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STRUCTURAL ANALYSIS REPORT for the LACROSSE BOILING WATER REACTOR SPENT FUEL POOL STRUCTURE

Prepared Under Project 5101
for
DAIRYLAND POWER COOPERATIVE

by
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1. SUMMARY

This report, prepared for Dairyland Power Cooperative (DPC), presents the results of the structural analyses performed by Nuclear Energy Services, Inc. to verify the adequacy of the fuel storage pool structure to accommodate the additional dead weight, vertical and lateral seismic loads of the high density fuel storage racks. Detailed structural analyses of various structural members of the pool (pool floor, walls) have been performed to verify the adequacy of the design to withstand the loadings associated with normal operations, the severe and extreme environmental conditions of the 1/2 safe shutdown and safe shutdown earthquakes and the abnormal loading conditions of an accidental cask drop event.

The response of the fuel storage pool structure to the specified static loading conditions have been evaluated by means of linear elastic analysis using the finite element method. Applicable loads and load combinations have been considered using the guidelines given in USNRC Standard Review Plan Section 3.8.4. The allowable section strength of the reinforced concrete members have been calculated based on the ultimate strength design methods described in ACI-318-71. For the specified loading conditions, the maximum stresses of the storage pool structure have been calculated and shown to be less than the allowable values.

It has been concluded from the results of the structural analysis that the spent fuel storage pool design is sufficiently adequate to withstand the loadings associated with normal operating and abnormal conditions.

2. INTRODUCTION

Nuclear Energy Services, Inc. (NES) has designed the crash pad and the high density spent fuel storage racks for the Dairyland Power Cooperative to be installed in the LaCrosse Boiling Water Reactor fuel storage pool. The structural design of the high density spent fuel storage racks is given in NES document 81A0546, Rev. 2, dated August 7, 1978 (Reference 1). The spent fuel shipping cask drop analysis is given in NES document 81A0550, Rev. 2, dated September 20,1978 (Reference 2).

This report (NES 81A0095) presents the results of the structural analysis that have been performed by Nuclear Energy Services, Inc. to evaluate the adequacy of the fuel storage pool structure to withstand loadings associated with the additional dead load and seismic response of the high density spent fuel storage racks and the reaction loads resulting from a cask drop event. The fuel storage pool floor and walls have been mathematically represented by a three dimensional finite element model consisting of plate elements and having appropriate boundary conditions. The response of the finite element model of the storage pool structures to the applicable loads have been determined using linear static analysis methods. Loads and load combinations have been developed based on the guidelines given in USNRC Standard Review Plan Section 3.8.4 (Reference 6). The adequacy of the reinforced concrete members have been evaluated using ultimate strength design methods for reinforced concrete structures. The applicable codes, regulatory standards, structural acceptance criteria are also presented in the report. The detail loading and structural calculations are given in Appendices A through D.

3. DESCRIPTION OF SPENT FUEL POOL STRUCTURE

The fuel storage pool is located inside the reactor containment building (south of the reactor pressure vessel) between elevation 659'-5-5/8" and 701'-3". The fuel storage pool is a 11' x 11' x 40' deep reinforced concrete structure lined with AISI Type 316 stainless steel plate. The 56 inch thick storage pool floor is lined with 3/8 inch thick stainless steel plate and is supported along its perimeter by the four pool walls and along its mid-span by a 29 inch thick wall. The pool walls, which vary in thickness, are lined with a 1/16 inch thick stainless steel sheet. A detailed layout of the pool floor and its supporting walls are shown in Reference 3. Elevation sections of the pool floor, the north, south, east and west walls including their detailed reinforcement patterns, changes in wall thickness and pool floor support walls are indicated in Figures 3.1 and 3.2.

In the arrangement of the storage racks, and crash pad in the fuel storage pool (shown in Figure 3.3), the two-tier 9 x 8 and 4 x 10 storage rack are located adjacent to the east, west and north walls of the pool and the crash pad is located adjacent to the south wall of the pool.

The horizontal seismic loads are transmitted from the rack structures to the fuel storage pool walls at three elevations (the top grid of the upper tier rack section, centerline of the inter-section of upper and lower rack tiers, and the bottom grid of the lower tier rack section) through adjustable pads attached to the rack structures. The vertical dead-weight and seismic loads are transmitted to the storage pool floor by the rack support feet. The impact loads associated with the cask drop event are transmitted to the pool floor by the crash pad.

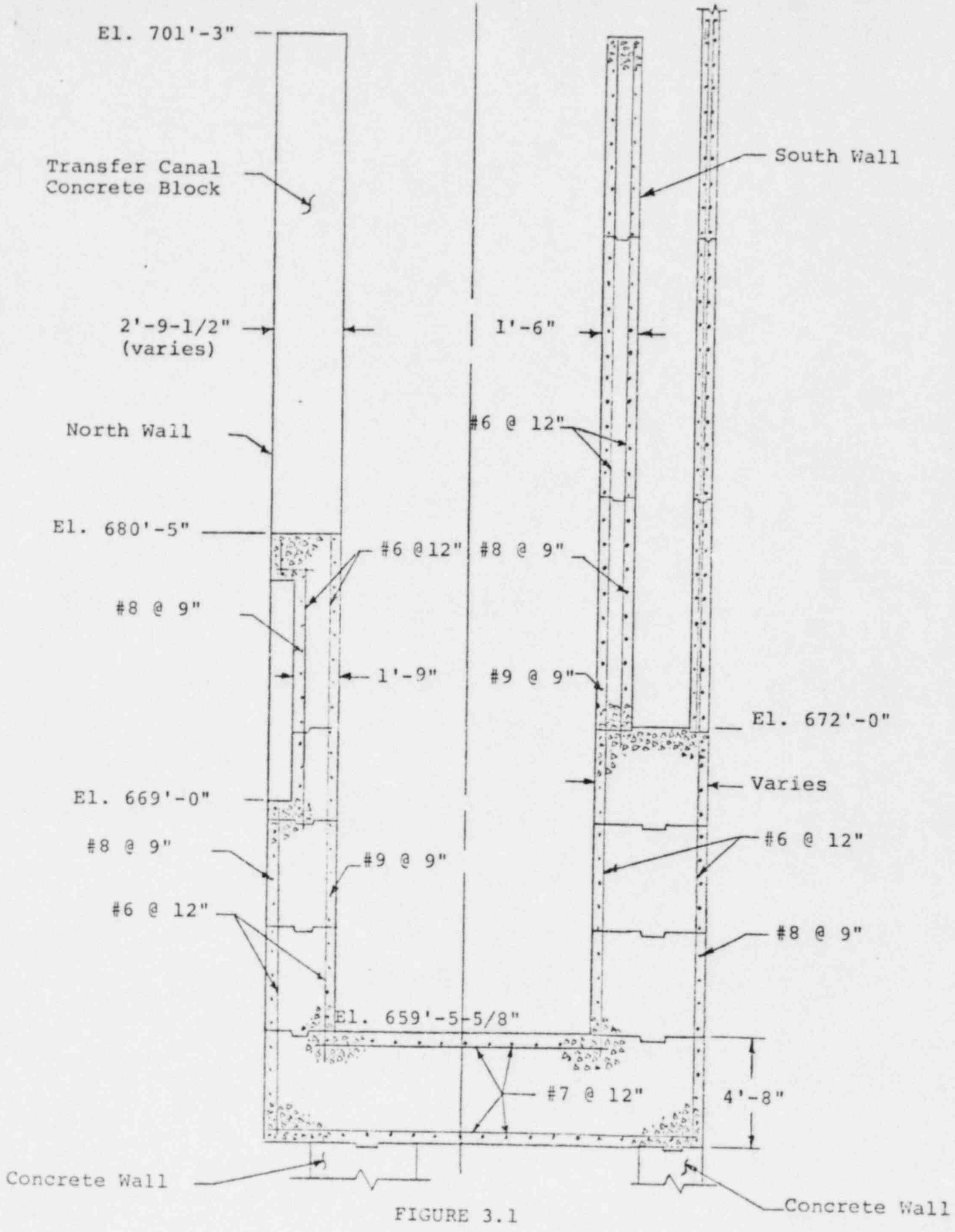

FIGURE 3.1

FUEL STORAGE POOL ELEVATION - NORTH AND SOUTH WALLS

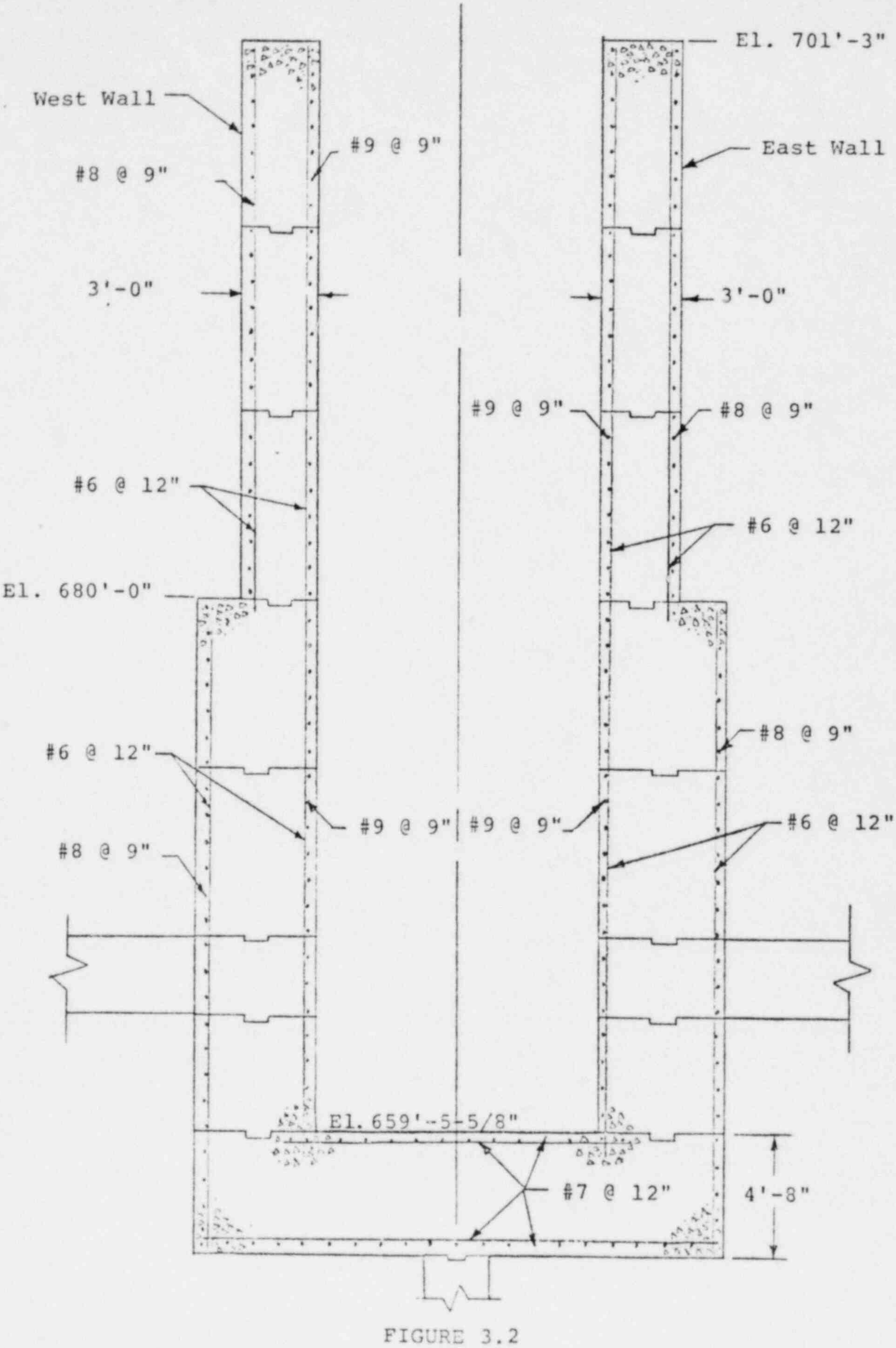

FIGURE 3.2

FUEL STORAGE POOL ELEVATION - EAST AND WEST WALL

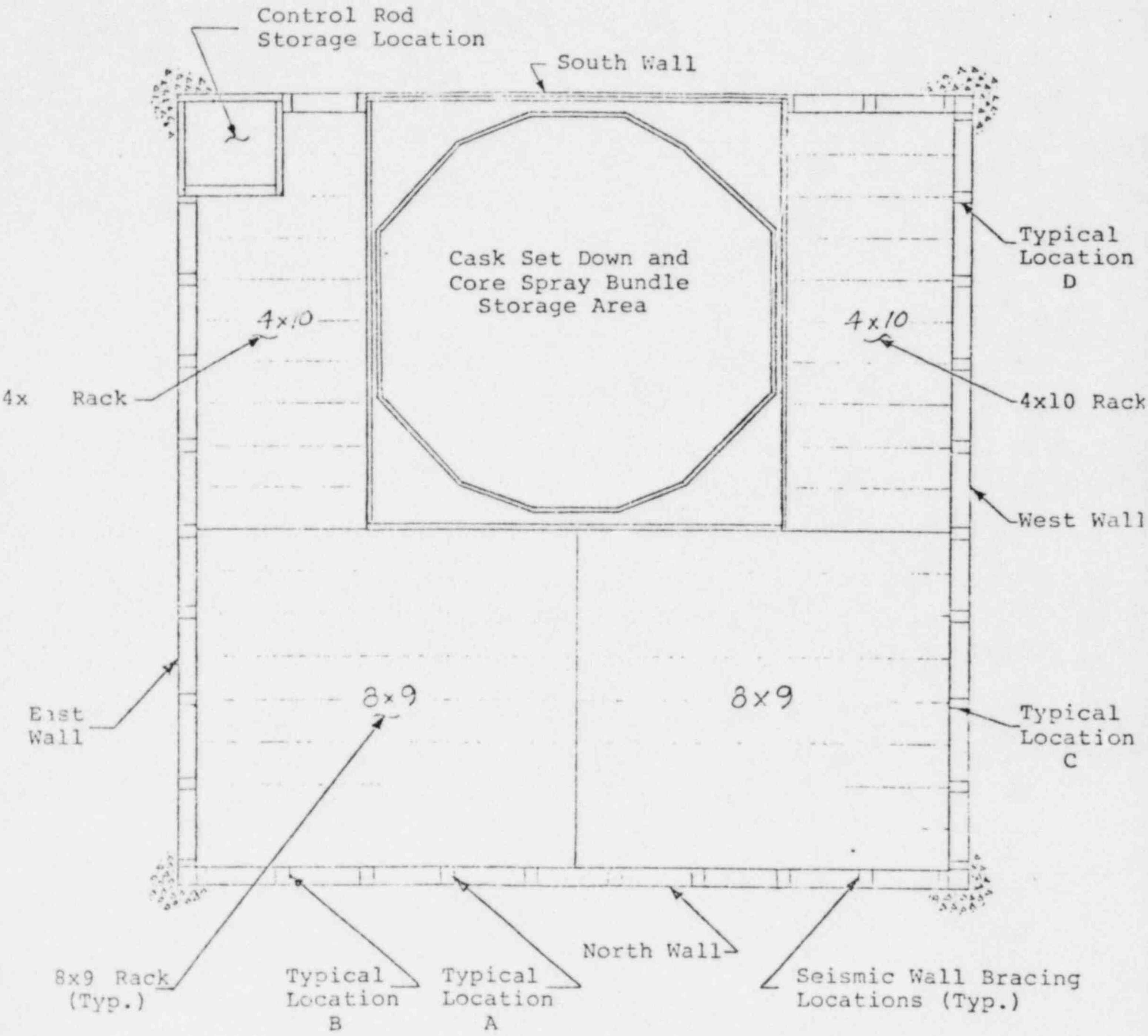

FIGURE 3.3

SPENT FUEL STORAGE RACK ARRANGEMENT PLAN

4. APPLICABLE CODES, STANDARDS AND SPECIFICATION

The following design codes, regulatory guides and references have been used in the structural analysis of the fuel storage pool structure.

