DAIRYLAND POWER COOPERATIVE

La Crosse, Wisconsin

54601

July 11, 1979

In reply, please
refer to LAC-6404

DOCKET NO. 50-409

Director of Nuclear Reactor Regulation
ATTN: Mr. Dennis L. Ziemann, Chief
Operating Reactors Branch #2
Division of Operating Reactors
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

SUBJECT: DAIRYLAND POWER COOPERATIVE
LA CROSSE BOILING WATER REACTOR (LACBWR)
PROVISIONAL OPERATING LICENSE NO. DPR-45
APPLICATION FOR AMENDMENT TO LICENSE

REFERENCE: (1) DPC Letter, LAC-6356, Linder to Ziemann, Dated June 26, 1979

Dear Mr. Ziemann:

As stated in Reference (1), enclosed is the complete set of detailed calculations, including summary of results, of a reanalysis of a spent fuel shipping cask drop accident with the pool water at the 680-foot elevation.

If there are any questions concerning this submittal, please contact us.

Very truly yours,

DAIRYLAND POWER COOPERATIVE

Frank Linder

Frank Linder, General Manager

FL:HAT:abs

Enclosures

458 278

7907300388

STATE OF WISCONSIN)
)
COUNTY OF LA CROSSE)

Personally came before me this 12th day of July, 1979, the above named Frank Linder, to me known to be the person who executed the foregoing instrument and acknowledged the same.

Ann Miller
Notary Public, La Crosse County
Wisconsin
My Commission Expires March 2, 1980.

458 280

CC: J. G. Keppler, Regional Director
U. S. Nuclear Regulatory Commission
Directorate of Regulatory Operations
Region III
799 Roosevelt Road
Glen Ellyn, IL 60137

Charles Bechhoefer, Esq., Chairman
Atomic Safety and Licensing Board Panel
U. S. Nuclear Regulatory Commission
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Coulee Region Energy Coalition
P. O. Box 1583
La Crosse, WI 54601

458 280

NUCLEAR ENERGY SERVICES, INC.
NES DIVISION
SHELTER ROCK ROAD
DANBURY, CONN. 06810
(203) 748-3581

Mr. Hugh A. Towsley
LaCrosse Boiling Water Reactor
Dairyland Power Cooperative
P.O. Box 135
Genoa, Wi. 54632

June 27, 1979
Project/Task No.: 5101
Reference No.: 5101-516

Subject: LACBWR Spent Fuel Shipping Cask Drop Analysis for Spent Fuel Pool Water Level at Elevation 680 Feet.

Reference: NES Memo 5101-517, from J. Risley To R. Milos, Same Subject, Dated 6/25/79.

Dear Mr. Towsley:

The attached memo provides a summary and the detailed calculations of the spent fuel shipping cask drop analysis for the LACBWR fuel pool, with the pool water at the 680 foot elevation. The original analysis, presented in NES 81A0550, was based on the pool water being at the 701 foot, 9 inch elevation.

In accordance with L. Papworth's instructions, report 81A0550 will be revised to incorporate the new calculations at the lower elevation.

If we can be of further assistance, please call.

Very truly yours,

NUCLEAR ENERGY SERVICES, INC.
NES Division

Richard Milos

Richard A. Milos
Project Manager

RAM:ma
Enc.
cc: R. E. Shimshak
L. G. Papworth
W. J. Manion
A. H. Yoli

458 287

NUCLEAR ENERGY SERVICES, INC.
SHELTER ROCK ROAD
DANBURY, CONNECTICUT 06810
(203) 748-3581

Inter-Office Correspondence

Ref. No.: 5101-517

Date: June 26, 1979

To: R. Milos

From: J. Risley *JR*

Subject: LACBWR Spent Fuel Shipping Cask Drop Analysis for Spent Fuel Pool Water Level at Elevation 680 Feet.

Reference: NES 81A0050, Rev. 2 "Spent Fuel Shipping Cask Drop Analysis For the LaCrosse Boiling Water Reactor."

The referenced document contains detailed calculations evaluating a postulated shipping cask drop analysis into the LACBWR spent fuel pool with the pool water elevation at 701'-9". The analysis evaluated the effects of the cask impacting both the cask area crash pad (Case 1) and the spent fuel storage racks (Case 2). A supplemental shipping cask drop analysis has been performed for these two analysis cases with the fuel pool water at 680'-0", which is equivalent to the bottom of the fuel transfers canal.

The shipping cask drop at this lower water elevation will develop smaller resisting drag forces and therefore generate slightly greater impact velocities and kinetic energies at impact than those presented in the referenced report. For the cask drop onto the crash pad (Case 1), the impact velocity and kinetic energy at impact increased approximately 3.9% and 7.8% respectively, from 46.49 fps to 48.28 fps and 40279 in.-k to 43427 in.-k. For the cask drop on top of the fuel storage racks (Case 2), the impact velocity and kinetic energy at impact increased approximately 7.6% and 15.7% respectively, from 37.93 fps to 40.8 fps and 26803 in.-k to 31018.1 in.-k.

These small increases in the velocity and kinetic energy of impact result in slightly greater damage to the crash pad and fuel storage racks. However, the overall conclusions and recommendations presented in the referenced report are applicable for the cask drop analysis at both fuel pool water elevations. A summary of results of the cask drop analysis for fuel pool water at elevation 680'-0" is presented in Attachment A. The detail calculations for the cask drop analysis are given in Attachment B.

458 283

RESULTS OF CASK DROP ON CRASH PAD

Load Case 1

Center Drop (22 Modules Effective)	Calculated Value	Allowable Value
Maximum Cask Velocity at Instant of Impact (ft/sec)	45.276	N/A
Maximum Kinetic Energy at Instant of Impact (in/k)	43427.0	N/A
Maximum Strain in Intermediate Cylinder (in/in)	0.321	0.485
Percent of Ultimate Strain in Intermediate Cylinder (%)	66.2	100
Total Deformation of the Crash Pad (in)	8.03	10.0
Maximum Reaction Load in Each Module (kips)	329.6	361.2
Maximum Compressive Stress in Inner Cylinder (ksi)	60.26	101.6
Maximum Strain in Inner Cylinder (in/in)	0.0104	0.243
Percent of Ultimate Strain in Inner Cylinder (%)	2.15	50.0
Maximum Compressive Stress in Outer Cylinder (ksi)	53.94	101.6
Maximum Strain in Outer Cylinder (in/in)	0.0054	0.243
Percent of Ultimate Strain in Outer Cylinder (%)	1.11	50.0
Maximum Punching Shear Stress in Impact Plate (ksi)	15.09	26.5
Maximum Punching Shear Stress in Base Plate (ksi)	19.98	26.5
Maximum Local Bearing Stress on Concrete Floor (under each module) (ksi)	2.64	4.17
Maximum Punching Shear Stress in Concrete Floor (under each module) (ksi)	0.0265	0.201
Maximum Reaction Load for the 22 Modules (kips)	7251.3	N/A

458 284

Load Case 1
Center Drop (22 Modules Effective) (continued)

	Calculated Value	Allowable Value
Maximum Average Bearing Stress on the Reinforced Concrete Floor (ksi)	1.53	2.1
Maximum Reaction Load on the Reinforced Concrete Slab ABCD (kips)	1648	5097.8
Average Shear Stress in Reinforced Concrete Slab ABCD (ksi)	0.108	0.201
Maximum Reaction Load on the 29" Thick Reinforced Concrete Wall Under Floor (kips)	[illegible]603.2	N/A
Maximum Compressive Stress in the 29" Thick Reinforced Concrete Wall Under Floor (ksi)	1.09	2.08

Load Case 2
Quadrant Impact (17 Modules Effective)

	Calculated Value	Allowable Value
Maximum Cask Velocity at Instant of Impact (ft/sec)	45.276	N/A
Maximum Kinetic Energy at Instant of Impact (in-k)	43417.0	N/A
Maximum Strain in Intermediate Cylinder (in/in)	0.347	0.485
Percent of Ultimate Strain in Intermediate Cylinder (%)	7	100.0
Total Deformation of the Crash Pad (in)	8.675	10.0
Maximum Reaction Load in Each Module (kips)	334.10	361.2
Maximum Compressive Stress in Inner Cylinder (ksi)	61.08	101.6
Maximum Strain in Inner Cylinder (in/in)	0.0113	0.243
Percent of Ultimate Strain in Inner Cylinder (%)	2.34	50.0
Maximum Compressive Stress in Outer Cylinder (ksi)	54.68	101.6
Maximum Strain in Outer Cylinder (in/in)	0.006	0.243

