Monticello Nuclear Generating Plant
Operated by Nuclear Management Company, LLC

September 7, 2006

L-MT-06-058
10 CFR 50.90

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Monticello Nuclear Generating Plant
Docket 50-263
License No. DPR-22

Response to Request for Additional Information for a License Amendment Request for Contingent Installation of a Temporary Fuel Storage Rack in the Spent Fuel Pool (TAC No. MD0302)

References: 1) NMC letter to U.S. NRC, "License Amendment Request for Contingent Installation of a Temporary Spent Fuel Storage Rack," (L-MT-06-013), dated March 7, 2006.

2) NMC letter to U.S. NRC, "Supplement to a License Amendment Request for Contingent Installation of a Temporary Fuel Storage Rack in the Spent Fuel Pool (TAC No. MD0302)," (L-MT-06-044), dated May 30, 2006.

On March 7, 2006, the Nuclear Management Company, LLC (NMC) submitted a license amendment request for the Monticello Nuclear Generating Plant (MNGP) (Reference 1) to revise the licensing basis to allow temporary installation of a Programmed and Remote (PaR) Systems Corporation 8x8 (64 cell) high-density fuel storage rack in the spent fuel pool (SFP) to maintain full core off-load (FCOL) capability. On May 30, 2006, the NMC submitted the associated criticality evaluation and supporting analyses (Reference 2) as a supplement to the license amendment request.

On June 9 and July 6, 2006, the U.S. Nuclear Regulatory Commission (NRC) requested additional structural information following the Standard Review Plan Section 3.8.4, Appendix D, format during teleconferences with the NMC. Enclosure 1 provides the requested PaR fuel storage rack module structural design related information in the accordance with Appendix D. Enclosure 2 provides copies of several figures and drawings referred to within Enclosure 1.

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On April 26, 2006, the NRC provided three requests for additional information (RAI) related to the thermal-hydraulic and criticality aspects of the March 7, 2006, license amendment request. The May 30, 2006, license amendment request supplement answered two of the three RAIs. The response to the remaining RAI is provided in Enclosure 3.

Enclosure 4 provides a non-proprietary copy of sections of the PaR Report on the high-density fuel storage rack module design that have not been previously submitted.

This letter makes no new commitments or changes to any other existing commitments.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on September 7, 2006.

John T. Conway
Site Vice President, Monticello Nuclear Generating Plant
Nuclear Management Company, LLC

Enclosures: (4)

cc: Administrator, Region III, USNRC
Project Manager, Monticello, USNRC
Resident Inspector, Monticello, USNRC
Minnesota Department of Commerce

ENCLOSURE 1

STRUCTURAL RAI INFORMATION RESPONSE

1.0 SUMMARY

On March 7, 2006, the Nuclear Management Company, LLC (NMC) submitted a license amendment request (LAR) (Reference 1) to revise the Monticello Nuclear Generating Plant (MNGP) licensing basis to allow temporary installation of a Programmed and Remote (PaR) Systems Corporation 8x8 (64 cell) high-density fuel storage rack module in the spent fuel pool to maintain full core off-load capability. On May 30, 2006, the NMC submitted the associated criticality evaluation and supporting analyses (Reference 2) for the temporary PaR fuel storage rack module.

On June 9 and July 6, 2006, the U.S. Nuclear Regulatory Commission (NRC) requested additional information in accordance with the guidance of Standard Review Plan (SRP) Section 3.8.4, Appendix D, "Technical Position on Spent Fuel Pool Racks," (Reference 3) format during teleconferences with the NMC.

> SRP [Standard Review Plan] Section 3.8.4, Appendix D, identifies the information that the NRC staff reviews with respect to the structural integrity of a spent fuel rack. He [the NRC reviewer] suggests that you provide information specific to the rack in line with the guidance there.

This RAI response provides the requested structural information and associated PaR and NMC documents. The MNGP was designed and constructed prior to issuance of the SRP, and consequently not designed to meet the SRP guidance. To facilitate staff review, however, applicable structural design information is provided following the SRP, Appendix D format.

2.0 BACKGROUND

The temporary 8x8 PaR fuel storage rack module to be used at the MNGP (if required) was originally slated to be installed in the Duane Arnold Energy Center (DAEC) spent fuel pool. This fuel storage rack module was not installed and has been made available to the NMC, to be installed if necessary, in the MNGP spent fuel pool (SFP) in the event a full core off-load (FCOL) becomes necessary prior to operation of the MNGP Independent Spent Fuel Storage Installation (ISFSI).

3.0 REVIEW USING SRP SECTION 3.8.4, APPENDIX D

The PaR Systems Corporation developed a "Fuel Storage System Design Report," (Reference 4) (contained on compact disc as Enclosure 4), hereafter referred to as the PaR Report, covering various design topics for the high-density spent fuel storage rack module sizes procured by DAEC. This report is applicable to the temporary 8x8 PaR fuel storage rack module to be installed at the MNGP (if required in the event of a FCOL). A copy of portions of this PaR Report have been provided to the NMC for application at the MNGP.

ENCLOSURE 1

STRUCTURAL RAI INFORMATION RESPONSE

Enclosure 2 provides copies of several figures and drawings that are referred to within this enclosure. Enclosure 4 provides a listing of the applicable sections of the PaR Report. It identifies the PaR Report sections submitted in the March 7, 2006, LAR; those submitted in the May 30, 2006, supplement; and those sections provided in this submittal.

SRP Section 3.8.4, Appendix D provides the current requirements and criteria for the NRC review of SFP fuel racks and associated structures. To facilitate NRC staff review, structural design information is summarized below. Specific references to the PaR Report are provided throughout this response describing how SRP Section 3.8.4, Appendix D, criteria are met.

(1) Description of the Spent Fuel Pool and Racks

(a) Support of the Spent Fuel Racks

The temporary PaR 8 x 8 high-density fuel storage rack is constructed of bolted anodized aluminum with a Boral neutron absorber in an aluminum matrix core clad with 1100 series aluminum at alternating cell locations. The high-density spent fuel storage rack module was manufactured by the PaR Systems Corporation. The module consists of an 8 by 8 array of tubes. The absorber material is sealed within two concentric square aluminum tubes. The rack is approximately 4.5 feet-square by 14 feet high. Nominal fuel element center-to-center spacing is 6.625 inches. A more detailed description of the PaR fuel storage rack modules is provided in Section 3.2, “Rack Description,” of the PaR Report (pages 3.0-2 and 3.0-3).

> Note: The PaR Report includes the following fuel storage rack module sizes: 8x8, 8x10, 8x11, 10x11, and 11x11 (see PaR Report, Section 3.1, “General,” page 3.0-1).

The 8x8 fuel storage rack module to be installed at MNGP, and the other module sizes, are a free standing design, constrained by friction only, and are designed to be unrestrained by additional seismic supports in the pool. (PaR Report, Installation Description, page 3.0-3.)

The maximum fuel storage rack module displacement was determined to be 1.05 inch (PaR Report, Section 5.4, “Dynamic Time History Analysis of Spent Fuel Racks,” page 5.4-14). The analysis to determine the maximum displacement was performed as described in Section 5.4 of the PaR report for a single 8x11 fuel storage rack module for DAEC. (See PaR Report, Section 5.4, page 5.4-5.) This configuration bounds the potential lifting and sliding of all the fuel storage rack module sizes discussed in the PaR report, including the 8x8 fuel storage rack module to be utilized, if required, at the MNGP.

The temporary 8x8 fuel storage rack module (if installed) will be placed on the cask pad in the SFP at the MNGP. Based on the maximum displacement analysis discussed previously, with the maximum displacement of 1.05 inches, there will not be any interface concerns between the temporary 8x8 fuel storage rack module and the existing spent fuel storage rack modules or the pool walls due to the immediate spacing, which will be greater than 6 inches.

There is no impact on the spent fuel pool liner since the temporary PaR 8X8 fuel storage rack module installation will be on the cask pad and will be located a distance greater than the maximum displacement of 1.05 inches from the cask pad edge to assure the fuel storage rack module will remain on the cask pad. The location of the fuel storage rack module will be procedurally controlled during installation to ensure it is correctly located on the cask pad. A description of interfaces between the 8x8 fuel storage rack module and the cask pad is provided in Section (3) of this enclosure.

The location of the temporary 8x8 PaR fuel storage rack module in relation to the existing fuel storage rack modules in the SFP is shown on the mark-up of MNGP Drawing No. NX-7865-15-36, entitled High Density Fuel Storage System Installation Arrangement, and is provided in Enclosure 2.

(b) Fuel Handling

The fuel handling drop accidents are not changed due to the addition of the temporary 8x8 PaR fuel storage rack module in the fuel pool. Section (4) of this enclosure discusses the evaluation of a fuel assembly drop on the PaR fuel storage rack module designs.

(2) Applicable Codes, Standards, and Specifications

The PaR fuel storage rack module is constructed from aluminum materials (except as indicated in the table below). The materials used for the PaR fuel storage rack modules construction are compatible with the SFP environment (i.e., negligible corrosion impact). Section 5.0.2 of the PaR report, “Material Properties,” (page 5.0-3) lists the following fuel storage rack module components and their respective material or material alloy.

Top and Bottom Casting	A356-T51
Side Panels	6061-T6
Angle Connectors	6061-T6
Cavity Weldment	5052-H32
Bolts	2024-T4
Rivets	5052 Body
ABS Plastic	Cycolac Grade T
Bearing Plate on Foot	304 Stainless
Tread Foot	6061-T6

“Allowable stresses were based on the Specification for Aluminum Structures – Aluminum Construction Manual” (PaR Report Table 5.5.4-1, “Normal Limits of Stress,” page 5.5-20).

(3) Seismic and Impact Loads

A Safe Shutdown Earthquake (SSE) time history was generated for the dynamic time history analysis of the fuel storage rack modules. The response spectrum for this generated time history and the DAEC response spectrum for the horizontal and vertical directions were plotted on Figures A and B in the PaR Report (Section 5.4, “Dynamic Time History Analysis of Spent Fuel Racks,” pages 5.4-8 and 5.4-9 respectively). The response spectra for the MNGP spent fuel pool has been overlaid on these two figures and the figures renamed as Figures AA and BB in Enclosure 2. The time history response spectrum that was used in the PaR analysis was plotted at a 6 percent damping value. The response spectrum for the MNGP was performed and is plotted at a 5 percent damping value. As shown on Figures AA and BB (provided in Enclosure 2) the 6 percent damping response spectra used in the analysis envelopes the MNGP 5 percent response spectra in the frequencies of interest. If a 6 percent damping curve was available it would lower the acceleration values, therefore, using a 5 percent damping curve for comparison is conservative. The MNGP response spectrum curves for the spent fuel pool were generated consistent with the guidance of Regulatory Guide 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants.”

As shown in Figures AA and BB in Enclosure 2, the time history response spectrum used in the PaR analysis bounds the MNGP response spectrum in the frequency range of interest (i.e., the frequency range of the 8x8 fuel storage rack module). The first natural horizontal frequency of the fuel storage rack module analyzed by PaR was 8 hz (0.125 second period) (see PaR Report, Section 5.3, "Model Description, Formulation and Assumptions for the Seismic Analysis of BWR Spent Fuel Racks," page 5.3-4). As shown on the plot, at this frequency of interest, the MNGP response spectrum is well below the time history response spectrum used in the PaR analysis. The first natural vertical frequency of the fuel storage rack module analyzed by PaR was 14 hz (0.07 second period) (see PaR Report, Section 5.3, page 5.3-4). Also, as shown on the plot, at this frequency of interest, the MNGP response spectrum is well below the time history response spectrum used in the PaR analysis. Accordingly, it is concluded that the seismic evaluations in the PaR Report are bounding for the MNGP. Therefore, the PaR 8x8 fuel storage rack module will withstand the MNGP SSE loads.

Consistent with Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," the seismic responses are combined by the square root sum of the squares (SRSS) for the three orthogonal directions.

The SRSS is:

$$SRSS = [(XZ)^2 + (YZ)^2]^{1/2}$$

The following assumptions were made relative to rack submergence in the SFP. It was assumed that all water entrapped within the fuel storage rack module envelope was included in the horizontal mass of the model. No sloshing effects were included due to the pool water moving with the pool walls due to the elevation of the rack modules. No increase in effective mass was used because the damping forces generated in the pumping of the confined water from the wall rack module gap is much greater than that added by external water mass effects. (See PaR Report, Section 5.3, page 5.3-6).

The PaR fuel storage rack modules discussed in the report are designed for Boiling Water Reactor (BWR) fuel assemblies. BWR fuel assemblies have a standard cross-sectional dimension, and hence the fuel assemblies modeled are consistent with those to be stored. The fuel assemblies were modeled as loose elements, free to impact on the fuel storage rack module structure through gap elements on both sides of the fuel assembly with a nominal initial clearance (gap) of 3/8 inch each side when inserted in the storage cavity. This gap is applicable to the MNGP due to the standard sizing of the BWR fuel assembly design. This approach conservatively assumed that all fuel assemblies impacted at the same time. It was also assumed that all fuel bundles were channeled (i.e., a fuel assembly) to result in the largest impact load to the fuel storage rack module structure (PaR Report, Section 4.3, "Seismic Model Description, Formulation and Assumptions," page 4.0-3a).

The dynamic analysis included interaction between the fuel assembly and the storage cavity with the use of gap elements. Interface elements allowed the fuel storage rack module to slide and/or rock (PaR Report, Section 5.4, page 5.4-5).

(4) Loads and Load combinations

The results of a dropped fuel bundle analysis and a verification test confirming the accuracy of the results are discussed in the following Sections of the PaR report.

- Section 5.6 - Equivalent Static Loads for Fuel Impact Conditions
- Section 5.7 - Dropped Fuel Bundle Analysis
- Section 6.3 - Simulated Dropped Fuel Bundle Test

Three fuel drop conditions were evaluated: (See PaR Report, Section 5.6, "Equivalent Static Loads for Fuel Impact Conditions;" page 5.6-3.)

1. 18 inch fuel drop on the corner of the top grid castings
2. 18 inch drop in the middle of the top casting
3. A fuel drop the full length of the storage cavity in the fuel storage rack module impacting on the bottom grid.

The buoyant weight used for the fuel bundle in the PaR analysis was 670 lbs which corresponds to a dry weight of 745 lbs (PaR Report, Appendix A.1, "Beam Section Properties, Module Dead Weight Estimate and Seismic Mass Input," page A.1-25). The maximum dry weight of a fuel assembly in the MNGP inventory is approximately 675 lbs which results in a buoyant weight slightly less than that used in the PaR evaluation.

A finite element model of a fuel storage rack module was used for the analysis of the three drop conditions (see PaR Report, Section 5.7, "Dropped Fuel Bundle Analysis;" page 5.7-1). The analysis showed that, except for localized stresses, the computed stresses were less than the allowable stresses. The analysis showed that the fuel bundle drop caused localized effects, and some components directly beneath the load showed localized stress concentrations, but results in no overstress condition thereby ensuring structural integrity of the fuel storage rack module.

A drop test was also performed which simulated an 18 inch drop on the top casting of the fuel storage rack module. The test results showed slight local deformation at the impact location. (See PaR Report, Section 6.3, "Simulated Dropped Fuel Bundle Test," page 6.3-4).

The addition of the 8x8 fuel storage rack module to the MNGP SFP structure has negligible effect on the overall floor loading. The existing fully loaded MNGP fuel storage rack floor loading is 2.1 ksf. The addition of one fully loaded 8x8 fuel storage rack module will not result in a floor loading over the design capacity of 2.7 ksf. Additionally the approximately 10,000 lb temporary 8x8 fuel storage rack module will be located on the cask pad in the SFP which has been evaluated for a 200,400 lb cask load.

The pool slab load imparted from an 8x11 fuel storage rack module rocking action is an equivalent static load of 75,083 lb. (See PaR Report, Section 4.4, "Dynamic Time History Analysis," pages 4.0-4 and 4.0-4a.) The analysis results for the 8x11 fuel storage rack module bounds the 8x8 fuel storage rack module proposed for temporary installation at the MNGP due to the larger mass of the 8x11 fuel storage rack module. The 8x8 fuel storage rack module will be located on the cask pad in the MNGP SFP.

The allowable cask pad loading of 200,400 lb bounds the equivalent static impact load of 75,083 lbs that would be exerted by the PaR 8x11 fuel storage rack module (used in the analysis) if it were installed. The PaR 8x8 fuel storage rack module, to be installed at the MNGP in the event a FCOL is required, weights less than 8x11 fuel storage rack module and hence would have a smaller impact load. The location of the fuel storage rack module will be controlled during the installation process to ensure proper placement on the cask pad in the SFP.

Load combinations used in the module rack analysis are: (See PaR Report, Section 4.7, "Dropped Fuel Bundle Analysis," page 4.0-9).

$D + L$
$D + L + E$
$D + L + T_O$
$D + L + T_O + E$
$D + L + T_a + E$
$D + L + DF$
$D + L + T_a + E^1$

Where,

D	=	Dead load, buoyant rack weight
L	=	Live load, buoyant fuel weight
T_O	=	Operating thermal loads
T_a	=	Accident thermal loads
E	=	OBE Seismic loads including impact of fuel and modules
E^1	=	SSE Seismic loads including impact of fuel and modules
DF	=	Dropped fuel bundle loads

The thermal loads resulting from combined expansion of the racks are negligible for the free standing design. However, load combinations containing T_O or T_a material yield strengths were taken at 212^{o}F, which for the aluminum alloys used in the fuel storage rack modules amounts to a reduction in yield of 5 percent, (PaR Report, Section 4.7.1, "Summary," page 4.0-8).

(5) Design and Analysis Procedures

An ANSYS computer model was used for a time history analysis from which the horizontal and vertical forces were determined. These forces were then applied to a SAP IV finite element model to determine stresses. Figure 3 in Section 5.3 of the PaR Report shows the mathematical model used for the single storage rack module time history analysis and Figure 4 shows the mathematical model for the double fuel storage rack module time history analysis (PaR Report Section 5.3, pages 5.3-11 and 5.3-12). A 3/8 inch clearance (gap) between the fuel assembly and the can was assumed at nodes 1 and 2, and 3 and 4 (PaR Report Section 5.3, pages 5.3-4 and 5.3-5). This model conservatively assumes that all fuel assemblies move in phase and move together at all times. Each fuel storage rack module leg is modeled as spring that can maintain or break physical contact and slide to each other. A 6 percent structural damping was used for both models (PaR Report Section 5.3, page 5.3-5).

All water entrapped within the fuel storage rack modules envelope was included in the horizontal mass of the model (PaR Report Section 5.3, page 5.3-6). No sloshing effects were included due to the pool water moving with the pool walls at the elevation of the fuel storage rack modules. No increase in effective mass was used because damping forces generated in "pumping" the confined water from the wall – rack gap is much greater than added external water mass effects (PaR Report Section 5.3, page 5.3-6). No lateral restraint is provided by the SFP walls for the free standing fuel storage rack module design. Consequently, there is no load interface between the fuel storage rack module and the SFP walls.

(6) Structural Acceptance Criteria

The normal allowables are based on the "Specification for Aluminum Structures – Aluminum Construction Manual," (PaR Report Section 5.5, pages 5.5-20 and 5.5-21). The acceptance criteria for the load combinations are (see PaR Report Section 2, page 2.0-2):

Load Combinations	Factored Allowable
D + L	S
D + L + E	S
D + L + T_O	1.5S
D + L + T_O + E	1.5S
D + L + T_a + E	1.6S
D + L + DF	1.6S
D + L + T_a + E^1	2.0S*

Where,

S	=	Normal allowable stresses
D	=	Dead load, buoyant rack weight
L	=	Live load, buoyant fuel weight
T_O	=	Operating thermal loads
T_a	=	Accident thermal loads
E	=	OBE Seismic loads including impact of fuel and modules
E^1	=	SSE Seismic loads including impact of fuel and modules
DF	=	Dropped fuel bundle loads

* PaR Report, on page 5.5-17 the factored allowable is S ≤ 1.6.

All results are within allowable criteria identified above. Based on the seismic input discussed previously in Section (3), which bounds the MNGP seismic criteria, the results stated in Section 5.5 of the PaR Report are also bounding for an installation of the PaR 8x8 fuel storage rack module at the MNGP. The seismic models used in the PaR Report are for the PaR 8x11 and the 11x11 fuel storage rack module sizes which are conservative with respect to induced loads for the smaller, PaR 8x8 fuel storage rack module intended for use at the MNGP (if required).

The maximum fuel storage rack module displacement was determined to be 1.05 inch (PaR Report Section 5.4, page 5.4-14). This provides a factor of safety of 5.7 to the minimum clearance distance of 6 inch to the nearest adjacent object in the SFP at MNGP. No significant rocking or liftoff was noted in the PaR evaluation (i.e., only pure rigid body sliding occurred). A low coefficient of friction of 0.2 was used for this evaluation which was based on testing of the PaR fuel storage rack modules. Testing included dry and wet conditions with two surface finishes. The results generally varied from a coefficient of friction of 0.23 to 0.29 for all conditions. Because the measured values discussed in the PaR Report do not show the effects of long term contact stress and corrosion, they were considered conservative. To arrive at a value of 0.2 for the coefficient of friction, the minimum measured value was reduced by approximately 15 percent to account for measurement uncertainties (PaR Report, Section 6.1, page 6.1-6).

