity of the pool slab will be maintained in the event of a heavy drop accident.

Response:

The load combinations, analysis procedures, and acceptance criteria are covered in Section 3.8.4 and are further referenced in Section 9.1.2.3.

The movable platform with hoists is the only crane operating over the spent fuel pool, and as described in Section 9.1.4, this crane handles only light loads.

The spent fuel cask trolley is described in Sections 9.1.5.2.2 and 9.1.5.5.2.2, along with a description of the paths of travel and the interlocks available to preclude any dropping of heavy objects over the spent fuel pool.

NRC Letter: September 15, 1983

Question 220.14 (Section 3.8.4.1.4, SRP 3.8.4.II)

Provide the sketches of the mathematical models used in the design of spent fuel racks. Describe the methods of analysis, boundary conditions, spring-mass locations, fluid modeling and damping considerations. Also describe the methods by which seismic and other loads are applied to the racks and the pool.

Response:

Introduction

The spent fuel racks consist of two parts, a subbase beam system and the 17 individual rack assemblies. The system of interconnected base beams is provided to bridge the space between embedment pads so that load transfer from the racks to the floor occurs only through the embedment pads. Each spent fuel rack, consisting of an 8 x 8 array of storage cells, is bolted to the base beams. Because the entire complement of base beams and 8 x 8 racks form a single structural unit, relative sliding between racks is eliminated. However, the base beam system is free to slide, inhibited only by friction in the horizontal plane, since it is not connected to the embedment plates. The storage racks are positioned such that adequate clearances are provided between the racks and pool walls to avoid impacting during seismic events.

1. METHODS OF ANALYSES

1.1 STATIC ANALYSIS

Static analyses of the rack and the subbase structure have been carried out separately in a conservative manner. The detailed rack model has been assumed fixed at points of attachment to the subbase structure, whereas the detailed model of the subbase structure consists of a representative portion of the system with proper boundary conditions. The seismic loads imposed on both the models have been determined by dynamic analyses that properly account for the beam-rack interaction.

1.1.1 Mathematical Model of the 8 x 8 Rack

In order to perform static stress analyses of the fuel storage rack structure, the rack has been mathematically modeled as a finite element structure consisting of discrete three-dimensional elastic plate elements interconnected at a finite number of points using the ANSYS computer program. The stiffness characteristics of the structural members are related to the plate thickness, cross-sectional area, effective shear area, and moment of inertia of the element section. To take advantage of the symmetry of the structure and loading conditions, only one-half of the rack was modeled, with the plane of symmetry located on the center line of the rack. All nodes in the plane of symmetry were restrained for translation in the horizontal X_2 direction and for rotation about the X_1 and X_3 axes. Six degrees of freedom (three translations and three rotations) are permitted at each of the remaining nodal points. Figure 220.14-1 illustrates the model. Pinned boundary conditions were applied at each location where the rack base plate is connected to the base beam system.

1.1.2 Mathematical Model of the Subbase Beam System

In order to perform detailed stress analysis of the subbase beam system, three ANSYS models have been developed to represent various scenarios of seismic response. These models also provide the equivalent subbase spring rates utilized in the dynamic analysis model.

1.1.2.1 Individual Rack Mode for Analysis of Subbase System

The subbase structure under an individual rack along the periphery of the base beam system has been modeled. The three-dimensional finite element model consists of the rigid rack connected to the base beams at the corner storage cells through the rack tie-down studs. The base beams are fixed at the interior ends and are coupled to the rack corner by compression-only links at the exterior ends. The rigid rack and its base are represented in the model by the rigid region feature of ANSYS computer program.

Stiffness characteristics of the three-dimensional structural beam elements are related to the cross-sectional area, effective shear area, and moment of inertia of the beam element sections. The storage cells through which the racks are connected to the beams are represented by the laminated, flat, triangular shell element having the thickness of the cell base plate and its reinforcement. For the rack tie-down stud, a three-dimensional spar element has been used.

