

STRUCTURAL EVALUATION OF THE ARKANSAS NUCLEAR ONE-UNIT I SPENT FUEL STORAGE FACILITY FOR CONSOLIDATED FUEL STORAGE

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#### EXECUTIVE SUMMARY

The purpose of this report is to present the results of the structural evaluation of the Arkansas Nuclear One-Unit I spent fuel storage facility for high density fuel storage. This activity was undertaken to determine whether it is possible to increase the fuel storage capacity of the existing spent fuel pool in the Unit I plant through utilization of high density fuel storage racks. This report discusses loading conditions, structural response to the critical loading conditions, definition of appropriate load combinations, and evaluation of the structural adequacy in accordance with the applicable criteria.

The evaluation utilized a detailed finite element model of the spent fuel poor to accurately quantify the structural response to various loading conditions. Computer techniques permitted assessment of all appropriate postulated load combinations, and a thorough comparison of forces and moments throughout the structure to allowable values established by the governing ACI Code.

As a result of this evaluation, it is concluded that the Arkansas Nuclear One-Unit I spent fuel pool has adequate capacity to resist all load combinations defined in the NRC Standard Review Plan (NUREG-0800). In addition, the margin between actual force and moment values and ACI Code allowable values may be adequate to permit future additional increase in the fuel storage capacity of the ANO Unit I spent fuel pool through fuel consolidation.

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#### 1.0 INTRODUCTION

This report is divided into various sections that address different aspects of the evaluation process, and an Appendix is provided for drawings which document the computer model of the spent fuel pool.

Section 2.0 discusses the finite element model utilized for this evaluation, including a detailed description of the representation of the component parts of the pool, boundary conditions applied to this model, and representation of shear walls and floor diaphragms that frame into the pool at various elevations and locations. Section 3.0 discusses the load development, including a description of each of the individual load cases, with references to applicable data for their derivation. Section 4.0 discusses the results for the controlling individual load case. Section 5.0 is a discussion of the post-processing that was carried out to transform the basic analysis results into the form required for evaluation in accordance with the specified design criteria, and Section 6.0 presents the results of the design criteria evaluation. Section 7.0 discusses miscellaneous loading conditions that were not explicitly addressed in the computer analysis, and addresses other structural considerations, such as the pool liner plate. Section 8.0 presents that were utilized.

To provide non-ambiguous quality assurance traceability, and facilitate discussion of the analysis results, SDT has assigned a unique acronym identifier to each individual computer analysis run. Tabulation of the results will reference these unique computer run identifiers, which will be defined where necessary. Microfiche of the computer

output and data tapes for each of these computer analysis run will be transmitted to Arkansas Power and Light Company for archival purposes, along with full quality assurance documentation of each of these computer analysis runs. In addition, the calculations that were prepared in conjunction with the finite element model generation, load development and criteria check will also be provided to Arkansas Power and Light for archival purposes.

#### 1.1 Evaluation Criteria

The criteria utilized for this evaluation are contained in Reference I (ANO-Unit I Design Criteria) and 4 (NRC Standard Review Plan). The original pool was designed in accordance with ACI 318-63 Code Criteria and load combinations, as specified in Reference I. However in the interest of obtaining a more comprehensive evaluation, Arkansas Power and Light Company has elected to use NRC Standard Review Plan (Reference 4) load combinations, and take guidance from ACI 349 (Reference 2) in the reinforced concrete evaluation. All other criteria specified in Reference I were applied to this evaluation, with operating specifications utilized to define applicable analysis parameters. Free standing fuel rack loads on the pool structure were obtained from the fuel rack vendor (Reference 9).

#### 1.2 Analysis Methodology

Due to the complexity of loadings and structural configuration, the finite element method was selected for the calculation of pool structural response. Since transverse shear is a relatively important concrete cross-section force component in this evaluation,

it was decided to utilize solid elements rather than thin shell elements that typically have less than adequate transverse shear formulation. The STARDYNE computer program (Reference 10) which has a long history of successful usage in the nuclear industry, and which has good quality control procedures, was used to perform the analysis.

Postprocessing was performed using a verified SDT postprocessor that performs load combinations and ACI code criteria checking for the combined effect of axial load and bending moment. Additional ACI criteria checks were carried out by hand calculations utilizing postprocessor results where appropriate.



# 2.0 SPENT FUEL POOL FINITE ELEMENT MODEL DEVELOPMENT

This section documents the finite element model utilized to carry out the spent fuel pool evaluation for Arkansas Nuclear One Unit 1. Included in this section is a discussion of the extent of the model, the structural boundary conditions, and the development of stiffnesses for shear walls and floor diaphragms that interact with the spent fuel pool. A set of detailed computer-generated geometry plots that fully defines the node numbers and element connectivity for the model is also provided in an Appendix. These plots serve to verify the geometry of the computer model as well as providing Arkansas Power and Light Company Engineering personnel with a means of potentially further utilizing the computer model or the detailed microfiche results.

#### 2.1 Spent Fuel Pool Geometry

The finite element model is comprised of an assemblage of eight node, three-dimensional solid elements and four node membrane elements. The model includes the pool floor and walls, the fuel transfer canal floor and walls, and the cask laydown area floor and walls. Also included are the supporting foundation walls beneath the pool. The pool walls and floor slab are modeled with two layers of three-dimensional eight node solid elements. The reason for this detail is that, in order to apply a thermal gradient to the walls and floor, it is necessary to define that gradient has a uniform temperature of differing magnitude at each brick centroid through the wall thickness. In addition to these solid elements, membranes of neglible thickness are added to the inside, outside and middle planes of the walls and floor, in order to permit to stress recovery at these locations, in addition to the centroids of each solid element. In this manner, stresses are computed at



2.1

five locations through the wall thickness, and these stresses are integrated to determine the section resultant forces and moments for the critera check phase. The south and west walls of the fuel transfer canal area, and the north and west walls of the cask laydown area are modeled with one layer of solid elements. These walls are included in the model only for the purpose of properly modeling the stiffness contribution of these components to the overall pool structure. Also, membrane elements have not been modeled for the exterior walls of the cask laydown area and fuel transfer canal area. The foundation walls below the pool floor are modeled with a single layer of solid elements since the thermal gradient defined for this region is relatively small or nonexistent. In the case where a small gradient exists, the uncracked section is assumed to resist the full thermal moment developed by this gradient. The foundation walls do include membrane elements on their inside and outside surfaces for the purpose of section force and moment derivation.

The spent fuel pool liner plate is not modeled explicitly, since this component is not meant to provide additional strength to the floors and walls. Liner plate strains, however, can be recovered from the inside membrane elements of the walls and floor to permit a structural assessment of the liner plate. The portion of the foundation beneath the cask laydown area floor is modeled for approximately six feet below the floor slab elevation. This region is extremely stiff, has no thermal gradients defined, and is considered rigid, relative to the rest of the structure. Figures I and 2 of the Appendix show the extent of the spent fuel pool model as discussed herein. Figures 3 through 15 fully describe the finite element model node and element numbering scheme.

## 2.2 Finite Element Model Boundary Conditions

The objective in applying boundary conditions to the finite element model is to correctly represent the interaction of the pool structure with adjacent auxiliary building floors and walls, and only impose rigidity assumptions at locations that are sufficiently remote, such that analysis results are not incorrectly influenced by assumed boundary conditions.

Several floor diaphragms and shear walls frame into the pool at various elevations and locations. These floors and walls are included in the finite element model as stiffness matrix additions, which economically represent the effect of these restraining structures without the expense of explicit modelling. The matrix elements are defined such that shear is transferred between adjacent nodes in the plane of these walls or floor diaphragms. The stiffness of these diaphrams is derived based on the shear stiffness of a concrete panel of the same dimensions as the component being considered, assuming that, due to cracking, one-half of this panel stiffness is available. Other boundary conditions applied to this model consist of restraining all degrees of freedom of the nodes at the bottom of the entire pool foundation, which is very remote from the pool structural areas of interest.

Table 2-1 documents the material properties utilized for the spent fuel pool finite element analysis, which were reviewed by AP & L Engineering prior to incorporation into the analysis. These properties are based on standard accepted values or the original design criteria specification for the plant. The modulus of elasticity for the pool structure is a composite value, determined based on a ratio of steel modulus to concrete modulus of 7.25.