1. ACI 318-71 - "Building Code Requirements for Reinforced Concrete" American Concrete Institute.
2. Uniform Building Code, 1973 Edition.
3. USNRC Standard Review Plan, Section 3.8.4.
4. "USNRC Proposed Position for Review and Acceptance of Spent Fuel Storage and Handling Application."
5. Nuclear Energy Services, Inc. document NES 81A0544, Rev. 0. "Quality Assurance Program Plan for the LaCrosse Boiling Water Reactor Spent Fuel Storage Rack Design Program", March 1978.
6. George Winter, et al - "Design of Concrete Structures", McGraw Hill Book Company, 1964.

5. LOADING CONDITIONS

The following load cases and load combinations have been considered in the analysis in accordance with the requirements of USNRC Standard Review Plan, Section 3.8.4 (Reference 6).

5.1 Load Cases

Load Case 1 - Dead Weight D (Normal Load)

The weight of the empty pool concrete structure is considered as the dead weight loading.

Load Case 2 - Live Load, L (Normal Load)

Under normal operations, the storage pool is subjected to the live loads associated with the hydrostatic pressure and the weights of the fully loaded racks, crash pad and spent fuel shipping cask.

Load Cases 3 to 6 - 1/2 Safe Shutdown Earthquake, E (Severe Environmental Load)

The fuel storage pool walls are individually subjected to the seismic inertia loading of the concrete walls, pool water mass, and the maximum seismic reaction loads of the fuel storage racks (Reference 1) for the 1/2 Safe Shutdown Earthquake event.

The load combinations (Section 5.2) involving the Safe Shutdown Earthquake (E') are less severe than those involving the 1/2 Safe Shutdown Earthquake (E) while the acceptance criteria for these load combinations are same. Therefore, the analyses have been performed for the 1/2 Safe Shutdown Earthquake loading condition only.

Load Case 7 - Thermal Loading, T_O (Normal Load)

Clearances are provided between the individual racks and between the racks and the pool walls to allow unrestrained growth of the racks for the maximum temperature differential based on a maximum pool temperature of 150°F. Consequently the storage racks will not impose any thermal loading on the storage pool walls. The spent fuel pool cooling system analysis (Reference 7) of the storage pool for the high density storage rack application indicates that the pool water temperature will not be greater than 120°F for the maximum heat load condition. The Technical Specifications, however, permit the fuel pool to operate at temperatures up to 150°F. The pool floor and walls are conservatively analyzed (Appendix C) for a linear thermal gradient of

80°F (150°F inside pool temperature and 70°F ambient temperature outside the pool) across the thickness of concrete elements.

Load Case 8 - Spent Fuel Shipping Cask Drop Impact Load I.L. (Abnormal Load)

The maximum reaction load associated with the spent fuel shipping cask drop event (Reference 2) are applied to the affected area of the pool floor.

5.2 Load Combinations

(a) For service load conditions, the following load combinations are considered using the ultimate strength design methods of ACI-318-71 (Reference 10).

(1) $1.4\ D + 1.7\ L$

(2) $1.4\ D + 1.7\ L + 1.9\ E$

(3) $0.75\ (1.4\ D + 1.7\ L + 1.7\ T_o)$

(4) $0.75\ (1.4\ D + 1.7\ L + 1.9\ E + 1.7\ T_o)$

(b) For factored load conditions, the following load combinations are considered using the ultimate strength design methods of ACI-318-71 (Reference 10).

(2) $1.4\ D + 1.7\ L + 1.9\ E > D + L + E'$*

(5) $1.4\ D + 1.7\ L + I.L.$

The detail calculations for various loading data and load combinations are given in Appendix A and C.

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*Lateral seismic inertia loading of the concrete walls, pool water mass and the maximum seismic reaction loads of the fuel storage racks for the 1/2 Safe Shutdown Earthquake (E) are 73% that of the Safe Shutdown Earthquake (E') (page A-8 of Appendix A). Therefore, load combination 1.4D + 1.7L + 1.9E involving 1/2 Safe Shutdown Earthquake is more severe than load combination D + L + E' involving Safe Shutdown Earthquake.

6. STRUCTURAL ACCEPTANCE CRITERIA

The following allowable stress/load limits constitute the structural acceptance criteria used for each of the loading combinations presented in Section 5.2.

Load Combinations	Limit
1, 2, 3, 4, 5	U

Where U is the required section strength based on the ultimate strength design methods described in ACI-318-71. The compressive strength of concrete at 28 days is taken as 3500 psi (Reference 10).

7. METHOD OF ANALYSIS

7.1 Mathematical Models

In order to perform the linear static analysis of the fuel storage pool structure, the various structural components (pool floor and walls) of the pool structure are represented by a composite three dimensional finite element model. As shown in Figures 7.1.a through 7.1.c, the three-dimensional finite element model consists of plate elements interconnected at a finite number of nodal points. Stiffness characteristics of the structural elements are related to the plate thicknesses. Six degrees of freedom (three translational and three rotational) are permitted at each nodal point. Nodal points are selected to adequately represent the changes in the wall thicknesses, discontinuity effects, various loadings and boundary conditions.

Appropriate boundary conditions, as shown in Figure 7.2, have been assumed at the interface of the storage pool and shield building.

7.2 Mathematical Formulation of the Static Analysis

The static analysis of the finite element model has been performed using the direct stiffness methods of structural analysis. If the force displacement relationship of each of the discrete structural elements is known (the element stiffness matrix) then the force-displacement relationship for the entire structure can be assembled using standard matrix methods as shown below.

For each element

$$k\ u = f \qquad (1)$$

where:

k = Element stiffness matrix
u = Element nodal displacement vector
f = Element nodal force vector

For the idealized system the equation of equilibrium may be written, in matrix form, as follows:

$$K\ U = F \qquad (2)$$

where:

K = Assembled stiffness matrix for the system

$$= \sum_{i=1}^{n} k$$

U = Nodal displacement vector for the system
F = External nodal point force vector

If sufficient boundary conditions are specified on U to guarantee a unique solution, Equation (2) can be solved for the nodal point displacements at each node in the structure, knowing the system stiffness matrix and external force matrix. From the displacement response of the system, the internal forces and stresses in each structural element can be calculated.

7.3 Stress Analysis

For the plate element the internal forces and moments are related to the stresses by the following equations.

$$\begin{Bmatrix} MX \\ MY \\ MXY \end{Bmatrix} = \left(\frac{T^2}{12}\right) \left[\begin{Bmatrix} SX \\ SY \\ SXY \end{Bmatrix}_{+Z} - \begin{Bmatrix} SX \\ SY \\ SXY \end{Bmatrix}_{-Z} \right]$$

$$\begin{Bmatrix} FX \\ FY \\ FXY \end{Bmatrix} = \left(\frac{T}{2}\right) \left[\begin{Bmatrix} SX \\ SY \\ SXY \end{Bmatrix}_{+Z} + \begin{Bmatrix} SX \\ SY \\ SXY \end{Bmatrix}_{-Z} \right]$$

Where:

T = Plate thickness

$+SX(\sigma_X)$ = Stress in element X direction on the positive Z surface.

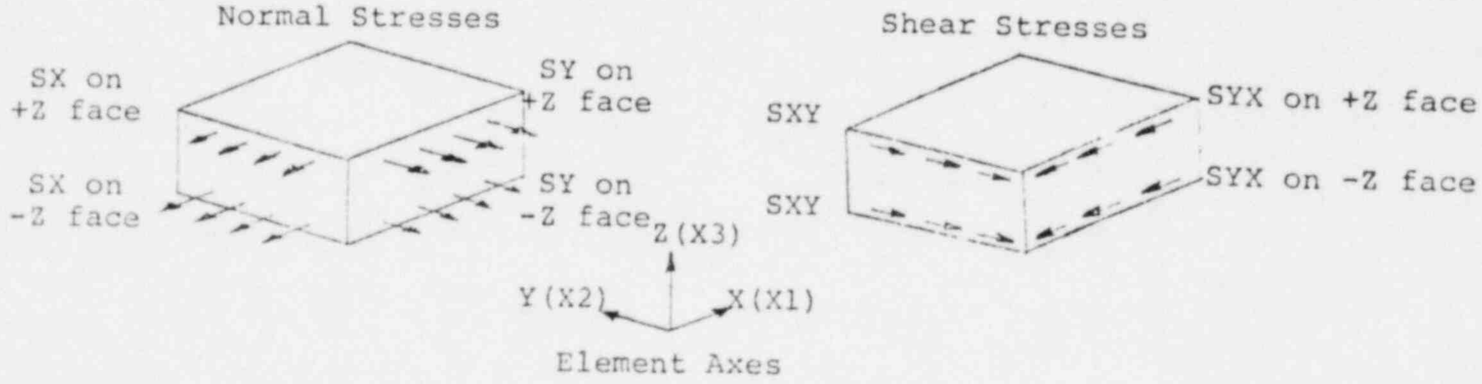
$+SY(\sigma_Y)$ = Stress in element Y direction on positive Z surface.

$+SXY(\sigma_{XY})$ = Shear stress on positive Z surface.

$-SX(\sigma_X)$ = Stress in element X direction on negative Z surface.

$-SY(\sigma_Y)$ = Stress in element Y direction on negative Z surface.

$-SXY(\sigma_{XY})$ = Shear stress on negative Z surface.



F_x, F_y, F_z = Element internal forces along element x, y and z axes.

M_x, M_y, M_z = Element internal moments about element x, y and z axes.

The maximum shear and compressive stresses are compared to the allowable shear and compressive stress values for a reinforced concrete element. The maximum tensile stresses are converted to the equivalent internal moments and the internal moments are compared with the allowable ultimate moment carrying capacities of the reinforced concrete sections. The ultimate moment carrying capacities of the reinforced concrete sections for various reinforcement patterns and wall thicknesses are calculated using the ultimate strength design methods of ACI-318-71 (Reference 10). The calculations are presented in Appendix B. The structural analysis and stress analysis calculations are performed using the STARDYNE computer program (Reference 13).