1.1.2.2 Two-Rack Model for Out of Phase Motion

In order to determine the stiffness characteristics and internal stress distribution in the beam support system of the interior racks and the interior end of the peripheral racks, an out-of-phase model, as shown on Figure 220.14-2, was prepared. The model consists of two racks resting on the beam support system. Each storage rack and its base is represented by a rigid cantilever on a rigid base. The rigid rack and base region are connected to the base beams at the corner storage cell flexible base plate through tie-down studs. Two cases with different boundary conditions were analyzed. In Case 1, all four ends of the base beams are fixed to represent the responses of typical interior racks to out-of-phase seismic loads (seismic loads in opposite direction). For Case 2, boundary conditions were changed from fixed to pinned end. Case 2 represents the responses of the peripheral racks and those in the second interior row to the out-of-phase seismic loads. The effects of longitudinal base beams are accounted for by rigid beams having large stiffness properties.

1.1.2.3 Integrated Base Beams/Shear Panel Model

In order to determine the maximum shear force in the rack tie-down studs and the maximum stress in the base beams due to horizontal seismic loads, a third integrated base beams/shear panel model was prepared. As shown on Figure 220.14-3, this model consists of individual rigid shear panels (representing the reinforced storage rack base plate) attached at four corners to the base beam structure by tie-down studs.

1.2 DYNAMIC ANALYSIS

Two methods of dynamic analysis have been utilized to perform the seismic response analysis of the BVPS-2 racks. In order to determine the maximum seismic loads experienced by the storage racks, a response spectrum analysis was performed. The conservatism of this method was further verified by performing non-linear dynamic analysis procedures. The latter method was also used to evaluate the sliding displacements and tipping of the racks, as well as the corresponding fall back loads.

1.2.1 Response Spectrum Analysis Model

The finite element model consists of elastic beam elements of STARDYNE representing the cross-sectional area, the effective shear area, and the moment of inertia of an 8 x 8 rack. The mass corresponding to the fuel assembly storage cells, poison elements, and hydrodynamic coupling effects are jumped at appropriate nodal points.

The seismic analysis is performed for fully loaded racks since this loading condition results in higher stresses and reaction loads. The inertia loads generated from this analysis have been statically applied to the models of the rack and the subbase structure. The vertical seismic analysis has been performed by proportionally increasing the deadweight stresses by the vertical acceleration associated with the vertical frequency of the rack. The results of the response spectrum analysis were compared to those of the non-linear analysis and were found to be more conservative.

1.2.2 Non-Linear Dynamic Analysis Models

Two models were developed to evaluate the design parameters resulting from seismic response. Both models incorporate the effects of fuel assembly impacts, hydrodynamic coupling, and the interface between the subbase structure and the pool floor. The fuel rack vendor, Nuclear Energy Services (NES), used their proprietary code NESCOM to perform the non-linear time history analysis.

1.2.2.1 Individual Rack Non-Linear Model

The model basically consists of two coincident lumped-mass cantilever beams supported on a rigid base, which interfaces with the ground through stop elements and springs that represent the equivalent subbase stiffness, as shown on Figure 220.14-4. One of the cantilever beams represents an 8 x 8 storage rack, and its dynamic characteristics have been matched to those of the rack. The other beam represents the stored fuel assemblies.

The effect of impact between the fuel and the rack has been modeled by providing gapped elements between each corresponding pair of nodes on the beams. The hydrodynamic coupling between the fuel and the rack and between the rack and the pool wall or adjacent rack has also been modeled.

The purpose of this model is to determine maximum loads experienced by the rack and subsequently transferred to the subbase structure. Two cases are analyzed: the individual motion of a peripheral rack and the out-of-phase motion of the interior racks. Equivalent spring rates of the subbase structure for these two cases are established as described in Section 1.1.2 and are appropriately modeled. Corresponding hydrodynamic mass matrices are used. The maximum horizontal shear and overturning moments for the two cases were compared with the results of response spectrum analysis. Conservative values have been used in the design of the racks. Tipping and fall-back loads are determined from the results of these analyses.