# Table 2-1

## Arkansas Power and Light Company ANO-1 Spent Fuel Pool Evaluation Summary of Material Properties

Item	Valu	Je	Reference
Concrete Compressive Strength	5,000	lb/in <sup>2</sup>	11.00
Reinforcing Yield Strength	40,000	Ib/in <sup>2</sup>	1
Reinforcing Elastic Modulus	$29.0 \times 10^{6}$	lb/in <sup>2</sup>	2
Concrete Elastic Modulus	$4.00 \times 10^{6}$	lb/in <sup>2</sup>	(Note I)
Concrete Poison Ratio	0.17		3
Concrete Thermal Expansion Coefficient	$5.5 \times 10^{-6}$	in/in/ <sup>0</sup> F	2
Concrete Weight Density	$8.68 \times 10^{-2}$	lb/in <sup>3</sup>	3
	(150	Ib/ft <sup>3</sup> )	

Note: 1)

Concrete composite elastic modulus based on a ratio of the elastic modulus of steel to concrete equal to 7.25.

#### 3.0 LOAD DEVELOPMENT

This section discusses the development and verification of the loads applied to the Arkansas Nuclear One-Unit I Spent Fuel Pool finite element model. A summary of the individual loads is presented in Table 3-1.

#### 3.1 Development of Individual Load Cases

To provide flexibility in forming load combinations, as discussed in Section 5.0, the analysis was performed for primary, uncombined loads on an individual basis. These loads consist of dead weight of the concrete, hydrostatic pressure, accident flood load, normal operating and accident thermal loads, a nominal 1.0 g east/west seismic acceleration, a 1.0g north/south seismic acceleration, fuel rack submerged deadweight load, and fuel rack seismic reaction loads. These loads are developed on an individual basis so that they may be combined after the analysis is complete, in any required manner to represent different magnitudes and directions of the various applied loadings. The loading due to the fuel handling crane is excluded from this evaluation, since it is concluded that this effect on the overall pool structure is beneficial when considering this in combination with other loadings. This conclusion is based upon the observation that the upper portion of the pool walls are subjected to a relatively small vertical axial load when the crane load is excluded. For shear as well as axial load-moment interaction, compressive axial load is beneficial, in terms of the section's capacity to resist these forces. Therefore, excluding the crane load in combination with other live loads is conservative.

Table 3-2 identifies the parameters utilized in defining the loads discussed herein. This table, along with the indicated references, documents the assumptions utilized for load development.

Deadweight of the concrete structure is defined as a 1.0g vertical acceleration. This 1.0g vertical acceleration results in a downward vertical force at each node of the finite element model, equal to the tributary weight assigned to each node, and a total downward force equal to the weight of the reinforced concrete structure. The unit weight of reinforced concrete is defined in Table 2-1.

The pool water level is defined as 39.5 feet above the top of the pool floor slab, and water density is defined as 62.4 pounds per cubic foot. The concentrated nodal forces due to hydrostatic pressure are derived by multiplying the hydrostatic pressure at the elevation of the finite element node being considered by the tributary surface area for that node. The tributary surface area of a node is calculated as one-fourth of the surface areas of the membrane elements surrounding the node point. This total pressure force is transformed into global forces based on the direction cosines of the vector normal to the surface of the membrane elements surrounding the node being considered. This load was verified by generating a summation of the nodal forces and comparing the resulting force with manual calculations for the volume of the pool times the water density.

Accident flood load is defined as a hydrostatic pressure on the outside of the east wall of the pool structure from elevation 335 to elevation 361, and was generated in a manner similar to that described above.



Accident and operating thermal loads are defined based on the temperatures of each compartment, as shown in Table 3-2. This load is developed as a uniform thermal load on each membrane and brick element in the model, based on linear interpolation between the compartment temperatures. This is a conservative definition of thermal loads since conduction through the concrete for a true steady state condition will result in temperatures on the outside surface of each wall significantly higher than the gross air temperature in the respective compartment. Thermal gradients may not necessarily develop in a linear manner prior to the steady state condition; however, the local effect of a gradient which decays more rapidly within the concrete will not result in a more significant gross structural response than that resulting from a pure linear gradient defined based on compartment air temperature and the pool water temperature. The one exception to this assumption is the stress in the liner plate due to the thermal loads of the beginning of the transient. This is considered, however, separate from the basic finite element analysis and discussed in Section 7.1.

The operating basis earthquake (OBE) is defined utilizing six separate individual loads in order to properly account for the various possible seismic motion directions and variation in fuel rack loadings. Reference 8 defines the response spectra from which the earthquake loads discussed herein were defined.

It is not necessary to treat the vertical earthquake loadings associatated with acceleration of the pool water mass and concrete mass as separate primary load cases since these loadings can be formulated in a post-processing step, utilizing the static



3.3

deadweight of concrete and hydrostatic load cases with the appropriate factor to account for dynamic amplification of the seismic motion.

The horizontal earthquake acceleration is defined by calculating the average spectral acceleration, reported in Reference 8, over the height of the pool, and applying this as an acceleration load in one horizontal direction and then in the orthogonal horizontal direction. Earthquake response of the pool water is defined based on the methodology outlined in Reference 5, Appendix F. The hydrodynamic loads are calculated as pressure profiles over the pool wetted surface and distributed to each node based on nodal tributary area. The resulting nodal forces were summed to determine the net resulting hydrodynamic forces in orthogonal directions, and these force resultants were verified using additional methodology in Reference 5, which defines the integrated pressure resultants. For simplicity, the combined east/west and north/south earthquake loadings are normalized to a 1.0g earthquake, and are combined with the appropriate g factor in a post-processing phase.

Reference 9 defines the fuel rack loads utilized in this analysis. They consist of a submerged deadweight loading, and a vertical and horizontal reaction loading due to the operating basis earthquake. These reaction loads are distributed to the pool floor node points based on the proximity of each pad to the surrounding nodes. The earthquake loads are distributed in the same proportion as the deadweight loads, with the total force equal to that specified in Reference 9. These loads were not normalized to 1.0g as was done for the pool water and concrete mass effects.



#### Table 3-1

## Arkansas Nuclear One-Unit 1 Spent Fuel Storage Facility Structural Evaluation Individual Load Case Description Table

No.	Notation	Description
1	D <sub>c</sub>	Dead weight of the concrete.
2	·н	Hydrostatic pressure due to water in the pool.
3	F	Accident flood load.
4	T <sub>0</sub> (1)	Normal operating thermal load.
5	T <sub>a</sub> (1)	Accident thermal load.
6	E <sub>ew</sub> <sup>(2)</sup>	Load generated by east-west 1.0g earthquake.
7	Ens <sup>(2)</sup>	Load generated by north-south 1.0g earthquake
8	D <sub>fr</sub>	Fuel rack dead weight load.
9	FR <sub>v</sub>	Reaction load of fuel racks during 0.067g vertical earthquake.
10	FRew	Reaction load of fuel racks during 0.1g east-west earthquake.
11	FR <sub>ns</sub>	Reaction load of fuel racks during 0.1g north-south earthquake.
OTE: (I)	Includes effects	of thermal moment on the foundation wells due to 2

NOTE: (1) Includes effects of thermal moment on the foundation walls due to 28° thermal gradient.

(2) Includes effect of pool hydrodynamic load, and pool wall horizontal inertial forces.

## Table 3-2

## Arkansas Power and Light Company ANO–1 Spent Fuel Pool Evaluation Summary of Load Definition Parameters

Item	Description	Reference
Pool Properties:		
Pool Water Elevation	401'-6"	6
Pool Normal Operating Temperature	150°F	6
Pool Accident Temperature	212 <sup>0</sup> F	4
Pool Hydrodynamic Forces	TID 7024, App F	5
Auxiliary Building Compartment Temperatures:		
Adjacent Pool North, East and South Walls	60°F	7
Adjacent Pool West Wall	32°F	7
Inside Foundation Walls	60°F	7
Inside Cask Laydown Area	60 <sup>0</sup> F	7
Inside Fuel Transfer Canal Area	60°F	7
Outside Foundation Walls Below Elevation 356' – 6"	32 <sup>0</sup> F	7
Thermal Stress Free Temperature	60°F	7
Operating Conditions		
Fuel Transfer Canal	Dry	
Cask Laydown Area	Dry	
Accident Flood Conditions	EL 335' to 361'	7
Seismic Ground Accelerations		
OBE Horizontal	0.10g	. 1
OBE Vertical	0.067g	1
SSE Horizontal	0.20g	1
SSE Vertical	0.1330	



## 4.0 FINITE ELEMENT ANALYSIS RESULTS

This section discusses the finite element analysis results; in particular, results for the controlling load case.