458 285

Load Case 2 Quadrant impact (17 Modules Effective) (continued)	Calculated Value	Allowable Value
Percent of Ultimate Strain in Outer Cylinder (%)	1.20	50.0
Maximum Punching Shear Stress in Impact Plate (ksi)	15.29	26.5
Maximum Punching Shear Stress in Base Plate (ksi)	20.26	26.5
Maximum Local Bearing Stress on Concrete Floor (under each module) (ksi)	2.68	4.17
Maximum Punching Shear Stress in Concrete Floor (under each module) (ksi)	0.027	0.201
Maximum Reaction Load for the 17 Modules (kips)	5679.7	N/A
Maximum Average Bearing Stress on the Reinforced Concrete Floor (ksi)	1.858	2.1
Maximum Reaction Load on the Reinforced Concrete Slab ABCD (kips)	2672.8	5097.8
Average Shear Stress in Reinforced Concrete Slab ABCD (kips)	0.175	0.201
Maximum Reaction Load on the 29" Thick Reinforced Concrete Wall Under Floor (kips)	4343.3	N/A
Maximum Compressive Stress in the 29" Thick Reinforced Concrete Wall Under Floor (ksi)	0.841	2.08

458 286

RESULTS OF CASK DROP ON STORAGE RACK

Straight Drop on Top of Storage Cell	Calculated Value	Allowable Value
Weight of Shipping Cask (kip)	100.00	N/A
Maximum Drop Height (Ft)	26.22	N/A
Maximum Cask Velocity at Instant of Impact (Ft/sec)	40.80	N/A
Maximum Kinetic Energy of Drop at Instant of Impact (in.k.)	31018.14	N/A
Number of Storage Cells Impacted	52	N/A
Maximum Strain in Each Storage Cell (in/in)	0.0230	0.485[1]
Per Cent of Ultimate Strain in Each Storage Cell (in/in)	4.74	100.0
Maximum Cell Deformation (in)	4.876	
Maximum Stress in Cell (ksi)	68.70	41.4[2]
Maximum Transmitted Reaction Load Per Storage Cell (kips)	83.62	N/A
Maximum Transmitted Reaction Load for 52 Cells (kips)	4348.2	N/A
Maximum Stress in the Weld Between the Cell Wall and the Base Plate (ksi)	19.71	28.0[3]
Maximum Stress in Rack Base Structure (ksi)	82.52	41.4
Maximum Stress in Jackscrew (ksi)	51.72	106.3[4]
Maximum Local Bearing Stress on Concrete Floor (ksi)	1.36	2.08
Maximum Bending Stress in the Bearing Plate (ksi)	12.49	41.4
Maximum Punching Shear Stress in the Liner Plate (ksi)	7.43	41.4
Maximum Local Bearing Stress on Concrete Floor (ksi)	1.72	2.08
Maximum Punching Shear Stress on Concrete Floor (ksi)	0.01	0.201

458 287

Straight Drop on Top of Storag- Cell	Calculated Value	Allowable Value
Maximum Compressive Stress in the 42" Thick Reinforced Concrete Wall Under Floor (ksi)	0.96	2.08
Maximum Reaction Load On Concrete Wall (kips)	6021.0	13104.0
Maximum Unsupported Plate Thickness That May be Perforated by Missle Free Fall Velocity, (in)		
BRL Formula	0.301	0.625
Stanford Research Institute Formula	0.303	0.625

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1. Ultimate strain for stainless steel.
2. The allowable stress value represents dynamic yield stress for stainless steel.
3. Allowable stress in the weld - $1.6 \times 21 \times \frac{30.0}{36.0} = 28.0$ ksi.
4. Buckling Stress for 17-4PH stainless steel at design temperature.

458 288

ATTACHMENT B

NUCLEAR ENERGY SERVICES INC.
NES DIVISION

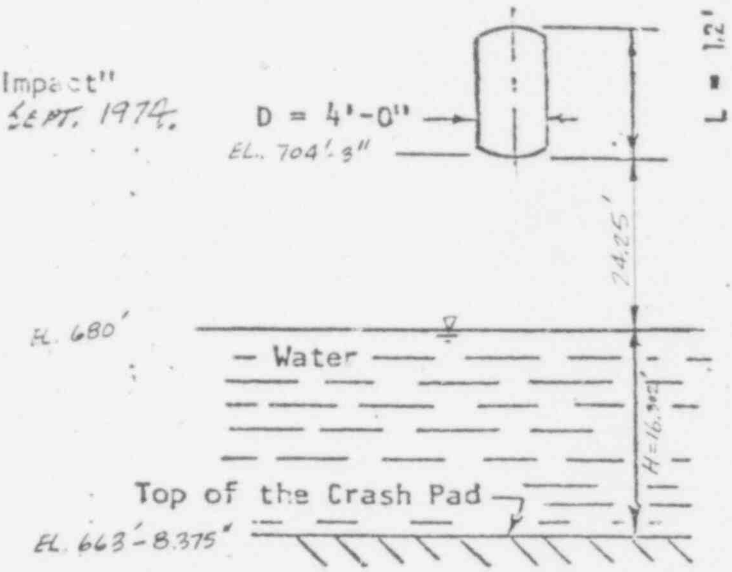
BY JR DATE 6/19/79 PROJ. 5101 TASK 099
CHKD. L.H. DATE 6-19-79 PAGE B-1 OF
LACBWR

	REF.
- STRUCTURAL EFFECTS OF LOWER WATER LEVEL -	
A LOWER SPENT FUEL POOL WATER ELEVATION (680' 0" VS. 701'-9") IS CONSIDERED IN THE ANALYSIS OF THE STRUCTURES SITUATED WITHIN THE SPENT FUEL POOL. THIS LOWER WATER ELEVATION IS APPROXIMATELY 1.969 FEET ABOVE THE STORAGE RACK. THUS DURING A SEISMIC EVENT, THE LATERAL ACCELERATION OF THE POOL WATER WILL GENERATE WATER SLOSHING EFFECTS. THE SLOSHING WATER WILL UNCOVER A PORTION OF UPPER TIER STORAGE RACK BUT WILL INDUCE A RELATIVELY SMALL AMOUNT OF LATERAL WATER PRESSURE ON THE RACKS. THEREFORE, THE LOWER WATER ELEVATION WILL RESULT IN INSIGNIFICANT EFFECTS ON THE STORAGE RACKS.	
DURING THE POSTULATED CASK DROP EVENT, THE LOWER WATER LEVEL WILL TEND TO INCREASE THE CASK IMPACT VELOCITY ON BOTH THE CASK CRASH PAD AND STORAGE RACKS. THE EFFECTS OF THE LOWER WATER LEVEL DURING A CASK DROP ANALYSIS ARE EVALUATED IN THE FOLLOWING PAGES BY FIRST CALCULATING THE IMPACT VELOCITY AND THE GENERATED KINETIC ENERGY TO BE APPLIED IN THE STRUCTURAL ANALYSIS OF THE CRASH PAD AND STORAGE RACK STRUCTURE.	

458 289

	REF.

CASK IMPACT VELOCITY



Ref. 10 "Design of Structures for Missile Impact"
BC-Top-9A, Rev. 2, Bechtel Corp., SEPT. 1974.

Diameter of the Cask, D = 4.0'

Length of Cask, L = 12.0'

Weight of Cask, W = 100,000.0 lbs.
= 100 k

Assumptions:

1. Cask drops from 3.0 feet above the CURB ELEVATION.
2. Cask drops vertically (longitudinal axis perpendicular to the floor).
3. Neglect loss of velocity during compression phase of liquid entry.
4. Neglect skin friction drag.
5. Assume constant drag coefficient.

All the above assumptions give conservative estimate of the striking velocity.

If the cask drops 24.25 feet to just hit the water surface, the initial velocity is

$$V_o = \sqrt{2gh} = \sqrt{2 \times 32.17 \times 24.25} = 39.5 \text{ ft/sec.}$$

The Reynolds number is, according to equation (5-7) of Ref. 10

$$R = \frac{V_o\, d}{\nu} = \frac{39.5 \times 4.0}{0.93 \times 10^{-5}} = 1.699 \times 10^{7}$$

Where ν is the kinematic viscosity of water.

REF.

Cask Impact Velocity (Cont'd.)

Since $L/d = \frac{12}{4} = 3$, the drag Coeff. is, according to Table 15-1 of Ref. 10 for the case of circular cylinder with axis parallel to flow and with $R > 10^3$

$$C_D = 0.86$$

The horizontal cross-sectional area is

$$A_o = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (4)^2 = 12.566 \text{ ft.}^2$$

Equation (5-5) of Ref. 10 gives

$$a = \frac{\gamma C_D A_o}{2W} = \frac{62.4 \times 0.86 \times 12.5666}{2 \times 10^5} = 0.00337 \text{ ft.}^{-1}$$

Equation (5-6) gives

$$b = \frac{\gamma g}{W} = \frac{62.4 \times 32.17}{10^5} = 0.02007 \text{ ft.}^{-2} \text{ sec.}^{-2}$$

The weight density of cask is

$$\gamma_m = \frac{W}{A_o L} = \frac{10^5}{12.566 \times 12.0} = 663.165 \text{ lbs./ft.}^3$$

According to equation (5-8) of Ref. 10, the terminal velocity is

$$V_2 = \left[g \left(1 - \frac{\gamma}{\gamma_m}\right) \frac{1}{a} \right]^{\frac{1}{2}}$$

$$= \left[32.17 \left(1 - \frac{62.4}{663.165}\right) \frac{1}{0.00337} \right]^{\frac{1}{2}} = 92.99 \text{ ft./sec.}$$

Since $H > L$, and according to equation (5-2)

$$Z_2(L) = V_2^2 + e^{-2aL} \left\{ \frac{bA_o}{2a^2} \left[e^{2aL} (1 - 2aL) - 1 \right] + V_o^2 + \frac{g}{a} \left(e^{2aL} \frac{\gamma}{\gamma_m} - 1 \right) \right\}$$

$$= (92.99)^2 + e^{-2 \times 0.00337 \times 12} \left\{ \frac{0.02007 \times 12.566}{2(0.00337)^2} \left[e^{2 \times 0.00337 \times 12} (1 - 2 \times 0.00337 \times 12) - 1 \right] + \frac{32.17}{0.00337} \left[e^{2 \times 0.00337 \times 12} \times \frac{62.4}{663.165} - 1 \right] + (39.5)^2 \right\}$$

458 291

REF.

