(DRAFT)

TECHNICAL EVALUATION REPORT

EVALUATION OF SPENT FUEL RACKS STRUCTURAL ANALYSIS

OYSTER CREEK NUCLEAR GENERATING STATION
GPU NUCLEAR

NRC DOCKET NO. 50-219

NRC TAC NO. 48787

NRC CONTRACT NO. NRC-03-81-130

FRC PROJECT C5506

FRC ASSIGNMENT 26

FRC TASK 525

Prepared by

Franklin Research Center
20th and Race Streets
Philadelphia, PA 19103

FRC Group Leader: R. C. Herrick

Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

Lead NRC Engineer: S. B. Kim

June 22, 1984

Franklin Research Center
A Division of The Franklin Institute
The Benjamin Franklin Parkway, Phila., Pa. 19103 (215) 448-1000

A-108

CONTENTS

CONTENTS (Cont.)

FOREWORD

This Technical Evaluation Report was prepared by Franklin Research Center under a contract with the U.S. Nuclear Regulatory Commission (Office of Nuclear Reactor Regulation, Division of Operating Reactors) for technical assistance in support of NRC operating reactor licensing actions. The technical evaluation was conducted in accordance with criteria established by the NRC.

Messrs. V. Con, M. Darwish, B. Dhillon, R. C. Herrick, and V. Luk of Franklin Research Center contributed to the technical preparation of this report.

1. INTRODUCTION

1.1 PURPOSE OF THE REVIEW

This technical evaluation report (TER) documents an independent review of GPU Nuclear's licensing report on high-density spent fuel racks for the Oyster Creek Nuclear Generating Station [1] with respect to the evaluation of spent fuel racks structural analyses, fuel racks design, and pool structural analysis. The objective of this review was to determine the structural adequacy of the Licensee's high-density spent fuel racks and spent fuel pool.

1.2 GENERIC BACKGROUND

The licensees have entered into a program of introducing modified fuel racks to their spent fuel pools that will accept higher density loadings of spent fuel in order to provide required additional storage capacity. However, before the higher density racks may be used, the licensees are required to submit rigorous analysis or experimental data verifying that the structural design of the fuel rack is adequate and that the spent fuel pool structure can accommodate the increased loads.

The analysis is complicated by the fact that the fuel racks are fully immersed in the spent fuel pool. During a seismic event, the water in the pool, as well as the rack structure, will be set in motion resulting in fluid-structure interaction. The hydrodynamic coupling between the fuel assemblies and the rack cells, as well as between adjacent racks, plays a significant role in affecting the dynamic behavior of the racks. In addition, the racks are free-standing. Since the racks are not anchored to the pool floor or the pool walls, the motion of the racks during a seismic event is governed by the static/dynamic friction between the rack's feet and the pool floor, and by the hydrodynamic coupling to adjacent racks and the pool walls.

Accordingly, this report covers the review and evaluation of analyses submitted for the Oyster Creek plant by the Licensee, wherein the structural analysis of the spent fuel racks under seismic loadings is of primary concern due to the nonlinearity of gap elements and static/dynamic friction, as well as fluid-structure interaction. In addition to the evaluation of the dynamic structural analysis for seismic loadings, the design of the spent fuel racks and the analysis of the spent fuel pool structure under the increased fuel load are reviewed.

2. ACCEPTANCE CRITERIA

2.1 APPLICABLE CRITERIA

The criteria and guidelines used to determine the adequacy of the high-density spent fuel racks and pool structures are provided in the following documents:

- OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications

- Standard Review Plan

  Section 3.7, Seismic Design
  Section 3.8.4, Other Category I Structures
  Appendix D to Section 3.8.4, Technical Position on Spent Fuel Pool Racks
  Section 9.1, Fuel Storage and Handling

- ASME Boiler and Pressure Vessel Code

  Section III, Subsection NF, Component Supports
  Subsection NB, Typical Design Rules

- Regulatory Guides

  1.29 - Seismic Design Classification

  1.60 - Design Response Spectra for Seismic Design of Nuclear Power Plants

  1.61 - Damping Values for Seismic Design of Nuclear Power Plants

  1.92 - Combining Modal Responses and Spatial Components in Seismic Response Analysis

  1.124 - Design Limits and Loading Combinations for Class 1 Linear-Type Component Types

- Other Industry Codes and Standards

  American National Standards Institute, N210-76

  American Society of Civil Engineers, Suggested Specification for Structures of Aluminum Alloys 6061-T6 and 6067-T6.

2.2 PRINCIPAL ACCEPTANCE CRITERIA

The principal acceptance criteria for the evaluation of the spent fuel racks structural analysis for the Oyster Creek plant are set forth by the NRC's OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications (OT Position Paper). Section IV of the document describes the mechanical, material, and structural considerations for the fuel racks and their analysis.