1.2.2.2 Sliding Analysis Model

The purpose of this model is to evaluate the horizontal motion of the entire assemblage of racks and the subbase structure. Two cases are analyzed. The first case considers all the racks in the pool fully loaded(17). The second case postulates that the left-most eight racks are fully loaded and the other nine racks are empty. For both cases a conservative coefficient of friction of 0.2 has been used.

The three-dimensional model consists of two pairs of coincident lumped mass beams as shown on Figure 220.14-3. The first pair represents the left-most eight racks and associated fuel assemblies. The second pair similarly represents the other nine racks. Both pairs have all the features described for the model in Section 1.1.2.1 of this response. The two pairs are located at the center of gravity of the racks they represent and are connected to a rigid base which models the subbase system. The interface to the floor is represented by friction elements and stop elements. In order to limit the number of elements in the model, all contacts between the subbase system and the embedment pads are not modeled. However, a conservative approach is adopted by minimizing the resisting moment due to friction forces.

The model was subjected to SSE time history and the resulting displacements for the two cases described above were found to be less than the allowable gap between the rack and the pool walls.

2. FUEL ASSEMBLY IMPACT LOADS

2.1 IMPACT ANALYSIS

Clearances are provided between fuel assemblies and the storage cells to avoid interferences during fuel storage and removal operations. The storage cell/fuel assembly clearance or gap results in the impacting of the fuel assembly and storage cell during a seismic event. The BVPS-2 fuel storage racks have been analyzed using both non-linear time history and linear response spectrum model superposition methods of dynamic analysis. In the non-linear time history analysis, the effect of impacting masses have been directly accounted for by inclusion of gapped impact elements in the nonlinear model. In the linear analysis, impacting has been conservatively accounted for by the following assumptions:

1. The effect of fuel assembly impact is a two-fold increase in the seismic inertia loadings produce by the impacting fuel assemblies mass, and

2. The impact and seismic inertia loads of the impacting masses are added to the seismic inertia loads of the non-impacting masses.

3. HYDRODYNAMIC MASS MATRIX FORMULATION

3.1 METHOD OF APPROACH

The hydrodynamic mass matrix can be essentially classified into:

1. Hydrodynamic mass to represent water between the fuel assembly and the can, or

2. Hydrodynamic mass to represent interaction between racks and between racks and pool wall.

The hydrodynamic mass matrix for the above cases have been calculated either by the program NESWAT or by using analytical formulas.

3.2 COMPUTER PROGRAM NESWAT

NESWAT is a proprietary computer program developed for NES and has the ability to compute the hydrodynamic mass matrix to represent the inertial effects an object incurs when subjected to vibration in a submerged condition. The program has the capability of computing the hydrodynamic mass matrix for cases in which several bodies are vibrating simultaneously, and the hydrodynamic mass matrix expresses the interactive influence of the fluid on the vibrating components.

4. WATER SLOSHING EFFECTS ON THE SPENT FUEL STORAGE RACKS

The water sloshing effects on the fuel racks have been evaluated using analytical methods described in Lockheed (1963).

Reference for Question 220.14

Lockheed Aircraft Corporation and Holmes & Narver, Inc., 1963. Nuclear Reactors and Earthquakes, TID-7024, Atomic Energy Commission.