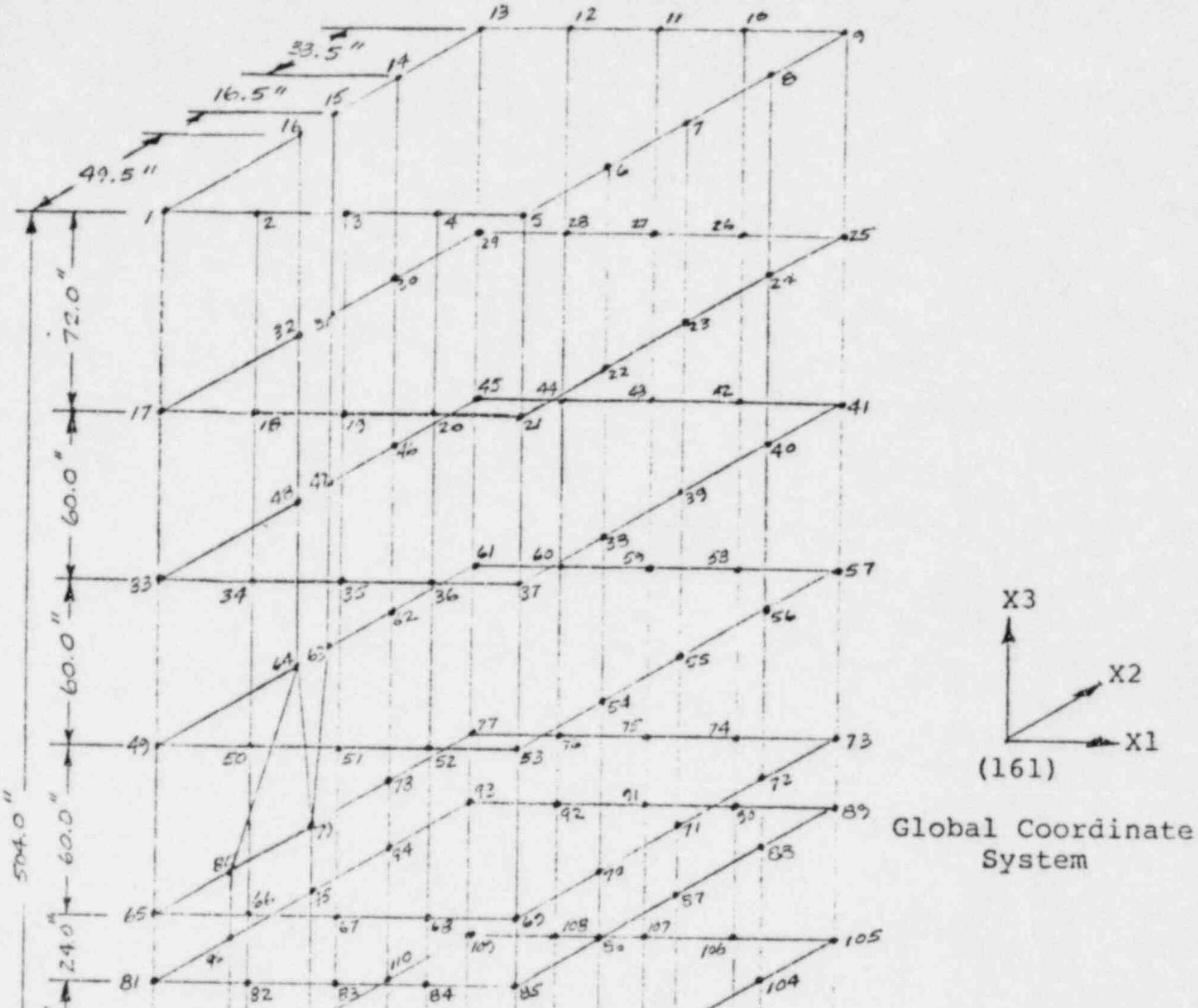


FIGURE 7.1.a

SPENT FUEL STORAGE POOL

FINITE ELEMENT MODEL NODE NUMBERS AND DIMENSIONS

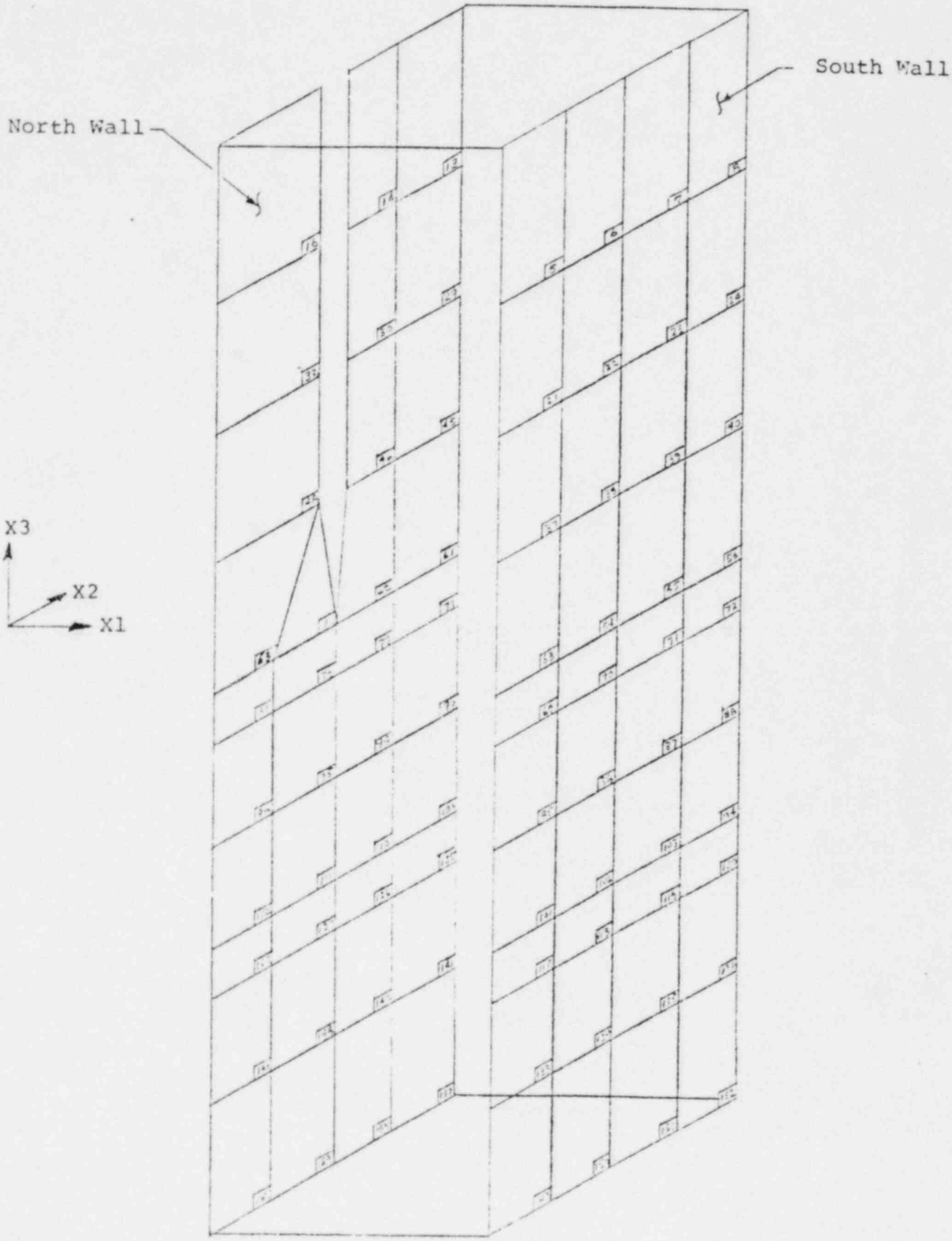


FIGURE 7.1.b

SPENT FUEL STORAGE POOL
FINITE ELEMENT MODEL - PLATE ELEMENT NUMBERS

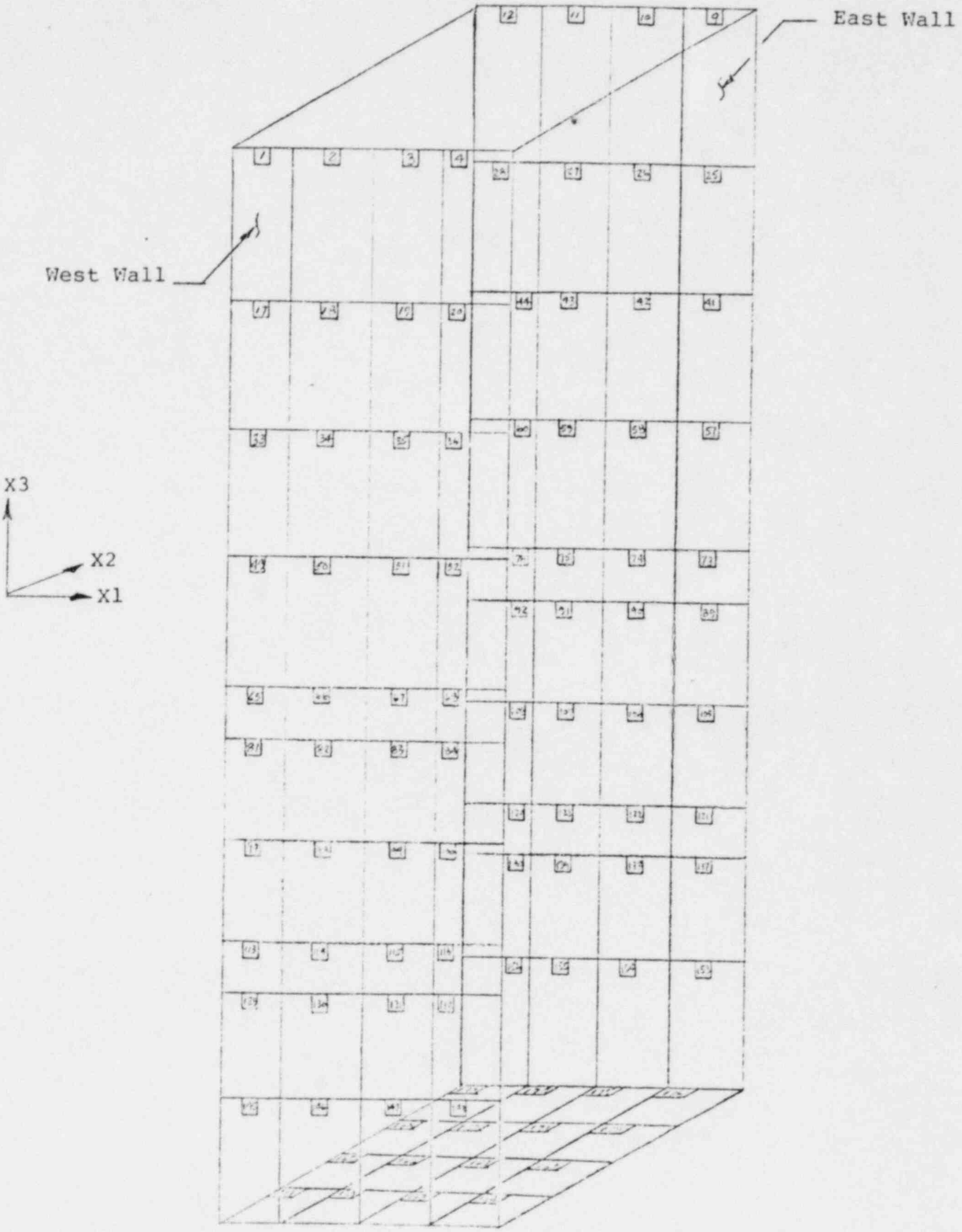


FIGURE 7.1:c

SPENT FUEL STORAGE POOL
FINITE ELEMENT MODEL - PLATE ELEMENT NUMBERS

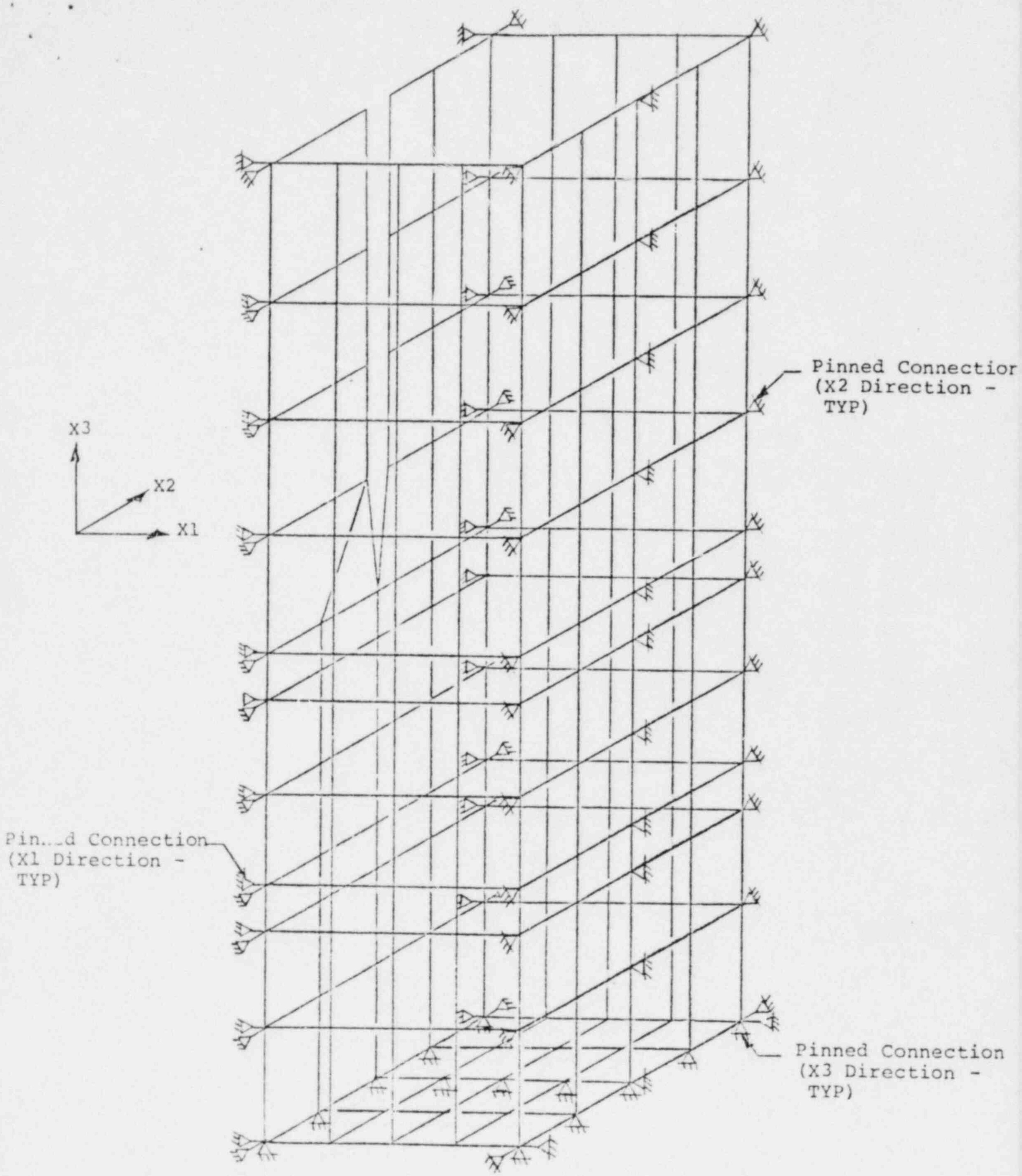


FIGURE 7.2
SPENT FUEL STORAGE POOL FINITE ELEMENT MODEL - APPROPRIATE BOUNDARY CONDITIONS

8. THE RESULTS OF THE ANALYSIS

The results of the static structural/stress analysis of the LaCrosse Boiling Water Reactor fuel storage pool performed with the STARDYNE computer code are contained in Reference 14.

Appendices A through D contain the loading data, allowable ultimate moment capacity of the pool floor and walls, thermal loading effects and seismic loading effects from other building structures.

8.1 Spent Fuel Storage Pool Structural Analysis

The results of the storage pool structural analysis for load combinations 1 and 2 which includes the effects of dead, live and earthquake loadings are summarized in Tables 8.1 and 8.2. These tables present the maximum shear stresses, compressive stresses and calculated design moments in each of the elements of different thickness in the pool structure and compares them with the allowable values as specified in the acceptance criteria of Section 6. From Table 8.1, it can be seen that for load combination 1, the maximum shear stress, compressive stress and critical design moments (for the horizontal and vertical reinforcements) are 0.058 ksi, 0.115 ksi, 243.6 K in/ft and 18.14 K in/ft respectively. These stress and moment values are considerably lower than the corresponding allowable values of 0.20 ksi, 2.082 ksi, 1260 K.in/ft and 528.6 K.in/ft respectively.

Table 8.2 presents the results for load combination #2. From this table it can be seen that the maximum shear stress, compressive stress, critical (horizontal and vertical reinforcements) design moment values of 0.075 ksi, 0.167 ksi, 695.3 K. in/ft and 77.8 K.in/ft respectively are lower than the corresponding allowable values of 0.20 ksi and 2.082 ksi, 2142.0 K in/ft and 528.0 K in/ft respectively.