The MNGP SFP has been previously modified to increase the original analyzed capacity from 740 to 2237 fuel assemblies by the installation of 13 High Density Fuel Storage System (HDFSS) modules, which replaced most of the General Electric (GE) low-density fuel racks. An evaluation (see Reference 5) of the SFP structural capacity was performed for the additional loads resulting from the replacement of the existing low-density fuel racks with the HDFSS modules. The evaluation demonstrated that the existing SFP structure was capable of supporting the increased loadings. The evaluation used a 2.7 ksi load assuming the HDFSS fuel storage rack modules were installed over the entire MNGP SFP floor area, which envelopes the proposed installation of the PaR 8x8 fuel storage rack module on the reinforced cask pad area within the MNGP.

(7) Materials, Quality Control, and Special Construction Techniques

The PaR 8x8 temporary fuel storage rack module is constructed from aluminum with material property values based on “Aluminum Standards and Data”, 1974-1975 published by the Aluminum Association (PaR Report, Section 5.0, page 5.0-3).

Existing MNGP procedures cover the handling of heavy loads, including the installation/removal of the temporary 8x8 PaR fuel storage rack module. These procedures provide controls for load handling, exclusion areas, equipment required, inspection and acceptance criteria before load movement, and steps / sequences to be followed during load movement, as well as defining safe load paths and special precautions. The design modification process identifies and prescribes any additional controls that are necessary for an installation.

REFERENCES

1. NMC letter to U.S. NRC, "License Amendment Request for Contingent Installation of a Temporary Spent Fuel Storage Rack," (L-MT-06-013), dated March 7, 2006.

2. NMC letter to U.S. NRC, "Supplement to a License Amendment Request for Contingent Installation of a Temporary Fuel Storage Rack in the Spent Fuel Pool (TAC No. MD0302)," (L-MT-06-044), dated May 30, 2006.

3. U.S. Nuclear Regulatory Commission, NUREG-0800, Standard Review Plan, Section 3.8.4, "Other Seismic Category I Structures, Appendix D to SRP Section 3.8.4 Technical Position on Spent Fuel Pool Racks," Revision 1, dated July 1981.

4. Programmed and Remote Systems Corporation, "Fuel Storage System Design Report," PaR Job 3091, Duane Arnold Energy Center Unit No. 1, Iowa Electric Light and Power Company, Cedar Rapids, Iowa, Contract No. 13764," Revision 3.

5. Bechtel Power Corporation, "Monticello Nuclear Power Station Reactor Building Seismic Evaluation of Spent Fuel Pool Structure, Prepared for the General Electric Company," dated January 1977.

ENCLOSURE 2

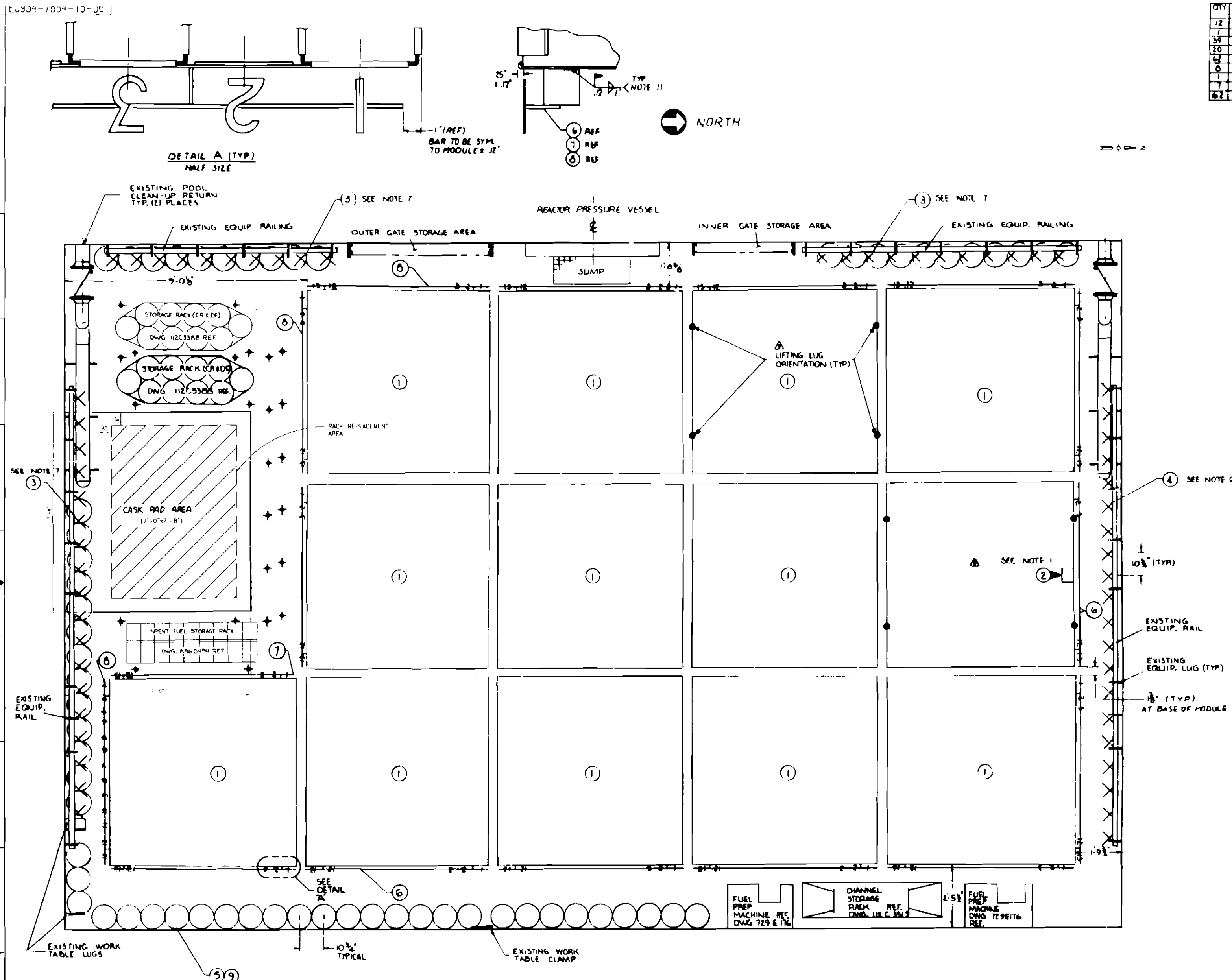
FIGURES / DRAWINGS REFERRED TO WITHIN ENCLOSURE 1

The following figures and drawing are enclosed.

FIGURE / DRAWING	TITLE
MNGP Drawing No. EC 934-7865-15-36	High Density Fuel Storage System Installation Arrangement With PaR 8x8 Fuel Storage Rack Module Location Identified (on cask pad)
Figure AA	Artificial Horizontal Time History Response Spectrum At 6% Damping Compared to Iowa Spec. M-303 Response Spectrum Overlaid With The Monticello Horizontal Time History Response Spectrum At 5% Damping.
Figure BB	Artificial Vertical Time History Response Spectrum At 6% Damping Compared to Iowa Spec. M-303 Response Spectrum Overlaid With The Monticello Vertical Time History Response Spectrum At 5% Damping.

3 Pages Follow

QTY	ITEM Nº	NAME	DESCRIPTION	FC
12	1	MODULE	C5442 E-103. G1	2B
1	2	MODULE	C5442 E-103 .G2	2B
39	3	C.R. HANGER	TYPE A C5442-E-108-G1	2B
20	4	C.R. HANGER	TYPE A1 C5442-E-108-G2	2B
62	5	C.R. HANGER	TYPE D C5442 E-110-G3	2B
8	6	IDENT. STRIPS	C5442 D-115- G2	4D
1	7	IDENT. STRIPS	C5442 D 115-G3	4D
7	8	IDENT. STRIPS	C5442 D-115-G4	4D
62	9	BRKT	C5442E-110-G2	2B



MONTICELLO SPENT FUEL STORAGE POOL (40'x26')
PLAN
SCALE ¾" = 1'-0"

LEGEND:

- X SYMBOL REPRESENTS THE TEMPORARY STORAGE POSITION OF A CONTROL ROD HUNG FROM THE EXISTING EQUIPMENT RAILING. 39 CONTROL RODS UTILIZE TYPE A HANGERS. 20 CONTROL RODS UTILIZE THE TYPE A1 HANGERS (NORTH WALL ONLY).
- ◯ SYMBOL REPRESENTS THE TEMPORARY STORAGE POSITION OF A CONTROL ROD UTILIZING THE TYPE D HANGER. THE TYPE D HANGER IS HUNG FROM THE TEMPORARY WALL BRACKET, SUPPORTED FROM THE POOL CURB AND STRADDLED BETWEEN THE TYPE A HANGERS. SEE SHEET 2 FOR DETAILS.
- ✦ SYMBOL REPRESENTS EXISTING SWING BOLTS VISIBLE AFTER HDFSS INSTALLATION.

NOTES:

1. (2)► NUMBER SPECIFIES MODULE ASS'Y, ARROW INDICATES PAINTED TUBE AND SPECIFIES MODULE ORIENTATION.
2. INSTALLATION WILL BE IN ACCORDANCE WITH INSTALLATION PROCEDURE C5442-1,2, et. al.
3. FOR MODULE BASE/SWING BOLT INTERFACE SEE DWG NO. C5442E-105.
4. FOR MODULE INSTALLATION TOOLS SEE C5442E-106.
5. SEE DWG. C5442E-102 SHEETS 2 AND 3 FOR INSTALLATION DETAILS.
6. TWENTY TYPE A1 CONTROL ROD HANGERS ARE TO BE HUNG FROM THE NORTH WALL EQUIPMENT RAILING.
7. DOUBLE TIERED STORAGE OF CONTROL RODS REQUIRES STAGGERING ITEM 3 AND ITEM 5.
8. ITEMS 3,4/5, CONTROL ROD HANGERS, ARE NOT INSTALLED CONCURRENT WITH MODULES. CONTROL ROD HANGERS ARE TO BE INSTALLED AS NEEDED TO MEET OPERATIONAL REQUIREMENTS.
9. FOR MODULE LIFTING TOOL ASS'T, SEE C5442E-400 AND TECHNICAL INSTRUCTION 22A5104.
10. ONE POSITION OF THE EXISTING CONTROL ROD/DEFECTIVE FUEL STORAGE RACK (DWG 112C3388) WILL BE USED AS A CONTROL ROD HANGER/GRAPPLE TRANSFER STATION.
11. FUEL SPACE IDENT. STRIPS MUST BE WELDED TO MODULES PRIOR TO INSTALLATION IN POOL.

GENERAL ELECTRIC C5442E-102A

HDFSS INSTLN. ARGMT. MONTICELLO — CONTROL A — FUNCTIONAL CLASS 2B

This map/document is to assist employees in the performance of their jobs. Your personal safety is provided for by using safety practices, procedures and equipment as described in safety training programs, manuals and SPAR's.

MONTI CAD DWG

SIGNIFICANT NUMBER	8700	--	350	1	C220 9011	1	4910
GROUP	1	2	3	4	5	CL	6

NSP MONTICELLO NUCLEAR GENERATING PLANT UNIT 1

MONTICELLO NUCLEAR GENERATING PLANT
HIGH DENSITY FUEL STORAGE SYSTEM INSTALLATION
ARRANGEMENT WITH P&R 8X8 FUEL-STORAGE RACK MODULE LOCATION IDENTIFIED

NORTHERN STATES POWER COMPANY
MINNEAPOLIS

SCALE NONE — REV A-A

EC934-7864-15-36

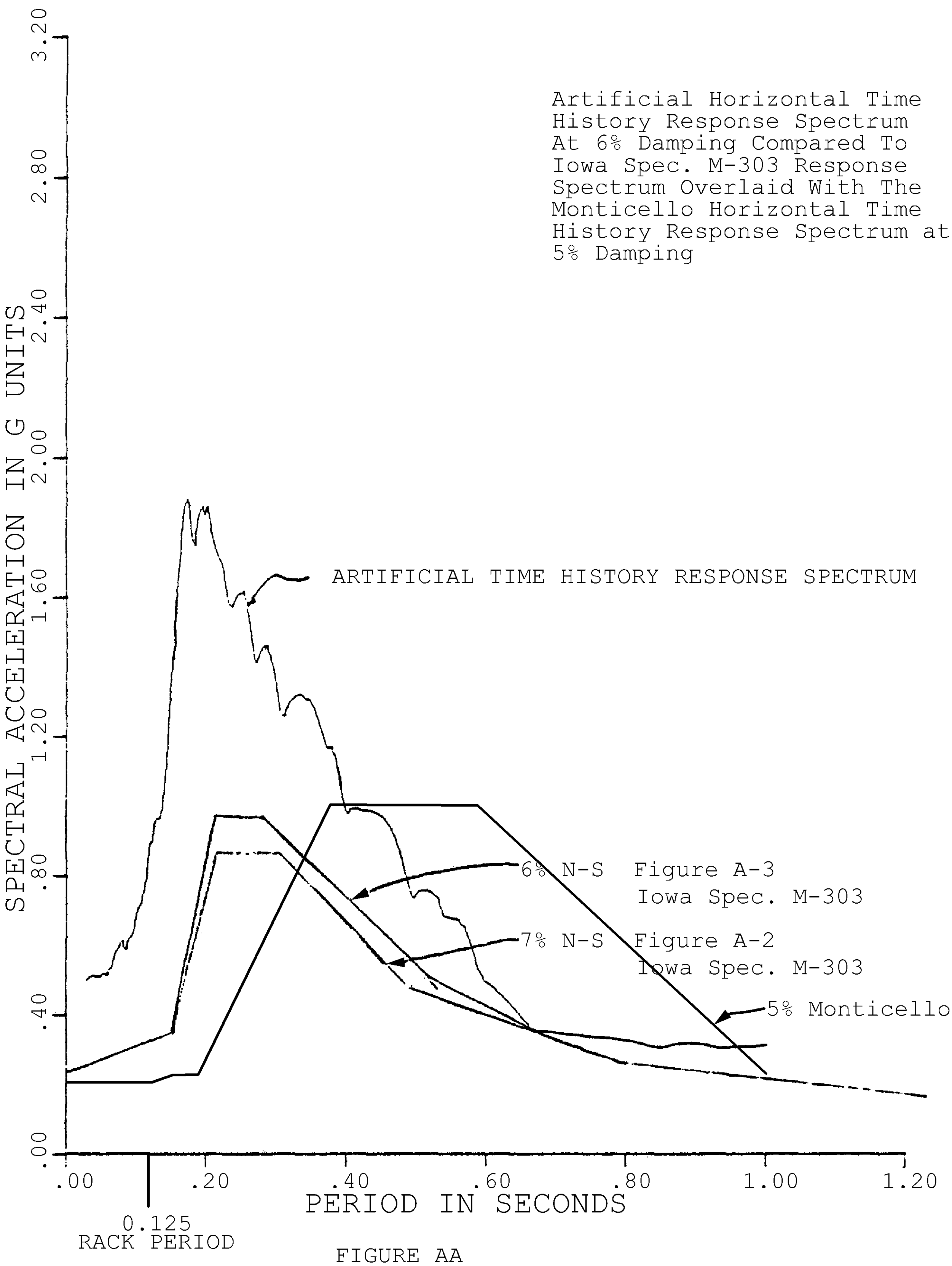

Artificial Horizontal Time History Response Spectrum At 6% Damping Compared To Iowa Spec. M-303 Response Spectrum Overlaid With The Monticello Horizontal Time History Response Spectrum at 5% Damping
ARTIFICIAL TIME HISTORY RESPONSE SPECTRUM
6% N-S Figure A-3 Iowa Spec. M-303
7% N-S Figure A-2 Iowa Spec. M-303
5% Monticello
SPECTRAL ACCELERATION IN G UNITS
3.20
2.80
2.40
2.00
1.60
1.20
.80
.40
.00
.00
.20
.40
.60
.80
1.00
1.20
PERIOD IN SECONDS
0.125
RACK PERIOD

FIGURE AA

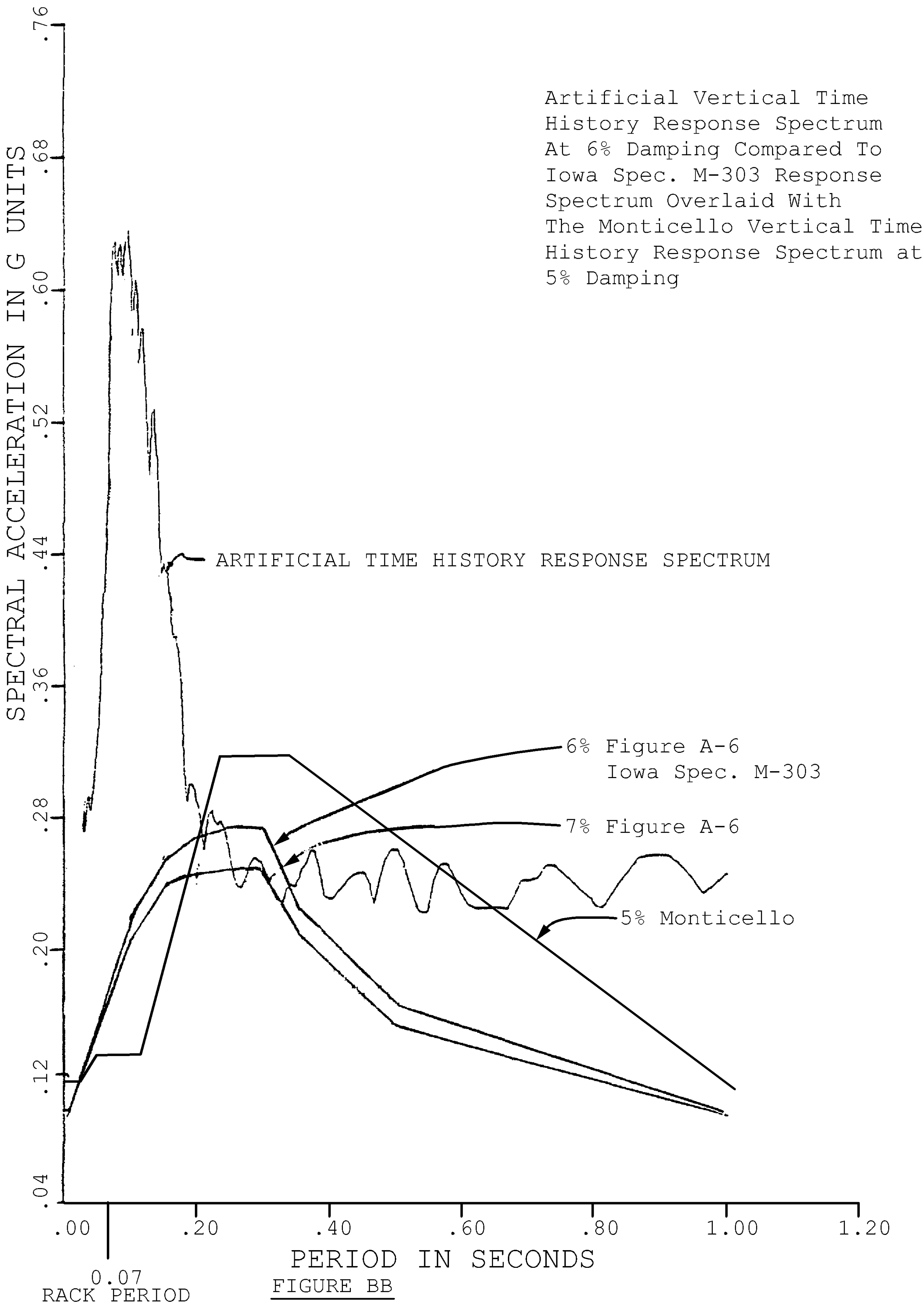

Artificial Vertical Time History Response Spectrum At 6% Damping Compared To Iowa Spec. M-303 Response Spectrum Overlaid With The Monticello Vertical Time History Response Spectrum at 5% Damping
SPECTRAL ACCELERATION IN G UNITS
.76
.68
.60
.52
.44
.36
.28
.20
.12
.04
ARTIFICIAL TIME HISTORY RESPONSE SPECTRUM
6% Figure A-6
Iowa Spec. M-303
7% Figure A-6
5% Monticello
.00
.20
.40
.60
.80
1.00
1.20
PERIOD IN SECONDS
0.07
RACK PERIOD

FIGURE BB

ENCLOSURE 3

THERMAL / HYDRAULIC RAI RESPONSE

1.0 SUMMARY

On March 7, 2006, the Nuclear Management Company, LLC (NMC) submitted a license amendment request (LAR) (Reference 1) to revise the Monticello Nuclear Generating Plant (MNGP) licensing basis to allow temporary installation of a Programmed and Remote (PaR) Systems Corporation 8x8 (64 cell) high-density fuel storage rack module in the spent fuel pool to maintain full core off-load capability. On May 30, 2006, the NMC submitted the associated criticality evaluation and supporting analyses (Reference 2) for the temporary PaR fuel storage rack module.