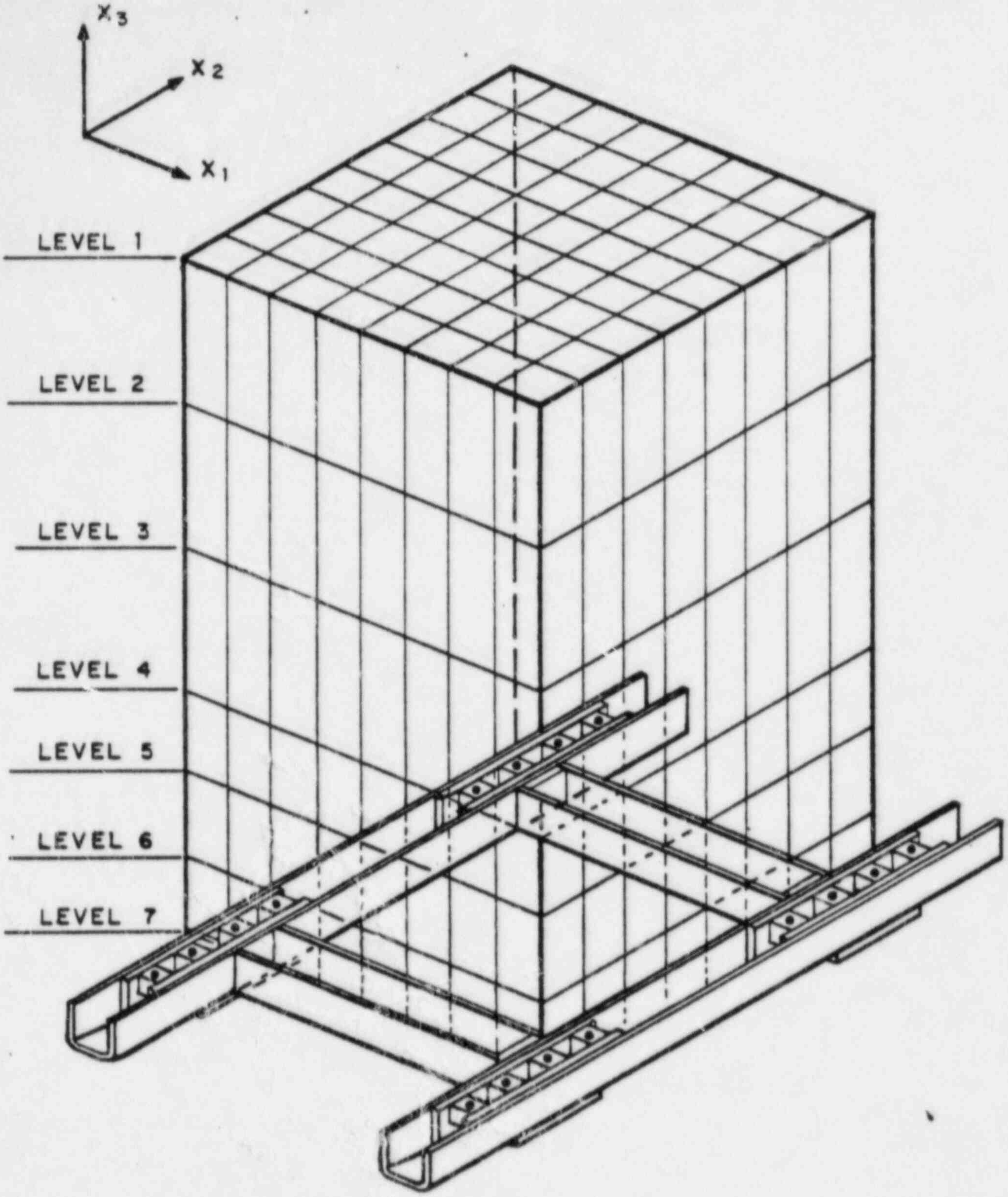

FIGURE 220.14-1
RACK STRUCTURE
BEAVER VALLEY POWER STATION - UNIT 2
FINAL SAFETY ANALYSIS REPORT

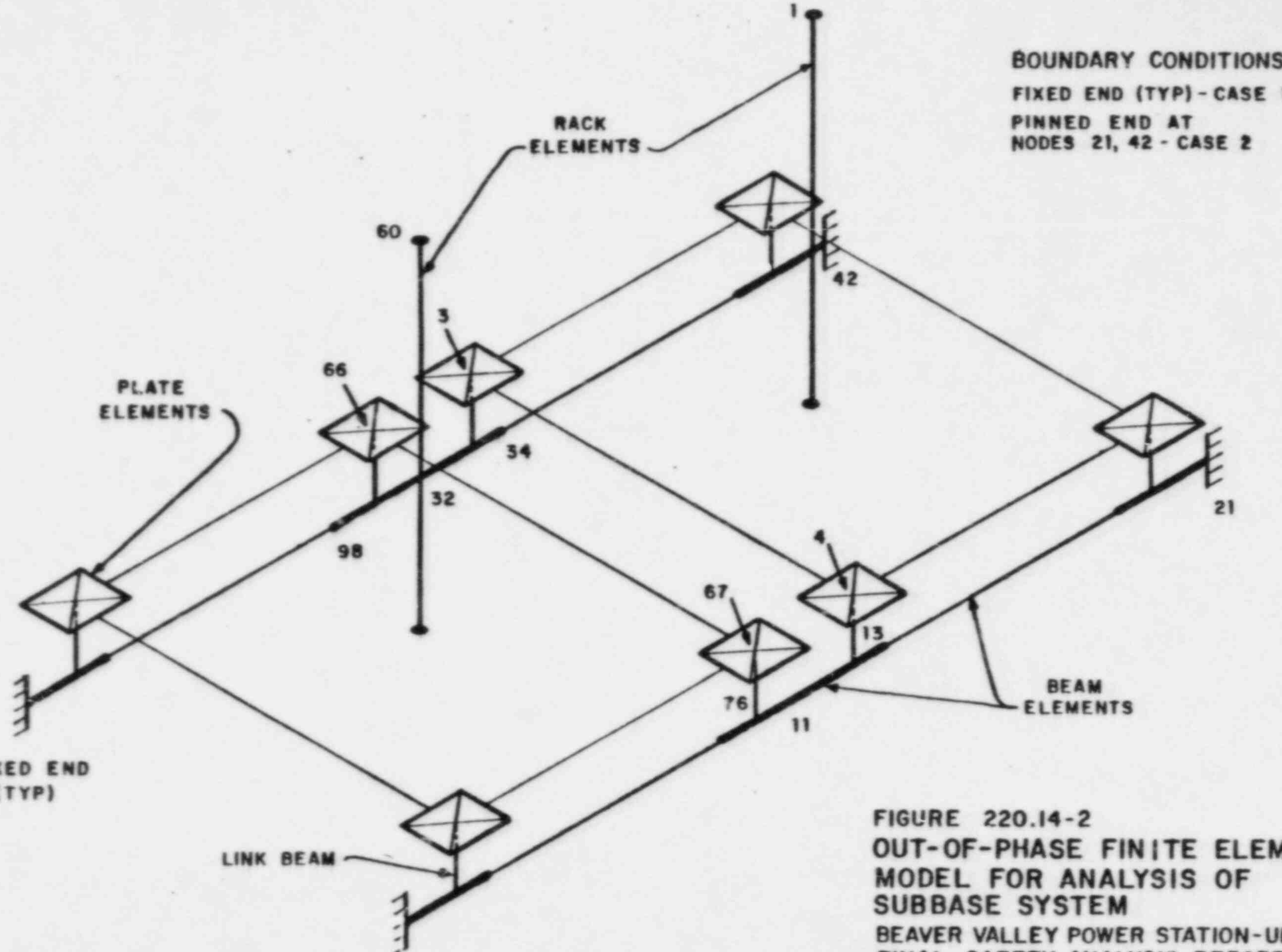

FIGURE 220.14-2
OUT-OF-PHASE FINITE ELEMENT MODEL FOR ANALYSIS OF SUBBASE SYSTEM
BEAVER VALLEY POWER STATION-UNIT 2
FINAL SAFETY ANALYSIS REPORT