#### 4.1 Verification of Results

The results of the finite element analysis were examined to insure that realistic deflections and stresses existed for each load case. Also, stresses and deflections in the base slab are examined for several load cases and compared to classical solutions. In addition, the finite element results were compared to results from ANO-2 analytical model presented in Reference 12 with very good agreement. The conclusion of this process is that the finite element model is behaving in a reasonable manner.

#### 4.2 Controlling Load Case Results

Based upon examination of the results for the individual primary load cases described in the previous section, one load case was determined to be controlling, and is described further in this section. The accident thermal load, defined as 212°F inside the pool, 60°F in all other compartments except those adjacent to the west wall, and the entire foundation below elevation 356 for which the temperature is defined as 32°F. This load results in a gradient across the pool walls and floor equal to 152°F, with the exception of the west wall and foundation walls which have a gradient of 180°F and 32°F, respectively.



Figures 4-1 through 4-4 are deformed geometry plots at varius sections and plans. These deformed geometry plots show the restraining effects that various parts of the structure have on the components that are being heated by the pool water. Based upon thorough investigation of the results, it is concluded that the accident thermal gradient is, by far, the controlling load case. This thermal gradient causes significant bending moments about horizontal and vertical axes, resulting in significant transverse and in-plane shear forces at several locations.

The fuel transfer canal separation wall responds to the thermal gradient by deflecting outward at the upper west corner. This response causes significant transverse shear forces at the upper east corner and the lower west corner at the bottom of the gate opening. Also, the overall temperature increase on this wall causes significant in-plane shear at the bottom of the gate opening, as a result of the restraining effect that the lower portion of the wall has on the upper portion, which is free to expand because of the gate opening.

The pool east wall is expanding vertically due to the average temperature increase in that wall. The east walls of the fuel transfer canal and cask laydown area are not subjected to this thermal load, and cherefore, they act as a vertical restraining force on the east wall of the pool. This results in significant vertical tensile forces in the east walls of the fuel transfer canal and cask laydown area, but more importantly, this also results in significant horizontal tensile forces in the top portion of the east pool wall, due to the poisson effect. This effect is illustrated in Figure 4-3.

The north and west walls of the pool are responding in a manner similar to the east wall, whereby adjacent walls with lower average temperature provide vertical restraint, thus inducing horizontal tension in the restrained wall. This can be observed in the pool west wall at the end adjacent to the fuel transfer canal, and for the north wall at the end adjacent to cask laydown.

The intersection of the north and west walls, however, responds in a considerably different manner. Since the north and west wall have the same average temperature, the restraint mechanism described for other regions does not exist at this corner; however, a different mechanism exists, which also results in significant horizontal tensile forces at the tops of these walls at this corner. SDT has constructed small parametric models to investigate the nature of this behavior in more detail. Based on these parametric models, it has been determined that the horizontal tensile force in this corner is primarily due to the vertical bending moment (causing vertical stresses) along the top edge of both of these walls at the corner intersection. This can be further visualized by describing the manner in which the thermal load is actually applied to a structure of this nature. A plate that is fixed on three edges and free at the top, subjected to a thermal gradient, could be idealized, for the purpose of calculating displacements, as a plate fixed on three sides and subjected to a bending moment along the free edge. This pseudo-thermal bending moment would be proportional to the moment of inertia of the plate, the elastic modulus of the material, and the thermal gradient. Extending this concept to the pool model, specifically at the corner where the west wall and the north wall intersect, it can be shown that the horizontal tension in the corner is due primarily to the membrane stiffness of these two walls resisting the bending moment applied to the top of the adjacent wall framing in at 90 degrees. Since the membrane stiffness of these

walls is much higher than the bending stiffness of the adjacent wall, most of the bending moment is resisted by this membrane tensile forces at this corner.

The base slab grows uniformly in all directions as a result of the overall temperature increase. This response results in significant in-plane horizontal tensile forces in all of the foundation walls. These foundation walls, however, are provided to primarily carry vertical load, and the fact that the sections are subjected to horizontal in-plane tensile forces is of secondary concern for the integrity of the pool. Significant transverse shears are also observed at the intersection of the foundation walls with the base mat.





Data from AFPSTA1A2-01

SDT

Figure 4-2 January 19 Arkansas Power and Light Company Arkansas Nuclear One - Unit 1 Spent Fuel Storage Facility Accident Thermal Deformed Geometry Plot Plan at Elevation 362'



Data from APFSTA1A2-01

Figure 4-3 Arkansas Power and Light Company Arkansas Nuclear One - Unit 1 Spent Fuel Storage Facility Accident Thermal Deformed Geometry Plot Elevation View of East Wall



Data from AFPSTA1A2-01



Figure 4-4 Arkansas Power and Light Company Arkansas Nuclear One - Unit 1 Spent Fuel Storage Facility Accident Thermal Deformed Geometry Plot Elevation View of West Wall

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Data from AFPSTA1A2-01



# 5.0 INITIAL POST-PROCESSING AND LOAD COMBINATION FORMULATION

This section discusses the process whereby the results of the finite element analysis are transformed as required for Code evaluation, and combined in various ways to arrive at the final load combinations specified in Reference 4.

# 5.1 Derivation of Section Resultant Forces and Moments

The results of the finite element analysis are in the form of normal stresses and shear stresses on the three orthogonal planes of the three-dimensional solid elements. Since the ACI Code is set up more directly to utilize section resultant forces and moments, the stresses resulting from the finite element analysis must be integrated to obtain these quantities. The areas of the pool considered in the evaluation include the pool foundation walls, the pool floor slab, and the four walls of the pool structure. Excluded from further evaluation are the outer walls of the fuel transfer canal area and the outer walls of the cask laydown area.

From the finite element analysis, the floor and walls of the pool structure have stresses defined at five locations through their thickness. These five points of stresses are integrated assuming a linear variation between points in order to produce the section resultant forces and moments for Code evaluation purposes. These resulting forces and moments include two normal forces in a plane for each integrated element, an in-plane shear force, two transverse shear force components, two bending moment components and one twisting moment component. These forces and moments are defined utilizing conventional shell theory, and are specified on a per-unit-length basis.

#### 5.2 Composite Load Formulation

Following the finite element analysis, the first post-processing step necessitated combination of the individual primary load cases into composite loads, such that the final load combinations could be performed simply by applying the factor specified in Reference 4 to the appropriate composite case. These composite load cases are defined as deadload, live locd, operating thermal load, accident thermal load, loads generated by 1.0g operating basis earthquake, and flood load. Table 5-1 shows the individual load cases along with the appropriate factors necessary to formulate these composite loads.

The composite deadload is obtained by combining the deadweight of concrete with the hydrostatic pressure loads. Live load consists of the submerged weight of the fuel racks, including their fuel complement. It would be logical to include only the fuel as live load, however, the loading is presented in Reference 9 as a total load, and as such, must conservatively be considered entirely as live load. Operating thermal, accident thermal and flood load are considered as their respective individual loads.

Reference 4 specifies that earthquake directions shall be combined by taking the square root of the sum of the squares (SRSS) of individual directional responses. Since this, by definition, does not consider the sign of the load, and since reinforced concrete must be evaluated based on the force and moment interaction for a particular section, it was not considered logical to proceed based on this simplifying specification of the Standard Review Plan. An alternative to this is to formulate earthquake response by adding the effects of the three orthogonal directions in various permutations to produce the same results as an SRSS methodolog is int maintaining the algebraic signs associated with the



forces and moments. Table 5-1 indicates the factors applied to each of the individual loads to arrive at four composite earthquake loads. Four other composite earthquake loads are derived in a similar manner.

## 5.3 Final Load Combination Formulation

Reference 4 specifies the load combinations required to be evaluated for this class of structure. Table 5-2 shows the seven load cases that result by elimination of load combinations that are not applicable to this structure. Out of these seven load cases, load case seven has been determined to be the controlling combination. The basic reason for this conclusion is that the thermal accident load is by far the controlling load on this structure and, as such, results in the maximum load combination.