The main safety function of the spent fuel pool and the fuel racks, as stated in that document, is "to maintain the spent fuel assemblies in a safe configuration through all environmental and abnormal loadings, such as earthquake, and impact due to spent fuel cask drop, drop of a spent fuel assembly, or drop of any other heavy object during routine spent fuel handling."

Specific applicable codes and standards are defined as follows

> "Construction materials should conform to Section III, Subsection NF of the ASME* Code. All materials should be selected to be compatible with the fuel pool environment to minimize corrosion and galvanic effects.
>
> Design, fabrication, and installation of spent fuel racks of stainless steel materials may be performed based upon the AISC** specification or Subsection NF requirements of Section III of the ASME B&PV Code for Class 3 component supports. Once a code is chosen its provisions must be followed in entirety. When the AISC specification procedures are adopted, the yield stress values for stainless steel base metal may be obtained from the Section III of the ASME B&PV Code, and the design stresses defined in the AISC specifications as percentages of the yield stress may be used. Permissible stresses for stainless steel welds used in accordance with the AISC Code may be obtained from Table NF-3292.1-1 of ASME Section III Code."

Criteria for seismic and impact loads are provided by Section IV-3 of the OT Position Paper, which requires the following:

- o Seismic excitation along three orthogonal directions should be imposed simultaneously.
- o The peak response from each direction should be combined by the square root of the sum of the squares. If response spectra are available for vertical and horizontal directions only, the same horizontal response spectra may be applied along the other horizontal direction.

- o Increased damping of fuel racks due to submergence in the spent fuel pool is not acceptable without applicable test data and/or detailed analytical results.

- o Local impact of a fuel assembly within a spent fuel rack cell should be considered.

Temperature qradients and mechanical load combination are to be considered in accordance with Section IV-4 of the OT Position Paper.

The structural acceptance criteria are provided by Section IV-6 of the OT Position Paper. For sliding, tilting, and rack impact during seismic events, Section IV-6 of the OT Position Paper provides the following:

"For impact loading the ductility ratios utilized to absorb kinetic energy in the tensile, flexural, compressive, and shearing modes should be quantified. When considering the effects of seismic loads, factors of safety against gross sliding and overturning of racks and rack modules under all probable service conditions shall be in accordance with the Section 3.8.5.II-5 of the Standard Review Plan. This position on factors of safety against sliding and tilting need not be met provided any one of the following conditions is met:

(a) it can be shown by detailed nonlinear dynamic analyses that the amplitudes of sliding motion are minimal, and impact between adjacent rack modules or between a rack module and the pool walls is prevented provided that the factors of safety against tilting are within the values permitted by Section 3.8.5.II.5 of the Standard Review Plan

(b) it can be shown that any sliding and tilting motion will be contained within suitable geometric constraints such as thermal clearances, and that any impact due to the clearances is incorporated."

3. TECHNICAL REVIEW

3.1 MATHEMATICAL MODELING AND SEISMIC ANALYSIS OF SPENT FUEL RACK MODULES

The spent fuel rack modules are totally immersed in the spent fuel pool. The water in the pool produces hydrodynamic coupling between the fuel assembly and the fuel cell, as well as between the fuel rack module and adjacent modules, significantly affecting the dynamic motion of the structure during seismic events [1, 2]. The modules are also free-standing, that is, they are not anchored to the pool floor or connected to the pool walls. Thus, frictional forces between the rack base and the pool liner act with the hydrodynamic coupling forces to both excite and restrain the module in horizontal displacement during seismic events. As a result, the modules experience highly nonlinear structural behavior under seismic excitation, and it is necessary to adopt a time-history analysis method to generate reliable and correct results. Pool slab acceleration data used in the analysis were derived from the original pool floor response spectra. A 4% structural damping for the racks was assumed for the safe shutdown earthquake (SSE) condition.

A lumped mass dynamic model was formulated in accordance with computer code DYNAHIS to simulate the major structural dynamic characteristics of the modules [1, 2]. Two sets of lumped masses were used, one to represent the fuel rack module and another to represent the fuel assemblies. The lumped masses of these racks were connected by beam elements. The lumped masses of fuel assemblies were linked to those of the rack by gap elements (nonlinear springs). The frictional elements (springs) were used to represent the frictional force between the rack base and pool surface. Hydrodynamic masses were incorporated in the model to approximate the coupling effect between the water and the structure. The model was subjected to the simultaneous application of three orthogonal components of seismic loads.

An elastostatic model was used to evaluate element stiffness characteristics for use in the dynamic model. The results generated from the dynamic model, in terms of nodal displacements and forces at nodes and elements, were introduced to the elastostatic model to compute detailed stress fields in the module and corner displacements.

The resulting stresses at potentially critical locations of the module were examined for design adequacy in accordance with the acceptance criteria. The possibilities of impact between adjacent racks and the tipping of the module were also evaluated.