The U.S. Nuclear Regulatory Commission (NRC) provided three requests for additional (RAI) information in a teleconference with the NMC on April 26, 2006. Two of the three RAIs were answered in Reference 2. The remaining RAI is restated below.[1]

(2) Please compare in table form, with an attendant discussion, the current SFP licensing basis analysis to the supporting analysis of the SFP with the installation of the additional 8X8 high-density spent fuel storage rack. The information should include, but not be limited to, number of fuel assemblies and their distribution, the distribution of heat load, type of calculation, method of calculation of peak and average values, bulk temperature, clad temperature, Boral temperature, time-to-boiling, etc.

The response to this RAI is provided within the remainder of this enclosure.

2.0 CALCULATIONAL METHODS

A summary description of the Spent Fuel Pool Cooling and Demineralizer System consists and heat loads is provided Section A below. Section B discusses the calculational methods and results.

A. Spent Fuel Pool Cooling and Demineralizer System Description

The Spent Fuel Pool Cooling and Demineralizer System consists of two circulating pumps (450 gpm each), two heat exchangers, two filter/demineralizers, piping, valves and the associated instrumentation. The system is designed to maintain a maximum SFP temperature less than 140°F. The pumps take suction from the skimmer surge tank which receives water from the top of the SFP. Water is continuously circulated

1 Table 2 at the end of this enclosure lists the three April 26, 2006, RAIs and their disposition. On August 24, 2006, additional draft thermal-hydraulic RAIs were received and are in review. Answers to these requests will be provided at a later date.

to the heat exchangers and filter/demineralizers before discharging the water through diffusers at the bottom of the SFP.

The removal of heat for an emergency heat load can be accomplished by the use of either the Spent Fuel Pool Cooling and Demineralizer System, or the Residual Heat Removal System. During refueling outages, full core offloads are allowed because heat loads are explicitly calculated and compared to cooling capabilities prior to any fuel movement that would increase the SFP heat load.

Currently, the maximum normal heat load is calculated to be 5.6×10^{6} Btu/hour at 96 hours after shutdown. The current emergency heat load is calculated as 20.0×10^{6} Btu/hour assuming a full core discharge 30 days after a return to power operations from a refueling outage and is completed within 150 hours after shutdown.

If SFP cooling capability is lost the time to achieve bulk pool boiling is greater than 10.3 hours, providing sufficient time to establish the required makeup rate of 43 gpm (the maximum evaporation rate after bulk boiling commences).

B. Calculation Methods / Distribution of Heat Load

The calculations used to determine the decay heat used in the evaluation were based on the criteria in ANSI/ANS-5.1-1994, “Decay Heat Power in Light Water Reactors,” (Reference 3) applying a one-sided 95 percent confidence level and an assumed power level of 1880 MWt. The fuel assembly batch power fractions assumed were based on the actual MNGP fuel bundle assembly cycle loading plans. Decay heat due to activation of fuel bundle structural components was included in the analysis in accordance with General Electric Services Information Letter 636, “Additional Terms Included in Reactor Decay Heat Calculations,” (Reference 4).

Other key parameters included in the calculation were the incorporation of a nominal operating cycle length of 24 months and a maximum river water temperature of 90°F.

Installation of the proposed temporary PaR 8x8 fuel storage rack module results in the addition of an additional 64 spent fuel storage locations (cells) that would be filled in the event of an emergency full core offload (resulting in a total of 2,301 locations). Conservatively, a total of 2,358 spent fuel storage locations (cells) were assumed filled upon completion of the full core offload scenario, which is greater than the pool capacity following installation of the temporary PaR 8x8 fuel storage rack module.

The results of the calculations (with the above considerations) to enable the installation of the proposed temporary PaR 8x8 fuel storage rack module resulted in the following:

Maximum Normal Heat Load

- 7.3×10^6 Btu/hour at 96 hours after shutdown
- 5.6×10^6 Btu/hour at 216 hours from shutdown

Emergency Heat Load

- 24.7×10^6 Btu/hour

The SFP heat loads are explicitly calculated and compared to the fuel pool cooling capabilities prior to any fuel movement. This ensures that the actual SFP heat load remains within the fuel pool cooling capability by delaying, if necessary, a FCOL until the SFP cooling capacity is sufficient to remove the decay heat (consistent with current NRC guidance). With respect to pool boiling, the effect of the additional heat load can be conservatively approximated by multiplying the current time to boiling of 10.3 hours times the heat load ratio. This results in a revised minimum time to boiling of approximately 8.3 hours. A time period of 8.3 hours provides more than sufficient time to establish the required makeup rate.

ENCLOSURE 3

THERMAL / HYDRAULIC RAI RESPONSE

Table 1 - Current Versus Proposed LAR Bases and Results

Bases/Results	Current Normal Heat Load	LAR Normal Heat Load	Current Emergency Heat Load	LAR Emergency Heat Load
Bases				
Methodology	ANSI/ANS 5.1-1994 (Note 7)	ANSI/ANS 5.1-1994 (Note 7)	ANSI/ANS 5.1-1994 (Note 7)	ANSI/ANS 5.1-1994 (Note 7)
Power Level (in MWt (Note 8))	1880	1880	1880	1880
SFP Capacity	2,237	2,358 (Note 1)	2,237	2,358 (Note 1)
Operating Cycle Length (Note 2) (in months)	18	24	18	24
Nominal Fuel Assembly Discharge	141 / RFO	152 / RFO	141 / RFO	152 / RFO
Maximum Mississippi River Temp. (Note 3)	90°F	90°F	90°F	90°F
GE SIL 636 Decay Heat	No	Yes	No	Yes
Maximum SFP Bulk Temperature	140°F	140°F	140°F	140°F
Results				
Maximum Heat Load (in Btu/hour)	$5.6x10^6$ @ 96 hours (Note 4)	$5.6x10^6$ @ 216 hours (Note 4) $7.3x10^6$ @ 96 hours	$20.0x10^6$ (Note 5)	$24.7x10^6$ (Note 5)
Heat Removal Capability (in Btu/hour)				$26.4x10^6$ Btu/hr
Minimum Time to Boiling (in hours)			10.3 (Note 6)	8.3

Notes:

1. The LAR requests an increase from 2,237 to 2,301 to accommodate a FCOL. For conservatism, the MNGP evaluation assumed total of 2,358 occupied storage locations.

2. MNGP has implemented a 2 year fuel cycle program.
3. Maximum source water temperature.
4. Discharge time is delayed such that the heat load does not exceed $5.6x10^6$ Btu/hour for normal discharges.
5. FCOL 30 days after last refueling discharge, completed 150 hours after shutdown.
6. Based on postulated bulk boiling conditions (loss of SFP cooling), the temperature of the fuel will not exceed 350°F. This is an acceptable temperature from the standpoint of fuel element integrity.
7. The MNGP uses the methodology described in ANSI/ANS-5.1-1994 (Decay Heat Power In Light Water Reactors) to calculate decay heat loads on a per-bundle or batch basis. The MNGP computer program derives the power history for each fuel bundle by multiplying the bundle Beginning-of-Cycle weight by the cycle exposure to determine the total bundle energy for a specific cycle of operation. A user specified power history can be defined to calculate the decay heat load of individual fuel batches. Individual fuel bundle decay heat at specified times, as well as total decay heat for the fuel bundles in the SFP, reactor, or for all bundles on site are program options. An uncertainty confidence interval of 1.65 times the ANSI/ANS-5.1 uncertainty was chosen consistent with MNGP Updated Safety Analysis Report assumptions.
8. The MNGP licensed thermal power level is 1775 MWt, the 1880 MWt analysis level was chosen for conservatism.

This program methodology has been verified by comparison of output to that contained in ANSI/ANS-5.1-1994 test cases. U.S. NRC Information Notice 96-039 (Reference 5) discussed issues associated with improper implementation of the ANSI/ANS-5.1 decay heat standard. The information notice was assessed by the NMC and reviewed for decay heat calculation impact. The review concluded that the issues identified in the IN have been properly accounted for in the MNGP program (i.e., the MNGP methodology properly implements the standard).

C. SFP and Fuel Assembly Component Maximum Temperatures

In support of the SFP re-racking during which the existing High Density Fuel Storage System (HDFSS) was installed at the MNGP in 1977, a full core discharge (normal cooling available) was evaluated which filled the last 484 storage locations. A maximum heat load of $27.2x10^6$ Btu/hour was calculated using the ORIGEN Code with the total SFP capacity of 2,237 storage locations filled by normal discharges and the full core offload. For these conditions the maximum water temperature for the SFP was determined to be less than 115°F, the maximum cladding temperature was 120.3°F, and the maximum Boral temperature in the storage tubes was determined to be 104.3°F. The emergency heat determined as part of the evaluation for the installation of the temporary PaR 8x8 fuel storage rack module is less than the HDFSS maximum heat load, and the associated temperatures previously determined remain reasonable.

The MNGP safety-grade RHR System is available to provide backup cooling of the SFP providing assurance that a total loss of pool cooling will not occur. However, assuming a total loss of SFP cooling does occur, the minimum time required to reach boiling under these conditions is 8.3 hours. This time period is well within the time necessary to establish a make up water source which will maintain SFP water inventory. Neglecting the preceding, under bulk boiling conditions the temperature of the fuel as determined by the analyses for the installation of the HDFSS will not exceed 350°F, which is acceptable from a fuel element integrity maintenance standpoint.

The present heat removal systems at the MNGP have adequate capacity to maintain the pool temperature within the current MNGP design basis. In the event of a loss of SFP cooling, the RHR System backup capacity exceeds that required to maintain the SFP bulk pool temperature below 140°F.

ENCLOSURE 3

THERMAL / HYDRAULIC RAI RESPONSE

Table 2 - Requests for Additional Information Status

The NRC issued three requests for additional information (RAIs) in a teleconference with the NMC on April 26, 2006. Two of the RAIs were answered in the supplement to the license amendment request (Reference 2). The three RAIs and their dispositions are restated below:

(1) Are there any limitations on the use of the PaR fuel rack in your LAR (i.e., only during a FCOL, by burnup, etc.)? Please state the limiting conditions explicitly.

Response provided in NMC letter dated May 30, 2006 (Reference 2).

(2) Please compare in table form, with an attendant discussion, the current SFP licensing basis analysis to the supporting analysis of the SFP with the installation of the additional 8X8 high-density spent fuel storage rack. The information should include, but not be limited to, number of fuel assemblies and their distribution, the distribution of heat load, type of calculation, method of calculation of peak and average values, bulk temperature, clad temperature, Boral temperature, time-to-boiling, etc.

Provided in this letter.

(3) Please compare in table form, with an attendant discussion, the current SFP licensing basis analysis to the supporting analysis of the SFP with the installation of the additional 8X8 high-density spent fuel storage rack. The information should include but not be limited to: number of fuel assemblies and their distribution, the distribution of burnup and enrichment, type of neutronic calculation to determine keff, (i.e., codes, cross sections, validation, etc.) estimation of uncertainty, maximum worth of the installed and fueled 8X8 high-density storage rack, etc.

Response provided in NMC letter dated May 30, 2006 (Reference 2).

REFERENCES

1. NMC letter to U.S. NRC, "License Amendment Request for Contingent Installation of a Temporary Spent Fuel Storage Rack," (L-MT-06-013), dated March 7, 2006.

2. NMC letter to U.S. NRC, "Supplement to a License Amendment Request for Contingent Installation of a Temporary Fuel Storage Rack in the Spent Fuel Pool (TAC No. MD0302)," (L-MT-06-044), dated May 30, 2006.

3. American National Standards Institute / American Nuclear Society (ANSI/ANS) 5.1-1994, "Decay Heat Power in Light Water Reactors."

4. General Electric Services Information Letter (SIL) 636, "Additional Terms Included in Reactor Decay Heat Calculations," Revision 1, June 6, 2001.

5. U.S. NRC Information Notice 96-039, "Estimates of Decay Heat Using ANS 5.1 Decay Heat Standard May Vary Significantly," dated July 5, 1996.

ENCLOSURE 4

PaR SYSTEMS DESIGN REPORT SECTION INDEX

This enclosure provides a non-proprietary copy of applicable sections of the PaR design report produced originally for the Duane Arnold Energy Center providing information on the design and analyses supporting the PaR high-density spent fuel storage rack module design.

PaR Report Section	Applicable Sections of the PaR Systems Report on the High-Density Rack Design	Previously Provided		Provided This Submittal[(3)]
		LAR Encl. 3[(1)] (Pages)	Supplement Encl. X[(2)]	
1.0	INTRODUCTION			X
2.0	DESIGN BASIS			X
3.0	SYSTEM DESIGN			X
3.1	General			X
3.2	Rack Description			X
3.3	Installation Description			X
4.0	SUMMARY AND CONCLUSIONS OF DESIGN REPORT			X
5.0	DETAILS OF THE DESIGN ANALYSIS			X
5.1	Nuclear Criticality Safety Analysis		X	
5.3	Model Description, Formulation and Assumptions for the Seismic Analysis of BWR Spent Fuel Racks	X (1-25)		
5.4	Dynamic Time History Analysis of Spent Fuel Racks, Duane Arnold	X (26-93)		
5.5	Module Stress Analysis	X (94-134)		
5.6	Equivalent Static Loads for Fuel Impact Conditions	X (135-150)		
5.7	Dropped Fuel Bundle Analysis	X (151-159)		
5.9	Pool and Rack Interface Loads			X
5.10	Poison Can Analysis			X
5.11	Module Lifting Frame Analysis			X
5.12	Module Shipping Skid Analysis			X
6.0	DESIGN TEST REPORTS			
6.1	Simulated Minimum Coefficient of Friction Test			X[(3)]
6.2	Bolt Clearance Test Report			X[(3)]
6.3	Simulated Dropped Fuel Bundle Test			X[(3)]

ENCLOSURE 4

PaR SYSTEMS DESIGN REPORT SECTION INDEX

PaR Report Section	Applicable Sections of the PaR Systems Report on the High-Density Rack Design	Previously Provided		Provided This Submittal(3)
		LAR Encl. 3(1) (Pages)	Supplement Encl. X(2)	
A.	APPENDIX			
A.1	Beam Section Properties, Module Dead Weight Estimate and Seismic Mass Input			X(3)
A.2	Tables of Allowable Stresses for Aluminum Structures			X(3)
A.3	Module Isometric			X(3)
A.4	Beam Section Properties and Allowable Stresses			X

Notes:

(1) NMC letter to the U.S. NRC, "License Amendment Request for Contingent Installation of a Temporary Spent Fuel Storage Rack," (L-MT-06-013) dated March 7, 2006.

(2) NMC letter to the U.S. NRC, "Supplement to a License Amendment Request for Contingent Installation of a Temporary Fuel Storage Rack in the Spent Fuel Pool (TAC No. MD0302)," (L-MT-06-044), dated May 30, 2006.

(3) These PaR Report sections were previously transmitted in an e-mail from the NMC to the NRC (Peter Tam), "FW: NRC e-mail Request, Dated 4/19 for Spent Fuel Storage Rack," dated April 19, 2006.

Rev. No.2
3-28-78

PROGRAMMED AND REMOTE SYSTEMS CORPORATION
3460 LEXINGTON AVE. NO., ST. PAUL, MINNESOTA 55112
AREA CODE 612 484-7261 TELEX #29-7473

January 1978

FUEL STORAGE SYSTEM DESIGN REPORT

PaR Job 3091

DUANE ARNOLD ENERGY CENTER UNIT NO. 1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

IA. ELECT. LT. & PR. CO.
REVIEW
Approved ✓
Appr. as Noted
Q.A.
Engr. 4/4/78
Grp. Ldr. 12-13-78
Sup. Engr. Const.
Ldr. Admin.
Prol. Engr. 1/9/79
Sup. Proj. Engr.
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Initial - Date

APPROVAL
CHK. Roger Hteyn DATE 5/29/80
APPR. for Pward DATE 6-13-80
ie: No. 7884-M303-23-1

PREPARED BY: ____________ Date 1-23-78
Engineering Project Manager

APPROVED BY: Karl E Neumeier Date 2-1-78
Engineering Manager

7884-M303-23-1

REVISION NO. ~~2~~ 3 Date 3-27-78

REVISION RECORD

Rev. No.	Date	Description	Chk'd By	Apprv'd By	Date
1	2-17-78	Table of Contents Header sht, rev. pg. Page 1.0-1, of Section 1.0 Sect. 5.13 NAI(new) Sect. 5.9 Sect. 5.4 (reissued) Sect. 6.3 A.1	[signature]	[signature]	2/10/78
2	3-27-78	Revised Pages 1.0-1, 2.0-1, 4.0-2, 4.0-3a, 4.0-4a, 4.0-8, 4.0-9, 4.0-10, 4.0-13, Rev. 3 of Section 5.3 Rev. 2 of Section 5.4 Rev. 2 of Section 5.9 Added Page 4.0-10a.	[signature]	[signature]	3/28/78

IA. ELECT. LT. & PR. CO.
REVIEW

Approved ______
Appr. as Noted ______
Q.A. ______
Engr. ______
Grp. Ldr. ______
Sup. Engr. Const. ______
Lic. Admin. ______
Proj. Engr. ______
Sup. Proj. Engr. ______
Initial - Date

NO	DATE	REVISIONS	BY	CHK'D.	ENGR	APPR.
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3	8/9/79	REV. PER DDC-307 ADDED PAGE 3.0-2	[initials]	DE	BE	[initials]

TABLE OF CONTENTS

APPENDIX

A.1 Beam Section Properties, Module Dead Weight Estimate and Seismic Mass Input

A.2 Tables of Allowable Stresses for Aluminum Structures

Table No.	Description
3.3.3	Factors of Safety for use with alum. Allowable Stress Specification
3.3.4a & 3.3.4b	Formulas for Buckling Constants
3.3.6	General Formulas for Determining Allowable Stresses
5.1.1a	Allowable Bearing Stresses for Building Type Structures
5.1.1b	Allowable stresses for Rivets, and Bolts for Building Type Structures

A.3 Module Isometric

A.4 Beam Section Properties and Allowable Stresses

1.0 INTRODUCTION

This report defines the complete design of the high density Spent Fuel Storage Modules to be installed at the Duane Arnold Energy Center (DAEC). The Spent Fuel Modules are being designed and fabricated in accordance with Iowa Electric Light & Power (IELP) Spec. No. M-303 and under IELP Contract Order No.13764.

The Spent Fuel Storage System is defined by assembly drawings, details and parts lists as shown in Section 3.0 of this report.

The equipment includes the following major items:

1) Spent Fuel Module Assembly
2) Module Lifting Fixture
3) Module Level Adjusting Tool

The design analysis includes the following calculations and tests:

Nuclear Criticality Safety Analysis
Spent Fuel Pool Cooling and Spent Fuel Assembly Heat Transfer Analysis
Seismic Model Description, Formulation and Assumptions
Time History Seismic Analysis
Module Stress Analysis
Equivalent Static Loads for Fuel Impact Conditions
Dropped Fuel Bundle Analysis
Module Bolt and Rivet Joint Connection Analysis
Pool and Rack Interface Loads
Poison Can Analysis
Module Shipping Skid Analysis
Dose Rate Calculations
Simulated Minimum Coefficient of Friction Test
Bolt Clearance Test Report
Simulated Dropped Fuel Bundle Test

2.0 DESIGN BASIS

The design is based on PaR document entitled, "Design and Fabrication Criteria For BWR Spent Fuel Racks:, Serial No. PARSP/3091. This document established criteria for the spent fuel racks based on (IELP) Specification No. M-303, latest industry and federal Standards, NRC Guidelines, and the PaR design and fabrication procedures. Criteria for the following topics are covered in this document.

Storage Rack Structure Geometry
Structure Materials
Structural Loads and Stresses for the Fuel Racks Criticality
Thermal Hydraulics
Quality Assurance

The Design Criteria also delineates the following design data.

Fuel Data
Pool Cooling System and Heat Load Data
Seismic Response Spectrums

The Loading Combinations and Factored allowables are given in Table 4-2 of the Duane Arnold NRC submittal for the racks and are reprinted here in Table 2-1.

TABLE 2-1

LOADING COMBINATIONS AND FACTORED ALLOWABLES

Load Combinations		Factored Allowable
1.	D + L	S
2.	D+L+E	S
3.	D+L+To	1.5S
4.	D+L+To+E	1.5S
5.	D+L+Ta+E	1.6S
6.	D+L+DF	1.6S
7.	D+L+Ta+E^1	2.0S

S = Normal allowable stresses

D = Dead load, buoyant rack weight

L = Live load, buoyant fuel weight

To = Operating thermal loads

Ta = Accident thermal loads

E = OBE Seismic loads including impact of fuel and modules

E^1 = SSE Seismic loads including impact of fuel and modules

DF = Dropped fuel bundle loads

3.0 SYSTEM DESCRIPTION

3.1 General

The equipment is defined by the following listed installations and assembly drawings, their related parts list and detail drawings.