Cask Impact Velocity (Cont'd)

or $Z_2(L) = 8647.1 + [-38.307 + 1560.25 - 8572.1] \times 0.922$

$= 2146.86 > 0$

∴ The cask will not float but will strike the floor.

Value of $Z_2(H)$ should be calculated

$$Z_2(H) = V_2^2 + e^{-2aH}\left\{\frac{bA_o}{2a^2}\left[e^{2aL}(1-2aL)-1\right] + v_o^2 + \frac{g}{a}\left(e^{2aL}\frac{\gamma}{\gamma_m}-1\right)\right\}$$

$$Z_2(H) = (92.99)^2 + e^{-2 \times 0.00337 \times 16.302}(-38.307 + 1560.25 - 8572.$$

$= 8647.1 - 6316.557 = 2330.53 > 0$

The striking velocity of the cask on top of the crash pad is, according to equation (5-4) Ref. 10,

$$V = \left[Z_2(H)\right]^{\frac{1}{2}} = (2330.582)^{\frac{1}{2}} = 48.276 \text{ ft./sec.}$$

Maximum kinetic energy of the cask at the instant of impact $= 1/2\ M_V^2$

$= 1/2 \times \frac{100}{32.2}(48.276)^2$

$= 3618.92$ ft. k.

$= 43427.0$ in. k.*

458 292

REF.

LOAD CASE 1 - CENTER DROP

Assume 22 Modules Effective - All except 3 Modules at each corner of Crash Pad.

Assume No Bending of Impact Plate.

A) Design for maximum reaction load on reinforced concrete floor

External Kinetic energy of the Cask = 43427.0 in.kips

Internal Strain Energy of the tensile modules

$$E_i = \frac{128.5}{1.166} \epsilon_x^{1.166} ALN$$

N = Number of modules effective in absorbing the energy = 22

A = Cross sectional area of intermediate cylinder = 3.17 in^2

L = Length of intermediate cylinder = 25 in.

Equating External and internal Energy - Assume all kinetic energy is absorbed by intermediate (tensile) cylinders.

$$\frac{128.5}{1.166} \epsilon_x^{1.166} ALN = 43427.0$$

Strain in Intermediate Cylinder

$$\epsilon_x = \left[\frac{1.166 E_i}{128.5 ALN}\right]^{1/1.166} = \left[\frac{1.166 (43427.0)}{128.5 (3.17)(25)(22)}\right]^{1/1.166}$$

$$\epsilon_x = 0.2793 \text{ in./in.}$$

Per Cent of Ultimate Strain

$$\% \epsilon_u = \frac{\epsilon_x}{\epsilon_u} \times 100 = \frac{0.2793}{0.485} = 57.6\%$$

458 293

Elongation of Intermediate Cylinder

$$\delta_x = \epsilon_x L = 0.279 \times 25.0 = 6.98 \text{ in.}$$

Maximum Stress - Intermediate Cylinder

$$\sigma_x = 128.5\, \epsilon_x^{\,0.166} = 128.5\,(0.279)^{0.166} = 103.98 \text{ ksi}$$

Maximum Transmitted Reaction Load Per Module

$$R_x = A\,\sigma_x = 3.17 \times 103.98 = 329.6 \text{ kips}$$

Maximum Stress - Inner Cylinder

$$= \frac{R_x}{A_i} = \frac{329.6}{5.47} = 60.26 \text{ ksi}$$

Max strain $= \left(\frac{60.26}{128.5}\right)^{\frac{1}{.166}} = 0.0104$ in/in. Percent of Ultimate Strain $= \frac{.0104}{.485} \times 100 = 2.15\%$

Maximum Stress - Outer Cylinder

$$= \frac{R_x}{A_o} = \frac{329.6}{6.11} = 53.94 \text{ ksi}$$

Max. Strain $= \left(\frac{53.94}{128.5}\right)^{\frac{1}{0.166}} = 0.00536$ in/in. Percent of Ult. Strain $= \frac{.00536 \times 100}{.485} = 1.11\%$

Maximum Punching Shear Stress - Impact Plate

$$= \frac{R_x}{\pi\, D_o\, t_{ip}} = \frac{329.6}{\pi(5.563)(1.25)} = 15.09 \text{ ksi}$$

Maximum Punching Shear Stress - Base Plate

$$= \frac{R_x}{\pi\, D_i\, t_{bp}} = \frac{329.6}{\pi(3.50)(1.5)} = 19.98 \text{ ksi}$$

Maximum Local Bearing Stress on Concrete Floor (under each module)

$$= \frac{R_x}{\text{Effective Area}} = \frac{329.6}{9.25 \times 13.5} = 2.64 \text{ ksi}$$

Maximum Punching Shear Stress on Concrete Floor (under each module)

$$= \frac{R_x}{\text{Effective Area}} = \frac{329.6}{4(54.0 + 3.5)(54.0)} = 0.0265 \text{ ksi}$$

Maximum Reaction Load on Concrete Floor -22 Modules

$$R = NR_x = 22 \times 329.6 = 7251.2 \text{ kips}$$

458 294

REF.

Maximum Average Bearing Stress on Concrete Floor of Pool

$$= \frac{R}{\text{Effective Area}} = \frac{7251.2}{70.0 \times 67.5} \doteq 1.53 \text{ ksi}$$

Maximum Total Reaction Load on Concrete Floor Slab ABCD (SEE PG. A-11 FOR
(5 Modules Acting)

$$R_{slab} = 5 R_x = 5 \times 329.6 = 1648 \text{ kips}$$

Maximum Average Shear Stress Around Slab Periphery

$$= \frac{R_{slab}}{\text{Peripheral Area}} = \frac{1648}{2(51.5 + 90)\ 54.0} = 0.108 \text{ ksi}$$

Maximum Reaction Load on 29" Thick Reinforced Concrete Wall Under Floor
(Assume $12+\frac{2\times5}{2}$ Modules Transmit Load)

$$R_{wall} = 17 R_x = 17 \times 329.6 = 5603.2 \text{ kips}$$

Maximum Compressive Stress in Reinforced Concrete Wall Under Floor

$$= \frac{R_{wall}}{\text{Wall Area}} = \frac{5603.2}{29.0 \times (70+2\times54)} = 1.09 \text{ ksi}$$

Design Check for Maximum Intermediate Cylinder Strain
(Assuming a Minimum Stress Increase Due to Impact of 20%)

Strain Energy Capacity of Intermediate Cylinders

$$E_i = \frac{116.9}{1.2} \epsilon_x^{1.20} \text{ ALN}$$

Equating External and Internal Energy and Rearranging -
Maximum Strain in Intermediate Cylinder

$$\epsilon_x = \left[\frac{1.2\ E_x}{116.9\ \text{ALN}}\right]^{1/1.20} = \left[\frac{1.2\ \ 43427.0}{116.9(3.17)(25)(22)}\right]^{1/1.20} = .321 \text{ in/in.}$$

Per Cent of Ultimate Strain

$$\% = \frac{\epsilon_x}{\epsilon_u} \times 100 = \frac{0.321}{0.485} \times 100 = 66.2\ \%$$

458 295

Maximum Intermediate Cylinder Elongation

$$\delta_x = \epsilon_x L = 0.321 \times 25.0 = 8.025 \text{ in.}$$

REF.

LOAD CASE 2 - QUADRANT IMPACT

Assume 17 Modules Effective - Column Lines A-G and 3-7

Assume Bending of Impact Plate and Adjacent Modules.

A) Design for maximum reaction load on reinforced concrete floor

External Kinetic energy of the Cask = 43427.0 in.kips

Internal Strain Energy of the tensile modules

$$E_i = \frac{128.5}{1.166} \epsilon_x^{\ 1.166} ALN$$

N = Number of modules effective in absorbing the energy

A = Cross sectional area of intermediate cylinder = 3.17 in^2

L = Length of intermediate cylinder = 25 in.