3.2 EVALUATION OF THE ELASTOSTATIC MODEL

3.2.1 Element Stiffness Characteristics

An analysis approach for stressed skin models was adopted to evaluate the stresses and deformations in the rack modules [1, 2]. Essentially, the module was represented by lumped masses linked by beam elements possessing equivalent bending, torsional, and extensional rigidities and shear deformation coefficients. These properties were used to find the stiffness matrix for the elastic beam elements.

Impact springs were placed between the lumped masses of the fuel rack and those of the fuel assemblies to simulate the effect of impact between them. The spring rates of these impact springs were determined from the local stiffness of a vertical panel and computed by finding the maximum displacement of a 6-in-diam circular plate built in around the bottom edge and subject to a specified uniform pressure.

Linear frictional springs were placed at the rack base to represent the effect of the static frictional force between the rack base and pool surface. Angular frictional springs between each mounting pad and the pool liner were not provided in the models, although the Licensee indicated [3] that such angular frictional springs may help to restrain the rotation of the module in the critical conditions, as when two or three legs of the rack are momentarily unloaded. Evaluation of the model with and without the angular frictional springs on each mounting pad indicates that the addition of such springs would add little to the displacement solution because the physical size of the mounting pad is very small compared to the rack module dimensions.

3.2.2 Stress Evaluation and Corner Displacement Computation

A Joseph Oat Corporation proprietary computer code, "EGELAST," was used to compute critical stresses and displacements in the rack module and its support. Nine critical locations were identified on the cross section of rack chosen for stress evaluation, including the four corners of the cross section, the midpoint of each of the four sides, and its center. For every time step, the stress and displacement results from the dynamic model were input to "EGELAST" for computation. Stresses were evaluated at each of the nine critical locations at each selected cross section of the rack. Displacements were calculated at each of the four corners of the cross section. Maximum stresses and corner displacements were determined for all time steps.

3.3 EVALUATION OF THE NONLINEAR DYNAMIC MODEL

3.3.1 Assumptions Used in the Analysis

The following two main assumptions were identified in the analysis:

a. All fuel rod assemblies in a rack module were assumed to move in phase. This was assumed to produce the maximum effects of the fuel assembly/storage cell impact loads.

b. The effect of fluid drag in the pool was conservatively neglected.

Review of the Licensee's submittal and responses indicates that the first assumption is not necessarily conservative based on the following reasons:

- Regardless of the initial position of each individual fuel assembly, all fuel assemblies within a fuel rack module will settle into in-phase motion soon after the rack module is set in motion. This is due to the fuel assembly being a column that pivots about its base.

- The model uses the lumped mass approach in which all fuel assemblies, rack structure, and hydrodynamic effects are lumped at ten discrete locations. Therefore, even if random positions of fuel assemblies are to be considered, the present model cannot be used to handle this situation.

With regard to the second assumption, review indicates that fluid drag is a complex issue, and there is insufficient published technical information from which to obtain a quantitative recommendation for the present situation [8].