The results of the storage pool structural analysis for load combinations 3 and 4 which includes the effects of dead, live, earthquake and thermal loadings are summarized in Table 8.3 and 8.4. These tables show that in the critical section (pool floor) the maximum moment of 702.9 K in/ft for load combination 3 and 4 is lower than the allowable value of 1200 K in/ft.

Table 8.5 presents the results for abnormal load combination 5 which includes the effects of dead, live and cask drop impact loads. From this table it can be seen that the maximum shear stress, compressive stress, critical (horizontal and vertical reinforcements) design moment values of 0.089 ksi, 0.153 ksi, 675.8 K in/ft and 149.5 K in/ft respectively are lower than their allowable values of 0.20 ksi, 2.082 ksi, 2142.0 K in/ft and 897.6 K in/ft respectively.

The effects of additional loadings from the adjacent building structures on the pool structures are evaluated in Appendix D. The sum of the ratios of maximum shear stress to allowable shear stress for the pool structure and for the over all building structure (Reference 15) is 0.479. Similarly, the sum of the ratios for the maximum moment to allowable moment is 0.432. Since these two ratios are less than 1, it can be concluded that the storage pool structures are adequate to withstand its own internal loadings as well as those from the adjacent building structures.

TABLE 8.1

RESULTS OF THE STORAGE POOL STRUCTURAL ANALYSIS
LOAD COMBINATION #1, 1.4 D & 1.7 L

STRUCTURAL ELEMENT DESCRIPTION	MAXIMUM* SHEAR STRESS		MAXIMUM** COMPRESSIVE STRESS		MAXIMUM TENSILE STRESS				MAXIMUM DESIGN MOMENT		ALLOWABLE MOMENT		DESIGN/ALLOWABLE MOMENT RATIO	
	Element No.	Stress (Ksi)	Element No.	Stress (Ksi)	Element No.	Horizontal Reinf. (Ksi)	Element No.	Vertical Reinf. (Ksi)	Horizontal Reinf. (K-in/ft)	Vertical Reinf. (K-in/ft)	Horizontal Reinf. (K-in/ft)	Vertical Reinf. (K-in/ft)	Horizontal Reinf.	Vertical Reinf.
Pool Floor (56" Element)	161	0.033	167	0.051	162	0.068								
North Wall														
El. 680'-5" to 701'-3" (36" Elements)	61	0.029	61	0.046	61	0.041	-	-	106.3	-	1260.0	528.0	0.084	-
El. 678'-5" to 680'-5" (33.5" Element)	78	0.027	80	0.068	77	0.056	77	0.007	125.7	15.7	1239.0	519.6	0.102	0.030
El. 659'-5.625" to 678-5" (36" Element)	141	0.058	128	0.115	128	0.094	125	0.007	243.6	18.14	1260.0	528.6	0.193	0.034
El. 659'-5.625" to 678-5" (21" Element)	158	0.035	159	0.063	126	0.041	-	-	36.2	-	714.0	299.2	0.051	-
South Wall														
El. 672'-0" to 701'-3" (18.0" Element)	86	0.023	71	0.072	70	0.011	69	0.007	7.13	4.54	504.0	211.4	0.014	0.022
El. 659'-5.625" to 672'-0" (57" Element)	133	0.029	135	0.059	149	0.009	-	-	58.5	-	2142.0	897.6	0.027	-
East Wall														
El. 680'-5" to 701'-3" (36" Element)	58	0.050	59	0.044	42	0.055	-	-	142.6	-	1260.0	528.0	0.113	-
El. 659'-5.625" to 680'-5" (57" Element)	148	0.039	145	0.051	67	0.061	-	-	396.4	-	2142.0	897.6	0.185	-
West Wall														
El. 680'-5" to 701'-3" (36" Element)	51	0.031	51	0.044	35	0.055	-	-	142.6	-	1260.0	528.0	0.113	-
El. 659'-5.625" to 680'-5" (57" Element)	148	0.039	145	0.051	67	0.061	-	-	396.4	-	2142.0	897.6	0.185	-

*Allowable Shear Stress = 0.201 Ksi
**Allowable Compressive Stress = 2.082 Ksi

TABLE 8.2

RESULTS OF THE STORAGE POOL ANALYSIS LOAD COMBINATION #2
1.40 + 1.7 L + 1.9 E - OBE SEISMIC EVENT

STRUCTURAL ELEMENT DESCRIPTION	MAXIMUM * SHEAR STRESS		MAXIMUM ** COMPRESSIVE STRESS		MAXIMUM TENSILE STRESS				MAXIMUM DESIGN MOMENT		ALLOWABLE MOMENT		DESIGN/ALLOWABLE MOMENT RATIO	
	Element No.	Stress (Ksi)	Element No.	Stress (ksi)	Element No.	Horizontal Reinf. (Ksi)	Element No.	Vertical Reinf. (Ksi)	Horizontal Reinf. (K-in/ft)	Vertical Reinf. (K-in/ft)	Horizontal Reinf. (K-in/ft)	Vertical Reinf. (K-in/Ft)	Horizontal Reinf.	Vertical Reinf.
Pool Floor	171	0.066	163	0.136	162	0.069								
North Wall														
El. 680'-5" to 701'-3" (36" Elements)	61	0.037	61	0.066	61	0.06	61	0.030	155.5	77.8	1260.0	528.0	0.123	0.147
El. 680'-5" to 701'-3" (21" Elements)	TRPT #1	0.027	1	0.056	1	0.041	1	0.02	36.2	17.6	714.0	299.2	0.051	0.059
El. 678'-5" to 680'-5" (33.5" Elements)	78	0.045	78	0.104	78	0.088	77	0.018	197.5	40.4	1239.0	519.6	0.159	0.078
El. 659'-5.625 to 678'-5" (36" Elements)	144	0.075	128	0.167	128	0.147	125	0.011	381.0	28.5	1260.0	528.0	0.302	0.054
El. 659'-5.625" to 678'-5" (21" Elements)	143	0.046	127	0.131	126	0.102	126	0.026	90.0	22.93	714.0	299.2	0.126	0.077
South Wall														
El. 672'-0" to 701'-3" (18" Elements)	86	0.027	102	0.083	70	0.016	70	0.008	10.4	5.2	504.0	211.2	0.021	0.025
El. 659'-5.625" to 672'-0" (57.0 Elements)	119	0.041	134	0.078	152	0.010	134	0.009	65.0	58.5	2142.0	897.6	0.030	0.065
East Wall														
El. 680' to 701'-3" (36.0" Elements)	58	0.041	42	0.071	42	0.092	42	0.011	238.5	28.5	1260.0	528.0	0.189	0.054
El. 659'-5.625" to 680' (57.0" Elements)	74	0.054	74	0.084	74	0.106	155	0.018	688.8	117.0	2142.0	897.6	0.322	0.130
West Wall														
El. 680'-0" to 701'-3" (36.0" Element)	51	0.041	35	0.071	35	0.092	35	0.011	238.5	28.5	1260.0	528.0	0.189	0.054
El. 659'-5.625" to 680'-0" (57" Elements)	67	0.056	67	0.084	67	0.107	146	0.018	695.3	117.0	2142.0	897.6	0.325	0.139

* Allowable Shear Stress = 0.201 ksi
** Allowable Compressive Stress = 2.082 ksi

TABLE 8.3

RESULTS OF THE STORAGE POOL STRUCTURAL ANALYSIS LOAD COMBINATION #3, 0.75(1.4D + 1.7L + 1.7T_o)

STRUCTURAL ELEMENT DESCRIPTION	MAXIMUM DESIGN MOMENT	ALLOWABLE MOMENT	DESIGN/ALLOWABLE MOMENT RATIO
	HORIZONTAL REINFORCEMENT (K-in/ft)	HORIZONTAL REINFORCEMENT (K-in/ft)	
Pool Floor (56"Element)	702.9	1200.0	0.586
<u>North Wall</u>			
El. 680'-5" to 701'-3" (36"Elements)	502.0	1260.0	0.398
El. 680'-5" to 701'-3" (21" Elements)	183.5	714.0	0.257
El. 678'-5" to 680'-5" (33.5" Elements)	451.4	1239.0	0.364
El. 659'-5.625" to 678'-5" (36" Elements)	605.0	1260.0	0.480
El. 659'-5.635" to 673'-5" (21" Elements)	210.8	714.0	0.295
<u>South Wall</u>			
El. 672'-0" to 701'-3" (18" Elements)	146.6	504.0	0.290
El. 659'-5.625" to 672'-0" (57" Elements)	774.2	2142.0	0.361
<u>East Wall</u>			
El. 680'-5" to 701'-3" (36" Elements)	529.2	1260.0	0.420
El. 659'-5.625" to 680'-5" (57" Elements)	1027.6	2142.0	0.488
<u>West Wall</u>			
El. 680'-5" to 701'-3" (36' Elements)	529.2	1260.0	0.420
El. 659'-5.625" to 680'-5" (57" Elements)	1027.6	2142.0	0.480

TABLE 8.4

RESULTS OF THE STORAGE POOL STRUCTURAL ANALYSIS LOAD COMBINATION #4, 0.75(1.4D + 1.7L + 1.9E + 1.7T_O)

STRUCTURAL ELEMENT DESCRIPTION	MAXIMUM DESIGN MOMENT	ALLOWABLE MOMENT	DESIGN/ALLOWABLE MOMENT RATIO
	HORIZONTAL REINFORCEMENT (K-in/ft)	HORIZONTAL REINFORCEMENT (K-in/ft)	
Pool Floor (56" Element)	702.9	1200.0	0.586
<u>North Wall</u>			
El. 680'-5" to 701'-3" (36" Elements)	538.9	1260.0	0.428
El. 680'-5" to 701'-3" (21" Elements)	210.8	714.0	0.294
El. 678'-5" to 680'-5" (33.5" Elements)	505.3	1239.0	0.408
El. 659'5.625" to 678'-5" (36" Elements)	708.0	1260.0	0.562
El. 659'-5.625" to 678'-5" (21" Elements)	251.1	714.0	0.352
<u>South Wall</u>			
El. 672'-0" to 701'-3" (18" Elements)	149.1	504.0	0.296
El. 659'-5.625" to 672'-0" (57" Elements)	779.1	2142.0	0.364
<u>East Wall</u>			
El. 680'-5" to 701'-3" (36" Elements)	601.2	1260.0	0.477
El. 659'-5.625" to 680'-5" (57" Elements)	1246.9	2142.0	0.582
<u>West Wall</u>			
El. 680'-5" to 701'-3" (36" Elements)	601.2	1260.0	0.477
El. 659'-5.625" to 680'-5" (57" Elements)	1246.9	2142.0	0.582

TABLE 8.5

RESULTS OF THE STORAGE POOL STRUCTURAL ANALYSIS
LOAD COMBINATION #5, D + L + 1.25 E + I.L. - CASK DROP EVENT

STRUCTURAL ELEMENT DESCRIPTION	MAXIMUM* SHEAR STRESS		MAXIMUM** COMPRESSIVE STRESS		MAXIMUM TENSILE STRESS				MAXIMUM DESIGN MOMENT		ALLOWABLE MOMENT		DESIGN/ALLOWABLE MOMENT RATIO	
	Element No.	Stress (Ksi)	Element No.	Stress (Ksi)	Element No.	Horizontal Reinf. (Ksi)	Element No.	Vertical Reinf. (Ksi)	Horizontal Reinf. (K-in/ft)	Vertical Reinf. (K-in/ft)	Horizontal Reinf. (K-in/ft)	Vertical Reinf. (K-in/Ft)	Horizontal Reinf.	Vertical Reinf.
Pool Floor	167	0.066	163	0.136	163	0.157								
North Wall														
El. 680'-5" to 701'-3" (36" Elements)	61	0.021	61	0.033	61	0.029			75.2	-	1260.0	528.0	0.060	-
El. 680'-5" to 701'-3" (21" Elements)	1	0.024	1	0.039	1	0.027	1	0.009	23.8	8.0	714.0	229.2	0.033	0.035
El. 678'-5" to 680'-6" (33.5" Elements)	80	0.044	80	0.085	80	0.000	77	0.016	179.6	35.9	1239.0	519.6	0.145	0.069
El. 659'-5.624" to 678'-5" (36" Elements)	141	0.070	160	0.18	125	0.134	125	0.005	347.3	13.0	1260.0	528.0	0.276	0.025
El. 659'-5.625" to 678'-5" (21" Elements)	159	0.046	159	0.153	127	0.104	126	0.033	92.0	28.7	714.0	299.2	0.129	0.096
South Wall														
El. 672'-0" to 701'-3" (18" Element)	102	0.027	103	0.075	70	0.006	70	0.001	4.0	1.0	504.0	211.2	0.008	0.005
El. 659'-5.625" to 672'-0" (57" Element)	152	0.089	149	0.139	152	0.019	152	0.015	123.5	97.5	2142.0	897.6	0.058	0.109
East Wall														
El. 680'-5" to 701'-3" (36" Element)	58	0.014	42	0.044	42	0.46	42	0.014	119.2	36.3	1260.0	528.0	0.095	0.069
El. 659'-5.625" to 680'-5" (57" Element)	14	0.055	74	0.085	153	0.061	155	0.023	396.4	149.5	2142.0	897.6	0.185	0.167
West Wall														
El. 680'-5" to 701'-3" (36" Element)	51	0.013	35	0.034	35	0.047	35	0.014	121.8	36.3	1260.0	528.0	0.096	0.069
El. 659'-5.625" to 680'-5" (57" Element)	67	0.053	67	0.086	67	0.104	146	0.023	675.8	149.5	2142.0	897.6	0.315	0.167

* Allowable Shear Stress = 0.201 ksi

** Allowable Compressive Stress = 2.082 ksi

9. CONCLUSIONS

The results of the structural analysis of the fuel storage pool structure indicate that the maximum stresses and internal moments in the pool floor and walls resulting from the loadings including those associated with the augmented spent fuel storage requirements are within the allowable limits for Seismic Category 1 structure. It is, therefore, concluded that the design of the LaCrosse Boiling Water Reactor Spent Fuel Storage pool is adequate to withstand the normal and abnormal loading conditions.