Equating External and Internal Energy - Assume 15% of kinetic energy used up in bending of impact plate and adjacent modules.

$$\frac{128.5}{1.166} \epsilon_x^{\ 1.166} ALN = 43427.0 \times 0.85$$

Strain in Intermediate Cylinder

$$\epsilon_x = \left[\frac{1.166\ E_i}{128.5\ ALN}\right]^{1/1.166} = \left[\frac{1.166\ (43427.0)(0.85)}{128.5\ (3.17)(25)(17)}\right]^{1/1.166}$$

$$\epsilon_x = 0.303 \text{ in./in.}$$

Per Cent of Ultimate Strain

$$\%\epsilon_u = \frac{\epsilon_x}{\epsilon_u} \times 100 = \frac{0.303}{0.485} = 62.5\ \%$$

458 296

Elongation of Intermediate Cylinder

$$\delta_x = \epsilon_x L = 0.303 \times 25.0 = 7.575 \text{ in.}$$

Maximum Stress - Intermediate Cylinder

$$\sigma_x \doteq 128.5\, \epsilon_x^{\ 0.166} = 128.5\,(0.303)^{0.166} = 105.40 \text{ ksi}$$

Maximum Transmitted Reaction Load Per Module

$$R_x = A\, \sigma_x = 3.17 \times 105.40 = 334.10 \text{ kips}$$

Maximum Stress - Inner Cylinder

$$= \frac{R_x}{A_i} = \frac{334.10}{5.47} = 61.08 \text{ ksi}$$

Max. strain $= \left(\frac{61.08}{128.5}\right)^{\frac{1}{.166}} = 0.0113$ in/in

Percent of ult. strain $= \frac{.0113 \times 100}{.485} = 2.34\%$

Maximum Stress - Outer Cylinder

$$= \frac{R_x}{A_o} = \frac{334.10}{6.11} = 54.68 \text{ ksi}$$

Max. strain $= \left(\frac{54.68}{128.5}\right)^{\frac{1}{.166}} = 0.0058$ in/in

Percent of ult. strain $= \frac{0.0055}{.485} \times 100 = 1.20\%$

Maximum Punching Shear Stress - Impact Plate

$$= \frac{R_x}{\pi\, D_o\, t_{ip}} = \frac{334.10}{\pi(5.563)(1.25)} = 15.29 \text{ ksi}$$

Maximum Punching Shear Stress - Base Plate

$$= \frac{R_x}{\pi\, D_i\, t_{bp}} = \frac{334.10}{\pi(3.50)(1.5)} = 20.26 \text{ ksi}$$

Maximum Local Bearing Stress on Concrete Floor (under each module)

$$= \frac{R_x}{\text{Effective Area}} = \frac{334.10}{9.25 \times 13.5} = 2.68 \text{ ksi}$$

Maximum Punching Shear Stress on Concrete Floor (under each module)

$$= \frac{R_x}{\text{Effective Area}} = \frac{334.10}{4(54.0 + 3.5)(54.0)} = 0.027 \text{ ksi}$$

458 297

Maximum Reaction Load on Concrete Floor - 17 Modules

$$R = NR_x = 17 \times 334.10 = 5679.7 \text{ kips}$$

REF.

Maximum Average Bearing Stress on Concrete Floor of Pool

$$= \frac{R}{\text{Effective Area}} = \frac{5677.7}{52.25 \times 58.5} \doteq 1.858 \text{ ksi}$$

Maximum Total Reaction Load on Concrete Floor Slab ABCD
(8 Modules Acting)

$$R_{slab} = 8 R_x = 8 \times 334.10 = 2672.8 \text{ kips}$$

Maximum Average Shear Stress Around Slab Periphery

$$= \frac{R_{slab}}{\text{Peripheral Area}} = \frac{2672.8}{2(51.5 + 90)\ 54.0} = 0.175 \text{ ksi}$$

Maximum Reaction Load on 29" Thick Reinforced Concrete Wall Under Floor
(Assume $9+\frac{8}{2}$ Modules Transmit Load)

$$R_{wall} = 13 R_x = 13 \times 334.10 = 4343.3 \text{ kips}$$

Maximum Compressive Stress in Reinforced Concrete Wall Under Floor

$$= \frac{R_{wall}}{\text{Wall Area}} = \frac{4343.3}{29.0 \times (70+2\times 54)} = 0.841 \text{ ksi}$$

Design Check for Maximum Intermediate Cylinder Strain
(Assuming a Minimum Stress Increase Due to Impact of 20%)

Strain Energy Capacity of Intermediate Cylinders

$$E_i = \frac{116.9}{1.2} \epsilon_x^{1.20} \text{ ALN}$$

Equating External and Internal Energy and Rearranging -
Maximum Strain in Intermediate Cylinder

$$\epsilon_x = \left[\frac{1.2 E_x}{116.9 \text{ ALN}}\right]^{1/1.20} = \left[\frac{1.2\ (43427)\ (0.85)}{116.9(3.17)(25)(17)}\right]^{1/1.20} = 0.347 \text{ in/in}$$

Per Cent of Ultimate Strain

$$\% = \frac{\epsilon_x}{\epsilon_u} \times 100 = \frac{0.347}{0.485} \times 100 = 71.6\ \%$$

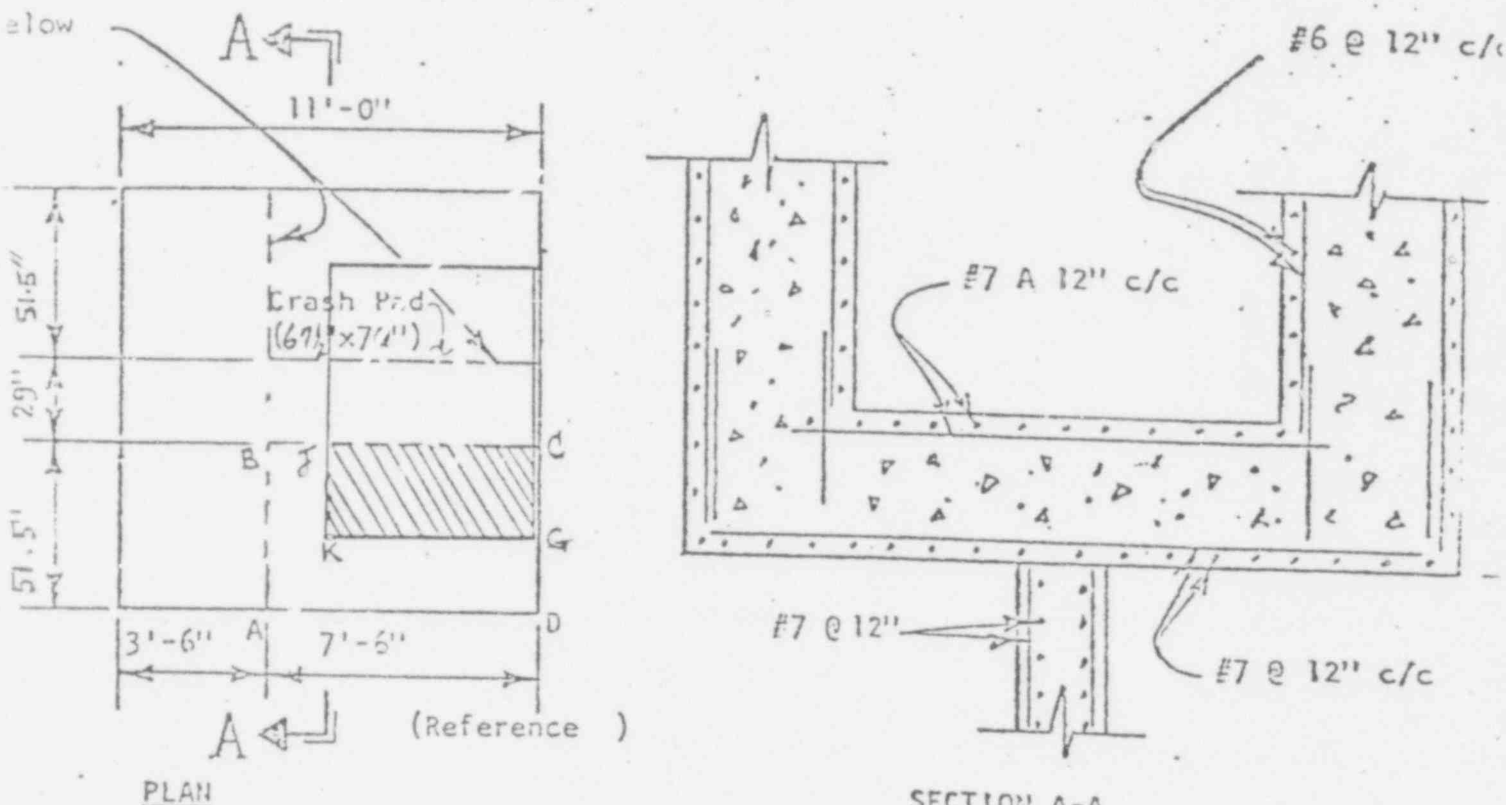
458 298

Maximum Intermediate Cylinder Elongation

$$\delta_v = \epsilon_x L = 0.347 \times 25.0 = 8.675 \text{ in.}$$

REF.