3.3.2 Lumped Mass Model

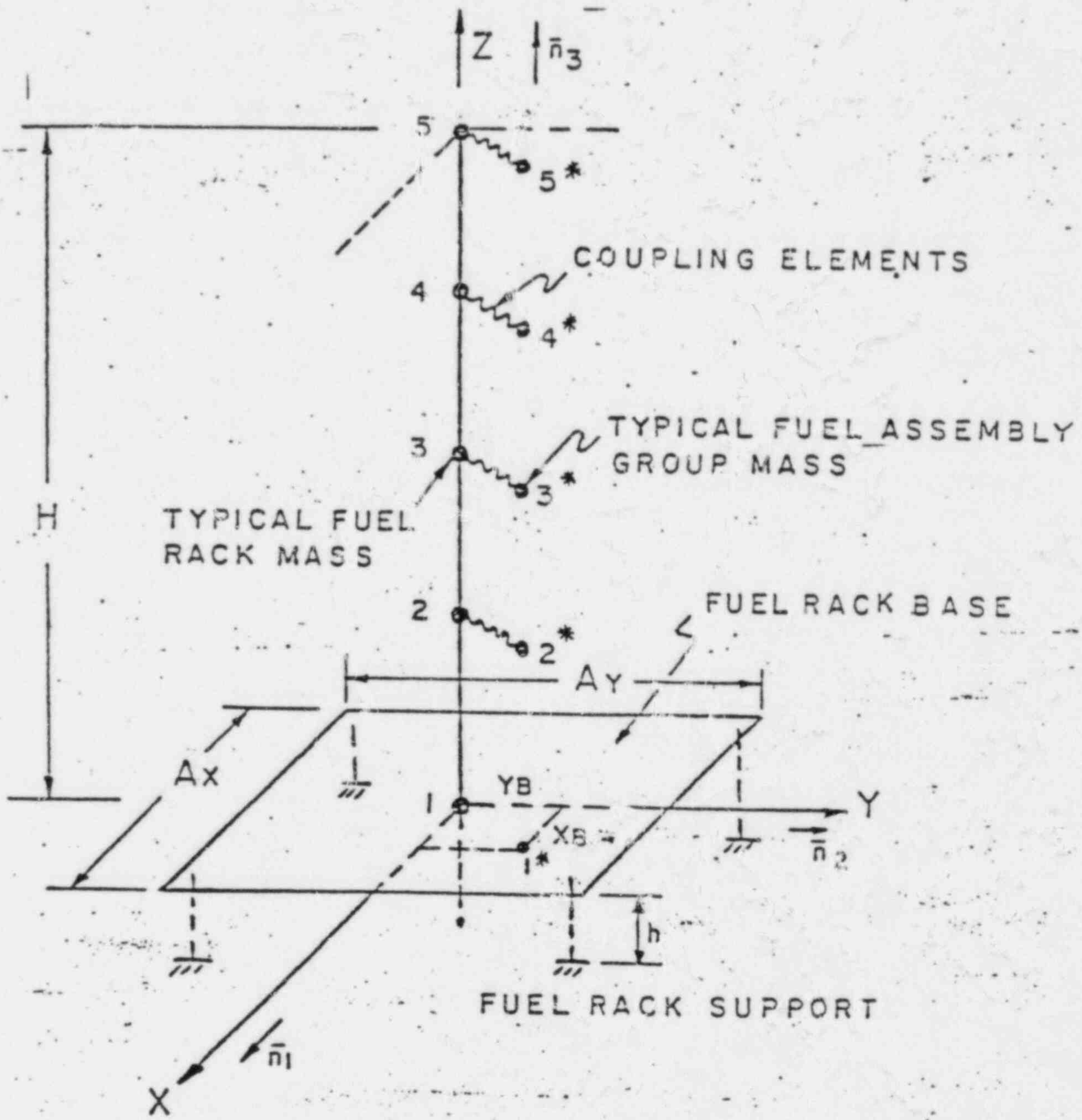
The lumped mass approach was used in the dynamic model, wherein the mass of the fuel rack was lumped at five equidistant locations as shown in Figure 1. For horizontal motion, the rack mass was proportioned at one-quarter of the total mass for each of the three middle mass nodes and at one-eighth of total mass each for the top and the bottom nodes. The mass of the base plate and support structure was lumped with the bottom node. For the fuel assemblies, five lumped masses were used in a similar pattern of distribution. For vertical motion, two-thirds of the racks' dead weight acted at the bottom mass node, with the remaining one-third applied at the top node. All of the dead weight (gravitational force) of the fuel assembly was at the bottom node.

3.3.3 Hydrodynamic Coupling Between Fluid and Rack Structure

When a totally immersed fuel rack is subject to seismic excitation, hydrodynamic coupling forces act between the fuel rack and fuel assembly masses, as well as between the fuel rack and adjacent structures. The Licensee used the linear model of Fritz [4] to estimate these coupling effects. In evaluating the hydrodynamic coupling between adjacent racks, the Licensee assumed that the rack was surrounded on all four sides by rigid walls separated from the rack module by an equivalent gap. The conservativeness of this assumption is questionable because the rigid wall approach eliminates all but one possible interaction between adjacent racks.

3.3.4 Equations of Motion

The Licensee included 32 degrees of freedom in the lumped mass model. All rack mass nodes were free to translate and rotate about two orthogonal horizontal axes. The top and bottom rack mass nodes had additional freedom for translation and rotation with respect to the vertical axis. The bottom fuel assembly mass node was assumed fixed to the base plate, while the remaining four fuel assembly mass nodes were free to translate along the two horizontal axes.



XB, YB - LOCATION OF CENTROID OF FUEL ROD GROUP MASSES - RELATIVE TO CENTER OF FUEL RACK

n_i = UNIT VECTORS

Figure 1. Dynamic Model

The structural behavior of the lumped mass model was completely described in terms of 32 equations of motion, one for each degree of freedom, which were obtained through the Lagrange equations of motions.

3.3.5 Seismic Inputs

With respect to seismic excitation, the Licensee indicated in the original submittal [1] that the model was subjected to simultaneous application of the three orthogonal excitations. However, in response [9] to a list of questions, the Licensee stated that only the vertical seismic motion and the horizontal seismic motion components were considered and that the specified horizontal seismic component was broken into two additional components acting along the x and y directions. In a communication with the Licensee on May 24, 1984, it was learned that the horizontal seismic motion was assumed to act at an angle of 45° to the rack for division into X and Y components.

Evaluation of this approach has indicated that the placement of the horizontal seismic excitation of a 45° angle with respect to the fuel rack module was an arbitrary assumption. This assumption and approach is valid to show the dynamic response under three-dimensional excitation, but the effect of the specified earthquake excitation in the X and Y directions should also have been shown for cases in which the fuel rack properties differed in the X and Y directions.