10. REFERENCES

1. Nuclear Energy Services, Inc. "Structural Analysis Design Report for the LaCrosse Boiling Water Reactor High Density Spent Fuel Storage Racks, NES Document 81A0546 (Rev. 2), revision dated 8/7/78.
2. Nuclear Energy Services, Inc. "Spent Fuel Shipping Cask Drop Analysis for the LACBWR Nuclear Power Plant", NES Document 81A0550, (Rev. 2), September 20, 1978.
3. Sargent and Lundy Engineers "LACBWR" Project Drawings.
4. Nuclear Energy Services, Inc. Drawings for LaCrosse Boiling Water Reactor Spent Fuel Storage Racks.
5. Nuclear Energy Services, Inc. Document NES 81A0544, Rev. 0, "Quality Assurance Program Plan for the LaCrosse Boiling Water Reactor Spent Fuel Storage Rack Design Program", March 1978.
6. USNRC Standard Review Plan, Section 3.8.4.
7. Nuclear Energy Services, Inc. "Evaluation of the Spent Fuel Pool Cooling System LaCrosse Boiling Water Reactor High Density Fuel Storage Rack Program" NES Document 81A0549 (Rev. 1), July 1978.
8. Dairyland Power Cooperative, "LaCrosse Boiling Water Reactor Technical Specifications" DPRA-6 (Appendix A).
9. "USNRC Proposed Position for Review and Acceptance of Spent Fuel Storage and Handling Applications".
10. ACI 318-71 - "Building Code Requirements for Reinforced Concrete", American Concrete Institute.
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12. George Winter, et. al. - "Design of Concrete Structures", McGraw Hill Book Company, 1964.
13. MRI/Stardyne 3 - Static and Dynamic Structural Analysis System for Scope 3.4 "Operating System User's Information Manual", Revision B, Control Data Corporation, April 1978.

14. "LaCrosse Boiling Water Reactor Spent Fuel Storage Pool Stardyne Structural Analysis Project 5101, Task 237", NES Computer Output Binder No. S32, June 1978.

15. Gulf United Services, Document SS-1162 "Seismic Evaluation of the LaCrosse Boiling Water Reactor".

16. "Structural Analysis and Design of Nuclear Plant Facilities", American Society of Civil Engineers, 1976.

17. ST-57 "Circular Concrete Tanks Without Prestressing" Portland Cement Associates, Chicago, Illinois.

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19. Roark, R. J., "Formulae for Stress and Strain" McGraw-Hill Book Company, 1965.

APPENDIX

A. LOADING DATA

B. SPENT FUEL STORAGE POOL FLOOR AND WALL ALLOWABLE ULTIMATE MOMENT CAPACITY

C. EQUIVALENT THERMAL MOMENT CALCULATIONS

D. EFFECTS OF SEISMIC LOADINGS FROM ADJACENT BUILDING STRUCTURES

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APPENDIX A

REF.

LOADING DATA

The loading cases to be applied to the spent fuel storage pool model are considered in accordance with the requirements of USNRC Standard Review Plan, Section 3.8.4 (Reference # 6).

For service load conditions - using ultimate strength design, the combination of load cases as specified by Section 3.8.4 for concrete structures are:

1. 1.4D + 1.7L
2. 1.4D + 1.7L + 1.9E

(REF # 6)

WHERE:

D = DEAD LOADS OF THE STORAGE POOL

L = LIVE LOADS ASSOCIATED WITH THE WEIGHTS OF THE FULLY-LOADED RACKS, CRASH PAD, SPENT FUEL SHIPPING CASK AND HYDROSTATIC PRESSURES.

For these load combinations, the stresses and moments generated must be less than U which is the ultimate section strength required to resist design loads based on the strength design moments described in ACI 318-71 (Reference # 10).

For service load conditions - using ultimate strength design and including the thermal

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LOADING DATA	REF.

STRESSES GENERATED DUE TO TEMPERATURE DIFFERENTIAL ACROSS POOL FLOOR AND WALLS.

THE LOAD COMBINATIONS AS PRESCRIBED BY SECTION 3.8.4 (REF #6) ARE:

3. $0.75(1.4D + 1.7L + 1.7T_o)$

4. $0.75(1.4D + 1.7L + 1.9E + 1.7T_o)$ (REF #6)

WHERE: T_o = THERMAL EFFECTS AND LOADS DURING NORMAL OPERATING OR SHUTDOWN CONDITIONS, BASED ON MOST CRITICAL STEADY-STATE CONDITION.

E — LOADS GENERATED BY 1/2 SAFE SHUTDOWN EARTHQUAKE.

NOTE: THE SPECIFIED COMBINATIONS TO INCLUDE THE SHUT SHUTDOWN EARTHQUAKE $(D+L+T+E')$ IS LESS SEVERE THAN THOSE INCLUDING THE 1/2 SAFE SHUTDOWN EARTHQUAKE $0.75(1.4D + 1.7L + 1.7T + 1.9E)$ AND THEREFORE IS NOT PREFORMED.

FOR FACTOR LOAD CONDITIONS WHICH REPRESENT ABNORMAL LOADING CONDITIONS, USING ULTIMATE STRENGTH DESIGN METHODS, LOAD COMBINATIONS ARE:

5. $D + L + 1.25E + I.L.$

WHERE: I.L. - LOADS ASSOCIATED WITH CASK DROP EVENT.

LOADING DATA

REF.

DEAD LOAD ANALYSIS 'D'

THE DEAD WEIGHT OF THE POOL INCLUDES THE WEIGHT OF THE REINFORCED CONCRETE WALLS AND FLOOR ONLY.

THE DEAD WEIGHT LOADS AND STRESSES IN THE POOL STRUCTURE ARE ANALYTICALLY DETERMINED BY APPLYING A VERTICAL 1 G ACCELERATION TO THE "SPENT FUEL POOL MODEL" WITH APPROPRIATE BOUNDARY CONDITIONS. THE WEIGHT OF THE POOL IS DETERMINED BY APPLYING A REINFORCED CONCRETE DENSITY IN APPLICABLE UNITS.

CONCRETE DENSITY $= 144 \text{ lb}/\text{FT}^3$

$$= \frac{144}{1000} \times \frac{\text{FT}^3}{1728} = 0.83 \times 10^{-4} \text{ K}/\text{in}^3 \checkmark$$

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LOADING DATA

REF.

LIVE LOAD ANALYSIS 'L'

The max. live load in the spent fuel pool floor includes the full pool water weight, the weight of the fully loaded racks, weight of a spent fuel shipping cask. The live load on the spent fuel pool walls includes the hydrostatic pressure of the water.

The weight of each of the load contributors is converted into a pressure load (Pg. A-4 & A-5) and applied to the appropriate quad-plate in the spent fuel pool model.

POOL FLOOR PRESSURE LOADING

1. Pool water pressure load - (assuming full pool)

Water depth in pool = (EL. 700'-9") - (EL. 659'-5625")
= 41.28125' ✓

Pressure load on floor = $\frac{11' \times 11' \times 41.28125 \times 62.4}{11' \times 11'}$ ✓

= 2575.95 ✓ lb/sq.ft or 0.0179 ✓ kip/sq.in.

2. Weight of fuel storage racks + fuel

= 650.0 lb/cell (8x9 x 2 tiers x 2 racks + 4x10 x 2 tiers x 2 racks) = .650 K x 440 cells = 286.0 kips ✓ REF.1

Pressure load on floor assumed uniform under rack

Area = 2 x [8x9 + 4x10] x (7" pitch)^2 = 10976 ✓ in^2

Pressure load = $\frac{\overset{286}{\cancel{2912}} \text{ kips}}{10976 \text{ in}^2}$ = 0.0265 ✓ k/in^2

LOADING DATA

REF.

③ CASK WEIGHT = 100^{K} REF. 2

CASK CRASH PAD AREA ≈ 70" × 70" = 4900 in^2 REF. 2

CASK PRESSURE LOAD = $\frac{100^{K}}{4900\ in^2} = 0.0204\ K/in^2$ ✓

④ CASK DROP REACTION LOAD = 7174.3 KIPS REF. 2

CASK DROP PRESSURE LOAD = $\frac{7174.3^{K}}{4900\ in^2} = 1.464\ K/in^2$ ✓

POOL WALL PRESSURE LOADS

① HYDROSTATIC PRESSURE LOAD RESULTING FROM THE POOL WATER IS EQUAL TO ωh WHERE $\omega = 62.4\ \#/ft^3$ TIMES THE HEIGHT FROM THE WATER SURFACE.

THE AVG. PRESSURE LOAD ON QUAD PLATES AT EACH ELEVATION IS TAKEN AS THE ω TIMES THE HEIGHT TO THE MID-HEIGHT OF THE QUAD-PLATES.

THEREFORE: HYDROSTATIC PRESSURE = $\omega h = \frac{62.4}{144} \times h$ (FEET) ✓

QUAD PLATE NO.	AVG. HEIGHT TO WATER SURFACE (Ft.)	PRESSURE LOAD (K/in^2)
1 - 16	$6/2 = 3.0'$	0.0013 ✓
17 - 32	$6.0' + 5.0/2 = 8.5'$	0.00368 ✓
33 - 49	$11.0 + 5.0/2 = 13.5'$	0.00585 ✓
48 - 64	$16.0 + 5.0/2 = 18.5'$	0.00802 ✓
65 - 80	$21.0 + 2/2 = 22.0'$	0.00953 ✓
81 - 96	$23.0 + 4/2 = 25.0'$	0.0108 ✓
97 - 112	$27.0 + 4/2 = 29.0'$	0.01257 ✓
113 - 128	$31.0 + 2/2 = 32.0'$	0.01387 ✓
129 - 144	$33.0 + 4/2 = 35.0'$	0.01517 ✓
145 - 160	$37.0 + 5/2 = 39.5'$	0.01712 ✓

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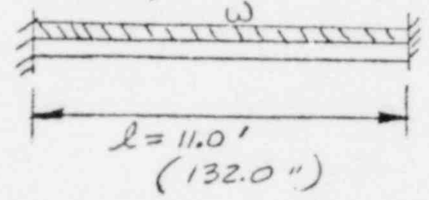
LOADING DATA | REF.

FUEL POOL SEISMIC ANALYSIS

A SEISMIC ANALYSIS OF THE SPENT FUEL POOL INCLUDING A FULL COMPLIMENT OF FUEL STORAGE ASSEMBLIES IS COMPLETED BY CALCULATING THE MINIMUM WALL FREQUENCY AND DETERMINING A LATERAL ACCELERATION FROM THE RESPONSE SPECTRA AT THAT ELEVATION. THIS LATERAL G IS THEN APPLIED TO THE DEAD WEIGHT AND LIVE LOADS AND COMBINED WITH THE SEISMIC BRACING LOADS CALCULATED IN REF. 1, TO DETERMINE THE SEISMIC STRESSES IN THE POOL WALLS AND FLOOR GENERATED BY AN EARTHQUAKE.

MINIMUM FREQUENCY OF WALL - ASSUMING A 12" DEEP STRIP OF WALL 11' LONG FIXED AT BOTH ENDS, AND LATERALLY LOADED BY A PORTION OF WATER 11' LONG, 11' WIDE AND 1' DEEP:



$$W = \omega l = \frac{62.4}{1000}\ ^{K}/_{FT^3} \times 11' \times 11' \times 1' + \frac{144}{1000} \times 1.75' \times 11' = 10.332^{K}$$

MOMENT OF INERTIA OF 1.75' THICK SLAB $I_c = \frac{1}{12}(12)(21.0)^3$

$= 9261.0 \text{ IN}^4$

LATERAL FREQUENCY $= 3.55\sqrt{\dfrac{384\ EI}{Wl^3}}$ REF. 1.9

$$= 3.55\sqrt{\frac{(384)(9261.0)(3000)}{(10.332)\ (11 \times 12)^3}} = 75.22 \text{ CPS}$$

LOADING DATA | REF.

FROM ACCELERATION SPECTRA: REF 5

ACCELERATION VALUE $G_{SSE} = 0.45$; $G_{\frac{1}{2}SSE} = 0.33$

② THE EQUIVALENT STATIC PRESSURE LOAD:

$$\text{PRESSURE LOAD } (\tfrac{1}{2}\text{ SSE}) = \frac{62.4}{1000} \times \frac{(11.0)(1.0)(1.0)(0.33)}{144}$$
$$= 0.001573 \checkmark \ ^{K}/_{in^2}$$

$$\text{PRESSURE LOAD (SSE)} = 0.001573 \times \frac{0.45}{0.33} = 0.002145 \checkmark \ ^{K}/_{in^2}$$

③ SEISMIC BRACING LATERAL PRESSURE LOADS:

THE SEISMIC BRACING IS LOCATED AT 3 ELEVATIONS. (SEE "NES SPENT FUEL RACK DRAWINGS") REF. 4

THE TOTAL LATERAL WALL LOADS AT EACH ELEVATION IS CONVERTED INTO A PRESSURE LOAD AND APPLIED AT THE APPROPRIATE ELEVATIONS IN THE "POOL MODEL".

A. UPPER GRID – max. WALL LOAD (SSE) = 46.8^{K} REF. 1
(½ SSE) = 34.3^{K}

$$\text{SSE PRESSURE LOAD} = \frac{46.8^{K}}{(11)(2.0)(144)} = 0.0148 \checkmark \ ^{K}/_{in^2}$$

$$\tfrac{1}{2}\text{ SSE PRESSURE LOAD} = \frac{34.3^{K}}{(11)(2.0)(144)} = 0.0108 \checkmark \ ^{K}/_{in^2}$$

NOTE: PRESSURE LOAD IS APPLIED AT UPPER GRID SEISMIC BRACING ELEVATION COINCIDING WITH QUAD-PLATES 65-80 (Pg 7-5, 7-6) AND THEREFORE THE PRESSURE LOAD IS DISTRIBUTED OVER THE 2' DEPTH (Pg 7-4).