Load case seven is evaluated by including the effects of the SSE earthquake considering the eight possible seismic motion direction combinations as previously discussed. In accordance with the requirements of References 2 and 4, where it is determined that live load cancels out or reduces the effect of a particular earthquake load, live load is excluded from that combination. Also, when it is determined that deadweight, including hydrostatic, reduces or cancels out an earthquake load, deadweight is reduced by ten percent. SSE response is defined as 2.0 times OBE response. For the fuel rack reaction loads, this is a conservative assumption since Reference 9 specifies a value less than 2.0 times OBE for the SSE reaction forces.



		Description		•	Dead Load	Live Load	Operating Thermal Load	Accident Thermal Load	Loads Generated by	.1g Operating	Basis Earthquake		Flood Load			
	5		FR <sub>ns</sub>		,	,	,		1.0	-1.0	1.0	-1.0				
	l Evaluati s		FR		ŧ	1	•	•	1.0	0.1	1.0	1.0	•			
	ne-Unit   ructural ite Load		FR		,	ı	,	,	1.0	0.1		,	,			
ble 5-1	clear Or cility Str Compos		D <sub>fr</sub>		ţ	1.0	1	i	1	•	1	1	,			
To	sas Nu age Fay ary of		Ens		i	,	1	1	0.1	-0.1	0.1	-0.1	r			
	Arkan el Storo Summ		Eew		•	•	1	,	0.1	0.1	0.1	0.1	•			
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			°		1.0	,	1	,	0.067	0.067	-0.067	-0.067	•			
		Composite Loads			D		To	Ta	ц ш	E2	E <sub>3</sub>	E4	-	SDT	Struc Dyna Techr	ctural amics nology

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## Table 5-2

#### Arkansas Nuclear One-Unit I Spent Fuel Storage Facility Structural Evaluation Load Combination Summary Table

lo.	Load Combination	$\underline{\text{Reference}^{(1)}}$
I.	1.4D + 1.7L + 1.9E	Load Case 2
2	.75(1.4D + 1.7L + 1.7T <sub>o</sub> )	Load Case 4
3	.75(1.4D + 1.7L + 1.7T <sub>o</sub> + 1.9E)	Load Case 5
4	D + L + T <sub>o</sub> + E'	Load Case a
5	$D + L + T_{o} + F$	Load Case b
6	D + L + T <sub>a</sub>	Load Case c
7	D + L + T <sub>a</sub> + 1.25E'	Load Case d

Notes:

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(1) Reference 4 Section 3.8.4.

(2) E' Represents a load generated by .20g safe shutdown earthquake (SSE). For simplicity, this is taken conservatively as 2.0E.
#### 6.0 ACI CRITERIA POST-PROCESSING

This section discusses the methodology utilized to carry out the ACI Code evaluation of the spent fuel pool facility. Included in this section is a discussion of the post-processing carried out to account for the change in the moment due to thermal loading as reinforced concrete sections experience normal tensile cracking. In addition, the methods utilized to determine the acceptability of the structure relative to in-plane shear, transverse shear, and twisting moments are discussed.

#### 6.1 Flexure and Axial Loads

Chapter 10 of Reference 2 (ACI 349-80) is the basis for qualifying the structure for combined effects of axial force and bending moment. Capacity reduction factors are taken as .9 and .7 for axial tension and compression, respectively. The restrained thermal moments from the linear structural analysis are processed to account for changes in the thermal moment magnitude as the section cracks, such that the section's curvature and static equilibrium are maintained. The relieved thermal moment is then defined as the moment required to maintain that static equilibrium and curvature for the cracked concrete section. For a given section, subjected to the combined effect of axial load and bending moment, following accepted ACI techniques, for the given magnitude of axial force, the allowable magnitude of bending moment is calculated. Table 6-1 presents the results of this evaluation for the controlling load combination for the spent fuel pool. This table identifies the critical sections for each pool and foundation component, along with the allowable bending moment associated with the section axial force, and the ratio of the actual relieved section moment to the allowable section



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moment for the applied section axial force. Redistribution of force and moment was considered in regions near the top of the pool walls. This is considered logical since, if the section yields, not only will the forces and moments be redistributed, but much of the thermally-induced force and moment will be relieved. As seen from Table 6-1, all of the locations shown have significant margin relative to their ultimate strength.

Creep effects are not considered to be important since the loads associated with the normal service life of the spent fuel pool constitute a very small percentage of the ultimate strength of the concrete sections. Accident thermal and seismic loads are considered to be short duration loads and thus do not cause appreciable creep.

Figures 6-1 through 6-6 present contour plots of the bending moments and concrete and reinforcing stresses resulting from the controlling load combination. These results were obtained by relaxation of the thermal bending moment, maintaining section equilibrium and curvature. These plots indicate the restraining effect that the portion of the floor slab in the fuel transfer canal has on the pool floor slab. This is due to the ambient condition in the fuel transfer canal versus accident thermal temperatures in the pool floor slab. Also, the slab below the cask lay down area causes a similar concentration of stresses near this region for the same reason. Since the pool walls and foundation do not provide as high a degree of restraint on the pool floor slab, the bending moments along the east and west walls tend to be lower than elsewhere in the floor slab. Concrete and reinforcing stresses follow the same pattern of stress distribution as their associated bending moments, with the top of the slab in compression and the bottom in tension.



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#### 6.2 Evaluation for Shear and Torsion

Section 11 of Reference 2 (ACI 349-80) presents the Code requirements for evaluation for concrete structures subjected to shear and torsion. Within this Reference, it is specified that walls and slabs shall be evaluated by calculation of the section force extending in a plane across the entire width or height, and located at a distance from the face of the reaction area equal to the distance from the compressive face of the section to the centroid of the tensile steel. This section of the Code allows an averaging approach to be taken when evaluating wall and slab-type structures. Tables 6-2 and 6-3 present the results for the transverse shear force and in-plane shear force evaluation, respectively.

As seen in Table 6-2, several areas of the structure are close to their allowable values. Specifically, regions of the pool walls near the corners have high transverse shear. The east and west walls of the pool have been designed with a heavily-reinforced area at the top. One function of this embedded beam is to carry the offset crane loads, however, the shear reinforcing provided in this area also serves to carry the transverse shears, and provides a significant margin.

Table 6-3 shows the results of the in-plane shear evaluation. In accordance with ACI methodology, sections for in-plane shear evaluaton are defined at locatons that are not closer to the base of the walls than one-half the wall height or length. The fuel transfer canal wall just above the bottom of the gate opening has very high in-plane shear due primarily to the restraining effect that the lower portion of the wall has on the free edge of the upper portion at the gate opening when subjected to thermal expansion.



6.3

The east foundation wall is shown in Table 6-3 to be over code allowable for in-plane shear. This shear is due almost entirely to the floor slab thermal growth and as such is a secondary effect. As this wall yields, not only will much of the applied shear force be reduced, but other portions of the foundation, such as the west wall will pick up the load. In addition, other walls are located in the vicinity of the foundation but were not included in the pool model. These walls will provide additional redundancy to the foundation's ability to resist the in-plane shear forces.



			Lo	cation	Section Axial Force	Section Resultant Moment(2,4)	Section Allowable Moment(3)	Moment Code Ratio
	Pool	Flo	or Sla	b: (AFPSTA1A2-09)			÷	
		Eas Sou	st - We ith End	st Section at (Element 320)	-47.58	1005.	1321.	0.76
		Nor at	th - S Mid-sp	outh Section an (Element 320)	-35.50	1093.	1869.	0.59
6.5	Pool	Fou	Indatio	n: (AFPSTA1A2-10)				
		Sou Sec 286	South Wall, Horizontal Section at Top (Element 2865)		-17.31	315.7	811.8	0.39
		Eas Sec 287	t Wall tion a 7)	, Horizontal t Top (Element	-18.30	351.2	827.4	0.42
		Wes Sec 28 S	st Wall stion a 57)	, Horizontal t Top (Element	-16.68	391.8	801.7	0.49
	Unit	5:	Kips/I	nch, Kip-inches/I	nch			
ASS I	Note:	s:	1) NU 2) Po	REG-0800 Load Comi sitive moment caus	bination (D + L ses tension on o	+ T <sub>a</sub> + 1.25E') outside surface	of walls and lo	ower surface
Structural Dynamics Technology	<ul> <li>Allowable moment is based on strength design method per ACI 349/80.</li> <li>4) T<sub>a</sub> moments are relieved, maintaining equilibrium and curvature of section.</li> </ul>							

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Section Axial Force	Section Resultant Moment(2,4)	Section Allowable Moment(3)	Moment Code Ratio
-35.58	1262.	2235.	0.57
-38.51	1284.	2121.	0.61
14.58	219.8	1027.	0.21
	Section Axial Force -35.58 -38.51 14.58	Section Section Axial Resultant Force Moment(2,4) -35.58 1262. -38.51 1284. 14.58 219.8	Section Axial Force         Section Resultant Moment(2,4)         Section Allowable Moment(3)           -35.58         1262.         2235.           -38.51         1284.         2121.           14.58         219.8         1027.