I-21602-E	Spent Fuel Pool Installation
A-22556-E	Module Spent Fuel Typical
D-22044-C	Channel Storage Location
D-22045-C	Channel Storage Location
AD-21949-01-D	Level Adjusting Tool
A-22766-E	Module Lifting Fixture

The existing GE (2x10) BWR Storage Racks will be replaced by "high density" aluminum modules providing a maximum storage capacity of 2050 fuel bundles. The cavities are on nominal 6.625" center-to-center spacing and are fabricated in the following module sizes:

Module Size	Quantity	Cavities
8 x 8	1	64
8 x 10	2	160
8 x 11	9	792
10 x 11	5	550
11 x 11	4	484
	Total Cavities	2050

3.2 Rack Description

The high density poison BWR spent fuel racks are an all anodized aluminum construction, with a fuel spacing of 6.625" center-to-center.

The poison material is a 5.250" wide piece of boral 146" long which overlaps the active fuel length 1 inch on the top and bottom. There is a single piece of boral between fuel elements. The boral is isolated from the pool water by being seal welded between two concentric square tubes, hereafter called poison cans.

The poison cans are positioned into every other storage location of the module to provide the required boral geometry. They are supported in the module by top and bottom castings.

The top casting is 12" deep with 5.90 ± .05 openings. Into the top surface of the bottom casting there are cast pockets in every other opening which loosely captures the poison can. The bottom surface of the top casting has a mating tapered pocket which tightly positions the top of the poison can. The bottom castings have cast holes which are machined to support the bottom fitting of the fuel assembly. The top casting provides lateral support at the upper fuel fitting elevation.

The top and bottom castings are positioned by bolted 1/2" plates that run the full length of the module on all four sides. The corner of the plates are riveted and doweled together with angle connections.

In the four corners of the bottom casting, leveling screws allow for 1 1/2" level adjustment. The bottom bearing pad pivots on the leveling screw so that the full pad area is in contact with the floor, regardless of existing floor flatness and possible rocking modes from seismic. These feet can be remotely adjusted by a long handled tool(AD-21949-01-D) which is inserted down through the length of the cavity and engages into a mating square hole in the foot. The bottom of the pad bears against the pool liner, is 6" diameter- 304 stainless; and is bolted to the upper aluminum threaded portion with a plastic insulator sandwiched between. This sandwich prevents galvanic corrosion between these dissimilar metals. The plastic is volumetrically trapped in a pocket to preclude any creep during the 40 year design life.

3.3 Installation Description

Drawing I-21602-E, shows the new module arrangement with their feet locations relative to existing swing bolts, and existing modules. The racks are of a free standing design (constrained only by friction), and therefore, are unrestrained by additional seismic supports in the pool.

These rack sizes were chosen so that the support feet would be approximately in the centers of the existing swing bolt patterns.

The edges of all peripheral modules have clearances to walls and header pipes of 6.652" and 3" to swing bolts. These clearances provide ample cooling and sufficient space to preclude any rack impacts to these due to calculated seismic drift of the racks.

At the bottom casting elevation there are two 3/4 inch bosses on each internal rack sides of the side sheets. Alternating sides of the racks have these bosses either inboard or outboard. The boss patterns are then arranged so that each rack horizontally interlocks together with approximately 1/4" of clearance. Under seismic excitation these bosses provide that all the modules move as a group. The bosses also aid in proper module to module positioning during installation. The modules are a line-to-line fit at the top casting elevation.
Sheet 2 of the installation drawing shows the cavity location system. Bosses on the top casting maintain a .75" clearance from the outside sheet of one rack to the next.

4.2 Spent Pool Cooling & Fuel Assembly Heat Transfer

The maximum decay heat load is 1.82 (10^7) Btu/hr, which occurs when the spent fuel pool contains 2084* fuel assemblies including a full core unload completed 181 hours after shutdown.

Under full core unload conditions, the bulk water temperature cannot be maintained below the desired maximum value of 150°F by the spent fuel pool cooling system alone. It is therefore necessary to connect the residual heat removal system to the spent fuel pool. When this is done the pool temperature can be maintained well below 150°F.

Under normal fuel storage conditions, the maximum bulk water temperature that occurs when the spent fuel pool has external means of cooling is 142°F. This temperature occurs when the pool is cooled by one pump and one heat exchanger of the spent fuel pool cooling system.

An analysis was made of the natural circulation cooling of maximum power spent fuel assemblies in the most restrictive natural circulation flow loop in the spent fuel pool. The analysis included the 7x7, the 8x8, and the retrofit 8x8 fuel assembly types. The maximum coolant temperature at the outlet of any fuel assembly type was calculated to be 172.2°F while the maximum clad temperature was calculated to be 189.5°F. Under these conditions there is no boiling in any fuel assembly.

*NOTE: Heat load calculations are conservatively based on 2084 total assemblies, whereas total cavities installed at DAEC will be 2050. The reduction of these 34 cavities was derived after the thermal analyses were started by IELP because of reactor gate interferences.

If all external means of cooling for the spent fuel pool are lost, the bulk water temperature will rise until it reaches saturation (212°F). The time required for this to occur is at least 6 hours.

Once saturation is reached, the water will boil and the level of the pool will fall unless makeup water is added at a rate of 33.6 gallons per minute.

An analysis was made of the natural circulation cooling of maximum power spent fuel assemblies under loss of cooling conditions. The analysis included the 7x7, the 8x8, and the retrofit 8x8 fuel assembly types. The results indicate that net boiling occurs in the upper third of the active fuel. The maximum void fraction at the outlet of any fuel assembly type was calculated to be 0.860, while the maximum clad temperature was calculated to be 260.1°F.

4.3 Seismic Model Description, Formulation and Assumptions

In this Section the development of the seismic design approach is presented. The seismic qualifications are done via a time history analytical solution of a simplified model. The loads computed from this analysis are used as input into a detail static model to determine member and plate stresses.

Various dynamic effects were accounted for in the simplified model which included the following:

1. Members of the simplified model were sized to simulate overall flexibility characteristics of the detail rack structure.

2. The fuel bundles were modeled as loose elements free to impact on the rack structure thru a 3/8" gap which is the clearance of the fuel assembly inside the storage cavity. This idealization conservatively assumed that all fuel bundles impacted at the same instant. Also it assumed that all assemblies were channeled, so as to provide the largest impact load onto the rack structure due to this stiffer section.

3. Added water mass effects were included due to rack submergence. No increase in damping was used due to the water.

4.4 Dynamic Time History Analysis

Using the ANSYC computer code, a planar analysis was done of two racks (10x11) and (8x11) side by side in the lo and 8 cavity plane. These racks had the potential to lift up, interact (bang together at top or bottom), and slide. Simplified rack models were used as determined in the previous section. Masses of the structure, fuel, and water were applied at the proper location. The racks were subjected to a simultaneous vertical and horizontal SSE time histories that were conservative based on Iowa Specification response spectrums. The following friction conditions were used:

1) .8 coefficient of friction Full of Fuel
2) .2 coefficient of friction Empty of Fuel

Condition 1) was considered for producing the largest loads. Nodal load sets when maximums occured at various times throughout the earthquake were extracted, and are summarized in Section 5.4. A static analysis of the detailed SAP IV model using these loads was done in Section 5.5.

Under this high coefficient of friction, μ, very little lateral displacement was noted. The motion was confined primarily to flexible body rocking with a total vertical lift-off of approximatley 1". The rack to rack impact load was calculated at 120,000 #.

The following table summarizes the per foot impact load and equivalent static nodal load at the foot for some of the rack sizes.

	8 x 11	10 x 11
Peak Impact Load	197600#	250985#
Equivalent Static Load	75083#	94823#

Condition 2) was analyzed to determine the largest credible rack displacement relative to pool floor. Displacement of 1.05" was calculated, for this condition. No significant rocking or lift off was noted for these conditions; i.e., only pure rigid body sliding occurred. A .1μ was used to simulate a .2μ for an empty rack. This was determined by taking the ratio of the horizontal to vertica mass for the empty rack divided by the same ratio for the full rack times .2μ. For Example: The total horizontal mass divided by the vertical mass for full and empty racks respectively which are taken from the mass summary on page 5.3-6 are:

FULL RACK = 1062/881 = 1.205

EMPTY RACK = [136 + 181 + (745-672)] / 136 = 2.86

Therefore the effective coefficient of friction for the empty rack based on the full rack mass is:

$(1.205/2.86)\ .2\mu \approx .1\mu$

The following chart summarizes the minimum nominal clearances for the spent fuel racks from various items in the pool. These clearances are then divided by the calculated displacement of 1.05" for SSE to define a factor of safety for each item.

Desctiption	Minimum Nominal Clearance	Factor of Safety
Spent Fuel Walls	6.56 + .00" - .75"	5.49
Channel Storage Rack	2.313 - .00" + .25"	2.2
Reactor Gate Storage Brackets	5.68 + .00" - .75"	4.68
Other Wall Mounted Objects	5.39 + .00" - .75"	4.42
Existing Floor Swing Bolts	5.00 Min.	4.76

4.5 Module Stress Analysis

The equilibrium force sets at $.8\mu$, as determined in the previous section were used as input loads for the 3-D detailed finite element SAP IV model for 11x11 and 8x11 racks. These force sets include the dead, live, and seismic loading at that time instant when a particular nodal force is maximum. Because only a planar time history analysis was done, an equivalent set of loads was applied orthoginally to account for the seismic loads in the other horizontal direction. These resultant loads were then combined on a square root sum of the square (SRSS) method. This resultant is very conservative because it doubles up on the vertical loading.

The results of the SAP IV analysis show that the stresses from all load cases are less than the allowable limits for the SSE condition.

4.6 Equivalent Static Loads For Fuel Impact Conditions

The impact energy losses of the inertia resistance of module and collapsing of the bottom tripod on the fuel bundle fitting were quantified for the 18" vertical drop to determine the net impact energy.

Using the SAP IV model, spring rates were determined at various impact locations on the module. A static impact load was then determined for each of these locations by equating the elastic structural strain energy with the net impact energy. (Drop conditions 1 & 2).

For an unimpeded fuel drop through an empty cavity, the static load to shear out the bottom fuel support was determined. (Drop condition 3).

Condition 4) is an accident condition of a jammed fuel bundle in a storage cavity. Here the total load is limited to the crane capacity.

The following presents the static loads for the various drop and accident conditions.

Condition	Description	Load
1	18" drop, middle of 11x11	48.24 Kips
2	18" drop, corner of 11x11	59.30 Kips
3	Drop thru an empty cavity	39.1 Kips
4	Jammed fuel bundle uplift	4.0 Kips

4.7 Dropped Fuel Bundle Analysis

An analysis of dead and live loading (rack and fuel weight) was first conducted on the SAP IV detail model. It was shown for this loading that all rack members are within 1.0 times the normal allowable values.

Equivalent static loads for different dropped fuel bundle cases were determined in Section 5.6. For conditions 1 and 2 these loads were applied to the SAP IV finite element model of the module and combined with rack and fuel loading. Stresses for each member were than tabulated and compared against its allowable. All members were below 1.6 times normal allowables for drop conditions 1 and 2.

For condition 3 a stress analysis of a concentrated 100 kips load applied in the centers of the bottom casting of the largest rack (11x11) in conjunction with the rack and fuel loading was performed. It was then determined that this concentrated load needed to be factored down to 47.34 kips to maintain all member stresses within acceptable limits of 1.6 times the normal allowables. This load is 1.21 times greater than the calculated shear out load of the fuel support of 39.1 kips of Section 5.6, and therefore is acceptable.

An analysis was not done for condition 4, jammed fuel bundle. The resulting stresses for this condition are assumed to be 4/48.4 = .082 of condition 1 stresses.

4.7.1 Summary

The following table summarizes the loading combinations and factored allowable limits of Table 2-1 compared to the calculated stress interaction of rack members for the various combinations. These values are calculated in Sections 5.5 and 5.7 of this report. The analysis computed specific values for combinations of equations 3,6, and 7. Values for the remaining equations were computed from extrapolation of these previous values. The extrapolation is based on the following:

1) Thermal loads resulting from combined expansion of the racks is negligible for the free standing design. However load combinations containing To or Ta material yield strengths are taken at 212 degrees F which for the aluminum alloys used amounts to a reduction in yields of 5%.

2) IELP Spec. M-303 defines SSE accelerations as twice those of OBE.

* The interaction is defined as the following ratio, (computed stress/ normal allowable stress). For casting beam members the combined bending and axial stress interaction is $f_a/F_a + f_b/F_b$. The total sum is the factor allowable limit of Table 2-1 for various load combinations, i.e., for load combinations 1,2, and 3, this sum must be less than 1.0. For load combination number 7 the side panels were evaluated for shear buckling using the following interaction for combined axial and shear stress = $f_a/1.6\ F_a + (f_v/1.6\ F_v)^2 \leq 1.0$. For plate buckling the factored allowables were limited to 1.6 times normal allowables.

Equation No.	Loading Combination	Factored Allowable Limit	Largest Calculated: Side Plates	Largest Calculated: Casting
1	D + L	1.0	.219 [7]	< .484*
2	D + L + E	1.0	< 1.0*	< 1.0 *
3	D + L + To	1.0	.226*	.509 [1]
4	D + L + To + E	1.5	< 1.5*	< 1.5*
5	D + L Ta + E	1.6	< 1.6*	< 1.6*
6	D + L + DF			
	Condition 1	1.6	.299 [8]	.633 [2]
	Condition 2	1.6	.726 [9]	.513 [3]
	Condition 3	1.6	.381 [10]	1.2 [4]
	Condition 4	1.6	< .024*	.052*
7	D + L + Ta + E^1	2.0	.708 [6]	1.618 [5]

1. See Table 5.7.3-2
2. See Table 5.7.3-3
3. See Table 5.7.3-4
4. See Table 5.7.3-5 and Page 5.6-16
5. See Table 5.7.4-4
6. See Table 5.5.4-46 (for shear buckling
7. See Table 5.7.3-6
8. See Table 5.7.3-7
9. See Table 5.7.3-8
10. See Table 5.7.3-9

* Extrapolated values

4.8 Module Bolt and Rivet Joint Connection Analysis

From the plane stress output of the SAP IV analysis, force distribution along the sides and edges of the 1/2" side panels were determined for the seismic load cases and dropped fuel bundle conditions. Bolt and rivet patterns were then sized per aluminum standards for each of the load cases.

4.9 Pool and Rack Interface Loads

The dead plus SSE seismic vertical floor load for the racks and fuel is calculated to be 989#/cavity. For 2050 total cavities and a pool of 20' x 40' this amounts to a total vertical uniform floor loading of 2535 psf, which is acceptable compared to the 3200 psf allowable given in Bechtel report entitled "Evaluation of Spent Fuel Pool Seismic Response Spectrum and Floor Structure", dated September 1977.

The total horizontal shear on the floor in each direction is 669#/cavity or 1,371,450# total.

The bearing stress under each foot is calculated to be 4393 psi, and its associated punching shear stress is calculated at 76.8 psi. The stresses in the threaded foot and ABS plastic insulators are shown to be within acceptable limits.

4.10 Poison Can Analysis

The poison cans are not considered to be primary structural elements. However, because air is trapped between the concentric tubes, the inner and outer tubes must be able to withstand the hydrostatic loading associated at the rack depth in the spent fuel pool. The loading due to internal air pressure from external heating, for example, pool boiling, is conservatively ignored since it opposes the hydrostatic pressures and amounts to less than 4 psi. at 212°F pool water temperature compared to the 13 psi. hydrostatic loading. A one-inch wide cross section of the can was represented as a beam model and analyzed using the computer program "SAGS", Static Analysis of General Structures, available thru Structural Dynamics Research Corporation, 5729 Dragon Way, Cincinnati, Ohio.

Stresses at the corners and weld seam location of the can were shown to be within normal allowable limits.

4.11 Lifting Frame and Lifting Eye Analysis

The Lifting Frame is shown on drawing AD-22766-E. This 2 point lift fixture is comprised of a main cross tube with air actuated lift dogs at the ends. The stroke of the lift dogs is such that it is capable of engaging racks ranging from 8 to 11 cavities wide. The lift dogs engage in mating machines holes in the top casting of the rack.

All members on the lifting frame and the casting lifting eye were designed with a safety factor greater than 3:1 on the minimum yield of the material.

4.12 Module Shipping Skid Analysis

A long hand analysis of the shipping skid was conducted for racks oriented horizontally, vertically, and in tilted positions for an upending condition. The analysis showed that all members and interface bolts have a safety factor greater than 3:1 on minimum yield.

4.13 Minimum Coefficient of Friction Test

To verify the minimum coefficient of friction for loading geometry, environments, and pressure as found on feet assemblies of spent fuel modules sliding on the floor liner plates of spent fuel pools, simulated friction tests were conducted.

These tests were done under ideal conditions with no considerations given to long term contact effects and corrosion effects. Therefore, they represent the minimum friction forces and do not attempt to define their maximums.

For nominal contact pressures , minimum coefficient of friction measured were .23 - .29 for all conditions.

A coefficient of friction of .2 based on these tests was used in the seismic time history analysis to determine maximum module relative displacement. This value is 15% below a minimum measured value of .23 to account for measurement uncertainties.

4.14 Bolt Clearance Test Report

The purpose of this test was to determine ultimate shear load capacity of bolted joints of 2 bolts with different body clearances, seating torques and hole misalignment. The values were then compared against identical bolt patterns with a dowel pin press fitted in the middle of the bolt pattern. This test was done primarily to demonstrate equal load sharing ability of the 3/4" bolts and 1" dowel pins used on the rack side sheets bolted to the bottom castings.

Conditions tested were:

1) The plates bolted together with two 3/4-10 bolt torqued to 600 in-# with body hole of .015" clearance. Body hole pattern was .015" less than the mating hole pattern so that it is a line to line fit on outside edges of the bolts. Theoretically all the load would be on the first bolt in this case.
2) Same as (1) except body hole clearance, .005" and hole patterns in line.
3) Same as (2) except a 1" dowel with a.0003-.0007" press fit was added to the middle of the bolt pattern, and body hole clearance of .015".
4) Same as (2) except finger tight.

The minimum ultimate shear stress for conditions 1,2, and 4, is 38.18 ksi, and 36.29 ksi for condition 3 where a 1" dowel pin was press fitted in the middle of the hole pattern. This corresponds to a 5% reduction to the strength due to unequal load sharing.

4.15 Simulated Dropped Fuel Bundle Test

In this test, a 10x7 top casting was supported on the corners of wooden blocks that were approximately the same stiffness as the side sheets.. An 1100# concrete block was dropped on the middle of the casting, an equivalent distance to obtain the same net impact energy as determined in Section 5.6. Load cells were located at the corners of the casting and were summed to obtain the total impact force time history.

Peak values of 25,000# were measured, corresponding to the 18" bundle drop. Several drops were made, and in all cases there was no loss in casting integrity. Because of uncertainties in stiffness and damping of the wooden supports, the conservative calculated impact loads in Section 5.6 were used in lieu of the measured values.

5.0 DETAILS OF DESIGN ANALYSES

This section contains the detail design analyses as listed below with their respective subsection number.

5.1 Nuclear Criticality Safety Analysis

5.2 Spent Fuel Cooling and Spent Fuel Assembly Heat Transfer Analysis

5.3 Model Description, Formulation and Assumptions For The Seismic Analysis of BWR Spent Fuel Racks

5.4 Time History Seismic Analysis

5.5 Module Stress Analysis

5.6 Equivalent Static Loads for Fuel Impact Conditions

5.7 Dropped Fuel Bundle Stress Analysis

5.8 Module Bolt and Rivet Joint Connection Analysis

5.9 Pool and Rack Interface Loads

5.10 Poison Can Analysis

5.11 Module Lifting Frame Analysis

5.12 Module Shipping Skid Analysis

5.0.1 Structural Calculation Nomenclature

The nomenclature used in the calculations is the same as used in the AISC Manual of Steel Construction Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, and Section NF Appendix XVII ASME.

A = Cross-sectional area, subscripts used for identification

E = Modulus of elasticity

F_a = Allowable stress, axial compression

F_b = Allowable stress, bending

F_p = Allowable stress, bearing
F_t = Allowable stress, tension
F_v = Allowable stress, shear
F_y = Yield strength
F_u = Tensile strength
I = Moment of inertia
J = Polar moment of inertia
K = Effective length factor (columns)
M = Bending moment
P = Applied load
R = Reaction load
S = Section modulus
V = Shear load
W = Weight

a,b,etc. = General dimensions, distance between loads,etc.
c = Distance from neutral axis to extreme fibre of beam
b = Beam or flange width
d = Depth of beam, diameter of round member
f = Computed stress, same subscripts used as for F
l = Length, in inches
r = Radius of gyration
t = Thickness
w = Distributed load, lb/in.

Seismic Calculations

F' = Allowable stress, "design" seismic loading. Same subsripts used as for F.

f' = Calculated stress,"design" seismic loading
g_v = vertical seismic accel.
g_h = horizontal seismic accel.