B. INTERMEDIATE GRID – max. WALL LOAD (SSE) = 93.5^{K}
(½ SSE) = 68.5^{K}

$$\text{SSE PRESSURE LOAD} = \frac{93.5^{K}}{(11)(2.0)144} = 0.0295 \checkmark \ ^{K}/_{in^2}$$

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½ SSE PRESSURE LOAD = $\frac{68.5}{(11)(2.0)\,144} = 0.0216^{\checkmark}\ \mathrm{K/in^2}$

c. <u>LOWER GRID</u> MAX. WALL LOAD (SSE) = 52.6^K
(½ SSE) = 38.6^K

SSE PRESSURE LOAD = $\frac{52.6^K}{(11.0)(5.0)144} = 0.00664^{\checkmark}\ \mathrm{K/in^2}$

½ SSE PRESSURE LOAD = $\frac{38.6}{(11.0)(5.0)\,144} = 0.00487^{\checkmark}\ \mathrm{K/in^2}$

<u>COMPARISON OF SEISMIC LOADINGS FOR ½ SSE AND SSE EVENTS</u>

RATIO OF SEISMIC INERTIA LOADING OF THE CONCRETE WALLS, AND POOL WATER MASS FOR ½ SSE AND DBE (PG. A-7) = $\frac{0.001573}{0.002145} = 0.733$ OR 73.3 %

RATIO OF THE MAX. SEISMIC REACTION LOADS OF THE FUEL STORAGE RACKS FOR ½ SSE AND SSE EVENT:

UPPER GRID (PG. A-7) (REF #1) = $\frac{34.3}{46.8} = 0.733$ OR 73.3 %

INTERMEDIATE GRID (PG. A-7) (REF #1) = $\frac{68.5}{93.5} = 0.733$ OR 73.3 %

LOWER GRID (PG. A-7) = $\frac{38.6}{52.6} = 0.734$ OR 73.4 %

SINCE THE RATIO OF THE ½ SSE TO SSE SEISMIC LOADS IS APPROXIMATELY 73 %, THE LOAD COMBINATIONS INVOLVING THE ½ SSE EVENT WILL BE MORE SEVERE.

	REF.
APPENDIX B	

SPENT FUEL POOL FLOOR AND WALL ALLOWABLE ULTIMATE MOMENT CAPACITY

THE STRUCTURAL ACCEPTANCE CITERIA FOR THE LACBWR SPENT FUEL STORAGE, (SECTION 6 OF REPORT) IS SPECIFIED IN USNRC STANDARD REVIEW PLAN, SECTION 3.8.4 (REF. 6).

FROM (REF # 6), FOR THE FACTORED LOAD COMBINATIONS, AS SPECIFIED IN APPENDIX A, THE ALLOWABLE LIMITS (SHEAR, COMPRESSION, TENSILE) WHICH CONSTITUTE THE ACCEPTANCE CITERIA ARE THE ULTIMATE SECTION STRENGTH REQUIRED TO RESIST DESIGN LOADS AND MOMENTS BASED ON THE ULTIMATE STRENGTH DESIGN METHODS OF ACI 318-71 (REF. 10).

FROM REF #10, THE ALLOWABLE SHERE STRESS IS $4\Phi\sqrt{f'_c}$ [WHERE: $\Phi = 0.85$ & $f'_c = 3500$ psi] REF #10
OR 201.1 PSI. THE ALLOWABLE COMPRESSION STRESS IS $0.85\,\phi\, f'_c$ [WHERE: $\phi = 0.7$ & $f'_c = 3500$ PSI] REF #10
OR $(0.85)(0.7)(3500) =$ 2082.5 PSI. THE ALLOWABLE TENSILE STRESSES (ULTIMATE STRENGTH DESIGN) ARE RESPRESENTED BY THE ALLOWABLE ULTIMATE MOMENT CAPACITY OF VARIOUS CONCRETE SECTIONS (A FUNCTION OF THE STEEL AREA AND SLAB THICKNESS) AND COMPARED WITH THE DESIGN MOMENTS OBTAINED IN THE "SPENT FUEL STORAGE POOL ANALYSIS".

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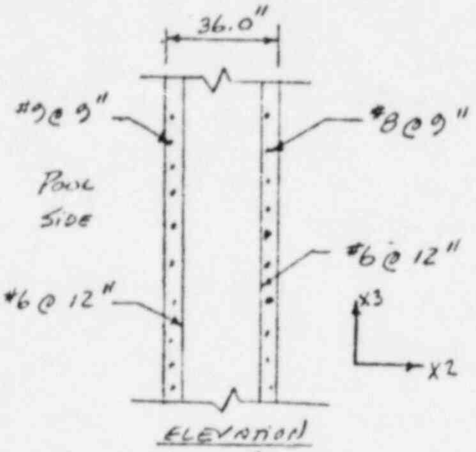
CONCRETE WALL ULTIMATE MOMENT CAPACITY | REF.

EAST WALL - EL. 680'-0.0" to 701'-3.0"

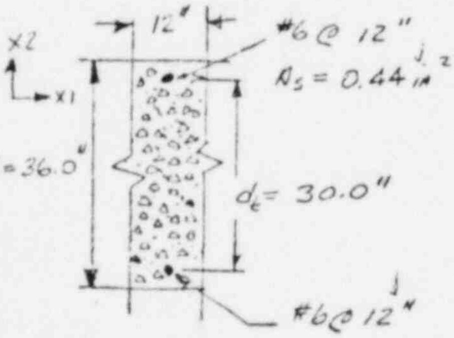


ELEVATION
WALL CROSS-SECTION (TYP)

DESCRIPTION THE EAST WALL FROM AN ELEVATION OF 680'-0.0" TO 701'-3.0" IS CONSTRUCTED OF REINFORCED CONCRETE 3.0' THICK. THE LATERAL REINFORCEMENT INCLUDES SIZE #9 @ 9" ON THE POOL SIDE OF THE WALL AND SIZE #8 @ 9" ON THE FAR SIDE. THE VERTICAL REINFORCEMENT INCLUDES SIZE #6 @ 12" ON BOTH SIDES ON THE WALL. REF.3

ULTIMATE MOMENT CAPACITY (PER LINEAR FOOT OF WALL)

M_u (ABOUT X2 AXIS)



TENSILE REINFORCEMENT RATIO $P_t = \frac{A_s}{bd}$ REF.12

$$P_t = 0.44/(36)(12) = 0.001 ✓$$

$$P_b \text{ (BALANCED RATIO)} = (.85)^2 \frac{f_c}{f_y}\left(\frac{87000}{87000+f_y}\right)$$

$$= (.85)^2 \frac{3500}{40,000}\left(\frac{87000}{127000}\right) = 0.0433 ✓$$

$$P_{max} \text{ (ALLOWABLE)} = .75 P_b = 0.032 ✓ > 0.001$$

ENSURES STEEL YIELDING CONTROLS.

ULTIMATE MOMENT (VERTICAL REINFORCEMENT) $M_{ULT_{X2}} = A_s f_y d_t$ REF.1

$$M_{ULT_{X2}} = (0.44)(40 \text{ ksi})\left(\frac{30}{12}\right) = 44 ✓ \text{ K-FT}$$

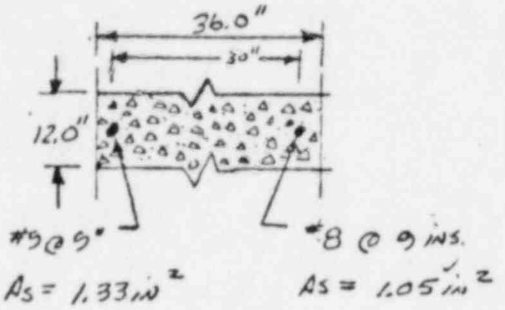
OR 528 K-IN / FT OF WALL

(SINCE TENSILE STEEL EQUALS COMPRESSION STEEL, NO ADDITIONAL MOMENT CAPACITY FROM CONCRETE)

CONCRETE WALL ULTIMATE MOMENT CAPACITY

REF.

MULT (ABOUT X3 AXIS)



TENSILE REINFORCEMENT RATIO

$$= \frac{A_s}{bd} = \frac{(1.33)}{(36)(12)} = 0.0031 ⊄$$

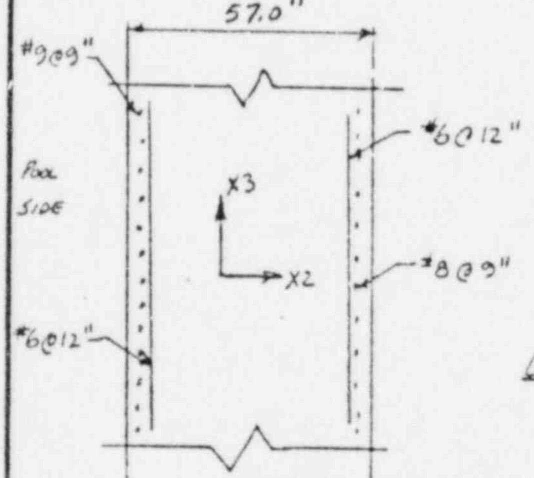
STEEL YIELDING -

THE MINIMUM ULTIMATE MOMENT CAPACITY OF THE WALL IS DETERMINED BY ASSUMING THE SMALLER AMOUNT OF REINFORCEMENT YIELD IN TENSION.

$$M_{ULT}\left(\substack{\text{HORIZONTAL}\\ \text{REINFORCEMENT}}\right) = A_s\, F_y\, d_t = (1.05)(40.0)\frac{30}{12} = 105^{\checkmark}\ \text{K-FT}$$

OR 1260✓ K-IN / FT OF WALL

EAST WALL - EL. 659'-5.625" TO 680'0"



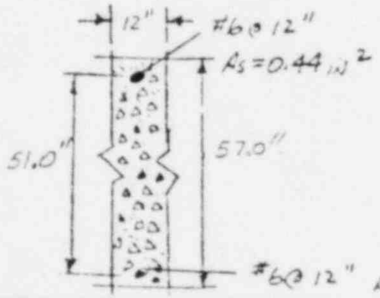
ELEVATION
WALL CROSS-
SECTION (TYP)

THE POOL EAST WALL IS 57.0" THICK FROM AN ELEV. 680'-0.0" DOWN TO POOL FLOOR. SIMILAR REINFORCEMENT IS USED AS IS FOUND IN THE THINNER UPPER SECTION.

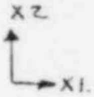
REF. 3

ULTIMATE MOMENT CAPACITY
(ABOUT X1 AXIS)

$$P = \frac{A_s}{bd} = \frac{0.44}{(12)(57)} = 0.0006^{\checkmark} ⊄$$



$$M_{ULT}\left(\substack{\text{VERTICAL}\\ \text{REINFORCEMENT}}\right) = (0.44)(40)\left(\frac{51.0}{12}\right)$$



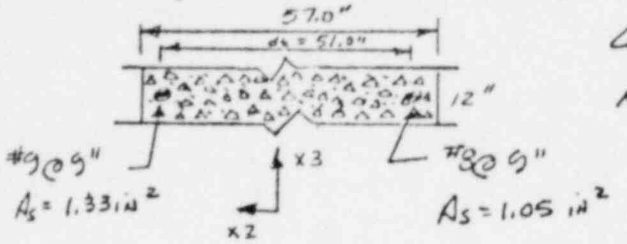
$$= 74.8^{\checkmark}\ \text{K-FT}$$

OR 897.6✓ K-IN / FT OF WALL

CONCRETE WALL ULTIMATE MOMENT CAPACITY

REF.

MULT (ABOUT X3 AXIS) THE MIN. ULT. MOMENT CAPACITY RESULTS WHEN MIN. AREA OF REINFORCEMENT IS IN TENSION.



$$\rho_t = \frac{1.05}{(57)(12)} = 0.00153 \text{ ok}$$

$$M_{ULT}\left(\begin{smallmatrix}\text{HORIZONTAL}\\ \text{REINFORCEMENT}\end{smallmatrix}\right) = A_s F_y d_t = (1.05)(40)\frac{51.0}{12} = 178.5^{\checkmark} \text{ K-FT}$$

OR $2142^{\checkmark}$ K-IN/FT OF WALL

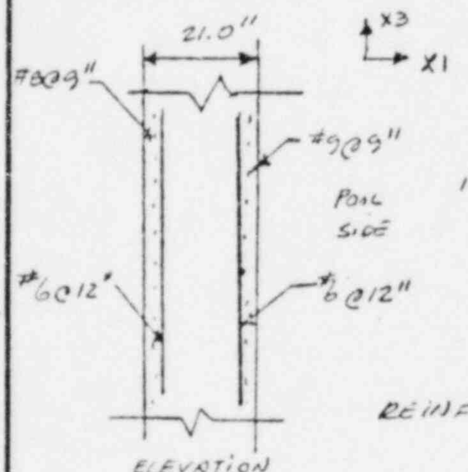
WEST WALL ULTIMATE MOMENT CAPACITY

REF 3

THE DIMENSIONS AND REINFORCEMENT ARE SIMILAR AT ALL ELEVATIONS TO THOSE OF THE EAST WALL. THEREFORE THE ULTIMATE MOMENT CAPACITIES OF THE SECTIONS WILL BE SIMILAR TO THE EAST WALL ULTIMATE MOMENT CAPACITIES.

NORTH WALL ULTIMATE MOMENT CAPACITY EL. 659'-5.625" TO EL. 678'-5" AND 680'-5" TO 701'-3"

REF 3

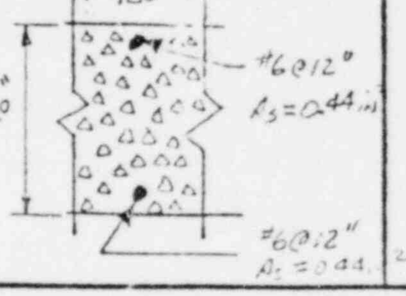


ELEVATION

THE NORTH WALL FROM ELEV. 659'-5.625" TO 678'-5" AND 680'-5" TO 701'-3" IS 21.0" THICK BEING LATERALLY REINFORCED WITH #9@9" ALONG POOL SIDE AND #8@9" ALONG FAR SIDE. THE WALL IS ALSO REINFORCED VERTICALLY WITH #6 @ 12".

MULT (ABOUT X2 AXIS)

$$\rho_t = \frac{A_s}{bd} = \frac{0.44}{(12)(21.0)} = 0.00175^{\checkmark} \text{ ok}$$



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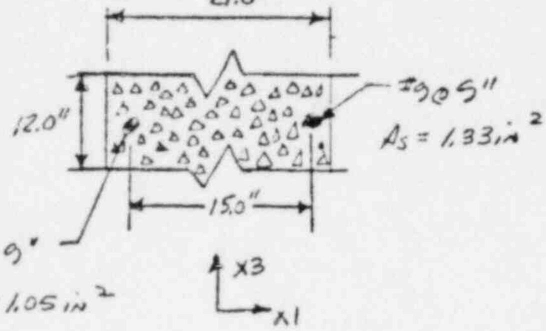
CONCRETE WALL ULTIMATE MOMENT CAPACITY

REF.