Units: Kips/Inch, Kip-inches/Inch

Notes:	1) 2)	NUREG-0800 Load Combination (D + L + $T_a$ + 1.25E') Positive moment causes tension on outside surface of walls and lower surface
Structural Dynamics Technology	3) 4)	of floor slab. Allowable moment is based on strength design method per ACI 349/80. T <sub>a</sub> moments are relieved, maintaining equilibrium and curvature of section.

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Location	Section Axial Force	Section Resultant Moment(2,4)	Section Allowable Moment(3)	Moment Code Ratio
West Pool Wall: (AFPSTA1A2-08)				
Vertical Section at Bottom Mid-span (Element 2306)	-32.89	1298.	2219.	0.58
Horizontal Section near Bottom South End (Element 2808)	-34.82	1217.	2059.	0.59
Vertical Section at Top Mid-span (Average Elements 6304,5804,	14.67			
5504,4004 - APPSTAIA2-12)	14.97	205.0	1015.	0.20

Units: Kips/Inch, Kip-inches/Inch

R Notes:	1)	NUREG-0800 Load Combination $(D + L + T_2 + 1.25E')$
A	2)	Positive moment causes tension on outside surface of walls and lower surface of floor slab.
Structural Dynamics Technolog	3) 4)	Allowable moment is based on strength design method per ACI 349/80. ${\rm T}_{\rm a}$ moments are relieved, maintaining equilibrium and curvature of section.

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Location	Section Axial Force	Section Resultant Moment(2,4)	Section Allowable Moment <sup>(3)</sup>	Moment Code Ratio
uel Transfer Canal Separation all: (AFPSTA1A2-07)				
Vertical Section Below Elevation of Bottom of Gate Opening (Element 3313)	-40.93	769.2	1147.	0.67
Horizontal Section at Bottom of Wall (Element 2818)	-31.80	540.0	872.5	0.62
Vertical Section at Top East End (Average Elements 4818,5318,5818,6318 - AFPSTALA2-12A)	-6.624	166.0	397.6	0.42
Horizontal Section at West End of Wall Above Elevation of Bottom of Gate Opening (Average Elements 4314 thru 4318 - AFPSTALA2-12A)	-16.58	369.4	587.0	0.63

Units: Kips/Inch, Kip-inches/Inch

- Notes: Structural Dynamics Technology
  - 1) NURFG-0800 Load Combination (D + L +  $T_a$  + 1.25E')
    - Positive moment causes tension on outside surface of walls and lower surface of floor slab.
    - 3) Allowable moment is based on strength design method per ACI 349/80.
    - 4) T<sub>a</sub> moments are relieved, maintaining equilibrium and curvature of section.

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	Location	Section Axial Force	Section Resultant Moment(2,4)	Section Allowable Moment(3)	Moment Code Ratio
Cas (AF	k Laydown Separation Wall: PSTA1A2-06)				
	Vertical Section Below Elevation of Bottom of Gate Opening (Element 3335)	-34.62	466.3	664.6	0.70
	Horizontal Section at Bottom Mid-span (Element 2335)	-34.35	396.7	572.4	0.69
	Vertical Section at East End of Wall Above Elevation Of Bottom of Gate Opening (Element 3834)	-13.41	188.4	367.0	0.51

Units: Kips/Inch, Kip-inches/Inch

Notes:	1) NUREG-0800 Load Combination (D + L + Ta + 1.25E')
4	<ol> <li>Positive moment causes tension on outside surface of walls and lower. of floor slab.</li> </ol>
Structural Dynamics Technology	<ol> <li>Allowable moment is based on strength design method per ACI 349/80.</li> <li>T<sub>a</sub> moments are relieved, maintaining equilibrium and curvature of second</li> </ol>

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	Location	Section Axial Force	Section Resultant Moment(2,4)	Section Allowable Moment(3)	Moment Code Ratio
Pool	North Wall: (AFPSTA1A2-11)			지 않는 것이 봐.	
	Vertical Section at Middle West Edge (Element 3839)	-3.483	292.1	433.5	0.67
	Horizontal Section at Middle West Edge (Element 3839)	-38.50	1002.	1384.	0.72
	Vertical Section at Top West End (Average Elements 6339,5839,5339,4839 - AFPSTA1A2-12)	0.496	170.2	307.3	0.55

Units: Kips/Inch, Kip-inches/Inch

- Notes: 1) NUREG-0800 Load Combination (D + L +  $T_a$  + 1.25E')
  - Positive moment causes tension on outside surface of walls and lower surface of floor slab.
  - 3) Allowable moment is based on strength design method per ACI 349/80.
  - 4) Ta moments are relieved, maintaining equilibrium and curvature of section.

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	Location	Section Shear(2)	Allowable Section Shear(3)	Code Shear Ratio
Pool	Floor Slab: (AFPSTA1A2-04)			
	North-South Section at Middle (Average Elements 314 thru 320)	1.701	7.230	0.24
	East-West Section at North Edge (Average Elements 300,307,314,321, 328,335)	6.257	21.69	0.29
2001	Foundation: (AFPSTA1A2-04)			
	South Foundation Wall, Horizontal Section at Top (Average Elements 2364 thru 2371)	5.792	14.58	0.40
	East Foundation Wall, Horizontal Section at Top (Average Elements 2374 thru 2381)	3.518	7.305	0.48

#### Units: Kips/Inch

- Structural Dynamics Technology Notes:
  - 1) NUREG-0800 Load Combination (D + L +  $T_a$  + 1.25E')
    - 2) Shear forces are linearly interpolated to a distance from the face of the effective support equal to the distance from the section compressive face to the centroid of the tensile steel.
    - 3) Allowable shear is based on strength design method per ACI 349/80.

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	Location	Section Shear(2)	Allowable Section Shear(3)	Code Shear Ratio
Pool	Foundation: (AFPSTA1A2-04)			
	West Foundation Wall, Horizontal Section at Top (Average Elements 2350 thru 2361)	3.813	6,589	0.58
West	Pool Wall: (AFPSTA1A2-04)			
	Vertical Section at Top North Corner (Element 6302)	25.79	31.79	0.81
	Horizontal Section at Mid-Height (Average Elements 3802 thru 3808)	3.376	7.860	0.43
	Horizontal Section at Top (Average Elements 5802 thru 5808)	6.148	8.463	0.73

	Units:	Kip	s/Inch
Se la	Notes:	1) 2)	NUREG- Shear effect
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- 1) NUREG-0800 Load Combination (D + L +  $T_a$  + 1.25E')
  - 2) Shear forces are linearly interpolated to a distance from the face of the effective support equal to the distance from the section compressive face to the centroid of the tensile steel.
  - 3) Allowable shear is based on strength design method per ACI 349/80.

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Location	Section Shear(2)	Allowable Section Shear(3)	Code Shear Ratío
East Pool Wall: (AFPSTA1A2-04)			
Vertical Section at Top South End (Element 6323)	17.80	31.79	0.56
Horizontal Section Near Top (Average Elements 5823 thru 5829)	3.875	8.372	0.46
Fuel Transfer Canal Separation Wall: (AFPSTA1A2-04)			
Vertical Section at West End Below Bottom of Gate Opening (Average Elements 2313,1813,3313)	0.898	5.018	0,18
Horizontal Section at Bottom of of Wall (Average Elements 2313 thru 2318)	1.235	5.468	0,23

#### Units: Kips/Inch

- Notes: Structural Dynamics Iectnology
  - 1) NUREG-0800 Load Combination (D + L +  $T_a$  + 1.25E')
    - 2) Shear forces are linearly interpolated to a distance from the face of the effective support equal to the distance from the section compressive face to the centroid of the tensile steel.
  - 3) Allowable shear is based on strength design method per ACI 349/80.