3.3.6 Integration Time Step

With respect to the integration time step, the Licensee indicated that a central difference scheme was used in the DYNAHIS program (developed by General Electric Company) to perform the numerical integration of the equations of motion discussed in the previous section. In a May 7, 1984 meeting [5], the Licensee stated that a time step of 0.00002 s was selected based on the lowest vibratory period of the fuel rack. However, the Licensee is currently conducting a continuing investigation of the effect of time step size upon the stability of the dynamic displacement solution.

3.3.7 Frictional Force Between Rack Base and Pool Surface

The Licensee used the maximum value of 0.8 and the minimum value of 0.2 to cover the range of static coefficient of friction between rack base and pool liner. According to Reference 5, the Licensee indicated that the maximum coefficient of friction usually produces the maximum rack displacement. The analysis results reported in References 1 and 2 and partially included in Section 3.3.8 of this report show that the opposite can be true. The Licensee should provide further amplification of this matter.

Rabinowicz, in a report to General Electric Company, focused attention on the mean and the lowest coefficient of friction [6]. Rabinowicz also discussed the behavior of static and dynamic friction coefficients, indicating that the dynamic, or sliding, coefficient of friction is inversely proportional to velocity. Thus, the use of static and dynamic coefficients of friction could produce larger rack displacements; that is, the higher value of static friction could permit the buildup of energy that may require a larger displacement at a lower value of dynamic friction to dissipate.

The key to the importance of the complicating consideration of static and dynamic friction appears to be whether significant rack energy is dissipated in sliding friction. If only minimal rack energy is dissipated in sliding friction, then more complete methods of modeling friction would make very little difference in the resulting computed displacement. The discussions of rack displacement in the following section increase the concern of this subject.

Further clarification by the Licensee is recommended.

3.3.8 Rack Displacement Results

For the Licensee's mathematical model, the no-collision-of-adjacent-racks criterion requires that the maximum rack displacement be smaller than half of the gap between racks. While it is acceptable to use an average, or equivalent, gap for the purpose of assessing the contribution of fluid action around a fuel module with unequal spacing from other modules, the actual minimum gap must be used for comparison with the computed displacements. Although the module may, under the influence of seismic excitation and induced fluid forces, move toward the position of equal gaps from its initial position, repeated collision with adjacent modules could take place before any minimum gap is widened. Thus, comparison of the computed fuel module displacements with the minimum gap is essential. It appears that the Licensee compared displacements to the equivalent gap. The following module displacement data were selected from the Licensee's reports [1, 2]:

Rack Type	Cell/Module	Array Size	Height of Rack Baseplate from Pool Liner	Coefficient of Friction U	Maximum X-Displacement
E	312	20x16	11.5 in	0.8	0.1254 in
				0.2	0.655 in
F	315	21x15	6 in	0.8	1.298 in
				0.2	0.535 in

All racks were fully loaded in these cases.

It was noted that rack module F had a maximum computed displacement of 1.298 in, whereas the installed clearance with the adjacent module was 1.5 in as shown by the Licensee's Figure 2.1 [1]. Thus, 1.298 in was greater than half the 1.5-in gap and indicates that collisions could occur.

Comparison of the rack displacement data for racks E and F listed above indicated dramatically different displacements exhibited by two similar racks. Assuming the maximum coefficient of friction for each rack is 0.8, rack F yielded a displacement 10 times larger than that of rack E. For rack E, the maximum displacement occurred with the minimum friction coefficient of 0.2. The major difference between modules E and F appeared to be the height of the support leg, 11.5 versus 6.0 in.

It has been recommended, through a set of questions submitted to the Licensee via the NRC, that the Licensee provide time-history plots of rack displacement for these racks in order to clarify the review. Computed displacements for intermediate values of friction coefficient, such as 0.4 and 0.6, may show a trend and therefore be useful in establishing a relationship between the coefficient of friction and rack displacement.

3.3.9 Impact with Adjacent Racks

As indicated in the Licensee's submittal [1,2], one of the Licensee's structural acceptance criteria is the kinematic criterion. This criterion seeks to ensure that adjacent racks will not impact during seismic motion. As shown in Figure 2, gaps between racks vary from rack to rack. In response to FRC's list of questions [7], the Licensee stated that an equivalent gap was used to simplify the inter-rack interaction problem to a standard configuration [5]. This equivalent gap will form a bounding space around the rack and fluid is assumed not to cross this bounding space. The reviewer has raised concern regarding this technique (see Section 4 for further details).

3.3.10 Stress Results

According to References 1 and 2, all critical stresses are within the allowables required by the stress criteria described in Section 2. Of all cases reported, the full rack with maximum coefficient of friction of 0.8 yields the highest stress factors.

3.4 REVIEW OF SPENT FUEL POOL STRUCTURAL ANALYSIS

3.4.1 Spent Fuel Floor Structural Analysis

The Oyster Creek fuel pool slab is a reinforced concrete plate structure with additional beams and end walls. The analysis was presented to demonstrate structural integrity for all postulated loading conditions and compliance with ACI-349 and NUREG-0800.