5.0.2 Material Properties

All rack materials are specifed in PaR Document PARSP/3091 and are reprinted here in the following cart. All aluminum material property values based on: Aluminum standards and Data, 1974-1975 published by the Aluminum Association (Reference 9)

Description	Alloy	Finish	F_y Min. Yield at 212° F
Top & Bottom Casting	A356-T51 Sand Cstg.	Partial machined, sand-blasted and Duranodic (grey) (anodized)	16,000 psi
1/2" Side Panels	6061-T6	Duranodic Anodize (black)	32,000 psi
Angle Connectors	6061-T6	Duranodic Anodize (black)	32,000 psi
Cavity Weldment	5052-H32	Sulfuric Anodize (clear)	23,000 psi
Bolts	2024-T4	Sulfuric Anodize (black)	42,000 psi
Rivets	5052 Body	Sulfuric Anodize (black)	
ABS Plastic	Cycolac Grade T		
Bearing Plate On Foot	304 Stainless	Machined	25,000 psi
Thread Foot	6061-T6	Hard Anodize (black)	35,000 psi

Other material properties for aluminum are:

Modulus of Elasticity "E" = 10.2 (10^6) psi @ 100 degrees F

Modulus of Rigidity "G" = 3.8 (10^6) psi

Density = .098 lb/in^3

Other material properties used for 304 stainless are:

Modulus of Elasticity "E"	= 27.7 (10^6) psi @ 200 degrees F.
Modulus of Rigidity "G"	= 10.6 (10^6) psi
Density	= .28 $lb/in.^3$

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SECTION 5.9

FUEL STORAGE SYSTEM DESIGN REPORT

DUANE ARNOLD ENERGY CENTER UNIT NO. 1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

PaR Job: 3091

Design Calculations

POOL AND RACK INTERFACE LOADS

PREPARED BY [signature] DATE 1-6-78

CHECKED BY George L. Hoblit DATE 1-21-78

REVISION NO. 2 DATE 3-27-78

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHECKED BY	APPRV'D BY	DATE
1	2-17-78	Corrected typo pg. 5.9-3 line 8 para. 2	H.J.H.	[signature]	2/18/78
2	3-27-78	Revised Page 5.9-3 and 5.9-4	H.J.H.	[signature]	3/28/78

POOL AND RACK INTERFACE LOADS

The seismic analysis description is given in Section 5.3 . The broadened envelope response spectra and time histories or results of the time history analysis are given in Section 5.4.

The maximum floor load, calculated as shown in spring K_f on Figure 4, Section 5.3 was 647875#, given from Figure 2, Section 5.4. An 8x11 and 10x11 rack were utilized in this analysis for a total rack dead weight of 148,274# ($\simeq$ 750#/cavity). The dead weight of the water and concrete floor within this two rack area of 65.9 ft.^{2} was assumed to be 212,656# for a dead weight of 360,930#. Therefore, just the seismic load in the floor expressed as a fraction of total dead load is -[1-(647,875/360,930)] = 0.79. Since there are 21 total racks or 10 1/2 such pairs combining this maximum by an SSRS method the total seismic load on a per unit basis is:

$$\sqrt{10.5}/10.5 \quad (.79) = .244 \text{ (Total Dead Load)}$$

Therefore, the combined dead plus seismic loading is 1.24 (Total Dead Load). The per cavity load contribution of the fuel and racks is 1.24 (750#) = 930#/cavity. For the entire pool (2050 cavities) the total load is 1,960,500. Depending on the complexity floor model this load can be distributed just over the rack area or the entire pool area.

Since a planar model was used, the above loads are the resultant of a combined 2 direction (one horizontal and one vertical) seismic. If a three direction seismic is required in the pool floor analysis these loads should be scaled up. The base accelerations are shown in Figure A and B of Section 5.4 are .5 and .28 g respectively, Therefore the ratio of 3 direction RMS to 2 direction RMS is given by:

$$\frac{\sqrt{.5^2 + .5^2 + .28^2}}{\sqrt{.5^2 + .28^2}} = 1.33$$

The combined dead plus seismic loading for 3 direction now becomes:

$$.24 \ (1.33) + 1 = 1.32$$

This value yields a total per cavity load of 989# or a total load of 2,028,300#. Since the spent fuel pool is 20' x 40' or 800 ft.^{2} total area, the total uniform vertical seismic loading is 2535 psf.

The maximum sum of all the horizontal leg forces of Figure 5-c is 132,650#. On a per cavity basis this is 669#. This load should be applied in both E-W and N-S directions.

The maximum bearing stress under the rack feet is calcualted to be 4393 psi.

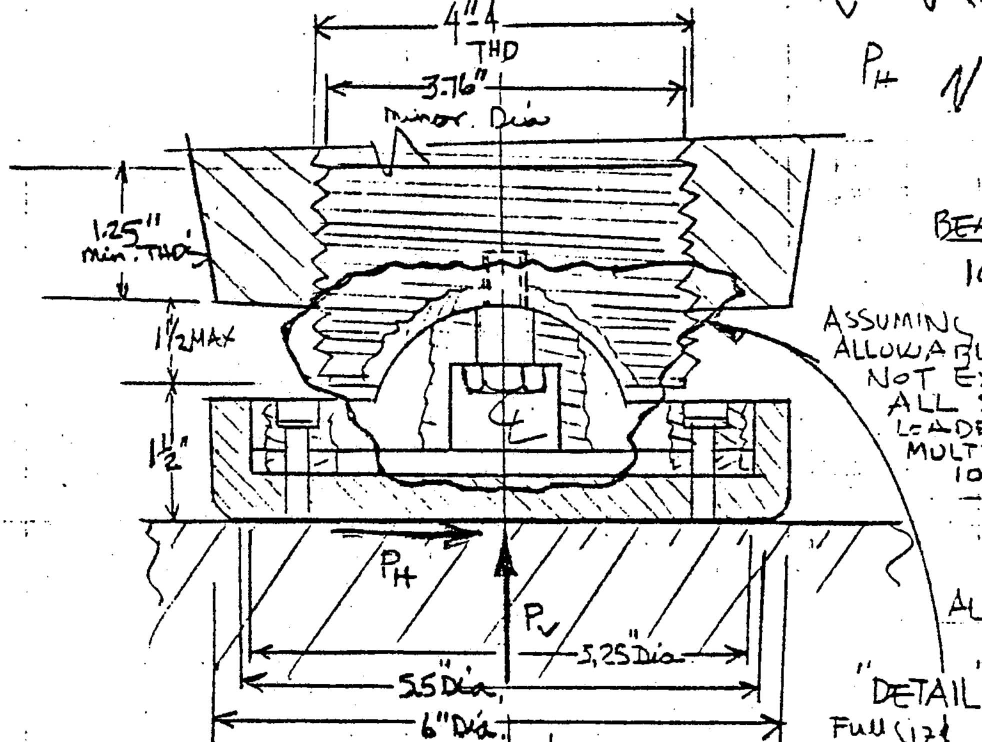
These loads should be used for both OBE and SSE.

FOOT ANALYSIS - SEISMIC

FORM THE TIME HISTROY ANALYSIS (see ~~section~~ 54) THE LARGEST VERTICAL & HORIZ. REACTIONS ON TWO FEET RESP. 134120# & 67043# FOR THE 10x11 RACK. FACTORING THESE LOADS FOR 11x11 RACK: 147532# & 73747 THE PER FOOT SRSS IS:

$$P_V = \sqrt{2(147{,}532)^2}/2 = 104321^{\#}$$

$$P_H \quad \sqrt{2(73747)^2}/2 = 52147^{\#}$$



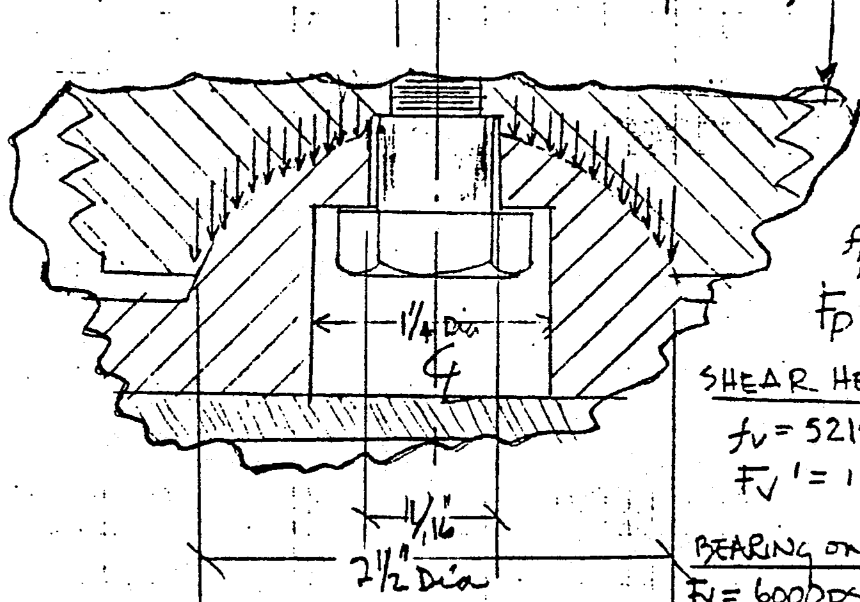
BEARING STRESS ON CONCRETE

$104321 / (\pi/4)(5.5)^2 = 4393$ psi

ASSUMING 3700 psi CONCRETE, "FB" THE ALLOWABLE BEARING STRESS SHOULD NOT EXCEED $.35\,\phi f_c'$, EXCEPT WHEN ALL SIDES ARE WIDER THEN THE LOADED AREA THE AREA MAY BE MULTIPLIED BY 2 (See ACI 318-71, 10.14 page 33)

ALL. CONCRETE BEARING STRESS

$(2).35(.7)(3700) = 4403$ psi



BEARING STRESS ALUM HEMI-SPH

PROJECTED AREA "Ap" =

$A_p = \pi/4(2\tfrac{1}{2}^2 - .687^2) = 4.53\text{ in}^2$

f_p $104321/4.53 = 23{,}029$ psi

F_p (6061 T-6) $= 34$ ksi; $\frac{f_p}{F_p} = .67$

SHEAR HEMI-SP

$f_v = 52147 / \pi/4(2\tfrac{1}{2}^2 - 1\tfrac{1}{4}^2) = 14334$ psi

$F_v' = 12.8$ ksi; $\frac{f_v}{F_v'} = 1.120$

BEARING ON PLASTIC $= 104321/\frac{\pi}{4}(5.25)^2 = 4821$ psi

$F_y = 6000$ psi $F_p = .9(6000) = 5400$ psi

SHEAR THD' FOOT $f_v = 52147 / \pi/4(3.76)^2 = 4698$ psi, $F_v' = 12.8$ ksi; $\frac{f_v}{F_v} = .367$

BENDING THD' FOOT $f_b = 3/2(52147)/\pi/32(3.76)^3 = 14988$ psi, $F_b' = 28$ ksi; $\frac{f_b}{F_b'} = .535$

AXIAL THD'-FOOT $f_a = 104321/\pi/4(3.76)^2 = 9400$ psi, $F_a' = 19$ ksi; $\frac{f_a}{F_a'} = .495$

INTERACTION $(f_v/F_v)^2 + f_a/F_a' + f_b/F_b' = (4.7/12.8)^2 + 9.4/19 + 14.98/28.0 = 1.165$

BY ______ DATE 1/__/78 SUBJECT ______ SHEET NO ____ OF ____

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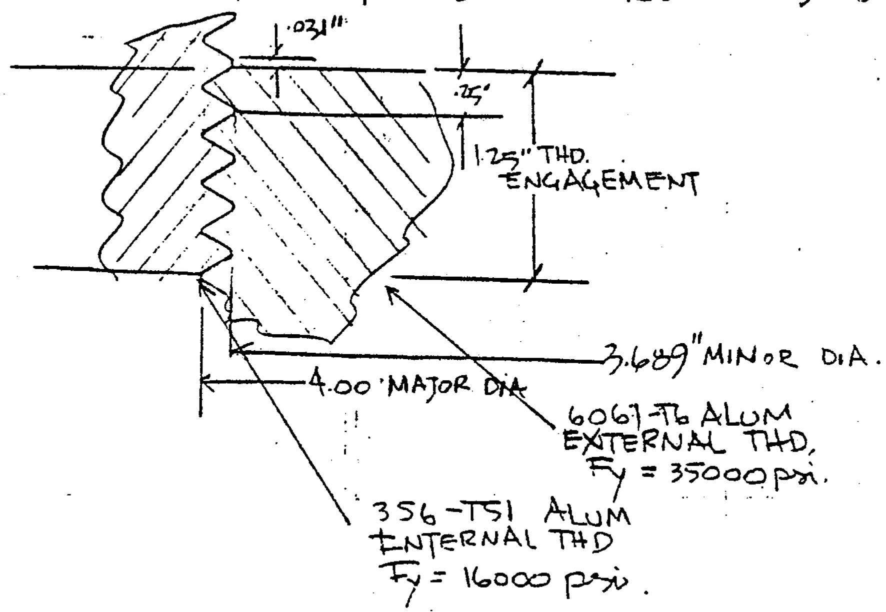
FOOT ANALYSIS (cont'd)

SHEAR ON LEVELING SCREW THREADS 4"-4 UC THREADS

MINIUM THREAD ENGAGEMENT = 1.25"

THREAD PITCH = 4 THD/in

NO. OF THD'S ENGAGED = 1.25(4) = 5



SHEAR STRESS ON INTERNAL THD.

$f_v = 104321 / 5(\pi)(4)(.25-.031) = 7581\ psi.$

$F_v' = 1.6(.4)(16000) = 10240\ psi$; $\frac{f_v}{F_v'} = .740$

SHEAR ON EXTERNAL THD

$f_v = 104321 / 5(\pi)(3.689)(.25-.031) = 8220\ psi$

$F_v' = 1.6(.4)(35000) = 22400\ psi$; $\frac{f_v}{F_v'} = .367$

PUNCHING SHEAR ON SPENT POOL FLOOR

FLOOR THICKNESS = 72"

$A = \pi(6")72" = 1357\ in^2$

$f_v = 104321/1357 = 76.86\ psi.$

FOOT ANALYSIS : D + L + DF

FOR THE 11 X 11 RACK , D + L = 22690 #/FOOT

$$D + L + DF = 22690^{\#} + \frac{48240^{\#}}{4} = 34{,}750^{\#}/\text{FOOT (COND. 1)}$$

$$= 22690^{\#} + 59{,}300^{\#} = 81{,}990^{\#}/\text{FOOT (COND. 2)}$$

$$= 22690^{\#} + \frac{39{,}100^{\#}}{4} = 32{,}465^{\#}/\text{FOOT (COND. 3)}$$

CHECK BEARING STRESS ON CONCRETE :

$$f_{c,p} = \frac{D+L+DF}{(\pi/4)(5.5'')^2} = 1462 \text{ PSI}; \quad \frac{f_p}{F_p} = .332 \text{ (COND. 1)}$$

$$= 3451 \text{ PSI}; \quad = .784 \text{ (COND. 2)}$$

$$= 1366 \text{ PSI}; \quad = .310 \text{ (COND. 3)}$$

CHECK BEARING STRESS ON ALUM. HEMI-SPH. :

$$f_p = \frac{D+L+DF}{4.53 \text{ IN}^2} = 7671 \text{ PSI}; \quad \frac{f_p}{F_p} = .225 \text{ (COND. 1)}$$

$$= 18{,}100 \text{ PSI}; \quad = .532 \text{ (COND. 2)}$$

$$= 7167 \text{ PSI}; \quad = .211 \text{ (COND. 3)}$$

CHECK BEARING STRESS ON PLASTIC :

$$f_p = \frac{D+L+DF}{\pi/4 (5.25'')^2} = 1605 \text{ PSI}; \quad \frac{f_p}{F_p} = .297 \text{ (COND. 1)}$$

$$= 3787 \text{ PSI}; \quad = .701 \text{ (COND. 2)}$$

$$= 1500 \text{ PSI}; \quad = .278 \text{ (COND. 3)}$$

CHECK AXIAL STRESS ON FOOT THREAD :

$$f_a = \frac{D+L+DF}{\pi/4 (3.76)^2} = 3130 \text{ PSI}; \quad \frac{f_a}{F_a} = .165 \text{ (COND. 1)}$$

$$= 7384 \text{ PSI}; \quad = .388 \text{ (COND. 2)}$$

$$= 2924 \text{ PSI}; \quad = .154 \text{ (COND. 3)}$$

FOOT ANALYSIS: D + L

FOR THE 11 X 11 RACK, $D + L = 750^{\#}/_{CAV}\,(11)(11)/4 = 22{,}690^{\#}/\text{FOOT}$

BEARING STRESS ON CONCRETE $f_{c,p} = \dfrac{22{,}690^{\#}}{(\pi/4)(5.5'')^2} = 955$ PSI
($< F_c = 4403$ PSI)
$f_c/F_c = .217$

BEARING STRESS ON ALUM. HEMI-SPHERE

$f_p = \dfrac{22{,}690^{\#}}{4.53\ IN^2} = 5009$ PSI ($< F_p = 34{,}000$ PSI)
$f_p/F_p = .147$

BEARING STRESS ON PLASTIC $f_p = \dfrac{22{,}690^{\#}}{\pi/4\,(5.25'')^2} = 1048$ PSI ($< F_p = 5400$ PSI)
$f_p/F_p = .194$

CHECK FOOT THREAD STRESSES:

AXIAL STRESS ON FOOT THD $f_a = \dfrac{22{,}690^{\#}}{\pi/4\,(3.76'')^2} = 2044$ PSI ($< F_a = 19{,}000$ PSI)
$f_a/F_a = .108$

REF. FORMULAS IN SECTION 4.3 AND TABLE 3.3.25 OF SPECIFICATIONS FOR ALUMINUM STRUCTURES, THE ALUMINUM ASSOCIATION INC., SECTION 1, APRIL 1976.

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SECTION 5.10

FUEL STROAGE SYSTEM DESIGN REPORT

DUANE ENERGY CENTER UNIT NO. 1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

PaR Job: 3091

Design Calculations

POISON CAN ANALYSIS

PREPARED BY [signature] DATE 1-10-78

CHECKED BY George L. Gollish DATE 1-23-78

REVISION NO. ____________ DATE ____________

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHK'D BY	APPRV'D BY	DATE

BY ______ DATE 12/6/77 SUBJECT ______ SHEET NO ______ OF ______
CHKD. BY ______ DATE 1/23/78 JOB NO. ______

POISON CAN ANALYSIS

CONSIDER STRESSES ON CAN DUE TO HYDRAULIC PRESSURE OF SPENT FUEL POOL. WATER DEPTH A BOTTOM OF POISON CAN IS [37'-9"] - [1'-3"] = 36.5'

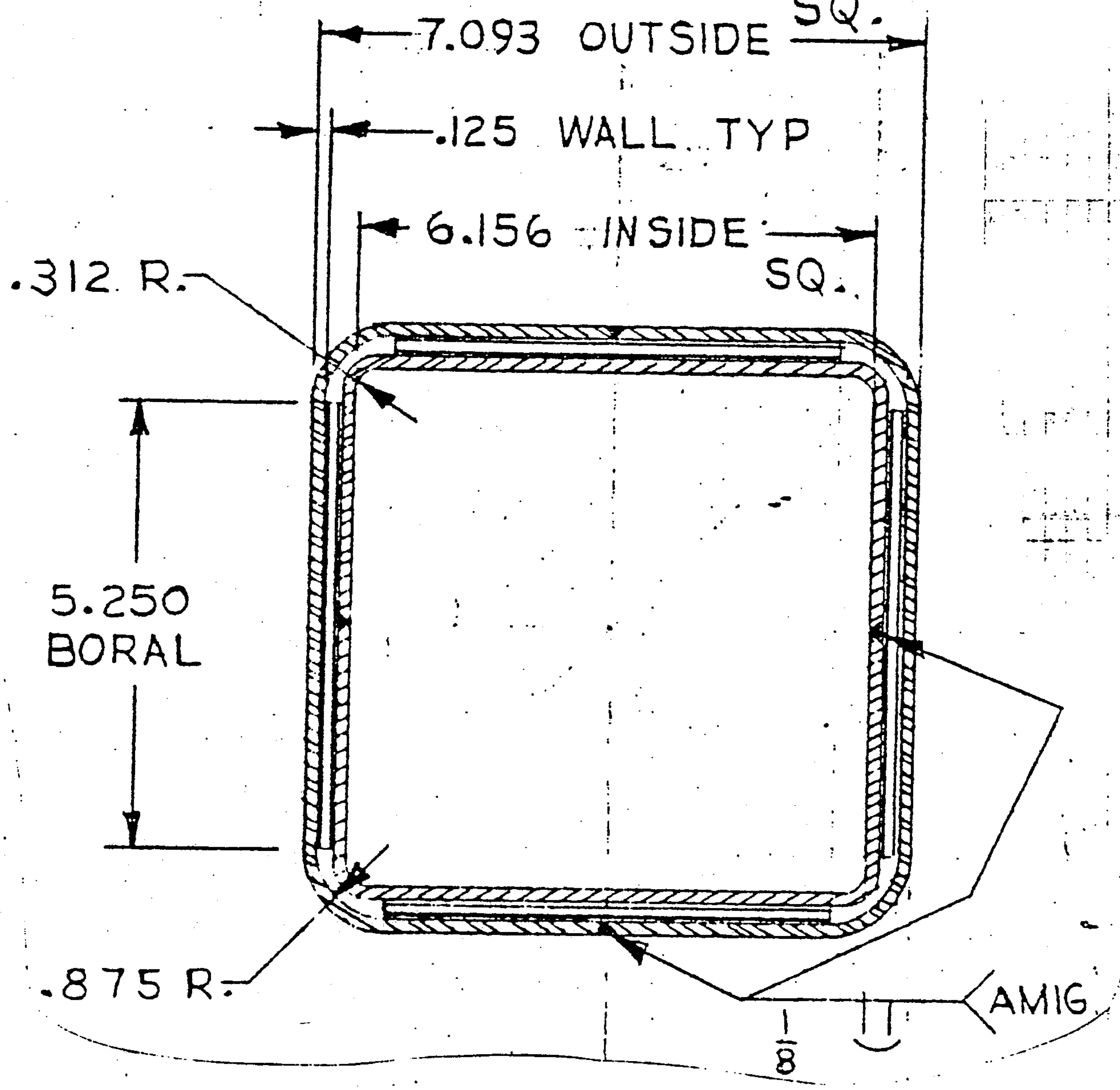
THE GAP BETWEEN INNER & OUTER TUBE IS

7.093
-6.156
.937
-.500
.437 (NOMINAL)

GAP PER SIDE .437/2 = .218"
BORAL THK = .115"
NOM. CLEARANCE = .103"

THE TRIANGULAR PRESSURE DISTRIBUTION IS GIVEN BY THE FOLLOWING

(1) $w = \frac{62.2}{144}(36.5) - \frac{62.2}{144}l = 15.7\text{ psi} - .432\, l$, where l = LENGTH OF CAN IN FEET

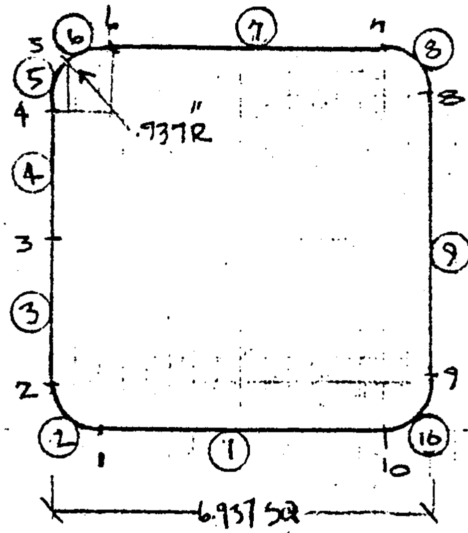


BY ... DATE ...	SUBJECT	SHEET NO ... OF ...
CHKD. BY ... DATE 1/13/78		JOB NO.