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Location	Section Shear(2)	Allowable Section Shear(3)	Code Shear Ratio
Fuel Transfer Canal Separation Wall: (AFPSTA1A2-04)			
Vertical Section at East End (Element 6318)	4.610(4)	5.054	0.91
Horizontal Section at Top (Average Elements 5814 thru 5818)	5.179	5.869	0.88
Cask Laydown Area Separation Wall: (AFPSTA1A2-04)			
Vertical Section Below Gate Opening (Average Elements 2335,2835,3335)	0.741	3.861	0.19
Horizontal Section at Bottom of Wall (Average Elements 2334,2335,2336)	1.504	4.810	0.31

#### Units: Kips/Inch

Notes:

1) NUREG-0300 Load Combination (D + L +  $T_a$  + 1.25E')

- 2) Shear forces are linearly interpolated to a distance from the face of the effective support equal to the distance from the section compressive face to the centroid of the tensile steel.
- 3) Allowable shear is based on strength design method per ACI 349/80.
- Transverse shear adjusted based upon cracked section equilibrium moment gradient.

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Location	Section Shear(2)	Allowable Section Shear(3)	Code Shear Ratio
Pool North Wall: (AFPSTA1A2-04)			
Vertical Section at Top of Wall (Average Elements 5839,6339)	4.407	5.580	0.79

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			Location		Section Shear	Allowable Section Shear(2)	Code Shear Ratio
	Pool	Floor	Slab: (AFPSTA1A2-(	04)			
		North (Aver	-South Section at M age Elements 314 th	1id-length nru 320)	4.796	30.28	0.16
6.16	Pool	East- (Aver 331,3 Found	West Section at Mid age Elements 303,31 38) ation: (AFPSTA1A2-(	H-length 10,317,324	4.329	10.43	0.42
		South (Aver	Wall Section at Mi age Elements 1864 t	d-height hru 1871)	7.983	14.57	0.55
		East (Aver	Wall Section at Mid age Elements 1874 t	l-height hru 1881)	17.29	12.50	1.38
		West (Aver	Wall Section at Mid age Elements 1850 t	l-height hru 1861)	9.847	12.38	0.80
	West	Pool	Wall: (AFPSTA1A2-04	)			
-	R	Section 5302	on Near Top (Averag thru 5308)	e Elements	5.751	31.68	0.13
Y	JUnit	s: Ki	ps/Inch				
Technolog	Note	s: 1) 2) 3)	NUREG-0800 Load C Allowable shear i Foundation wall s	ombination s based on hear force	$(D + L + T_a + 1.25E')$ strength design metho is calculated at mid-	d per ACI 349/80 height.	
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		Location	Section Shear	Allowable Section Shear(2)	Code Shear Ratio
	East Pool W	all: (AFPSTA1A2-04)			
	Sectio 5323 t	n Near Top (Average Elements hru 5329)	1.114	31.68	0.04
	Fuel Transf (AFPSTA1A2-	er Canal Separation Wall: 04)			
5.17	Lower ( Avera	Wall Below Bottom of Gate Opening ge Elements 3313 thru 3318)	11.04	23.38	0.47
	Upper ( (Average)	Wall Above Bottom of Gate Opening ge Elements 4314 thru 4318)	12.82	13.87	0.92
	Cask Laydown (AFPSTA1A2-	n Area Separation Wall: 04)			
	Section (Average	n Below Bottom of Gate Opening ge Elements 3334 thru 3336)	3.371	17.60	0.19
	Pool North W	Nall: (AFPSTA1A2-04)			
S	Section Element	n Near Top of Wall (Average ts 5838,5839)	10.41	14.00	0.74
-	Units: Kips	s/Inch			
Structural Dynamics Technology	Notes: 1) 2)	NUREG-0800 Load Combination (D + L Allowable shear is based on streng	+ T <sub>a</sub> + 1.25E' th design metho	) od per ACI 349/8(	) <b>.</b>

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FIGURE 6-1 Arkansas Power and Light Company Arkansas Nuclear One - Unit 1 Floor Slab Bending Moments Causing North-South Direction Stresses



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### 7.0 MISCELLANEOUS LOADINGS AND OTHER EFFECTS

This section discusses the evaluation of the pool liner plate and horizontal reinforcing in the pool walls, and addresses miscellaneous loading conditions.

#### 7.1 Liner Plate Evaluation

Reference 12 discusses the calculations carried out to evaluate the adequacy of the liner plate for ANO-2. This evaluation considered the effect of differential coefficient of thermal expansion of the liner plate versus the concrete for the accident thermal load case. It has been shown by experience that this loading is, by far, the controlling load on the liner plate. The liner plate in ANO-Unit 1 is very similar in detail and anchorage as that in the Unit 2 pool.

The ANO-2 evaluation was carried out considering the load-deflection characteristics of the anchors, and the interaction between the stiffnesses of the liner plate panels and these anchors. This evaluation also addressed the possibility that there is a buckled liner plate in series with the unbuckled liner plates being evaluated. Based on the evaluation, it was determined that a factor of safety of 4.3 exists for the liner plate. Additional loads associated with the new horizontal fuel rack reactions are negligible when compared to the thermal effects, and in view of the substantial safety factor involved, are not of concern. Based on the similarity in anchorage and liner plate details between the pools of Unit I and Unit 2, it is concluded that the Unit I pool liner plate is adequate.



### 7.2 Miscellaneous Loads

Several loads have not been explicitly addressed in this report since they are not appropriate for this evaluation or since they have been eliminated by other licensing considerations. These loads include postulated cask drop, rack uplift, fuel drop, and heavy loads handling. The question of cask drop and heavy loads handling has been addressed previously by Arkansas Power and Light Company. Rack uplift and the associated impact loading have not been evaluated at this time since they are still under development by the fuel rack vendor, and fuel rod drop is to be evaluated by fuel rack vendor. However, in view of the significant reserve capacity of the pool floor to resist additional shear forces and bending moments, it is reasonable to assume that these postulated loading conditions will not affect the conclusion that the structure is adequate to resist the applied loads.

### 8.0 CONCLUSIONS

Based on the results presented in Section 6, it is concluded that the spent fuel pool structure is adequate to carry the additional loadings associated with high density fuel storage racks. In addition, it is believed that the pool will be adequate for higher loads due to full fuel consolidation, however, this condition has not been formally evaluated. Since the primary effect of additional fuel is to increase the forces and moments in the base slab and foundation, and these components already have significant margin, as seen in the Section 6 tables and contour plots, SDT does not believe that additional loading due to full consolidation will present a problem.



### 9.0 REFERENCES

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- 3. Troxel, Davis and Kelly, "Composition and Properties of Concrete," McGraw-Hill, 1968.
- NUREG-0800, "Standard Review Plan for Review of Safety Analysis Reports for Nuclear Power Plants," Revision 1, U.S. Nuclear Regulatory Commission, July 1981.
- 5. TID-7024, "Nuclear Reactors and Earthquakes," U.S. Atomic Energy Commission, Washington D.C., August 1963.
- 6. Arkansas Nuclear One Unit 1, Operating Procedure 1104.6, "Spent Fuel Cooling System, Revision 4, July 16, 1975.
- 7. Bechtel Calculations 80, Job 6600-1, "Design of Spent Fuel Pool Walls & Slabs for Dead, Live and Hydrostatic Loads," July 1974.
- Specification APL-C-502, "Technical Specifications for Earthquake Resistent Design of Equipment Located in Auxiliary Building for the Arkansas Nuclear One - Unit I Power Plant," Arkansas Power & Light Company, Little Rock, Arkansas, Revision I, April 1, 1982.
- 9. Westinghouse Electric Corporation Letter GLD-82-059, dated September 2, 1982.
- 10. STARDYNE User Information Manual, Control Data Corporation, Revision C, 1980.
- 11. Bechtel Calculations 11406-080, Job 11406-080, "Check of Spent Fuel Pool for Additional Loads Caused by Increasing the Fuel Rack Capacity," April 1979.
- SDT Report APL-02-013, "Structural Evaluation of the Arkansas Nuclear One -Unit 2 Spent Fuel Storage Facility for Consolidated Fuel Storage," Revision 0, dated November 24, 1982.