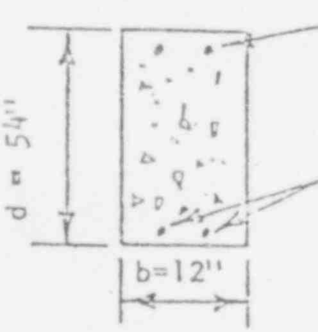
A III - LOAD CARRYING CAPACITY OF REINFORCED CONCRETE FLOOR OF THE FUEL STORAGE WELL



PLAN

SECTION A-A

Concrete strength $f'c = 3500$ psi
Steel yield stress $f_y = 40,000$ psi



$$P = \frac{As}{bd} = \frac{0.6}{12 \times 54} = 9.24 \times 10^{-4}$$

$$P_{max} = 0.75(\phi)^2 \frac{f'c\ (87.0)}{f_y\ (87.0+f_y)}$$

$$= 0.75\ (0.85)^2 \times \frac{3.5\ (87.0)}{40.0\ (127.0)}$$

$$= 0.032$$

458 299

REF.

The reinforced concrete floor of the fuel storage well is supported by continuous walls around its perimeter and is also supported at its midspan by a 29 inch thick wall as shown on the previous page. The reinforced concrete slab is 54 inches thick and its unsupported portions (A,B,C,D) are only 51.5" x 90". During a cask drop event the slab A,B,C,D will be loaded at its corner on the area indicated by C,G,K,J.

Due to the short spans and depth of the slab, the boundary conditions and the nature of the loaded area, failure of the slab A,B,C,D by bending or diagonal tension shear cracking is unlikely. The load-carrying capacity (strength) of the slab will be governed by punching of the slab along the surface of a truncated pyramid around the loaded area C, G, K, J.

Shear area of the truncated pyramid

$$= (KJ + d + JC + d) \times 2d$$

$$= (21.5 + 54 + 70 + 54) \times 2 \times 54 = 21546\ \text{in.}^2$$

Allowable shear stress $= 4\sqrt{f'_c}$

$$= 4\sqrt{3500} = 236.64\ \text{psi.}$$

Load carrying capacity of the slab A,B,C,D

$$= 21546 \times .2366$$

$$= 5097.8\ \text{K.}$$

458 300

REF.

ANALYSIS OF SHIPPING CASK ACCIDENTAL DROP ON STORAGE RACKS

TRANSPORTATION OF A SPENT FUEL SHIPPING CASK INTO AND OUT OF THE SPENT FUEL STORAGE POOL PRESENTS A POSSIBILITY OF A CASK BEING ACCIDENTALLY DROPPED ONTO THE SPENT FUEL STORAGE RACKS SITUATED IN THE POOL. THIS ACCIDENTAL DROP SITUATION IS ANALYZED TO DETERMINE ITS EFFECT ON THE STORAGE RACKS AND POOL LINER.

THE CASK IS ASSUMED TO WEIGH 100^{k} AND BE DROPPED FROM A HEIGHT 3 FEET ABOVE THE SPENT FUEL POOL CURB ELEVATION. THE RACK IS ASSUMED TO IMPACT AT THE CENTER OF A 8x9 SPENT FUEL STORAGE RACK COMPRESSING THE MAX. NUMBER OF CELLS AND PRODUCING THE LARGEST REACTION LOADS TO BE TRANSMITTED TO THE POOL FLOOR.

THE STRUCTURAL ACCEPTANCE CITERIA IS TO ENSURE THAT THE LEAK-TIGHTNESS INTEGRITY OF THE POOL FLOOR LINER BE MAINTAINED DURING THIS EVENT.

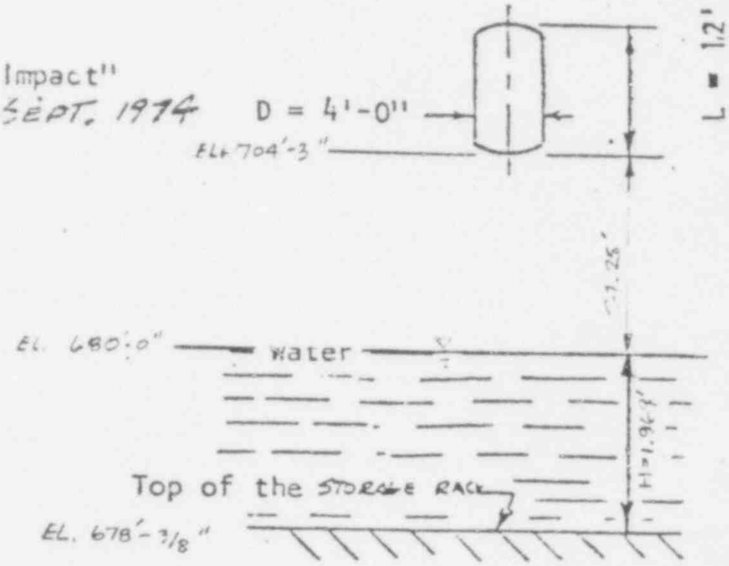
POOR ORIGINAL

458 306

REF.

CASK IMPACT VELOCITY

Ref. 10 "Design of Structures for Missile Impact"
BC-Top-9A, Rev. 2, Bechtel Corp., SEPT. 1974



Diameter of the Cask, D = 4.0'

Length of Cask, L = 12.0'

Weight of Cask, W = 100,000.0 lbs.
= 100 k

Assumptions:

1. Cask drops from 3.0 feet above the CURB ELEVATION.
2. Cask drops vertically (longitudinal axis perpendicular to the floor).
3. Neglect loss of velocity during compression phase of liquid entry.
4. Neglect skin friction drag.
5. Assume constant drag coefficient.

All the above assumptions give conservative estimate of the striking velocity.

If the cask drops 24.25 feet to just hit the water surface, the initial velocity is

$$V_o = \sqrt{2gh} = \sqrt{2 \times 32.17 \times 24.25} = 39.5 \text{ ft/sec.}$$

The Reynolds number is, according to equation (5-7) of Ref. 10

$$R = \frac{V_o\, d}{\nu} = \frac{39.5 \times 4.0}{0.93 \times 10^{-5}} = 1.699 \times 10^7$$

Where ν is the kinematic viscosity of water.

458 302

	REF.

Cask Impact Velocity (Cont'd.)

Since $L/d = \frac{12}{4} = 3$, the drag coeff. is, according to Table 15-1 of Ref. 10 for the case of circular cylinder with axis parallel to flow and with $R > 10^3$

$$C_D = 0.86$$

The horizontal cross-sectional area is

$$A_o = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (4)^2 = 12.566 \text{ ft.}^2$$

Equation (5-5) of Ref. 10 gives

$$a = \frac{\gamma C_D A_o}{2W} = \frac{62.4 \times 0.86 \times 12.5666}{2 \times 10^5} = 0.00337 \text{ ft.}^{-1}$$

Equation (5-6) gives

$$b = \frac{\gamma g}{W} = \frac{62.4 \times 32.17}{10^5} = 0.02007 \text{ ft.}^{-2} \text{ sec.}^{-2}$$

The weight density of cask is

$$\gamma_m = \frac{W}{A_o L} = \frac{10^5}{12.566 \times 12.0} = 663.165 \text{ lbs./ft.}^3$$

According to equation (5-8) of Ref. 10, the terminal velocity is

$$V_2 = \left[g \left(1 - \frac{\gamma}{\gamma_m}\right) \frac{1}{a} \right]^{\frac{1}{2}}$$

$$= \left[32.17 \left(1 - \frac{62.4}{663.165}\right) \frac{1}{0.00337} \right]^{\frac{1}{2}} = 92.99 \text{ ft./sec.}$$

THE CASK IMPACT VELOCITY AT STORAGE RACK ELEVATION ACCORDING TO EQUATION (5-1) OF REF. 10, FOR $(0 \leq x \leq L)$:

$$Z_1(x) = g/a + bA_0(1-2ax)/2a^2 + e^{-2ax}(V_0^2 - g/a - bA_0/2a^2), \quad (0 \leq x \leq L) \quad (5\text{-}1)$$

$Z_1(x)$ FACTOR IS THE MATHEMATICAL FUNCTION OF THE DIFFERENT VARIABLES AFFECTING THE

REF.

CASK IMPACT VELOCITY. FROM REF. 10 :

5.2.1 LIQUID DEPTH IS LESS THAN OR EQUAL TO MISSILE LENGTH ($H \leq L$)

5.2.1.1 <u>If $Z_1(x)$ is Negative or Zero at Depth $x = H$ ($Z_1(H) \leq 0$)</u>

The missile will not strike the target. It will penetrate a depth $H_1 \leq H$ such that $Z_1(H_1) = 0$, and then float to the liquid surface.