Licensee's Assumptions

1. The floor slab was modeled with plate elements, and the reinforced concete beams are represented by beam elements. The walls were not represented in the model. The slab was assumed to be clamped at the reactor wall and simply supported at the remaining walls.

2. The stiffness and strength properties were based on complete cracking of concrete.

3. All the racks were fully loaded and a 40-ft column of water was included in dead weight.

4. The dynamic model analysis was based on nine master degrees of freedom, which corresponded to the locations of concentrated loads (racks). The dynamic mass included the reinforced concrete mass and the virtual mass of water. The dynamic analysis considered both seismic excitation and impact loading from rack analysis.

The effect of assumed boundaries in the first assumption was conservative for slab moments on the north-south span, but may not be conservative for the east-west span, especially when the effects of hydrostatic and hydrodynamic loads on the walls are considered.

The other assumptions were reviewed and found to be satisfactory.

3.4.2 Dynamic Analysis of Pool Floor Slab

The Licensee described the general formulation of the dynamic model analysis procedure. The dynamic analysis was performed for both veritcal seismic excitation and impact loading from racks. A nine degrees of freedom model is used with 4% damping for OBE events and 7% damping for SSE events. The maximum slab deflections at the nine selected coordinates were compared to the corresponding displacements from the static finite element analysis, and the amplification factors were obtained.

The results of the Licensee's analysis indicated a fundamental frequency of 28.3 Hz and the amplification factors of 0.005 for the seismic event and 0.919 for the rack impact loads.

The above approach is the most commonly used and generally accepted procedure. However, the resulting dynamic amplification factor of 0.005 for the seismic event appears to be quite low.

In addition to the dynamic analysis considered by the Licensee, this review of the seismic analysis of the spent fuel rack modules and the analysis of the spent fuel pool structure has revealed the existence of high dynamic vertical forces in the mounting feet of the fuel rack modules. Dynamic loadings supplied by the Licensee in response to questions submitted through the NRC indicated that the instantaneous vertical force on a mounting foot of module F, for example, reaches a value of approximately 242,000 lb. Since the mounting foot on which this occurs is not defined, it must be applied to the worst case, that of the mounting foot incorporating a single 4.5-in-diam mounting pad and located adjacent to the spent fuel pool drainage channel. The resulting pressure on the liner and concrete exceeds 15,000 psi, which is greater than the strength of the concrete and may cause crushing of the concrete under the mounting pad and pool liner. In addition, since the load is applied to the spent pool floor immediately adjacent to the edge of the drainage channel, the Licensee should provide assurance that the corner of the drainage channel will not fail in shear if it cannot be proven that the high dynamic load will not be confined to another mounting foot of the fuel rack module.

3.4.3 Results and Discussion

The following critical loading combinations were considered by the Licensee:

a. $1.4\ D + 1.9\ E$
b. $0.75\ (1.4\ D + 1.4\ T_o)$
c. $0.75\ (1.4\ D \pm 1.4\ T_o \pm 1.9\ E)$
d. $D \pm T_o + E')$

where

D = dead load of slab plus 40-ft column of water and dead weight of fully loaded racks

T_o = thermal loading due to 21° temperature differential across the slab depth

E = OBE seismic load

E' = SSE seismic load.

The moments due to thermal gradient were based on an eqivalent homogenous slab with all floor curvatures suppressed and slab rigidity based on cracked condition.

The results of the analysis were summarized in Tables 8.2 through 8.7 of Reference 1. Table 8.7 of Reference 1 gives the critical pool floor structural integrity checks. It shows that the actual factored values of slab and beam moments and shears are lower than the ACI allowable values by a factor ranging from approximately 1.5 to 3.0.

3.5 REVIEW OF HIGH-DENSITY FUEL RACKS DESIGN

Comments and conclusions regarding Section 7 [1], entitled "Other Mechanical Loads," are contained in the following subsections.

3.5.1 Fuel Handling

In Section 7.1.1 [1], the Licensee discusses the mechanical loading due to fuel handling. A downward load of 1700 lb is considered to be acting on the rack; the load is applied on a 1-in characteristic dimension. No details were given in the report regarding the basis of this characteristic length. However, it is understood that this characteristic length is based on the two fuel cell wall thicknesses, each of 0.063 in.* Independent checking performed by the reviewer indicates that the local stress in the rack due to a 1700-lb downward load is in close agreement with the 14,000-psi stress shown in the report. Therefore, it can be concluded that the approach is conservative and that the analysis is satisfactory.

3.5.2 Dropped Fuel Accident I

Section 7.1.2 [1] demonstrates that the fuel assembly (600 lb), when dropped from 36 in above the storage location onto the base, will not penetrate the base plate.