M_{ULT} (VERTICAL REINFORCEMENT) $= A_s F_y d = (0.44)(40)\left(\frac{21-(2)3}{12}\right) = 22$ ✓ K-FT
OR 264 ✓ K-IN/FT OF WALL

<u>M_{ULT} (ABOUT X3 AXIS)</u> MIN. M_{ULT} WILL RESULT WHEN THE SMALLER REINFORCEMENT IS LOCATED IN TENSILE REGION.

$\rho_t = \frac{A_s}{bd} = \frac{1.33}{(12)(21)} = 0.00528$ ok

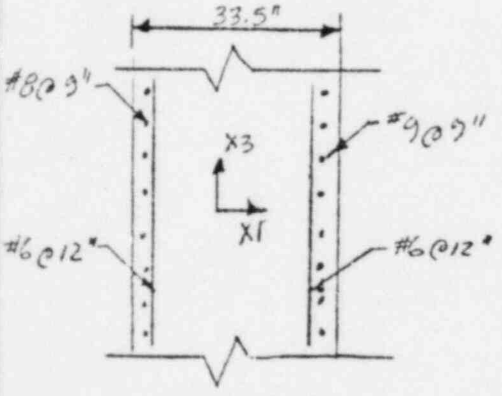


M_{ULT} (HORIZ. REINF.) $= A_s F_y d$
$= (1.05)(40.)\left(\frac{15}{12}\right) = 52.5$ ✓ K-FT

OR 630 K-IN ✓ / FT OF WALL

<u>NORTH WALL ULTIMATE MOMENT CAPACITY EL. 678'-5" TO 680'-5"</u>

THE NORTH WALL IS CONSTRUCTED OF A 33.5" THICK WALL REINFORCED WITH SIMILAR SIZES AS UPPER PORTION. | REF. 3

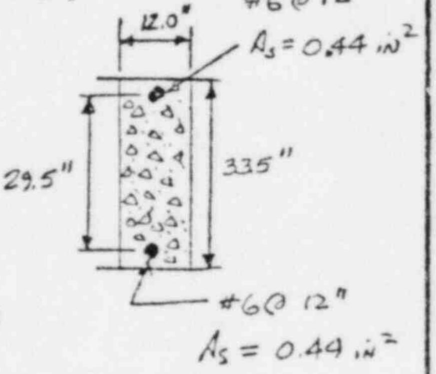


ELEVATION

FOR THE ULTIMATE MOMENT ABOUT THE X2 AXIS, TAKE A 1 FOOT SECTION:

$P = \frac{A_s}{bd} = \frac{0.44}{(12)(33.5)}$

$= 0.00105$ ok



M_{ULT} (VERTICAL REINFORCEMENT) $= A_s F_y d = (0.44)(40)\left(\frac{29.5}{12}\right)$
$= 43.3$ ✓ K-FT

OR 519.6 ✓ K-IN / FT OF WALL

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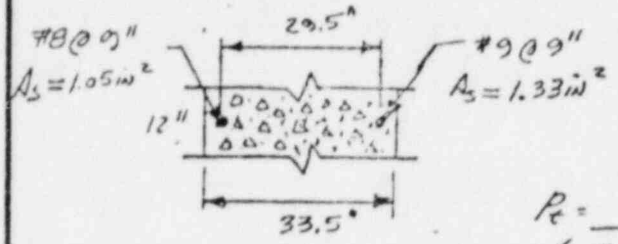
CONCRETE WALL ULTIMATE MOMENT CAPACITY	REF.

ULTIMATE MOMENT ABOUT X3 AXIS



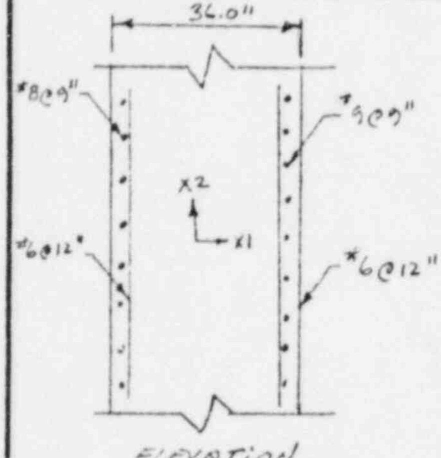
MIN. M_{ULT} RESULTS WHEN THE SMALLER STEEL AREA IS IN TENSION.

$$P_t = \frac{1.05}{(12)(33.5)} = 0.0026 \text{ ok}$$

$$M_{ULT}\left(\begin{matrix}\text{HORIZONTAL} \\ \text{REINFORCEMENT}\end{matrix}\right) = A_s f_y d = (1.05)(40.0)\left(\frac{29.5}{12}\right) = 103.25\checkmark \text{ K-FT}$$

OR 1239.0✓ K-IN/Ft OF WALL

NORTH WALL ULTIMATE MOMENT CAPACITY 659'-5.625" TO 701'-3"



ELEVATION

NOTE: THIS SECTION IS SIMILAR IN SIZE AND REINFORCEMENT TO THE 36" THICK SLAB OF THE EAST WALL. THEREFORE, THE M_{ULT}) WILL BE THE SAME. — REF 3

M_{ULT} (VERTICAL REINFORCEMENT) = 528✓ K-IN/Ft (Pg.B-2)

M_{ULT} (HORIZ. REINFORCEMENT) = 1260✓ K-IN/Ft.

SOUTH WALL ULTIMATE MOMENT CAPACITY EL 659-672'-0"

THE LOWER SECTION OF THE SOUTH WALL (EL. 659'-5.625" TO 672'-0") HAS A SIMILAR THICKNESS AND REINFORCEMENT AS THE EAST AND WEST WALLS.

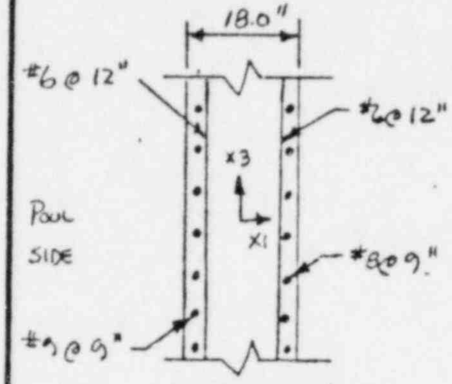
THEREFORE:

M_{ULT} (VERTICAL REINFORCEMENT) = 897.6✓ K-IN/Ft (Pg.B-3)

M_{ULT} (HORIZONTAL REINFORCEMENT) = 2142✓ K-IN/Ft (Pg.B-4)

CONCRETE WALL ULTIMATE MOMENT CALCULATIONS	REF.

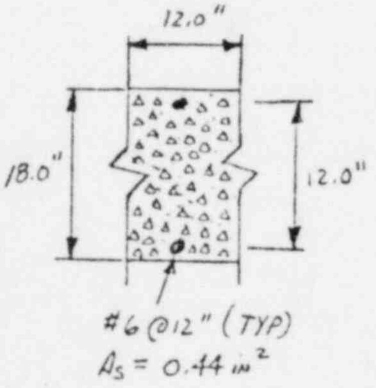
SOUTH WALL ULTIMATE MOMENT CAPACITY - 672' TO 701'-3"



ELEVATION

THE SOUTH WALL FROM ELEV. 672' TO 701'-3" IS 18.0" THICK AND SUPPORTED AT MID-POINT BY INTERSECTING WALL. THE SOUTH WALL IS LATERALLY REINFORCED WITH #9@9" ON POOL SIDE AND #8@9" ON FAR SIDE. THE WALL IS ALSO VERTICALLY REINFORCED WITH #6@12". REF-3

M_{ULT} (X2 AXIS) (VERTICAL REINFORCEMENT)

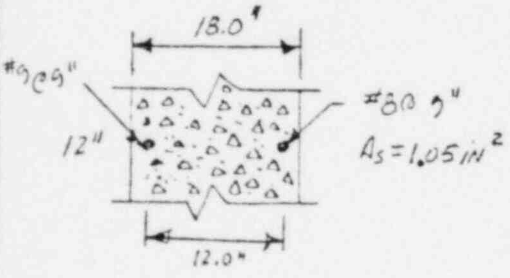


M_{ULT} (VERTICAL REINFORCEMENT) = $A_s F_y d$

$$= (0.44)(40)\left(\frac{18-(2)(3)}{12}\right) = 17.6\checkmark\ K\text{-}FT$$

OR 211.2✓ K-in / LINEAR Ft. OF WALL

M_{ULT} (X3 AXIS - HORIZONTAL REINFORCEMENT)



USING $A_{s\ min.} = 1.05\ in^2$

M_{ULT} (HORIZ. REINFORCEMENT)

$$= A_s F_y d$$

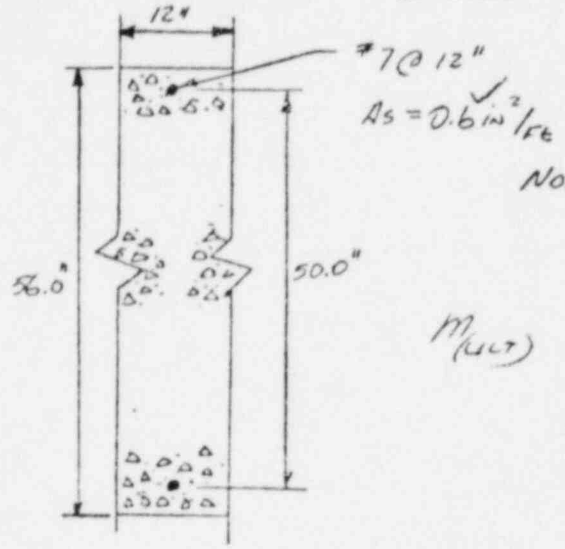
$$= (1.05)(40)\left(\frac{12}{12}\right) = 42.0\checkmark\ K\text{-}FT$$

OR 504✓ K-in / FT. OF WALL.

POOL FLOOR ULTIMATE MOMENT CAPACITY -

REF.

THE SPENT FUEL POOL FLOOR (EL. 654'-9" TO 659'-5") CONSISTS OF A 56" REINFORCED CONCRETE SLAB. SUPPORTED ALONG IT CENTERLINE IN THE E-W DIRECTION AND ALONG IT EDGES IN THE N-S DIRECTION. A TYPICAL 1 FT. CROSS-SECTION IS SHOWN BELOW.



ELEVATION

$$M_{ULT} = A_s F_y d$$

REF.3

NOTE: THIS CROSS-SECTION IS TYPICAL IN BOTH DIRECTIONS.

$$M_{(ULT)} = (0.6)(40)\frac{50}{12} = 100^{\checkmark} \text{ K-FT}$$

OR $1200^{\checkmark}$ K-IN/FT. OF FLOOR

APPENDIX C

- EQUIVALENT THERMAL MOMENT CALCULATIONS -

REF.

THE TEMPERATURE DIFFERENTIAL ACROSS THE POOL FLOOR AND WALLS RESULTING FROM SPENT FUEL ASSEMBLY STORAGE IN THE STORAGE POOL INTRODUCES THERMAL LOADS IN THE STRUCTURE. THE STEADY-STATE TEMPERATURE GRADIENT ACROSS THE WALLS ARE DETERMINED ASSUMING A BULK POOL WATER TEMPERATURE OF 150°F AND A AIR TEMPERATURE BEHIND THE WALL OF 70°F. AN ANALYSIS OF THE TEMPERATURE GRADIENT IN THE FUEL POOL CONCRETE WALL (PG. C-8, C-9) SHOWS A FAIRLY UNIFORM DECREASE IN TEMPERATURE FROM THE INNER TO OUTER FACES OF THE POOL WALLS AND FLOOR.

THE THERMAL MOMENTS PRODUCED FROM THIS LINEAR TEMPERATURE GRADIENT ARE A RESULT OF:

The inner fibers being hotter tend to expand more than the outer fibers, so if the segment is cut loose from the adjacent portions of the wall, Point *A* in Fig. 38 will move to *A'*, *B* will move to *B'*, and section

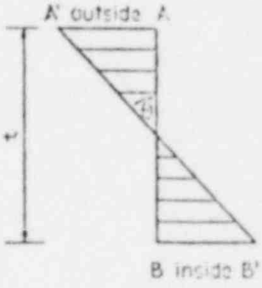


FIG. 38

(REF #17)

AB, which represents the stressless condition due to a uniform temperature change throughout, will move to a new position *A'B'*. Actually the movements from *A* to *A'* and *B* to *B'* are prevented since the circle must remain a circle, and stresses will be created that are proportional to the horizontal distances between *AB* and *A'B'*.

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EQUIVALENT THERMAL MOMENT CALCULATIONS	REF.

It is clear that $AA' = BB'$ = movement due to a temperature change of $\frac{1}{2}T$ or when e is the coefficient of expansion, that

$$AA' = BB' = \tfrac{1}{2}T \times e \text{ per unit length of arc,}$$

and

$$\theta = \frac{AA'}{\frac{1}{2}t} = \frac{T \times e}{t}$$

(REF. #17)

In a homogeneous section, the moment M required to produce an angle change θ in an element of unit length may be written as

$$M_t = EI\theta$$

Eliminating θ gives

$$M = \frac{EI \times T \times e}{t}$$

THE THERMAL GRADIENT INTRODUCES TENSILE STRESSES ON THE COLDER SIDE OF THE WALL PRODUCING HAIRLINE CRACKING IN THE EXTREME FIBERS. THE POOL WALLS AND FLOOR ARE SUBJECTED TO THIS HAIRLINE CRACKING AND THEREFORE THE MOMENTS OF INERTIA OF THESE SECTIONS WILL BE A FUNCTION OF A SECTION WITH THESE HAIRLINE CRACKS. FROM REF # 18 " DESIGN OF STRUCTURES FOR MISSILE IMPACT ", A COEFFICIENT FOR MOMENT OF INERTIA OF CRACKED SECTIONS IS OBTAINED FOR EACH WALL THICKNESS, APPLIED TO THE FULL SECTION MOMENT OF INERTIA TO CALCULATE A MODIFIED SECTION MOMENT OF INERTIA. THIS MODIFIED SECTION I IS THEN USED IN CALCULATING THE THERMAL MOMENTS DEVELOPED DUE TO THE TEMPERATURE GRADIENT.

REF # 18

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LCFOR

EQUIVALENT THERMAL MOMENT CALCULATIONS

REF.