5.2.1.2 <u>If $Z_1(x)$ is Positive at Depth $x = H$ ($Z_1(H) > 0$)</u>

The striking velocity at depth H is

$$V = \left[Z_1(H)\right]^{1/2} \qquad (5\text{-}3)$$

$$Z_1(x) = \frac{32.17}{0.00337} + (0.02007)(12.566)\left[1 - 2(.00337)(1.969)\right] / 2(.00337)^2$$

$$+ e^{-2(.00337)(1.969)}\left\{(39.5)^2 - \frac{32.17}{.00337} - \frac{(0.02007)(12.566)}{2(.00337)^2}\right\}$$

$$Z_1(x) = \left[9545.994 + 10956.01 - 18837.45\right]$$

$$Z_1(x) = \left[1664.554\right] > 0$$ ∴ THE CASK WILL NOT FLOAT BUT WILL STRIKE THE STORAGE RACK.

THE STRIKING VELOCITY OF THE CASK ON TOP OF THE STORAGE RACK IS, ACCORDING TO EQUATION 5-4), REF. 10 : $V = \left[Z_1(x)\right]^{1/2} = 40.8$ FT/SEC

MAXIMUM KINETIC ENERGY OF THE CASK AT INSTANT OF IMPACT $= \frac{1}{2} MV^2$

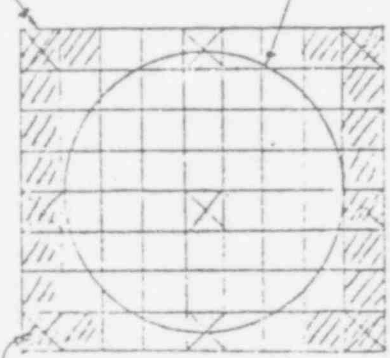
$$= \frac{1}{2} \times \frac{100}{32.2}(40.8)^2 \times 12 = 31018.14 \text{ in.K}$$

THE SHIPPING CASK WILL IMPACT THE TOP OF THE STORAGE RACKS WITH A MAXIMUM KINETIC ENERGY OF 31018.14 IN. K.. THE MAX. REACTION LOAD TRANSMITTED THROUGH THE STORAGE CELLS TO THE POOL FLOOR WILL RESULT WHEN THE SHIPPING CASK

REF.

IMPACTS THE MAX. NUMBER OF STORAGE CELLS OF A SPENT FUEL RACK RESULTING IN MINIMIZING STORAGE CELL BUCKLING AND THEREFORE MAXIMIZING TRANSMITTED REACTION LOAD TO POOL FLOOR.

THE CASK IS ASSUMED TO IMPACT AN 8x9 STORAGE RACK AT THE CENTER WHICH RESULTS IN MAX. REACTION LOADS TRANSMITTED TO THE CENTER LEG OF THE STORAGE RACK.



8x9 RACK PLAN

THE GRIDS ARE EXTREMELY RIGID AND THEREFORE THE NUMBER OF IMPACTED CELLS IS ASSUMED TO INCLUDE ALL CELLS INTERSECTED BY CASK PLAN OUTLINE.

NO. OF IMPACTED CELLS IS (72 − 20) = 52 CELLS

CONSERVATIVELY NEGLECT THE ENERGY LOSSES RESULTING FROM THE LOCAL DEFORMATION OF BENDING OF THE GRIDS WHICH WILL RESULT IN MORE DAMAGE TO STORED FUEL, POOL FLOOR LINER, AND REINFORCED CONCRETE FLOOR UNDER THE [illegible] RACK STRUCTURE.

THEREFORE, THE EXTERNAL KINETIC ENERGY OF 31018.14 K-IN IS ASSUMED TO BE ABSORBED AND TRANSMITTED THROUGH THE 4 ANGLES OF EACH OF THE 52 UNIFORMILY COMPRESSED STORAGE CELLS. THE ENERGY IS TRANSMITTED DOWN THROUGH THE ANGLES TO THE LOWER GRID AND INTO THE SUPPORT LEGS

REF.

FROM REF #1, AN INTERNAL STRAIN ENERGY EQUATION WAS DEVELOPED FOR UNIFORMLY COMPRESSING STAINLESS STEEL CYLINDERS. ASSUMING EACH STORAGE CELL TO BE UNIFORMLY COMPRESSED, THE INTERNAL STRAIN ENERGY IS:

$$E_i = \frac{123.5}{1.166} \epsilon_x^{1.166} ALN$$ ✓ REF. #1

WHERE: E_i = INTERNAL STRAIN ENERGY

ϵ_x = STRAIN IN UNIFORMLY COMPRESSED ELEMENT

A = COMPRESSED STORAGE CELLS AREA

L = STORAGE CELL LENGTH

N = NUMBER OF EFFECTED STORAGE CELLS

A = (4 ANGLE PER CELL) × (.527) = 2.108 in² ✓

L = 212.0" ✓ AND N = 52 ✓ CELLS

EQUATING INTERNAL STRAIN ENERGY TO EXTERNAL KINETIC ENERGY

$$\frac{123.5}{1.166} \epsilon_x^{1.166} (2.108)(212.0)(52) = 31018.14 \text{ K-in}$$

∴ STRAIN IN STORAGE CELLS $\epsilon_x = \left[\frac{(1.166)\ 31018.14}{(123.5)(2.108)(212.0)52} \right]^{1/1.166}$

$\epsilon_x = [0.0121]^{1/1.166}$ ✓ $= 0.0230$ ✓ in/in

PERCENTAGE OF ULTIMATE STRAIN $= \frac{0.023}{0.485} \times 100 = 4.74\%$ ✓

WHERE: ULTIMATE STRAIN $\epsilon_u = 0.485$ in/in ✓

MAXIMUM DEFLECTION OF STORAGE CELLS

$\Delta_x = \epsilon_x L = 0.023 \times 212.0 \text{ in} = 4.88$ ✓ INS

POOR ORIGINAL 458 306

REF.

TOTAL DEFLECTION OF 4.876 INS. IS DISTRIBUTED BETWEEN THE UPPER AND LOWER TIERS.

THE CLEARANCE BETWEEN THE TOP OF THE UPPER GRID AND THE TOP OF THE STORED FUEL IN THE UPPER TIER IS APPROXIMATELY 1.75 INS. ASSUMING THE UPPER TIER STORAGE CELLS TO DEFLECT ½ OF THE TOTAL (2.44 INS), THE CASK WILL IMPACT THE STORED FUEL IN THE UPPER TIER.

THE MAX. STRESS IN EACH STORAGE CELL = $128.5\ \epsilon_x^{0.166}$ ✓ REF. 18

$$\sigma_x = 128.5\,(0.023)^{.166} = 68.7\ ksi$$

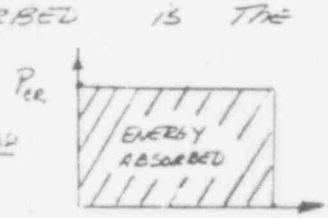
THE DYNAMIC YIELD STRESS FOR STAINLESS STEEL USING A 38% INCREASE OVER STATIC YIELD (REF. 1) IS = 30 x 1.38 = 41.4 ksi WHICH IS LESS THAN STORAGE CELL STRESS INDICATING YIELDING OF THE STORAGE CELLS. THE BUCKLING COMPRESSIVE STRESS IS CALCULATED AS 39.67 ksi, AND THEREFORE THE CELLS WILL FAIL AT THE LOWER BUCKLING STRESS. REF. 18

THE MAX. REACTION LOAD PER CELL $R_x = A\,\sigma_x = (2.108)(39.67) = 83.62^k$ ✓

The max. Transmitted Reaction Load for 52 Storage Cells

$$R = \Sigma R_x = (52)(83.62^k) = 4348.2^k$$ ✓

KINETIC ENERGY ABSORBED IN CELL BUCKLING: ASSUMING EACH CELL COMPRESSES BY 4.24 INS, THE ENERGY ABSORBED IS THE AREA UNDER THE LOAD-DEFLECTION CURVE.