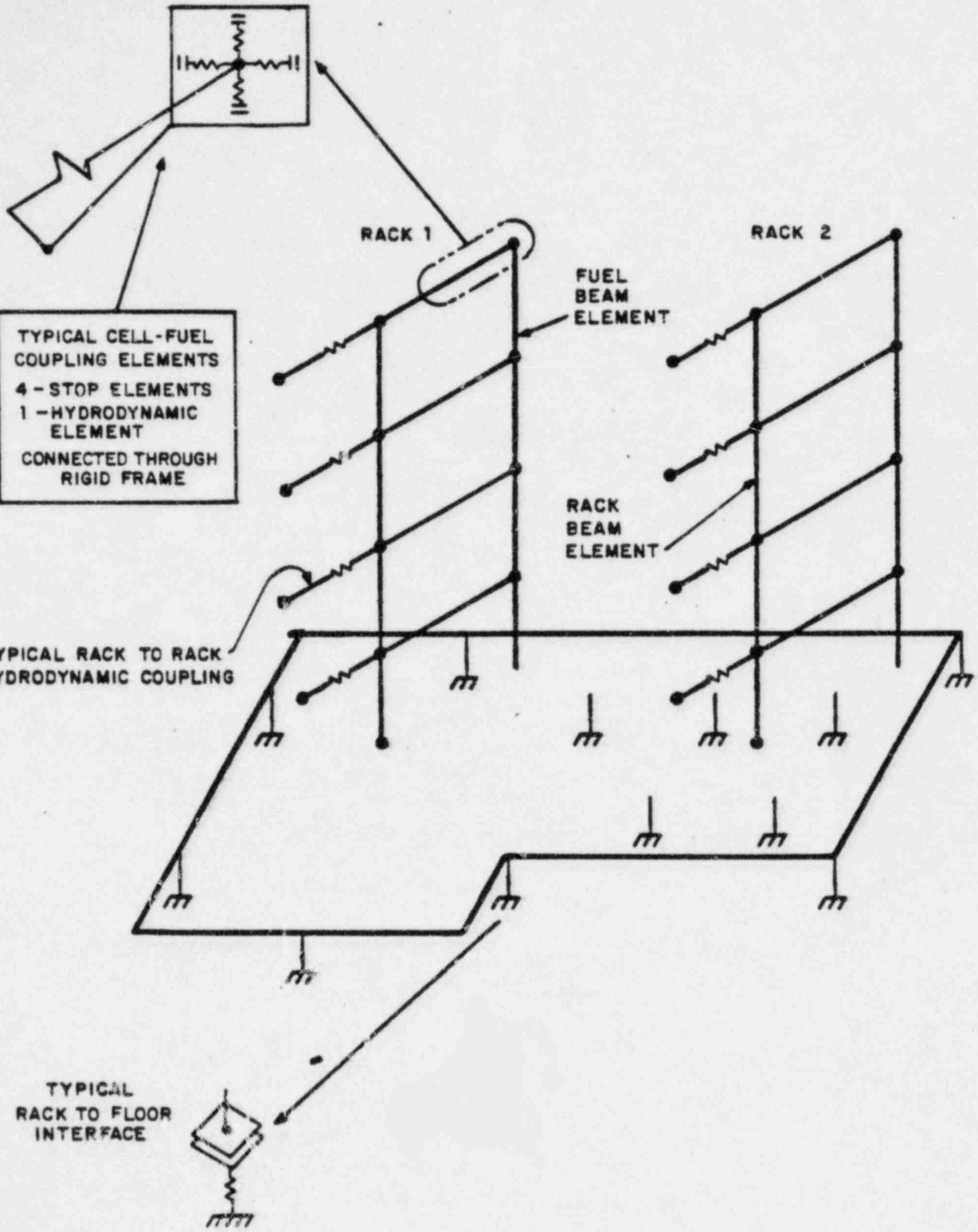

FIGURE 220.14-3
SLIDING ANALYSIS MODEL
BEAVER VALLEY POWER STATION-UNIT 2
FINAL SAFETY ANALYSIS REPORT