EAST WALL - THERMAL MOMENT CALCULATION EL. 680'-0" TO EL. 701'-3"

FROM EL. 680'-0" TO 701'-3", THE EAST WALL IS 36" THICK. THE HORIZONTAL REINFORCEMENT ON THE POOL SIDE IS #9 @ 9" ($A_s = 1.33 in^2$) AND ON THE OPPOSITE SIDE #8 @ 9" ($A_s = 1.05 in^2$)✓ (FIGURE 3.2✓ OF REPORT).

CRACKED SECTION MOMENT OF INERTIA CALCULATION

FROM " DESIGN OF STRUCTURES FOR IMPACT" (REF #12) THE CRACKED SECTION MOMENT OF INERTIA (I_{CR}) is : REF #12

$$I_{CR} = F b d^3$$

WHERE:
b = 12 INS (1 FT SECTION OF WALL)
d = DISTANCE FROM EXTREME COMPRESSION FIBER TO ℄ OF TENSILE REINFORCEMENT
F = COEFFICIENT FOR I OF CRACKED SECTION

$$P \text{ (RATIO OF TENSILE REINFORCEMENT)} = \frac{A_s}{bd} = \frac{1.05}{(12)36} = 0.00243 \checkmark$$

$$P' \text{ (RATIO OF COMPRESSIVE REINFORCEMENT)} = \frac{A_s'}{bd} = \frac{1.33}{(12)36} = 0.00308 \checkmark$$

$$n \text{ (MODULAR RATIO)} = \frac{E_s}{E_c} = \frac{29 \times 10^6}{3.6 \times 10^6} \approx 8.0 \checkmark$$

WHERE:
$E_s = 29 \times 10^6$ PSI
$E_c = 33 w^{3/2} \sqrt{f'_c} = (33)(150)^{3/2} \sqrt{3500} = 3.6 \times 10^6$ PSI REF #12
$f'_c = 3500$ PSI
$w = 150$ PCF

RATIO $pn = (0.00243)(8.0) = 0.0194$ ✓

FROM CHART PG 4-9 (REF #18) $F = 0.016$ ✓

$$I_{CR} = F b d^3 = (0.016)(12)(36-3)^3 = 6900 \checkmark in^4$$

EQUIVALENT THERMAL MOMENT CALCULATIONS

REF.

THERMAL INDUCED MOMENT = $\frac{E I_{CR} \times \Delta T \times \alpha_t}{t}$ REF #17

WHERE: E_c = 3.6×10^6 PSI ✓

I_{CR} = 6900 IN^4 ✓

T = TEMPERATURE DIFFERENCE ACROSS WALL
= 150 °F − 70 °F = 80 °F ✓

t = WALL THICKNESS = 36.0"

α_t = THERMAL EXPANSION COEFFICIENT
6.0×10^{-6} ✓ IN/IN/°F

$$\therefore \quad M_t = \frac{(3.6 \times 10^6)(6900)(80°F)\ 6.0 \times 10^{-6}}{(36)(1000)} = 331.2\checkmark \text{ K-IN}$$

EAST WALL − EL. 659' − 5.625" TO 680' − 0"

THE EAST WALL FROM EL. 659' − 5.625" TO 680' − 0" IS 57" THICK. THE WALL'S HORIZONTAL REINFORCEMENT IS #9 @ 9" ON THE POOL SIDE AND #8 @ 9" ON THE OPPOSITE SIDE.

THE TENSILE REINFORCEMENT RATIO (P) = $\frac{1.05}{(12)(57)}$ = 0.00153 ✓

THE I_{CR} = $F b d^3$ (REF # 18) REF #18

$F = 0.01$ (FOR $pN = 0.00153 \times 8.0 = 0.0122$ ✓)

$I_{CR} = 0.01\ (12)\ (57-3)^3 = 18{,}895.7$ ✓ IN^4

THERMAL INDUCED MOMENT = $E \frac{I_{CR} \times \Delta T \times \alpha_T}{t}$ ✓ REF #17

$$M_t = \frac{(3.6 \times 10^6)(18895.7)(80)(6 \times 10^{-6})}{(57)(1000)} = 572.8\checkmark \text{ K-IN}$$

- EQUIVALENT THERMAL MOMENT CALCULATIONS -

REF.

WEST WALL THERMAL MOMENT CALCULATIONS

THE TEMPERATURE CHANGE, WALL THICKNESS AND REINFORCEMENT ARE SIMILAR TO THOSE OF THE EAST WALL. THEREFORE, THE THERMAL MOMENT WILL BE THE SAME AS IN THE EAST WALL.

NORTH WALL THERMAL MOMENTS - EL 659'-5.625" TO 701'-3"

A PORTION OF THE NORTH WALL FROM EL. 659'-5.625" TO 701'-3" IS 21" THICK AND IS HORIZONTALLY REINFORCED WITH #9 @ 9" ON POOL SIDE AND #8 @ 9" ON THE OPPOSITE SIDE. (SEE FIGURE 3.1)

THE TENSILE REINFORCEMENT RATIO $(p) = \frac{1.05}{(12)(21)} = 0.00417$ ✓ ASSUMING A 1 FT SECTION OF WALL.

F (COEFFICIENT OF CRACKED SECTIONS) FOR pn RATIO = $(.00417)(8.0) = 0.033$ ✓ IS 0.025 ✓ (PG. 4-8 OF REF #15)

CRACKED MOMENT OF INERTIA $I_{CR} = (0.025)(12)(21.0-3)^3 = 1749.5 \text{ in}^4$ ✓

THERMAL MOMENT $= \frac{E\, I_{CR} \times \Delta T \times \alpha_t}{t}$ REF #17

$$M_t = \frac{(3.6\times10^6)(1749.5)(80)(6.0\times10^{-6})}{(21.0)(1000)} = 144.0 \text{ k-in}$$ ✓

NORTH WALL THERMAL MOMENTS - EL. 679'-5" TO EL. 680'-5"

THE NORTH WALL FROM EL. 679'-5" TO 680'-5" IS COMPOSED OF A 33.5" THICK WALL HORIZONTALLY REINFORCED WITH #9 @ 9" ON POOL SIDE AND #8 @ 9" ON THE OPPOSITE SIDE. (SEE FIGURE 3.1)

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EQUIVALENT THERMAL MOMENT CALCULATIONS

REF.

THE TENSILE REINFORCEMENT RATIO $p = \frac{A_s}{bd} = \frac{1.05}{(12)(33.5)} = 0.0026$ ✓

THE RATIO $pn = (0.0026)(8) = 0.0209$ ✓

FROM THE "COEFFICIENT FOR MOMENT OF INERTIA OF CRACKED SECTIONS" (PG. 4-8 OF REF # 18)

$F = 0.016$

$\therefore\ I_{CR}$ (CRACKED SECTION I) $= (0.016)(12)(33.5-3)^3 = 5447.5\ in^4$ ✓

THERMAL MOMENT = $\frac{E I_{CR} \times \Delta T \times \alpha_t}{t}$ REF #17

$$M_t = \frac{3.6\times10^6 \times (5447.5) \times 80 \times 6\times10^{-6}}{(33.5)(1000)} = \underline{280.1}\ k\text{-}in$$ ✓

NOTE: THE PORTION OF THE NORTH WALL WHICH IS 36" THICK, HAS SIMILAR REINFORCEMENT AS THE EAST WALL (36" THICK - PG. 3). THEREFORE THERMAL MOMENT WILL BE SIMILAR AND EQUAL TO <u>331.2</u> ✓ K-IN.

<u>SOUTH WALL THERMAL MOMENTS - EL 672' TO 701'-3"</u>

THE SOUTH WALL FROM EL. 672' TO 701'-3" IS 18.0" THICK AND REINFORCED ON THE POOL SIDE WITH #9 BARS @ 9" AND ON THE OPPOSITE SIDE WITH #8 BARS @ 9".

THE TENSILE REINFORCEMENT RATIO $p = \frac{A_s}{bd} = \frac{1.05}{(12)(18)} = 0.00486$ ✓

FROM REF # 18, THE COEFFICIENT FOR I_{CR} IS OBTAINED AS $F = 0.0285$ (FOR $pn = (.00486)(8) = 0.039$ ✓)

THEREFORE: $I_{CR} = Fbd^3 = (0.0285)(12)(18-3)^3 = 1154.3\ in^4$ ✓

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/KCBUR

EQUIVALENT THERMAL MOMENT CALCULATIONS — REF.

THE THERMAL MOMENT = $\dfrac{E\, I_{cr} \times \Delta T \times \alpha t}{t}$ — REF #17

$$M_t = \frac{(3.6\times10^6)(1154.3)(80)(6.0\times10^{-6})}{(18)(1000)} = 110.8 \text{ k-in} \checkmark$$

SOUTH WALL THERMAL MOMENT EL. 659'-5.625" TO 672'-0"

THE LOWER SECTION (57" THICK) HAS SIMILAR DIMENSIONS AND REINFORCEMENT AS EAST WALL AND THEREFORE THERMAL MOMENT WILL BE SIMILAR.

$$M_t = 572.8 \checkmark \text{ k-in}$$

POOL FLOOR THERMAL MOMENT

THE POOL FLOOR IS COMPOSED OF A 56" THICK SLAB REINFORCED WITH #7 BAR @ 12" ($A_S = 0.6$ in²)

TENSILE STEEL REINFORCEMENT RATIO $p = \dfrac{0.6}{(12)(56)} = 0.00089 \checkmark$

RATIO $pN = (0.00089)(8.0) = .0071$

THE CRACKED SECTION (I_{CR}) = Fbd^3, WHERE F IS FUNCTION OF RATIO pN. FROM PG. 4-8 OF REF # 18, F = 0.01 AND: — REF #18

$$I_{CR} = (0.01)(12)(56-3)^3 = 17865.2 \text{ in}^4 \checkmark$$

THERMAL MOMENT = $\dfrac{E\, I_{cr} \times \Delta T \times \alpha_t}{t}$ — REF #17

$$M_t = \frac{(3.6\times10^6)(17865.2)(80)(6.0\times10^{-6})}{(56)(1000)} = \underline{551.3 \text{ k-in}} \checkmark$$

NUCLEAR ENERGY SERVICES INC.
NES DIVISION

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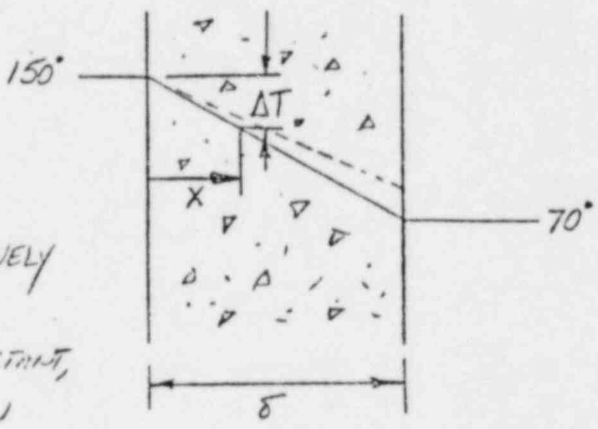
LACBWR FUEL POOL WALL TEMP. G

TEMPERATURE GRADIENT (STEADY STATE)
IN FUEL POOL CONCRETE WALL

ASSUMPTIONS

1. BULK POOL WATER TEMP. = 150°F
2. BOUNDARY LAYER TEMP. DROP NEGLIGIBLE
3. AIR TEMP. = 70°F BEHIND WALL
4. AIR BOUNDARY LAYER TEMP. DROP CONSERVATIVELY IGNORED.
5. CONCRETE THERMAL CONDUCTIVITY (K) CONSTANT, RESULTING IN LINEAR TEMP. DISTRIBUTION



ΔT BETWEEN CONCRETE LOCATION X AND BULK WATER TEMP. of 150°F ON PAGE 2/2 IN TABLE 1.

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LACBWR Fuel Storage Pool

TABLE 1

ΔT AS A FUNCTION OF WALL LOCATION (X)
AND BULK POOL TEMP. OF 150°F

		δ = Wall T			
		1'-6"	1'-9"	3'-0"	4'-8"
X	2"	9°	8°	4°	3°
	4"	18	15	9	6
	6"	27	23	13	9
	8"	36	30	18	11
	1'-0"	53	46	27	17
	1'-2"	62	53	31	20
	1'-4"	71	61	36	23
	1'-6"	80	69	40	26
	1'-8"		76	44	29
	1'-10"			49	31
	2'-0"			53	34
	2'-2"			58	37
	2'-4"			62	40
	2'-6"			67	43
	2'-8"			71	46
	2'-10"			76	49
	3'-0"			80	25
	3'-2"				54
	3'-4"				57
	3'-6"				60
	3'-8"				63
	3'-10"				66
	4'-0"				69
	4'-2"				71
	4'-4"				74
	4'-6"				77
	4'-8"				80

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LACROSSE FUEL POOL ANALYSIS

APPENDIX D

REF.

EFFECTS OF SEISMIC LOADINGS FROM ADJACENT BUILDING STRUCTURES

The spent fuel storage pool is located inside the containment/shield building and it will be subjected to the seismic loads from the adjacent building structures. The effects of these additional loadings can be conservatively considered by determining the ratio of the design moment to the allowable moment capacity for the building structure at the fuel storage pool elevation and adding it to the similar ratio from the pool analysis and comparing the sum of these two ratios to 1.

Refering to pages 4-32 and 4-26 of the Gulf United Services Report SS-1162 "Seismic Evaluation of the LaCrosse Boiling Water Reactor" (Reference 15)

Ratio of Maximum Seismic Moment to Yield Moment for element 17 (Nodes 19-20) $R_{mb} = 0.285$

Ratio of the maximum Seismic Shear to Ultimate Shear strength for element 17. $R_{vb} = 0.106$

From Table 8.2 of this report

Max. ratio of the design moment to allowable moment (Load Combination 2, element no. 61) for vertical reinforcement = $R_{mp} = \frac{77.8}{528.0} = 0.147$

Max. ratio of the shear stress to allowable shear stress $R_{vp} = \frac{0.075}{0.201} = 0.373$
(Load Combination 2, Element 144)

∴ the sum of these two ratios

$R_{mb} + R_{mp} < 1.0$

$0.285 + 0.147 = 0.432 < 1.0$ O.K

$R_{vb} + R_{vp} < 1.0$

$0.106 + 0.373 = 0.479 < 1.0$ O.K.

CONCLUSIONS : The design of the pool structure is adequate to withstand the loadings from adjacent structure as well as its own loadings.

NUCLEAR ENERGY SERVICES, INC.

SPEC NO. 81A0095

PAGE Append. OF

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