ENERGY ABSORBED = (83.62)(4.876)(52 CELLS) = 21202 K-in

REMAINING K.E. = 31018.14 − 21202
= 9816.12 K-IN

POOR ORIGINAL

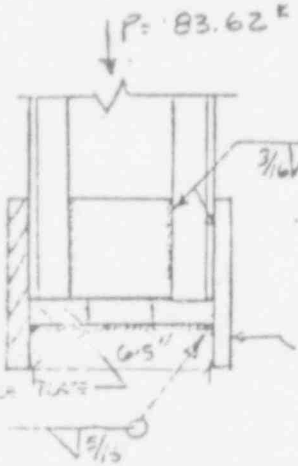
458 307

CASK DROP RACK COMPONET FAILURE SEQUENCE

AS THE CASK IMPACTS THE STORAGE RACK THE AXIAL LOADS GENERATED ARE TRANSMITTED DOWN THROUGH THE IMPACTED STORAGE CELLS INTO THE LOWER GRID. THESE AXIAL LOADS ARE THEN TRANSMITTED THROUGH THE GRID INTO THE NINE SUPPORT LEGS. THE CENTER SUPPORT LEG OBTAINING THE LARGEST PROPORTION OF THE LOAD, WILL FAIL FIRST BY SHEARING THE 17-4 ph JACKSCREW THROUGH THE TYPE 304 STAINLESS STEEL SUPPORT LEG BASE PLATE (SEE PG B-11) ONCE THE CENTER LEG YIELDS, THE AXIAL LOAD IS REDISTRIBUTED INTO THE PERPHERIAL SUPPORT LEGS. AS AXIAL LOAD INCREASES, STORAGE CELLS AT AND ADJACENT TO THE PERPHERIAL SUPPORT LEGS WILL BEGIN TO BUCKLE. BUCKLING WILL CONTINUE AND SPREAD TOWARDS THE CENTER OF THE RACK AS THE AXIAL LOAD INCREASES FORCING THE REMAINING LEGS TO FAILURE IN SHEAR. THE RACK WILL THEN DROP, THE SUPPORT LEG BOX SECTIONS IMPACTING INTO THE 8.0" DIA BEARING PADS. THE LOWER GRID IS NOW RE SUPPORTED BY THE SUPPORT LEG BOX SECTIONS SUPPORTED ON THE CONCRETE BEARING PADS. THE AXIAL LOADS CONTINUE TO INCREASE YIELDING THE GRIDS IN BENDING BETWEEN THE SUPPORTS AND YIELDING THE SUPPORT LEG BOX SECTIONS THROUGH COMPRESSION FAILURE. THE LOWER GRID WILL FINALLY FALL IMPACTING THE POOL FLOOR LINER IN AREAS BETWEEN THE SUPPORT LEG BEARING PADS.

REF.

Cell Weld Stress Analysis



Max. stress in 3/16" weld between cell angles and the 7" Lower Grid

$$= \frac{83.62}{2 \times 4 \times 4 \times 0.707 \times .1875}$$

$$= 19.71 \text{ Ksi}$$

$$< 1.6 \times 21 \times \frac{30.0}{36} = 28.0 \text{ Ksi.}$$

where 21.0 Ksi is allowable stress in weld for A-36 steel ($f_y = 36$ Ksi.) as per AISC Code, 30.0 Ksi. is yield stress for stainless steel and Factor 1.6 is increase in allowable stress permitted by USNRC Standard Review Plan 3.8.4 for extreme environment loading.

∴ the 3/16" weld will remain intact.

Max stress in 5/16" weld between base plate and 7" grid

Conservatively neglecting bending stress and considering only shear stress

$$\text{Max. Shear Stress} = \frac{83.62}{4 \times 6.5 \times .707 \times 0.3125}$$

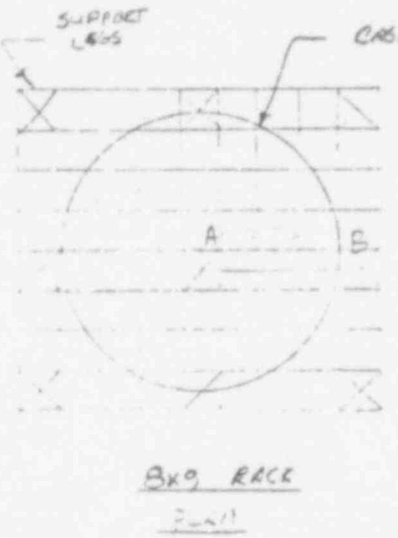
$$= 14.56 \text{ Ksi.} < 28.0 \text{ Ksi.}$$

Although bending effects are significant the 5/16" weld will not fail.

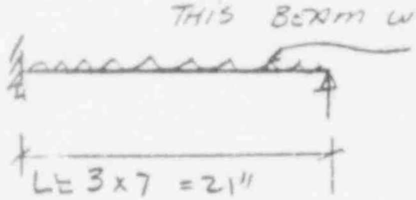
POOR ORIGINAL

REF.

Base Structure :



AFTER THE SHEARING FAILURE OF THE SUPPORT LEG BASE PLATE, THE GRID DROPS AND IS NOW SUPPORTED BY THE SUPPORT LEG BOX SECTIONS SITTING ON THE BEARING PLATES. THE REACTION LOAD will BE DISTRIBUTED IN THE LOWER GRID. CONSIDERING GRID MEMBER AB, THE TRIBUTARY REACTION LOAD ON THIS BEAM will BE FROM 3 CELLS.



Max. moment $= \frac{WL}{8} = \frac{3\times 83.62 \times 21}{8}$

$= 658.51$ Kin.

Beam properties $I_{xx} = 27.94$ in^4

Section modulus $S_{xx} = \frac{27.94}{3.5} = 7.98$ in.^{3}

Max bending stress $= \frac{658.51}{7.98} = 82.52$ Ksi.

> dynamic yield stress for stainless steel

∴ The lower grid structure will yield form the reaction load of Cask drop event

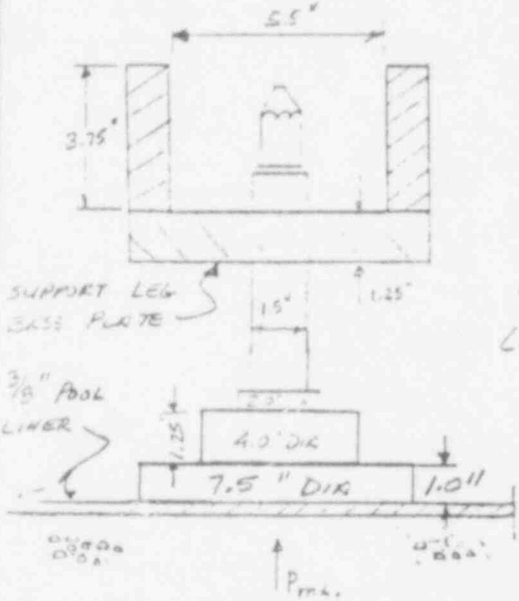
POOR ORIGINAL

NES 105 (2/74)

458 310

	REF.

LEG ASSEMBLY ANALYSIS While the lower grid is collapsing the transmitted reaction loads will be applied to the pool floor through the support legs. The support legs are designed to sustain a max. reaction load. Any load larger will result in support leg failure. Therefore the max. reaction load to produce support leg collapse will be transmitted to the pool floor. The support leg will fail initially by shearing the support leg base plate at the threaded connection with the jackscrew.



$$\text{Compressive Thread Area} = 1.25\,(.7854)\left(D - \frac{.9743}{n}\right)^2 = 1.757\ in^2$$

Where: D = 1.5" (Dia. of jackscrew) & n = No. of threads per inch = 6 — REF # 4

$$P_{max} = (41.4\ ksi)(1.757) = \underline{72.72^K}$$

Max. Punching Stress in 4" Base plate $= \dfrac{72.72^K}{\pi(2+1.25)1.25} = 5.7\,ksi$

< 41.4 ksi ok

Max. Punching Stress in 7.5" Bearing Plate at Leg Failure:

$$= \frac{72.72}{\pi(4.0 + (2)(1))\,1.0} = 3.86\,ksi < 41.4\,ksi \quad \underline{ok}$$

Max. Punching Stress in Pool Liner (1 - 3/8" plates):

$$= \frac{72.72}{\pi(7.5 + (2)(.375))(.375)} = 7.48\,ksi < 41.4\,ksi \quad ok$$

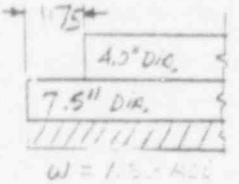
Max. Bearing Stress on Concrete Floor at Leg Failure:

$$= \frac{(72.72)(4)}{\pi[7.5 + 2(.375)]^2} = 1.36\,ksi < 2.08\,ksi \quad \underline{ok}$$ — REF. 14

POOR ORIGINAL

	REF.

THE MAX. BENDING STRESS IN THE 7.5" DIA. BEARING PLATE IS CALCULATED BY ASSUMING A 1" STRIP UNIFORMILY LOADED BY CONCRETE BEARING STRESS (1.36 KSI) IS CANTILEVERED FROM THE INTERFACE BETWEEN 4.0" AND 7.5" DIA. PLATES.