### APPENDIX

# ARKANSAS I NUCLEAR ONE - UNIT I

### SPENT FUEL POOL

### FINITE ELEMENT MODEL





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### ARKANSAS NUCLEAR ONE-UNIT ONE SPENT FUEL STORAGE FACILITY FINITE ELEMENT MODEL

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Sec.	2211	hair		10.00	pies.	2068	him.
2.18	1000	pine.	2012	hirs.	\$1.75.	2074	3195
	1124	ALC:	hear	here.	1:78	6128	

MIDDLE SURFACE

part.	- Part	THE	-	1000	1008	1203	
1414	poss.	perse	hoix.	bosy.	pass.	-	2019
	- him	bies.		hase .	bus?	2056	1010
2216	2003	2055	DOBS.	2054	206.2	pairs	20.23
4412	- burn	2012		\$0.00	boot .	pose	\$9.96
lain.	hats.	2078	putt	pare.	\$975.	daria.	1095
Link-	Sara.	\$ 225.	10/0	1011	10.0	\$110	how

OTSHEE SSIRE ME

#### CUBE ELEMENTS

226	105	304	255	282	201	-290
213	212	213	210	2119	238	301
220	719	250	21.2	218	215	214
227	226	225	124	-228	122	.121
274	733	232	221	130	229	228
241	240	239	238	237	2.96	2.95

#### INSIDE LAYER

	506	+05	-in	401	992	445	433.
1	413	412	911	49.05	109	100	901
ŀ	1623	819	41.8	4.1	4,6	615	4.16
	7427	\$25	+25	42%	425	422	621
ŕ	424	110	537	16.31	4.35	14.75	428
r	941	440	9.75	1428	4.27	428	#35

OUTVOL LAYER

#### SURFACE MEMBRANE ELEMENTS

125	125	104	,203.	198	- 193	
119	.01	. 111	114	104	128	
120	119	118	117	116.	115	114
	3.09	-125-1	1.2%	123	128	
174	123	174	191	4.90	129	128
141	148	1.29	1.38	3.37	1.16	1.18

#### INSIDE SURFACE

725	.85	104	292	302	294	3,00
	312	(Nec)	13.0	1.144	1.12	3.0
140	3/3	11.9	1.1	215	155	20
	226	323	124	721	222	14
116	122	212	3.6	202	179	11
÷.	143	1.8	124	027-1	224	

MODUL SURFACE

506	50%	508	10.3	507	501	300
413	582	522	110	509	508	507
629	518	518	517	516	325	514
\$27	528	525	524	323	122	821
574	532	\$37	931	530	529	528
191	540	6.24	138	527	5.86	5.25

OUTSIDE SURFACE

FIGURE 3

FLOOR ELEMENT AND NODE NUMBERS

a de la constante en des de anches de la maisme de la constante de la co

SDT Structural Dynamics Technology, Inc.

#### EAST WALL ELEMENT NUMBERS

and a second provide and we are the fit. Substitute the rest of the fit and the second s

#### FIGURE 4

\$1,29		8123	61.76	8125	6124	6)23
5623	58.78	5827	1626	5625	5624	5827
5129	5128	\$171	5124	5125	5124	5123
45.23	44.28	+627	4675	48.75	4624	1821
4229	97.29	9121	4125	4121	4124	4123
3629	16.18	2627	36.26	2624	3624	3523
1129	25.28	Mart	11.28	3525	1129	3113
1913	1619	28.()	2526	3475	2624	2823
2128	11.18	21,27	7128	2125	21,24	23.73

INSIDE SUBFACE

6.123	5328	6.727	6.326	6325	6724	6.32
5829	5828	1827	5826	5825	5824	1677
1329	5328	5327	5326	5325	5.524	5.923
4829	4828	4877	4828	4875	9829	462
9325	9528	4327	4326	9325	4725	4323
3679	3076	3827	1826	1825	5824	3823
1728	3328	3327	3328	3,525	1324	1923
2829	2828	2827	2926	2875	3824	.2877
2325	2378	2321	2326	2125	2324	2323

1	6528	6528	6527	\$5.26	#525	6529	\$527
	6029	8028	90.21	6076	6025	6024	6023
	5529	5528	5527	\$5,76	5525	57.24	1523
	5029	50.28	5027	5028	5025	1029	9028
1	4529	4528	4527	4128	4525	4528	4525
i	40.2%	40.58	9022	4028	140.25	4029	4923
1	2525	25.28	(152.)	1525	3525	15.24	25.23
1	30.29	30.78	X611	3026	20.25	10.24	3023
1	2539	2520	2521	2525	2525	2528	2523

OUTSIDE SURFACE

#### SURFACE MEMBRANE ELEMENTS

19	11				1210		this	8931	92	8012
123	100	3778	5128	Fut	1171	6725	5728		1111	8515
-	atta .	A228.	1124	9245	1225		5729	5123	1111	9813
	111	11/2	4728	4121	.4125	-4725.	\$7.0	.4723	2245	9713
81	-	1217	3723	9321	92.76	4725	12.28	8227	111	9913
14	and the	212%	10.04	1324	2726	17.25	1124	2122	2012	8513
	1111		(and	3427	8125		1224	823	1205	841.3
15	100	2124	2126	3.15.1	2726	27,85	2324	-2728	2772	8313
2.7	102	1228	2226	3327	1276	2225	2224	-2223	1022	823.5
	11	1729	1128	1721	1124	1725	1724	1723	133	8113
	1111	1229	1228	2.824	1224	1925	1.02%		100	4010

10.00	8.20	144	6424	84.78	1973.1	6424	6425	64.74		100 00 10000
		134								22
416	<u>818</u>	100	5929	5529	3827	78.28	5975	5329	5923	1 2 2 395
-	856	ALLS.	5429	1428	7927	3425	5425	1475	5475	1110
	754	22.52	8925	4929	43511	1925	4875	2974	4953	1000
180	182	148	8679	1427	4427	9426	9925	95/3	4923	2 2 9165
16.8	170	PLEE.	3325	.yij28	29435	3978	3825	29774	3923	10 10 ASA'S
-56	156	11 M	2425	1429	9927	7925	3925	1474	1623	100
744	246	100	2019	2928	5823	2925	2925	.2929	2973	33 8.165
732	138	24.92	2429	2628	29(27	2828	2425	.2929	2923	22 22 4245
720	723	124	1829	1928	927	216	1975	19.74	1923	4105
		and a	1429	1.454	1.427	1425	1935	1924	1423	11 ROAS

OUTSIDE LAVER

#### CUBE ELEMENTS

ARKANSAS NUCLEAR ONE-UNIT ONE SPENT FUEL STORAGE FACILITY FINITE ELEMENT MODEL

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Structural Dynamics Technology, Inc.

### ARKANSAS NUCLEAR ONE-UNIT ONE SPENT FUEL STORAGE FACILITY FINITE ELEMENT MODEL

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enterne a presente sente mente a del tramatamental elle como de colar se da sectar de la calmenta de contra seguine en esta el como de como de

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### ARKANSAS NUCLEAR ONE-UNIT ONE SPENT FUEL STORAGE FACILITY FINITE ELEMENT MODEL

CUBE ELEMENTS

8244 8208	A203	5,205	#205	8.704	620.8	6262	6200
5.10x ×10.6	3767	1104	2767	3,374	2,027	5102	1.100
1009 (1208)	2202	1278		5234		\$392	5290
4108 +108	4207	4/14	4795	with:	4703	*j01	ens.
1205 4208	420+	8705	97.05	4204	\$203	4203	\$2781
1029 1708	3703	3108	3105	3104	2303	3.762	37.00
1249 3258	3201	3206	3265	3194	122.8	1262	37.00
2108 210A	2002	2108	2125	2754	2703		2730
2259 2258	2101	3706	2205	2204	22519	1207	1540
1705 1708	1101	1706	7905	110x	110.9	1184	1200
1209 1208	1,20.7	1206	1.20%	104	1203	1200	1301

	 	_
7624		

consider astro	1.0407.	6405	- 5405	8904	1413	1952	1.10.10
strates and	-5,967	1.966	1805	5909	1.461.5	1957.	SAME.NR.
14100408 540	1.1617	9406	1404	5404	5602	1407	sin a
vinus: 497	4 421 <sup>3</sup>	¥905	4805	4904	×903	4902	\$335.1A
44785-478 - 440	# ¥407	4406	4405	vetu	4407	4907	avera a
29185308 290	R 3927	3906	5905	1904	3903	1902	19(213-38
94165408 940	8 7407	3926	3905	1974	3423	19822	THEST
29182998 280	# 3907	2906	2905	2504	2903	2904	198293
24.122400 240	# 2407	2406	2405	2404	246)	290(2	24/12/18
19189908 190	8 2907.	1906	1905	1.9014	1907	(92)	1.5001.908
19.00.000 190	8 1407	INDE	1405	1404	1403	1407	14001408