POISON CAN ANALYSIS

A BEAM COMPUTER MODEL FOR THE OUTER CAN IS SHOWN BELOW. HERE A 1" WIDE CROSS SECTION IS ANALYSISE USING CAN LENGTH OF 13'; PRESSURES GIVEN BY EQN(1) ARE 15.7 psi TOP 10.08 psi BOTTOM, THEREFORE THE EQUIVALENT "W_e" UNIFORM LOAD ⊥ TO THE CAN CROSS SECTION FOR A 1" WIDE STRIP IS:

$$W_e = [15.7 + 10.08]/2 = 12.9\ \#/in^2$$



AREA = .125(1) = .125 in²
$I = (1)(.125)^3/12 = .00016\ in^4$
$S = (1)(.125)^2/12 = .0026\ in^3$

CAN MATERIAL 5052H32 ALUM
F_{ty} = 23 KSI ; F_{tu} = 31 KSI
F_{tyw} = 13 KSI ; F_{tuw} = 25 KSI

ALOW. STRESS
F_a = 10.0 KSI F_b = 18.1 KSI

ALOW. STRESS (WELD AFFECT ZONE)
F_a = 8.00 KSI F_b = 10.24 KSI

STRESSES WERE BASED ON 15 #/in LOADING FROM THE COMPUTER OUTPUT SHTS. THE LARGEST STRESS OCCURS @ SPAN(5) JOINT(5) AXIAL = 67.8 # ; MOMENT = 37.4 in-#

$f_A = 67.8^{\#}/.125 = 542$ psi. $f_b = 37.4^{\#}/.0026 = 14384$ psi

TOTAL INTERACTION $f_a/F_a + f_b/F_b = .542/10.0 + 14.38/18.1 = .848$

F.S. = 15/(12.9)(.848) = **1.37** FACTOR OF SAFETY ON ALLOWABLE

STRESSES AT NODE 3 WELD AFFECTED ZONE ARE:
AXIAL = 52 # MOMENT = 25.4 in-#

$f_a = 52^{\#}/.125 = 416$ psi. $f_b = 25.4^{\#}/.0026 = 9731.8$ psi.

TOTAL INTERACTION $f_A/F_A + f_b/F_b = .416/8.00 + 9.731/10.24 = 1.00$

F.S. = 15/12.9(1.0) = **1.16** FACTOR OF SAFETY ON ALLOWABLE.

SINCE THE WELD IS FULL PENTRATION THE WELD IS AS GOOD AS PARENT MATERIAL.

S A G S

STATIC ANALYSIS OF GENERAL STRUCTURES

STRUCTURAL DYNAMICS RESEARCH CORPORATION

CAN

*** PLANAR FRAME ANALYSIS ***

SPAN	LENGTH	FORE END JOINT	AFT END JOINT	MATERIAL CODE	SECTION CODE	ROTATION ANGLE	TEMP.
1	5.06	10	1	1	1		
3	2.53	2	3	1	1		
4	2.53	3	4	1	1		
7	5.06	6	7	1	1		
9	5.06	8	9	1	1		

CURVED SPANS

SPAN	ANGLE	FORE END JOINT	AFT END JOINT	MAT. CODE	SECT. CODE	RADIUS	ROT. ANGLE	TEMP.
2	90.00	1	2	1	1	.9		
5	44.95	4	5	1	1	.9		
6	45.04	5	6	1	1	.9		
8	90.00	7	8	1	1	.9		
10	90.00	9	10	1	1	.9		

JOINT COORDINATES

JINT	X	Y	Z
1	.937	.000	
2	.000	.937	
3	.000	3.467	
4	.000	6.000	
5	.274	6.662	
6	.937	6.937	
7	6.000	6.937	
8	6.937	6.000	
9	6.937	.937	
10	6.000	.000	

MATERIAL PROPERTIES

CODE	E	POISSON'S	DENSITY	THERMAL COEFFICIENT	YIELD
1	11.00E+06	.447	.000E+00	.000E+00	3.600E+04

CROSS-SECTION PROPERTIES

CODE	AREA	MOMENT OF INERTIA	SHEAR RATIO
1	1.000E+00	1.600E-04	1.20

STATIC ANALYSIS OF GENERAL STRUCTURES
CAN

STRESS RECOVERY VALUES

JDE	COMBINED STRESS	POINT 1/3 C(Y)	C(Z)	R(EFF)	POINT 2/4 C(Y)	C(Z)	R(EFF)
1	0	1.000	1.000	1.000			

SPECIFIED RESTRAINTS

JOINT	DIRECTION	VALUE
9	12	
8	1	

LOADING NO. 1:

DISTRIBUTED LOADING

SPAN	DIR	COORDINATE	VALUE	FINAL SPAN	INC.
1	Y	MEMBER	1.500E+01	10	1

TOTAL APPLIED FORCES:
F(X) = 4.387E-05 F(Y) = 3.147E-05 F(Z) = .000E+00

CAN

*** LOADING NO. 1:

JOINT DISPLACEMENTS

JOINT	X	Y	ROTATION
1	-3.780E-03	-3.695E-03	-1.354E-02
2	-7.521E-03	6.840E-05	1.352E-02
3	-3.922E-02	8.036E-05	1.202E-05
4	-7.474E-03	9.234E-05	-1.354E-02
5	-2.385E-03	-1.303E-03	-2.026E-05
6	-3.778E-03	3.779E-03	1.352E-02
7	-3.754E-03	3.774E-03	-1.353E-02
8	.000E+00	2.395E-05	1.353E-02
9	.000E+00	.000E+00	-1.353E-02
10	-3.757E-03	-3.747E-03	1.352E-02

JOINT REACTIONS

JOINT	F(X)	F(Y)	MOMENT
8	2.785E-04	.000E+00	.000E+00
9	5.243E-05	5.561E-05	.000E+00
OTAL	3.309E-04	5.561E-05	.000E+00

	FORE END FORCES				AFT END FORCES			
SPAN	JT.	AXIAL	SHEAR	MOMENT	JT.	AXIAL	SHEAR	MOMENT
1	10	-5.20E+01	-3.80E+01	-2.26E+01	1	5.20E+01	-3.80E+01	2.26E+01
2	1	-5.20E+01	3.80E+01	-2.26E+01	2	5.20E+01	3.80E+01	2.26E+01
3	2	-5.20E+01	-3.80E+01	-2.26E+01	3	5.20E+01	2.19E-02	-2.54E+01
4	3	-5.20E+01	-2.19E-02	2.54E+01	4	5.20E+01	-3.80E+01	2.26E+01
5	4	-5.20E+01	3.80E+01	-2.26E+01	5	6.78E+01	-3.47E-02	3.74E+01
6	5	-6.78E+01	4.67E-02	-3.74E+01	6	5.20E+01	3.80E+01	2.26E+01
7	6	-5.20E+01	-3.80E+01	-2.26E+01	7	5.20E+01	-3.80E+01	2.26E+01
8	7	-5.20E+01	3.80E+01	-2.26E+01	8	5.20E+01	3.80E+01	2.26E+01
9	8	-5.20E+01	-3.80E+01	-2.26E+01	9	5.20E+01	-3.80E+01	2.26E+01
10	9	-5.20E+01	3.80E+01	-2.26E+01	10	5.20E+01	3.80E+01	2.26E+01

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SECTION 5.11

FUEL STORAGE SYSTEM DESIGN REPORT

DUANE ARNOLD ENERGY CENTER UNIT NO. 1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

PaR Job: 3091

Design Calculations

MODULE LIFTING FRAME AND CASTING LIFTING EYE ANALYSIS

PREPARED BY [signature] DATE 11-2-77

CHECKED BY [signature] DATE 1-23-78

REVISION NO. ________ DATE ________

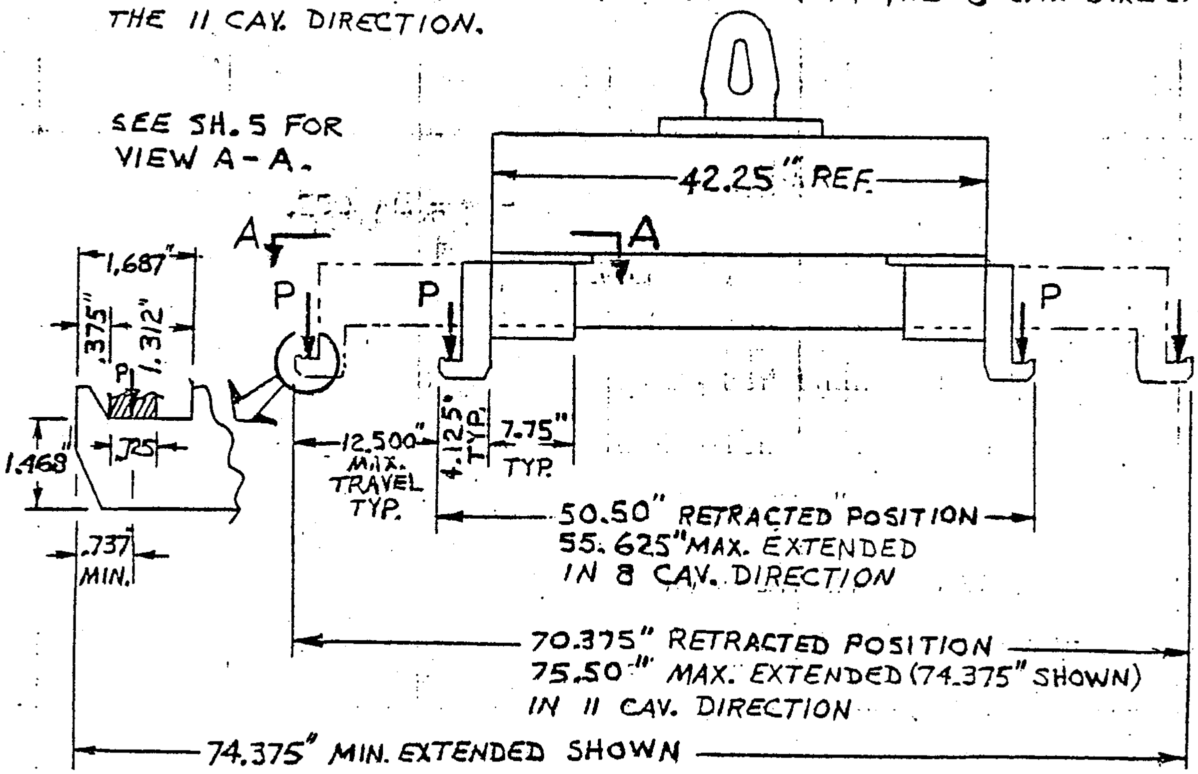
REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHK'D BY	APPRV'D BY	DATE

INTRODUCTION

The following calculations check the stresses in the lifting frame members and welds described by PaR fixture drawing AD-22556-E. The calculated stresses are compared to the yield strength F_y of the material and are shown to have a factor of safety F.S. on yield greater than 3.0. Nomenclature used is generally in accordance with A.I.S.C. Manual of Steel Construction, 7th Edition, 1973.

GENERAL FIXTURE ARRANGEMENT : SEE PaR DRAWING A-22556-E.
THE SAME FIXTURE IS USED FOR LIFTING IN THE 8 CAV. DIRECTION AND THE 11 CAV. DIRECTION.



NOTE: RETRACTED POS. ARE W/ LIFTIN EARS CENTERED IN OUTER CAVITIES.

DETERMINE MAX. LOAD P PER LIFTING FIXTURE EAR (FOR 11 x 11 MODULE)
APPROX. WT. PER CAVITY IS 136#. (SEE NOTE BELOW).

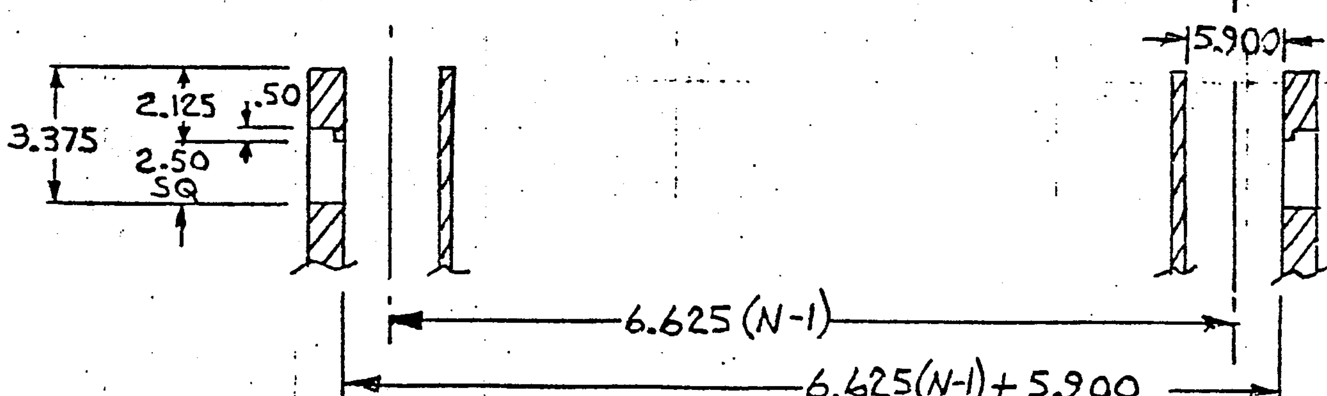
$$P = \frac{136^{\#}(11)(11)}{2} = 8228^{\#} \text{ PER LIFTING EAR}$$

DETERMINE MAX. TRAVEL BETWEEN RETR. 8 CAV. AND EXTEND. 11 CAV. CONDITIONS:

$$\frac{75.500'' - 50.500''}{2} = 12.500''$$

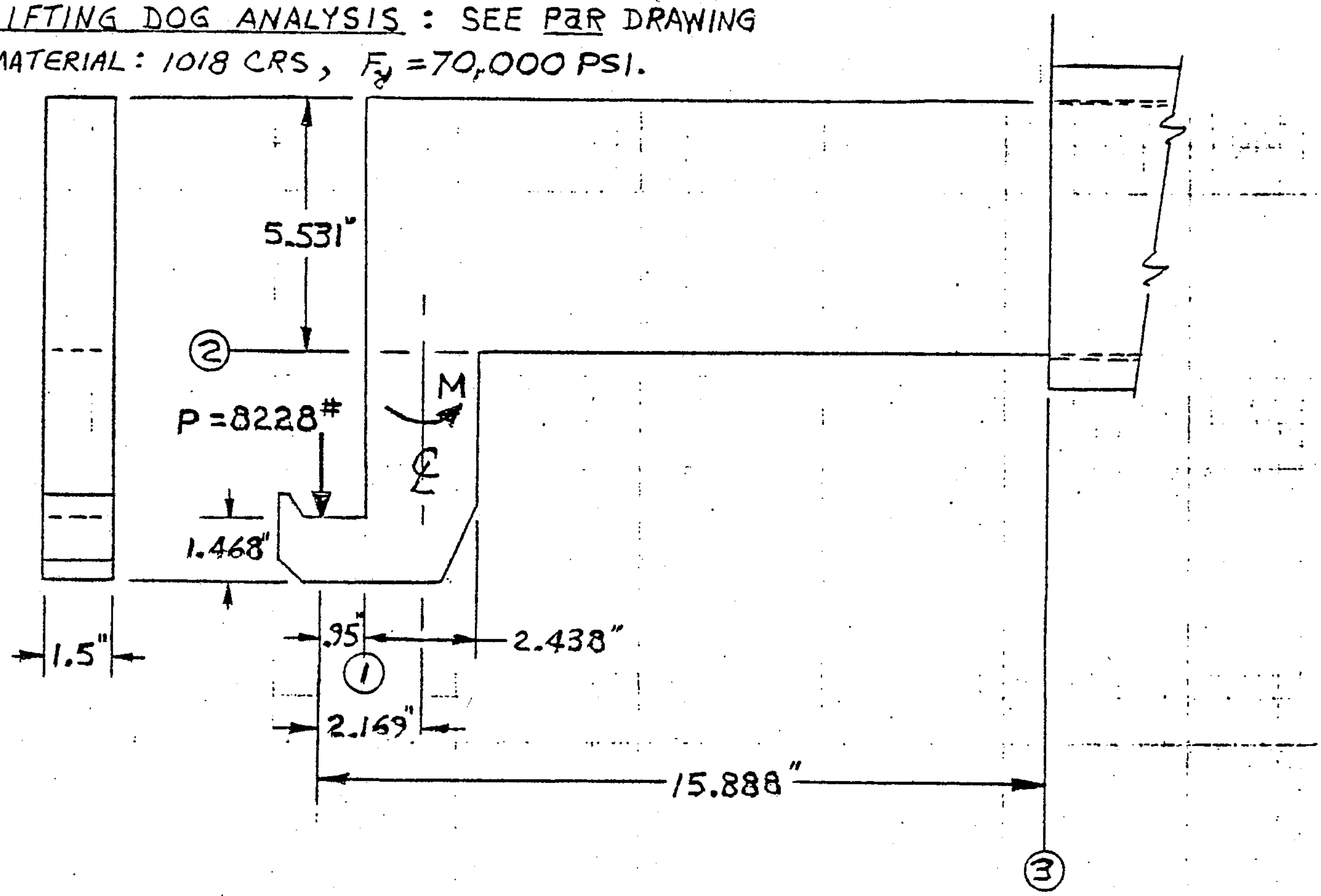
NOTE: 136#/CAV. USED IS CONSERVATIVE AS CALC. WT. IS 113#/CAV.

NOTE: CAVITY ARRANGEMENT IS 6.625" ℄ TO ℄, WITH 5.900" HOLES.
N IS THE NUMBER OF CAVITIES BEING CONSIDERED.



LIFTING DOG ANALYSIS : SEE P&R DRAWING

MATERIAL: 1018 CRS, F_y = 70,000 PSI.