BENDING MOMENT (1" STRIP) $= 1.36 \times \left(\frac{7.5-4}{2}\right)^2 \times \frac{1}{2}$

$=$ [illegible] K-IN

SECTION MODULUS OF 1" SECTION $= \frac{t^2}{6} = \frac{(1)^2}{6} = .167 in^3$

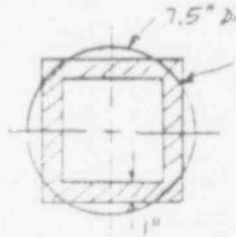
MAX. BENDING STRESS $= \frac{[illegible]}{.167} =$ [illegible] < 41.4 ksi OK

AS SUPPORT LEG COLLAPSES THE JACKSCREW IS SUBJECTED TO MAX. AXIAL REACTION LOAD $= 72.72^K$

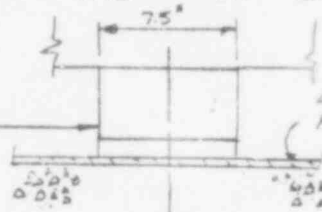
∴ AXIAL STRESS $= \frac{72.72^K}{1.406 in^2} = 51.72$ ksi < 106.3 ksi — P.E-7 Ref. 26

$A_{BxT} = 1.406 in^2$

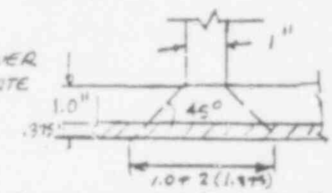
THE SUPPORT LEG COLLAPSES AND THE GRID FALLS. ASSUMING THAT THE SUPPORT LEG BASE PLATE COLLAPSES AND THE BOX CROSS-SECTION IMPACTS THE 7.5" DIA. BEARING PLATE.



YIELDED LEG PLAN



YIELDED LEG ELEVATION



CONSERVATIVE BEARING AREA PER PANEL = 3.75 in

THE STORAGE CELLS AND LOWER GRID WILL COLLAPSE AROUND THE SUPPORT LEG. THE MAX. LOAD APPLIED TO THE SUPPORT LEG BOX-SECTION IS THE BUCKLING LOAD OF THE STORAGE C[illegible] ABOVE THE LEG PLUS 1/4 THE LOAD OF 4 ADJACENT CELLS. $P = 83.62 + 4(1/4)83.62 = 167.24^K$

MAX. CONCRETE BEARING STRESS $= \frac{167.24^K}{(3.75)(4)\left(\frac{7.5+5.5}{2}\right)} = 1.72$ ksi < 2.09 ksi — REF. 14 OK

NOTE: BEARING AREA IS CONSERVATIVELY ASSUMED BOX CROSS-SECTION ONLY.

POOR ORIGINAL

458 312

	REF.
Analysis of the free fall of cask, fuel assemblies and storage rack structure from a height of 6" and possessing 9816.12 K-in of kinetic energy of the cask.	
Total weight of the cask, fuel assemblies & rack structure for each 1x1 array of storage rack (8x9 rack)	
$= \frac{100}{8 \times 9} + 2 \times 0.650 = 2.69$ K.	
(weight of each fuel assembly + shroud + rack structure = 650 lbs.)	
Remaining 9816.12 K-in of kinetic energy of the cask drop event OR $\frac{9816.12}{31018.14} \times 100 = 31.65\%$	P. B4
Remaining 31.65% of the kinetic energy of the cask for each 1x1 array of the 8x9 storage rack LESS A PROPORTION DISTRIBUTED INTO THE SUPPORT LEGS IS: $\frac{9816.12}{72 \text{ CELLS}} = 136.3$ K-in	
Additional kinetic energy acquired by the cask fuel assemblies and rack structure during a free fall of $6'' = 2.69 \times 6 = 16.14$ in.K	
∴ Total kinetic energy at the instant of impact to the floor liner plate $= 136.3 + 16.14 = 152.48$ in.K.	
Equivalent impact velocity V_s is given by	
$\frac{1}{2} M V_s^2 = 152.48$	

POOR ORIGINAL

458 313

REF.

or $\frac{1}{2}\frac{2.69}{386.4}V_s^2 = 152.48$

$\therefore V_s = 209.3$ in/sec.

$= \frac{209.3}{12} = 17.44$ ft./sec.

The analysis of liner plate that could be perforated by a missile having an impact velocity of 17.44 ft./sec and frontal area of 1x1 grid structure can be performed by using Ballistic Research Laboratory (BRL) equation and the Stanford Research Institute (SRI) formula given in Reference 10.

The BRL Formula is shown below, modified by setting a material constant K = 1 and solving directly for steel plate thickness, T, which will just be perforated by the missile,

PI-3 Ref 10

$$T = \frac{\left(\frac{MV_s^2}{2}\right)^{2/3}}{672D} \qquad (2-7)$$

where

T = Steel plate thickness to just perforate (inches).

M = Mass of the Missile (lb sec^2/ft) $= \frac{2690.0}{32.17} = 83.62$

W = Weight of the Missile (lb) = 2690.0

V_s = Striking Velocity of the Missile Normal to Target Surface (ft/sec) = 17.44 f/s

D = Diameter of the Missile (in.) $= \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 5.69}{\pi}} = 2.69$ in

A = Frontal Area of 1x1 Lower grid Structure $= \frac{4 \times 6.5 \times \frac{7}{16}}{2} = 5.69$ in^2

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	REF.

$$\therefore T = \frac{\left\{\frac{83.62}{2}(17.44)^2\right\}^{2/3}}{672 \times 2.69} = 0.301 \text{ in.}$$

SRI Formula is shown below (P.C-9 Ref.10)

$$\frac{E}{D} = \frac{S}{46,500}\left(16,000\, T^2 + 1,500\frac{W}{W_s}\cdot T\right)$$

T = steel thickness to be just perforated (in.)

D = diameter of the missile (in.) = 2.69

E = critical kinetic energy required for perforation (ft-lb), = $\frac{152480}{12}$

S = ultimate tensile strength of the target minus the tensile stress in the steel (psi) = 114000.0

W = length of a square side between rigid supports (in.), = 4"

W_s = length of a standard width (4 in.).

$$\therefore \frac{152480}{12 \times 2.69} = \frac{114000.0}{46,500}\left(16000 T^2 + 1500 \times 1 \times T\right)$$

or $T^2 + 0.09375 T - 0.1204 = 0$

$$\therefore T = \frac{-0.09375 \pm \sqrt{(0.09375)^2 + 4 \times 0.1204}}{2}$$

$= 0.303$ in

The thickness, t_p, of a steel barrier required to prevent perforation should exceed the thickness for threshold of perforations. It is recommended to increase the thickness, T, by 25 percent to prevent perforation.

$$t_p = 1.25T \qquad (2\text{-}8)$$

$= 1.25 \times 0.303$

$= 0.379$ inches

Provide 3/8" thick Plate under the storage rack structure

REF.

EFFECTS ON POOL FLOOR:

It is difficult to determine the maximum reaction load transmitted to the pool floor by the rack which has been deformed by the initial impact of the cask. The load transmitting capabilities of the deformed storage cells are much lower than that of the undeformed storage cells. Conservatively assume that the reaction load transmitted to the floor is equal to that developed in the undeformed storage cells at the instant of impact to the floor

Max. Kinetic Energy / cell at the instant of impact

= 152.48 in.K.

∴ Strain in the storage cell $= \varepsilon_x = \left[\frac{1.166 \times 152.48}{128.5 \times 2.108 \times 212}\right]^{1/1.166}$

$= 0.00705$ in./in.

Max. stress Developed in the cell $= 128.5(0.00705)^{0.166}$
= 56.45 ksi > BUCKLING STRESS (39.67 ksi), THEREFORE CELL WILL FAIL BY BUCKLING.

∴ Max. Reaction Load Transmitted to the Pool Floor

Per Storage Cell $= 2.108 \times 1 \times 39.67 = 83.62$ K.

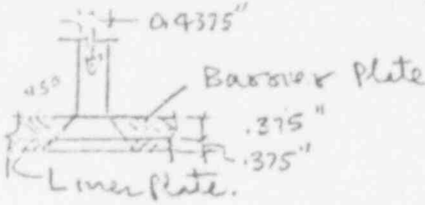
Max. Reaction Load Transmitted by 72 storage cells

$= (72)(83.62) = 6021.0$ K

Max. Punching shear stress in the 3/8" thick stainless steel Plate $= \frac{83.62}{4 \times 7 \times 2 \times 0.375} \doteq 3.98$ Ksi

	REF.

Max. Local Bearing Stress on Concrete Floor



$$= \frac{83.62}{4 \times 7 \times \{(0.375 + 0.375)2 + 0.4375\}}$$

$$= 1.54 \text{ Ksi.}$$

Max. Punching Shear Stress on Concrete Floor

$$= \frac{83.62}{4(54 + 7.0)54} = 0.006 \text{ Ksi.}$$

Max. Compressive stress on the wall under the pool Floor

$$= \frac{83.62(72)}{42(42 + 2 \times 54)} = 0.956 \text{ Ksi.} < 2.08 \text{ Ksi (allowable)}$$

Allowable Reaction Load on wall = $2.08 \times 42(42 + 2 \times 54) = 13{,}104$ K

CONCLUSIONS

(1) Drop of the Cask on top of the fuel storage racks will cause the following damages

a. The impacted storage cells will undergo significant local and axial deformations

b. The storage rack support feets will collapse

c. The storage rack base structure will fail

d. The storage rack structure with the cask on it will fall freely on top of the liner plate.

e. A 3/8" plate on top of the liner plate is required to preclude penetration of the liner plate and maintain the leak tight integrity of the pool.

f. The maximum reaction loads, bearing and shearing stresses developed in the reinforced