The 600-lb weight used in this calculation is not in agreement with the fuel assembly weight (800 lb) used in Section 7.1.1 [1]. It is understood that the effective weight to be used should include the buoyancy effect

*R. C. Herrick telephone communication with K. Singh on May 18, 1984.

(estimated as 75 lb acting upwards), resulting in a net effective load of about 725 lb, which is larger than the 600 lb used.

It can be concluded that, even by using the larger load, the base plate penetration estimated as 0.446 in will be increased slightly but will be less than the base plate nominal thickness of 0.625 in; therefore, the base plate will not be pierced.

Detailed calculations on this subject are given in the seismic analysis report by A. I. Solar [2], but the reviewed report did not mention these calculations.

3.5.3 Dropped Fuel Accident II

Section 7.1.3 of the report [1] discusses the effect of a fuel assembly dropping from 36 in above the rack and hitting the top of the rack. The report indicates that the maximum local stress is limited to 21 ksi and is less than the yield stress of the material of 25 ksi. However, no details were given about the possibility of local buckling, which could alter the cross-sectional geometry of the racks. Therefore, further details need to be obtained in order to clarify this point.

3.5.4 Local Buckling of Fuel Cell Walls

Section 7.2 of the report [1] demonstrates that the racks have adequate margin of safety for local buckling under a seismic (safe shutdown earthquake [SSE]) event. In view of the conservative assumptions used and the large margin of safety available, it can be concluded that local buckling under the SSE loading is not possible.

3.5.5 Analysis of Welded Joints in Rack

Section 7.3 [1] discusses the integrity of the welded joints in the rack under thermal and seismic loading.

Under thermal loading, the stresses in the welds are small. However, it appears that the Licensee did not cover the overall effect of seismic loading on the racks. Examination of the computer plots for the analysis of the simulated seismic effect on the racks reveals that the supporting pads lift alternately off the ground. Such a condition could induce concentrated loads of up to 240,000 lb on a single support of the structure. An analysis to investigate the effect of such a load is required.