SECTION	P (LB)	M (IN-LB)	A (IN^2)	$S = \frac{bh^2}{6}$ (IN^3)	$f_v = \frac{P}{A}$ ($\frac{LB}{IN^2}$)	$f_b = \frac{M}{S}$ ($\frac{LB}{IN^2}$)	F_{by}' ($\frac{LB}{IN^2}$)	F_b'/f_b
①	8228	7816	2.202	.538	3737	14508	64020	4.41
②	8228	17846	3.657	1.486	2250	12010	66400	5.53
③	8228	130,726	8.296	7.648	992	17093	68413	4.00

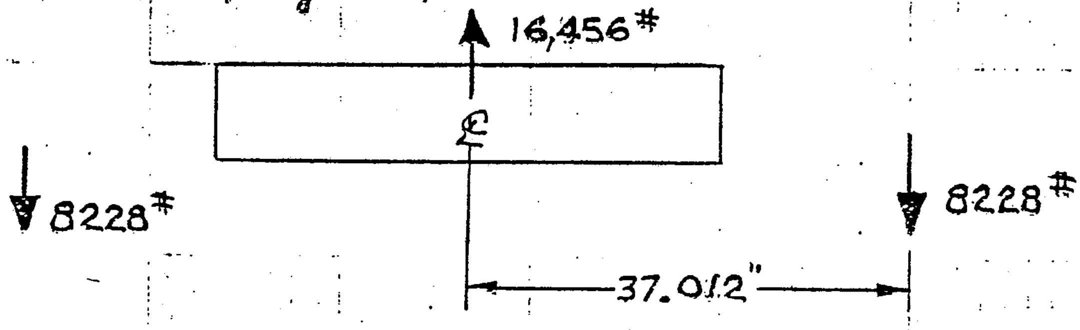
F_{by}' = BENDING YIELD COMBINED SHEAR AND TENSION

= $F_y - 1.6 f_v$ (SEE PARA. 1.6.3 A.I.S.C. MANUAL, P. 5-23)

FACTOR OF SAFETY ON YIELD $= \frac{F_b'}{f_b}$

MAIN CROSS TUBE ANALYSIS :

CHECK BENDING STRESS IN 10" x 10" x 3/8" SQUARE TUBE , $A = 13.8\ IN^2$, $S = 41.7\ IN^3$, $F_y = 36{,}000$ PSI.

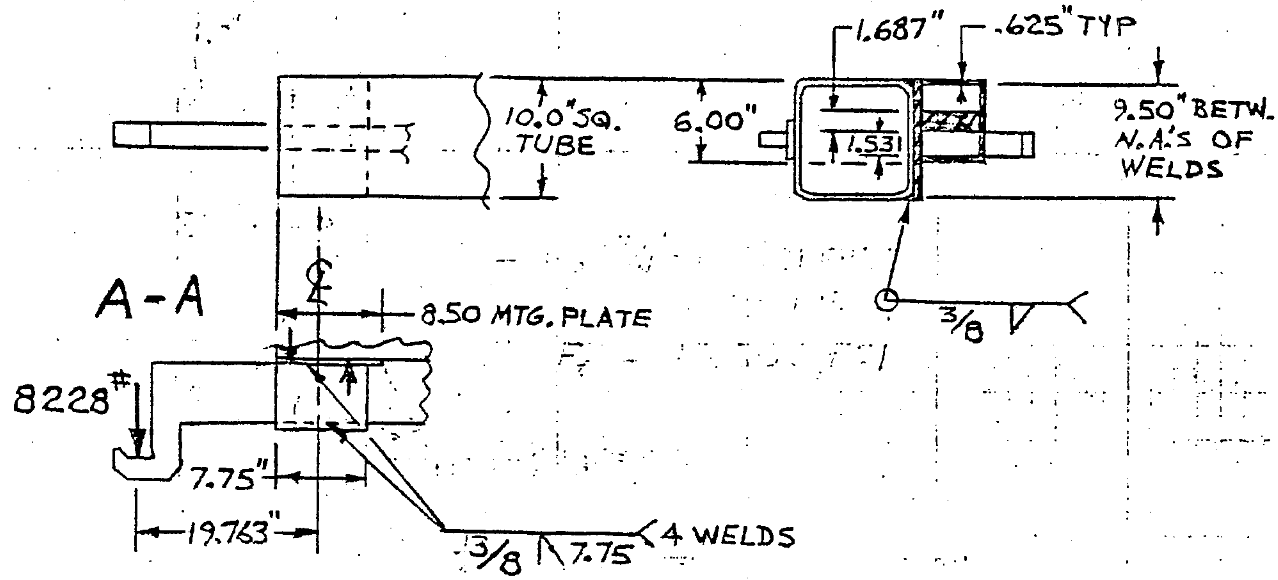


MOMENT AT ℄ = 8228# (37.012") = 304,539 IN-LB

$$f_b = \frac{M}{S} = \frac{304{,}539\ IN\text{-}LB}{41.7\ IN^3} = 7303\ PSI$$

$$F.S.\ ON\ YIELD = \frac{36000}{7303} = 4.93$$

DOGHOUSE PLATE AND WELD STRESS ANALYSIS



F_y = 30,000 PSI FOR DOGHOUSE

STRESS ANALYSIS FOR DOGHOUSE PLATES:

$$I_{PLATES} = \frac{(1.687 + .625)(7.75)^3}{3} = 358.73\ IN^4$$

$$f_{tb} = \frac{MC}{I} = \frac{8228^{\#}\left(19.763 + \frac{7.75}{2}\right)7.75''}{358.73\ IN^4} = 4202\ PSI$$

$$f_{tv} = \frac{8228^{\#}}{(.625 + 1.687)7.75} = 460\ PSI$$

$$\text{TOTAL } f_t = f_{tb} + f_{tv} = 4662\ PSI \quad (< F_t = 18{,}000\ PSI)$$

$$F.S. = \frac{30\,000}{4662} = 6.43$$

CHECK 3/8" WELD AROUND DOGHOUSE MTG. PLATE:

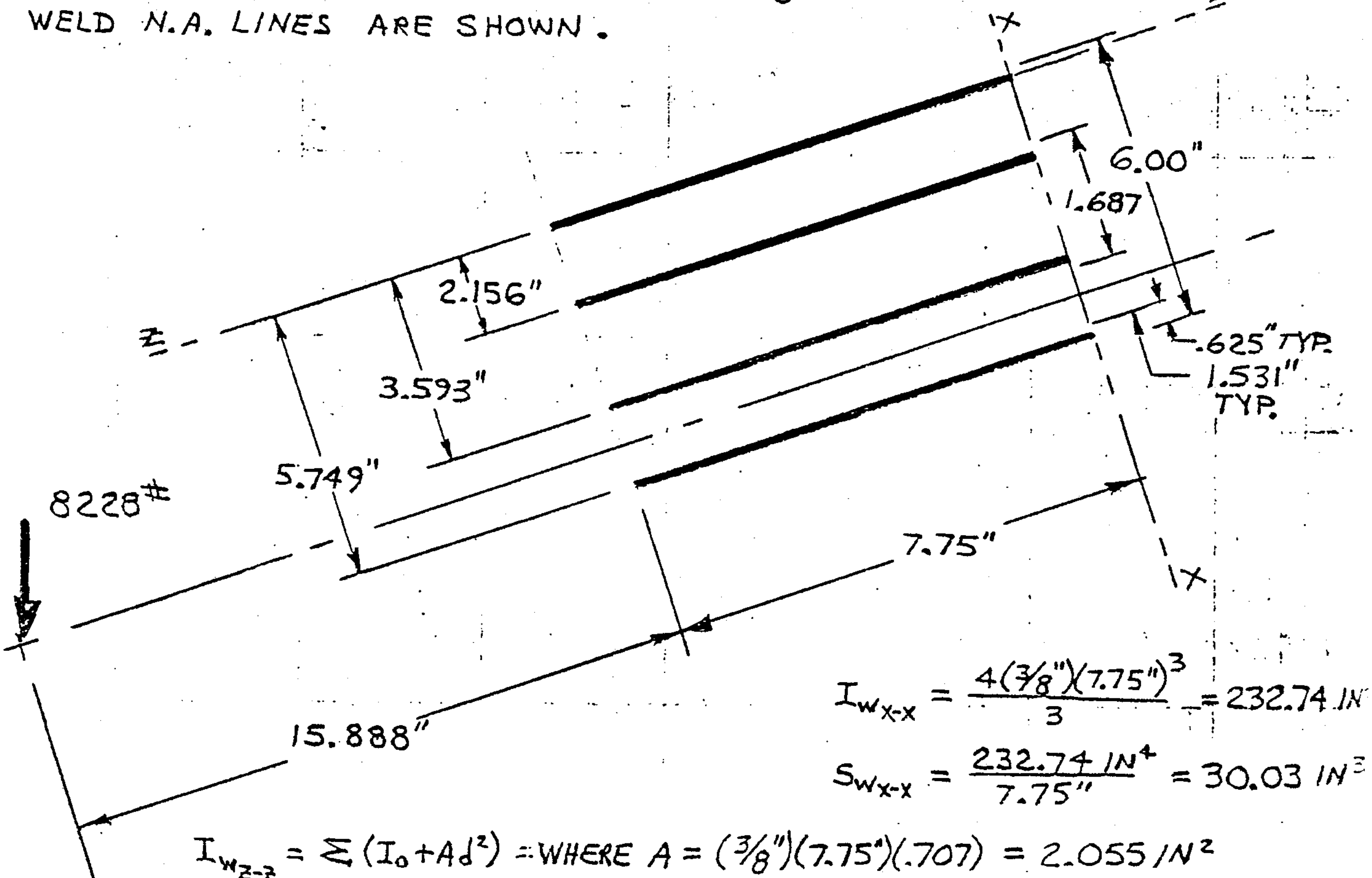
$$I_{WELD} = 2\left[\frac{3/8(8.50)^3}{3} + \frac{9.50(3/8)^3}{12} + 3/8(9.50)(.707)\left(\frac{8.50}{2}\right)^2\right] = 244.6\ IN^4$$

$$f_{tb} = \frac{8228\left(19.763 + \frac{8.50}{2}\right)8.50}{244.6\ IN^4} = 6866\ PSI$$

$$f_{tv} = \frac{8228^{\#}}{2(9.50 + 8.50)(3/8)(.707)} = 862\ PSI$$

$$f_t = f_{tb} + f_{tv} = 7728\ PSI\ (< F = 24{,}000\ PSI)\ ;\ F.S. = \frac{24000}{7728} = 3.10$$

CHECK DOGHOUSE PLATE WELDS: USE 3/8" WELDS.
WELD N.A. LINES ARE SHOWN.



$$I_{w_{x-x}} = \frac{4(3/8")(7.75")^3}{3} = 232.74\ IN^4$$

$$S_{w_{x-x}} = \frac{232.74\ IN^4}{7.75"} = 30.03\ IN^3$$

$$I_{w_{z-z}} = \Sigma(I_o + Ad^2) \text{ WHERE } A = (3/8")(7.75")(.707) = 2.055\ IN^2$$

$$= 4\left[\frac{3/8(3/8)^3}{36}\right] + 2.055(2.156^2 + 3.593^2 + 5.749^2) = 103.98\ IN^4$$

$$S_{w_{z-z}} = \frac{103.98\ IN^4}{6.000"} = 17.33\ IN^3$$

$$f_{vb_{xx}} = \frac{M_x}{S_{x-x}} = \frac{8228\#(15.888" + 7.75")}{30.03\ IN^3} = 6477\ PSI$$

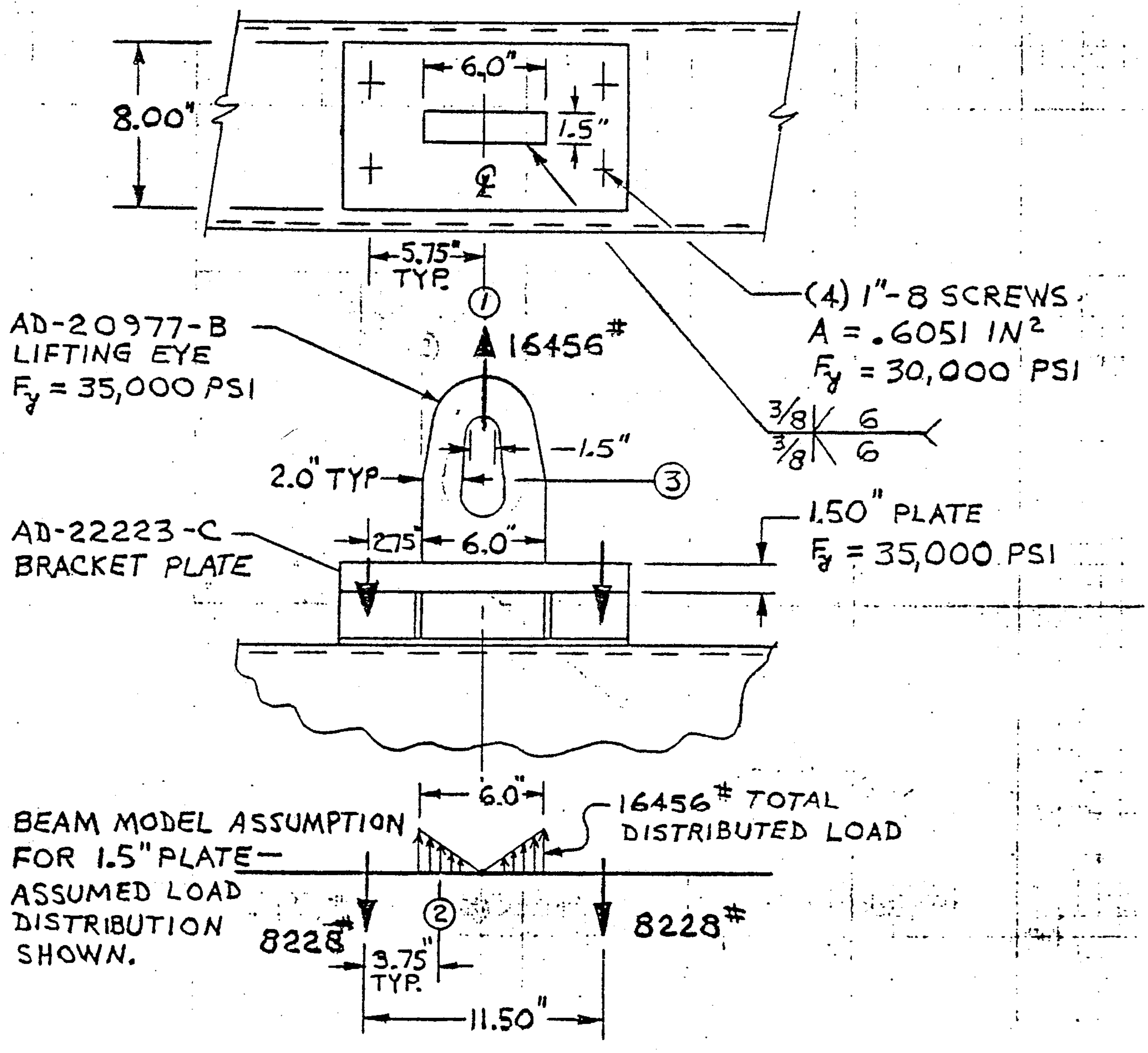
$$f_{vb_{zz}} = \frac{M_z}{S_{zz}} = \frac{8228\#(6.00" - .625" - \frac{1.531"}{2})}{17.33\ IN^3} = 2188\ PSI$$

$$f_v = \frac{P}{A} = \frac{8228\#}{4(3/8")(7.75)} = 708\ PSI$$

TOTAL STRESS $f_{vb_{xx}} + f_{vb_{z-z}} + f_v = 9373$ PSI ($< F = 24{,}000$ PSI)

$$F.S. = \frac{24000}{9373} = 2.56$$

LOAD HOOK ANALYSIS : SEE PaR DRAWINGS AD-20977-B AND AD-22223-C.



LOAD HOOK ANALYSIS (CONTINUED)

CHECK BENDING IN AD-20980-C PLATE AT LOCATION (2):

$$f_b = \frac{M}{S} = \frac{8228^{\#}(3.75'')}{\frac{8.0''(1.5)^2}{6}} = 10285 \text{ PSI}$$

$$\text{F.S. ON YIELD} \quad \frac{35000 \text{ PSI}}{10285 \text{ PSI}} = 3.40$$

CHECK TENSILE STRESS IN 1'-8 SCREWS:

$$f_t = \frac{16456^{\#}}{4(.6051 \text{ IN}^2)} = 6800$$

$$\text{F.S. ON YIELD} \quad \frac{30000 \text{ PSI}}{6800 \text{ PSI}} = 4.41$$

CHECK BENDING STRESS ON HOOK AT LOCATION (1):

$$f_b = \frac{M}{S} = \frac{8228^{\#}(.75'')}{\frac{2.0''(1.5)^2}{6}} = 8228 \text{ PSI}$$

$$\text{F.S. ON YIELD} \quad \frac{35000 \text{ PSI}}{8228 \text{ PSI}} = 4.25$$

CHECK TENSILE STRESS IN HOOK AT LOCATION (3):

$$f_t = \frac{P}{A} = \frac{8228^{\#}}{2.0''(1.5'')} = 2742 \text{ PSI}$$

$$\text{F.S. ON YIELD} \quad \frac{35000 \text{ PSI}}{2742 \text{ PSI}} = 12.76$$

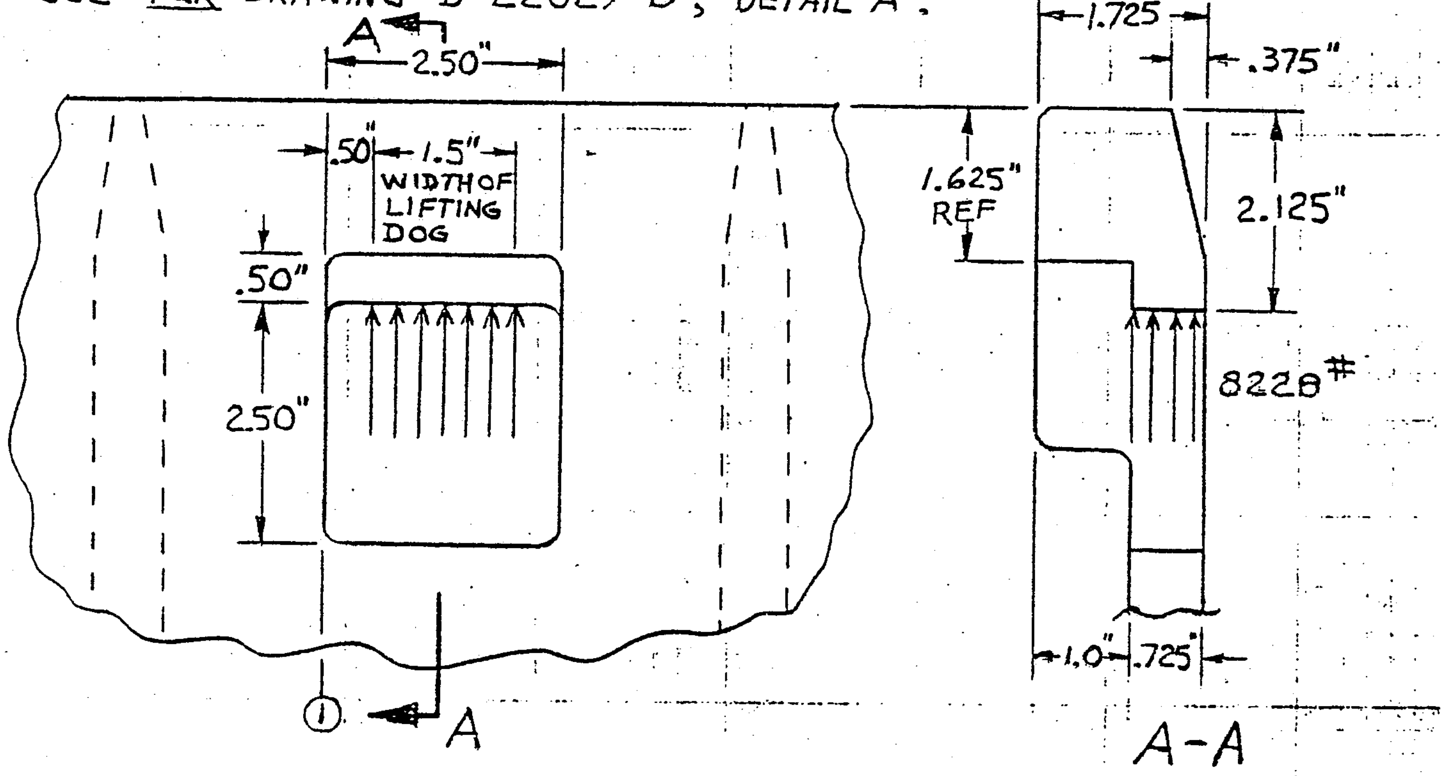
CHECK STRESS ON 3/8" HOOK WELD:

$$f_t = \frac{16456^{\#}}{2(3/8'')(6'')} = 3657 \text{ PSI}$$

$$\text{F.S. ON YIELD} \quad \frac{35000 \text{ PSI}}{3657 \text{ PSI}} = 19.57$$

MODULE CASTING LIFTING EYE ANALYSIS:

SEE P&R DRAWING D-22829-D, DETAIL 'A'.



CHECK BENDING AND SHEAR STRESSES AT LOCATION ①:

ASSUME AN AVERAGE HEIGHT AND WIDTH OF SECTION.