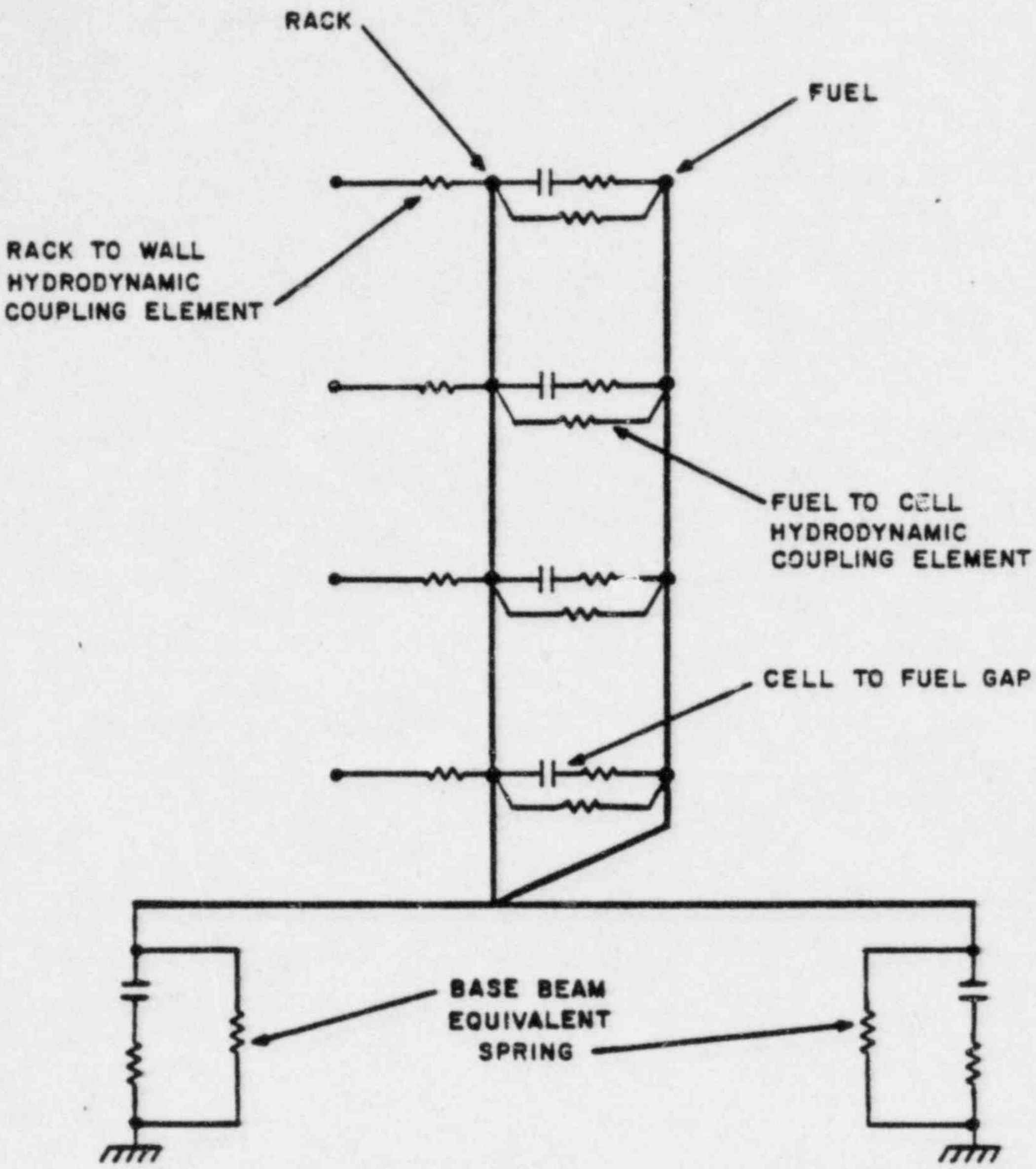

FIGURE 220.14-4

INDIVIDUAL RACK
NON-LINEAR MODEL

BEAVER VALLEY POWER STATION-UNIT 2
FINAL SAFETY ANALYSIS REPORT