OUTSIDE LAYER

1508	6507	6506	8505	8504	6503	#502
6058	6001	\$205	6005	6004	6003	6002
5528	5507	5506	5565	5504	\$507	\$507
5008	50.07	-sole-	5025	*20x	5065	1003
4508	4507	45:26	4505	9504	¥503	145.03
4008	4007	9036	4085	400×	406,3	4000
35.08	36.07	3506	1505	3504	2503	8903
1058	3007	1005	3623	3004	2003	N24
2508	2507	2506	2505	2504	2503	258

#### SURFACE MEMBRANE ELEMENTS

16308	6.307	6306	6305	6329	6.103	+303
5808	5467	1909	5803	5804	5853	5802
5.308	2.30.1	\$306	5.365	5304	5.903	3.307
NROR	4901	12804	4805	9804	1003	4802
9.308	4.80.7	4306	¥305	4304	4303	9.762
yeon	3601	1006	3805	30028	1803	1807
1961	1.06.6	2306	1305	3,304	3203	1903
/808	280.1	2806	2005	2804	1803	2902
2308	2701	2308	2905	2304	2303	2302

MIDDLY SURFACE

FIGURE 6

WEST WALL ELEMENT NUMBERS

a (and a new an and a second and a second and a second device a second and a second and a second and a second a

6108	6157	6126	\$105	6104	4103	6152
18.02	5807	5808	5415	1604	285.5	5407
5158	SIP.	51176	5105	5104	5107	5482
95.09	4527	4518	46.05	4504	4655	4502
4108	witte	41/8	4115	4104	4107	9,077
3409	76.01	9606	3605	3824	96.0 Y	1607
14,58	uk'	3116	1105	1104	3503	3113
2504	24.97	26.28	2865	26/24	260.7	2602
108	via.	2108	2105	7104	100.00	1102

INSIDE SURFACE


Structural Dynamics Technology, Inc.

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1853	1658	155	122	1520	1550	1422	1904
1152		1022	101	1005	pice.	4000	2807
<u>1118</u>		151	2555	2544	1054	-free	-1952
2100	1108	1551.	\$100	1505	1554	1103	1964
his	here	4451	455	inis.	here.		3452
iner	100		hice .	-	avax.	1403	3101
1.259	1258	100	2.354	1355	1.254	- 222	
free.	1108	- ini	4.500	-		1200	1100
120	1.52	101	1756	tin.	- price	- 1755	175
-	1.170	and.	1.00	\$ 205	1224	1203	101
1108-	1.0	144	1405	11.00	hits.	\$123	100
Sec. a	A COM	Same .	and a	Sec.	here's	Same	

INCIDE SUNFACE

7984	2859	1518	7852	-2558	- 2015	-2654	7653	285,2951
75.10	28.09	pice.	Peur.	- Pace	2605	PECs.		mapeo.
2540	2559	2558	\$557	7558	1555	2158	351	2552551
25.10	2508	25.08	2507	2006	2505	-	2503	2502501
2460	2002	Pase.	2857		P#55.	busa		PASPASI
2410	Eves .	2408	-	- 2105	buos	bury.	1002	2402401
2763	\$ 25.9	2358	\$ 352	2306	1295	2.857	2353	2352351
2710	P 109	2308	in the second	2 375	have	2304	1302	100000
2269	\$255	Pesa	\$252	prie .	\$255	2254	2.05	2252(3)
2210	\$200 ···	1000	2201	p.100		2204	201	2252 101
100	101	pice.	\$101	\$105	hias	hile	2102	101401
2010	2003	boom	2001	knes	kees	boos	boos	buchion
			-	HOPLE SU	RFACE			

restantion.	7658	3657.	2656	7655	2654	1053	- 165 2363 (2×50)
beipeiden.	have	2402	bees	here	hade	2623	BEDREOPEN
bsepsenssa.	pase	3557	5556	biss.	2554	200	- proprieta
asi <b>r</b> si <del>a</del> sos	psoe.	5502	5506	5505	DSilve	psai.	hisman
Des Dan Desa	pise	3457	bese	hers	-	5853	DASDASDASD
DALDALDADA.	berr	2407	bane	5425		buoz	
236 0 36 (7 35 3	2351	9357	2358	285		2352	225,235,0350
2310310303	2005	2307	have	hius .	2.85%	have	236 236 2 800
226.0250253	base.	\$257	204	p.255	besa	2252	bisbiap.es
521 021 520s	hore	hini	2006	p.cos	hear	1223	
bis pridica.	Dine.	hint	hine .	2105	hine	Birth .	DISDISTING
hos hos hous	baon	boaz	1000	bcas	hoos	1003	Bouncoproce

OUTSIDE SURFACE

FIGURE 7

WEST WALL NODE NUMBERS



A.8

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#### NODE NUMBERS

INSIDE SURFACE

CUBE ELEMENTS



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#### NODE NUMBERS

CUBE ELEMENTS



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## ARKANSAS NUCLEAR ONE-UNIT ONE SPENT FUEL STORAGE FACILITY FINITE ELEMENT MODEL

FUEL TRANFER CANAL FOUNDATION WALL 

Table 1 and 1 and

1001 1901 1901 1901 1901

HERE MERCHANTS

3040 3040 3040 3040 3040 3040

2589 2589 2589 2589

100 100 100 100 100 100 100 100 100

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1991 1995 1995 1995 1995

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Technology. Inc.





	-	-	-	-	-	-
19.1	20.92	2463	2445	1995	2005	2985
1411	1911	1961	1981	1885	3.994	1385
1141	1470	146.5	6941	1991	1480	1.455
-		-	CUN	E.EM	NTS.	

2967	2983	29452454	(9)8	2411	2956	2975	2054	2953	ini/mfi
7562	.99	rendered	2458	295.8	245.6	2455	2459	2452	2852 2858 2
1963	- 947	1965(358	1958	1071	1.956	1953	1954	1953	(952-195) 1
1987	1463	issocorb	1458	0451	1458	1455	1954	(453	1452 1451 1

WEST FOUNDATION WALL

the prepare and the set and the set and and and

THE THE TREE THE THE THE THE THE ARE THE THE THE

INSIDE MEMBRANES

NEW PORTER AND THE ADDE ADDE ADDE ADDE ADDE ADDE

2062 (10822010) 2014 (2011 - 2016 2016 2016 2014 2013 2013 2013 2013

1961 (196) 1956 1957 1956 1955 1954 1953 1953 1951 1951

DUTSIDE MEMBRANES

CORF. CI	ENENTS	
-	and the second data	

and the second second second	
the second se	
C1088-E21892973	
the second se	

1961	1887	1984	1.385	1364
48N1	)467	1486	1.885	1484
UN	t t cem	ENTS		

_	 		
		Α.	11





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#### NODE NUMBERS





and the second state of the se

CASK LAYDOWN AREA OUTSIDE WALL

WEST WALL



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#### NODE NUMBERS

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DUTSIDE WALL SURFACE

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FLORM EROST SECTION NODES



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CUBE ELEMENTS

1		£	1	. :		[]		1.1		1.1
-	876		-	* 19	8760	#75	8758	975	8756	8758
			16	454	8440	853	8618	#65	8656	8658
58.4	956		-	#54	#500	855	#55#	855	#558	8558
46	eve	10	-	eve	8450	841		845	8456	7455
355	836		14.2	#35	#360	875	#35.8	835	5258	8353
285	875	10	-	826	8250	825	8258	8753	.#255	#25 <b>5</b>
1.00	415		4	815	8160	8:5	8158	815	8156	8158
100	100	×1	1	805	6060	80%	8058	805	8054	8055

FUEL TRANSFER CANAL DIVISIOE WALL

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and contractions even and even and enter sets

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FIGURE 14

FUEL TRANSFER CANAL OUTSIDE WALL AND FLOOR ELEMENT AND NODE NUMBERS



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## ARKANSAS NUCLEAR ONE-UNIT ONE

# SPENT FUEL STORAGE FACILITY FINITE ELEMENT MODEL

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