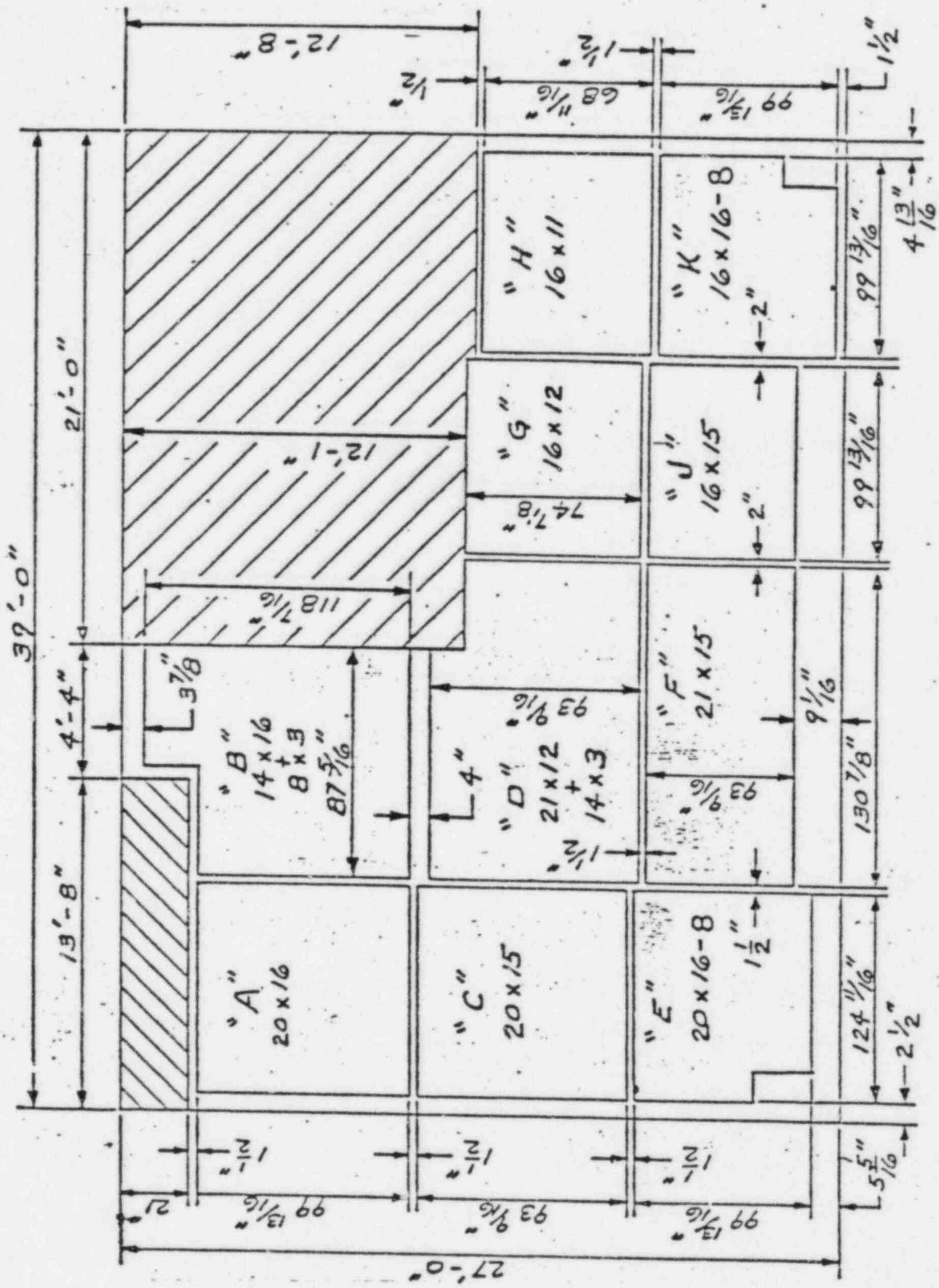


Figure 2. Module Layout

NAH2
FT CAL

Owen Rothberg - QUAD CITIES 2 YRS.
IPOC

4. CONCLUSIONS

Based on the review and evaluation, the following conclusions were reached:

- Although the Licensee's mathematical model for structural dynamics of the spent fuel rack modules under seismic loadings considers the three-dimensional dynamics of one rack module, it represents, nevertheless, a state-of-the-art approach because of the intensive computer resources and computer-run time required for non-linear, time-history, structural dynamics solutions.

- The seismic dynamic model considers only the case of fluid coupling to adjacent rack modules wherein the motion of each adjacent module normal to the boundary is assumed to be equal and opposite in its displacement to the module being analyzed. This assumption is implicit in the model which considers a rigid boundary at the center of each gap. Where the resulting reported rack module displacements are not small relative to the clearance between rack modules, it is concluded that the one case of fluid coupling is insufficient.

- While the Licensee's application of one horizontal seismic excitation motion at approximately 45° to the major axes, and resolved into components parallel to these major axes, is applied simultaneously with the specified vertical excitation to constitute a full three-dimensional analysis under excitation along three orthogonal directions as required by the acceptance criteria, the shorter base span of rack module F, for example, would appear to promote even greater displacements if the specified horizontal earthquake were applied in the direction of the short span.

- The use of an equivalent gap based upon an average of the gaps between rack modules is valid for the calculation of the sum of fluid effects; however, the average gap should not be used as a measure of allowable rack displacement before impact will occur. This implies that the racks will jiggle into the center of their available space prior to the possibility of an impact.

- The computed displacement of ~~1.298~~ ? in for rack module F is larger than half the stated clearance from an adjacent module; therefore, a possibility of rack module impacts does exist.

- The rack module base plates are adequate to resist the loads that occur as a result of a fuel assembly dropped from 36 in above the storage location. However, information provided with regard to dropping of a fuel element from 36 in above the rack is insufficient to determine if adverse local deformation would occur.

Closed By Sect 7.1, 7.2

Closed? p6-27

- Weld stresses due to thermal loadings are adequately addressed. However, additional analyses should be shown to indicate that the effect of seismic loads were included. Also, the effect of mounting pad loads due to pad liftoff and impact during seismic events was not addressed for either the rack module or the spent fuel pool where compressive and shear stresses in the concrete may also be high.

CLOSED

- With respect to the dynamic responses of the spent fuel pool, the Licensee should justify the very low dynamic amplification factor of 0.005.

- The Licensee should justify the use of slab and beam factored shear values that are lower than the ACI allowable values.

5. REFERENCES

1. NRC Docket No. 50-219
Licensing Report on High-Density Spent Fuel Racks, Oyster Creek Nuclear Generating Station
August 1983

2. A. I. Soler
Seismic Analysis of High-Density Fuel Racks
Joseph Oat Corporation
TM Report No. 678 GPU Oyster Creek Nuclear Station, Revision 1
April 24, 1984

3. Joseph Oat Corporation Submittal
Some Additional Comments by the Licensee on the Structural Analysis Method
May 10, 1984

4. R. J. Fritz
"The Effect of Liquids on the Dynamic Motions of Immersed Solids"
Journal of Engineering for Industry, February 1972, pp. 167-173

5. Joseph Oat Corporation Submittal
Preliminary Response to FRC Questions on a Meeting at FRC on May 7, 1984

6. E. Rabinowicz
"Friction Coefficient Value for a High-Density Fuel Storage System"
Report to General Electric Nuclear Energy Programs Division
November 23, 1977

7. FRC's Preliminary List of Questions Telecopied to NRC
May 1, 1984

8. R. G. Dong
"Effective Mass and Damping of Submerged Structures"
UCRL-52342, April 1, 1978

9. Joseph Oat Corporation Submittal
Second Response to FRC Questions
May 21, 1984