AVG. HEIGHT $\frac{1.625'' + 2.125''}{2} = 1.875''$

AVG. WIDTH $\frac{1.725''(2) - \frac{.375''}{3}}{2} = 1.662''$

AVG. AREA $(1.875'')(1.662'') = 3.537\ IN^2$

SECTION MODULUS $S = \frac{1.662''(1.875'')^2}{6} = .974\ IN^3$

$$f_b = \frac{M}{S} = \frac{\left(\frac{8228^\#}{2}\right)\left(.50'' + \frac{1.5''}{4}\right)}{.974\ IN^3} = 3696\ PSI$$

$$f_v = \frac{P}{A} = \frac{8228^\#}{2\,(3.537\ IN^2)} = 1163\ PSI$$

CASTING 356-T51, $F_y = 16{,}000\ PSI$

FOR SHEAR AND BENDING, $F_{by} = F_y - 1.6 f_v = 14139\ PSI$

F.S. ON YIELD $\frac{14139\ PSI}{3696\ PSI} = 3.82$

REF. PARA. 1.6.3 A.I.S.C. MANUAL, P. 5-23

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JANUARY 1978

SECTION 5.12

FUEL STORAGE SYSTEM DESIGN REPORT

PaR Job No. 3091

For

DUANE ARNOLD, UNIT NO. 1 (IOWA)

DESIGN CALCULATIONS

MODULE SHIPPING SKID

PREPARED BY [signature] DATE 1-18-78

CHECKED BY [signature] DATE 1-18-78

REVISION NO. ______ DATE ______

INTRODUCTION

An analysis of the shipping skid was conducted for racks orientated horizontally, vertically, and in tilted positions which occur for upending and shipping conditions. The computer program "SAGS" (Static Analysis of General Structures) was used to analyze a bracket on the skid. This program is available thru the Structural Dynamic Research Corporation SDRC, 5729 Dragon Way, Cincinnati, Ohio.

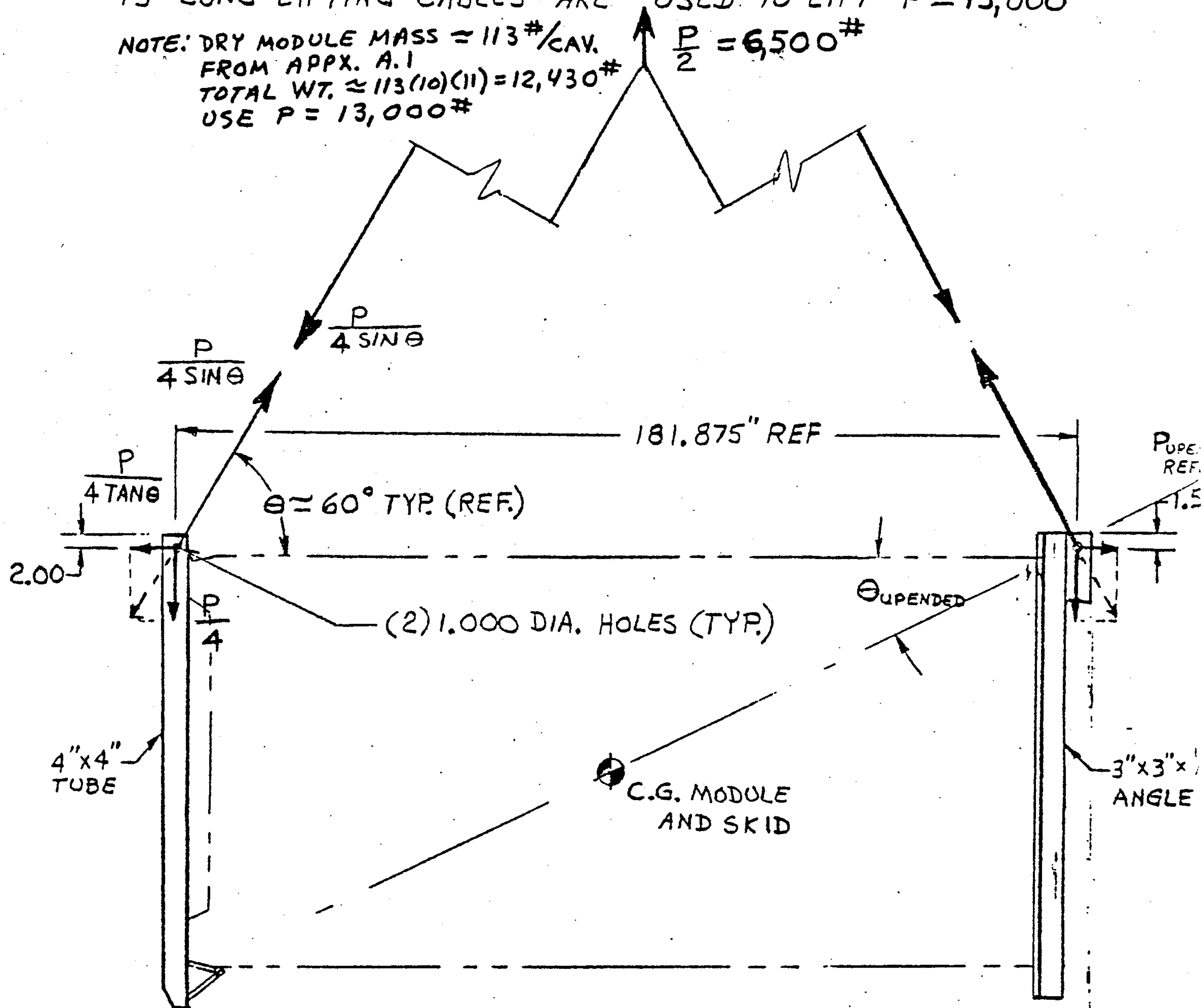
This analysis showed that all members and interface bolts have a safety factor greater than 3:1 on yield.

CHKD. BY ____ DATE ____ (AD-23190-D REF.) JOB NO. 3091

MODULE SHIPPING SKID ANALYSIS FOR FOUR POINT LIFT :

15' LONG LIFTING CABLES ARE USED TO LIFT $P \simeq 13{,}000^{\#}$

NOTE: DRY MODULE MASS $\simeq 113^{\#}$/CAV.
FROM APPX. A.1
TOTAL WT. $\simeq 113(10)(11) = 12{,}430^{\#}$
USE $P = 13{,}000^{\#}$



NOTE: ALL MEMBERS WILL BE DESIGNED WITH A GREATER THAN 3:1 F.S. ON YIELD. SINCE THE ALLOWABLE FOR TENSION IS EQUAL TO $.6F_y$, THIS CORRESPONDS TO .6(3) = 1.8:1 ON THE ALLOWABLE STRESS.

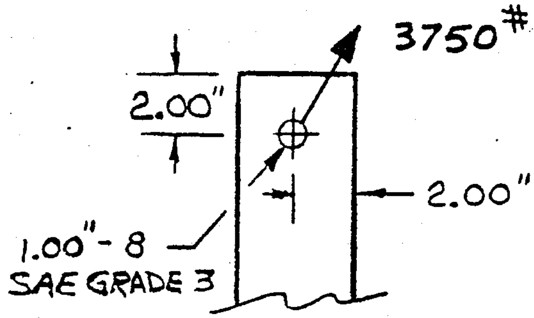
$$\frac{P}{4\tan\theta} = 1875^{\#}$$

$$\frac{P}{4\sin\theta} = 3750^{\#}$$

$$\frac{P}{4} = 3250^{\#}$$

ASSUME $P_{UPENDED} = 13000^{\#}$ AND $\theta_{UPENDED} \simeq 25°$ (SHOWN) AND 12° INTO PAPER.

CHECK RIP OUT SHEAR STRESS IN 4"x4" TUBE (1/4" WALL), $F_y = 36000$



$$f_v = \frac{3750^{\#}}{4(2.00")(.250")} = 1875 \text{ PSI} \quad (F_v = 14{,}400 \text{ PSI})$$

$$F.S. = \frac{14{,}400}{1875} = 7.68$$

CHECK BEARING STRESS

$$f_p = \frac{3750^{\#}}{2(1.00")(.250")} = 7500 \text{ PSI} \quad (< F_p = 32{,}400 \text{ PSI}$$

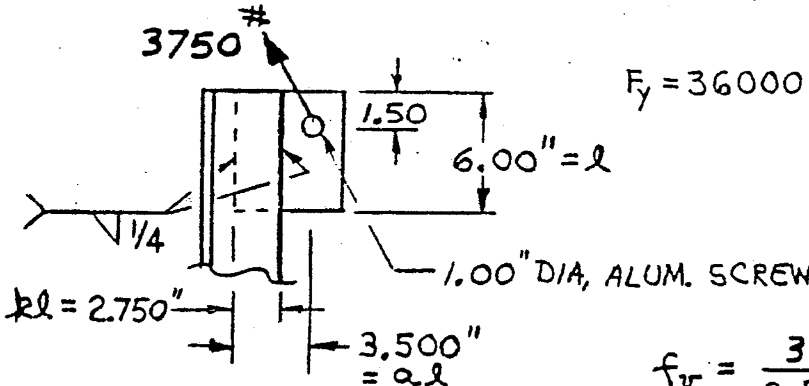
$$F.S. = \frac{32400}{7500} = 4.32$$

CHECK SHEAR STRESS ON 1.00" DIA. SCREW: $F_y = 85{,}000$ PSI, $F_v = 34{,}000$ PSI

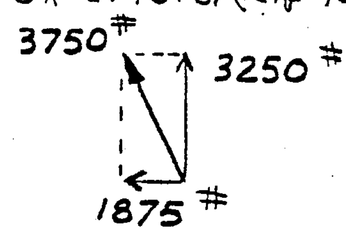
$$f_v = \frac{3750^{\#}}{2(\pi/4)(1.00)^2} = 2390 \text{ PSI} \quad (< F_v = 34{,}000 \text{ PSI})$$

$$F.S. = \frac{34000}{2390} = 14.24$$

CHECK RIP OUT SHEAR STRESS IN 3"x3"x 1/4" ANGLE TAB; TAB THK. IS 1/2".
SHEAR STRESS ON SCREW IS TWO TIMES ABOVE, OR 5140 PSI ($< F_v = 12{,}000$



$F_y = 36000$ PSI



$$f_v = \frac{3750^{\#}}{2(1.50")(.500")} = 2500 \text{ PSI} \quad (< F_v = 14{,}400 \text{ PSI})$$

$$F.S. = \frac{14400}{2500} = 5.76$$

$$a = \frac{3.500}{6.000} = .583$$

$$f_p = \frac{3750^{\#}}{(1.00")(.500")} = 7500 \text{ PSI} \quad (< F_p = 32{,}400 \text{ PSI})$$

$$k = \frac{2.750}{6.000} = .458$$

$$F.S. = \frac{32400}{7500} = 4.32$$

CHECK SHEAR STRESS ON 1/4" WELD SHOWN ABOVE: D = 4 FOR 1/4" WELD.
REF. A.I.S.C. MANUAL, 7th Ed, TABLE XIV, P. 4-68.

ALLOWABLE LOAD $P = CC_1 D\ell$ (FOR 3250# LOAD CONTRIBUTION)
WHERE $C_1 = 1.0$ FOR E70 ROD, AND $C = .64$ FROM TABLE XIV.

$$\therefore P \simeq .64(1.0)(4)(6.0) = 15.36 \text{ KIPS}$$

F.S. ON ALLOWABLE $\frac{15.36}{3.25} = 4.73$ (CONTRIBUTION DUE TO 3250# LOAD BASED ON 21000 PSI ALL[illegible]

CORRESPONDING STRESS IS $\frac{21000}{4.73} = 4440$ PSI

WELD SHEAR STRESS (CONTINUED):

CHECK SHEAR STRESS CONTRIBUTION DUE TO 1875# SHEAR LOAD.
USE TABLE XV, P 4-69, WHERE $a = \frac{1.5}{6.0} = .25$ AND $k = \frac{2.75}{6.0} = .458$

$P = CC_1D\ell = .95(1.0)(4)(6.0) = 22.8$ KIPS

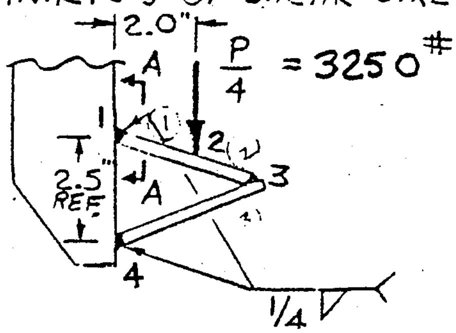
CORRESPONDING STRESS $\frac{1.875}{22.8}(21{,}000\text{ PSI}) = 1725$ PSI

TOTAL RESULTANT SHEAR STRESS ON WELD IS

$$\left[(4440)^2 + (1725)^2\right]^{1/2} = 4765 \text{ PSI} \quad (< F_v = 21{,}000 \text{ PSI})$$

$$F.S. = \frac{21000}{4765} = 4.40$$

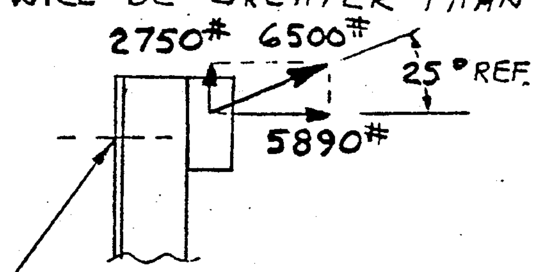
ANALYSIS OF SHEAR STRESS ON SUPPORT PLATE WELDS: SEE SHEETS 3B-3.



PLATES ARE 4.0" SQ.
REFER TO COMPUTER PRINTOUT LOADS
AT JOINT 1 (SEE SHEET 3E):
∴ TENSILE LOADS ARE F(X) = 1636#
AND F(Y) = 2631#.
MOMENT M = 2096 IN-LB
SEE SHEET 3B FOR SECTION 'A-A'.
NOTE: LOADS USED IN COMPUTER ANALYSIS ARE 3500# WHICH IS HIGHER THAN THOSE USED IN MODULE SKID ANALYSIS OF 3250# & ARE THEREFORE CONSERVATIVE.

MODULE SHIPPING SKID ANALYSIS FOR UPENDING CONDITION.

CHECK SHEAR AND TENSILE STRESSES ON 1.0"-8 SCREW, $A_t = .6051 \text{ IN}^2$
THIS SCREW SECURES MODULE TO THE SHIPPING SKID,
AND SCREW STRESSES FOR UPENDING CONDITION BELOW
WILL BE GREATER THAN FOR FOUR POINT LIFTING CONFIGURATION



1.0"-8 SCREW WITH .8647" MINOR DIA.
$F_y = 85{,}000$ PSI

$$f_v = \frac{2750\#}{\frac{\pi}{4}(1.0")^2} = 3500 \text{ PSI}$$

$$f_t = \frac{5890\#}{.6051 \text{ IN}^2} = 9735 \text{ PSI}$$

COMBINED SHEAR STRESS $\left(f_v^2 + \left(\frac{f_t}{2}\right)^2\right)^{1/2}$

$$= \left[3500^2 + \left(\frac{9735}{2}\right)^2\right]^{1/2} = 6000 \text{ PSI}$$

$(< F_v = 34000$ PSI$)$

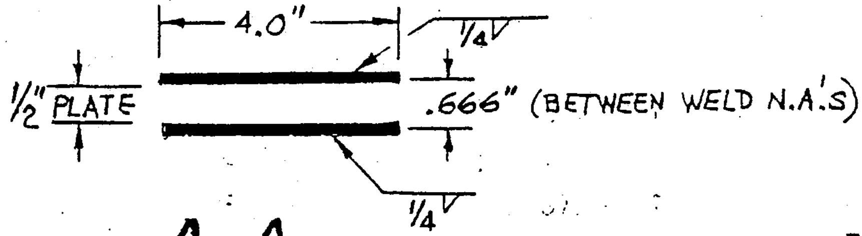
$$F.S. = \frac{34000}{6000} = 5.67$$

CHECK NO. OF ENGAGED THDS. REQ'D IN ALUM. CASTING WITH 5890# TENSILE LOAD, $F_v = .4(16{,}000) = 6400$ PSI, F.S. = 3 MIN.

$$\left[\frac{\frac{5890\#}{\pi(.8647")(1/8")}}{6400/3}\right] + 1 = 9.13 \text{ THDS. (MIN.)}$$

1.50" ENGAGEMENT IS AVAILABLE FOR 12 THREADS.

ANALYSIS OF SHEAR STRESS ON SUPPORT PLATE WELDS: (CONTINUED)



A-A

$$I_{weld} = \frac{2(4.0")(1/4")^3}{12} + 2(4.0")(.707)(.25")\left(\frac{.666"}{2}\right)^2$$

$$= .010 + .157 = .167\ IN^4$$

$$S_{weld} = \frac{.167\ IN^4}{.333"} = .501\ IN^3$$

$$f_{vb} = \frac{2096\ IN\text{-}LB}{.501\ IN^3} = 4184\ PSI$$

$$f_{vt} = \frac{\left[(1636)^2 + (2631)^2\right]^{1/2}}{2(4.0")(.707)(.25")} = 2191\ PSI$$

TOTAL SHEAR STRESS $f_v = f_{vb} + f_{vt}$

$$= 4184\ PSI + 2191\ PSI = 6375\ PSI$$

$(< F_v = 21{,}000\ PSI)$

$$F.S. = \frac{21000}{6375} = 3.29$$

STATIC ANALYSIS OF GENERAL STRUCTURES

STRUCTURAL DYNAMICS RESEARCH CORPORATION

BRACKT

*** PLANAR FRAME ANALYSIS ***

SPAN	LENGTH	FORE END JOINT	AFT END JOINT	MATERIAL CODE	SECTION CODE	ROTATION ANGLE	TEMP.
1	1.99	1	2	1	1		
2	2.01	2	3	1	1		
3	4.00	3	4	1	1		

JOINT COORDINATES

JOINT	X	Y	Z
1	.000	1.250	
2	1.890	.625	
3	3.799	.000	
4	.000	-1.250	

MATERIAL PROPERTIES

CODE	E	POISSON'S	DENSITY	THERMAL COEFFICIENT	YIELD
1	30.00E+06	.364	.000E+00	.000E+00	3.600E+04

CROSS-SECTION PROPERTIES

CODE	AREA	MOMENT OF INERTIA	SHEAR RATIO
1	1.000E+00	5.000E-03	1.20

STRESS RECOVERY VALUES

CODE	COMBINED STRESS	POINT 1/3 C(Y)	C(Z)	R(EFF)	POINT 2/4 C(Y)	C(Z)	R(EFF)
1	0	1.000	1.000	1.000			

SPECIFIED RESTRAINTS

JOINT	DIRECTION	VALUE
1	123456	
4	123456	

STATIC ANALYSIS OF GENERAL STRUCTURES

STRUCTURAL DYNAMICS RESEARCH CORPORATION

BRACKT

*** LOADING NO. 1:

JOINT DISPLACEMENTS

JOINT	X	Y	ROTATION
1	.000E+00	.000E+00	.000E+00
2	-3.215E-03	-1.022E-02	-1.596E-03
3	-1.593E-05	-7.304E-04	5.297E-03
4	.000E+00	.000E+00	.000E+00

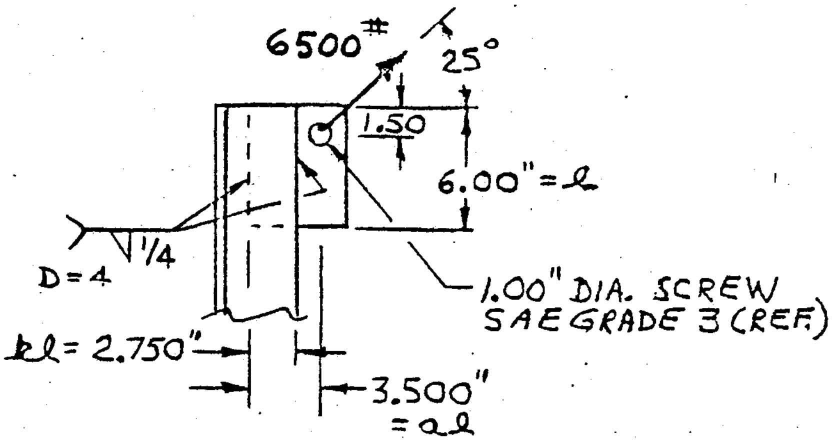
JOINT REACTIONS

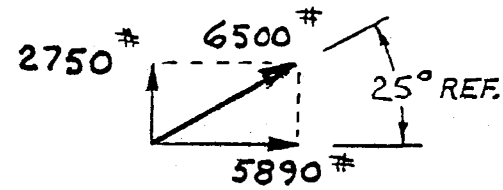
JOINT	F(X)	F(Y)	MOMENT
1	-1.636E+03	2.631E+03	2.096E+03
4	1.636E+03	8.685E+02	4.284E+02
TOTAL	4.377E-12	3.500E+03	2.524E+03

	FORE END FORCES				AFT END FORCES			
SPAN	JT.	AXIAL	SHEAR	MOMENT	JT.	AXIAL	SHEAR	MOMENT
1	1	-2.38E+03	1.98E+03	2.10E+03	2	2.38E+03	-1.98E+03	1.86E+03
2	2	-1.28E+03	-1.33E+03	-1.86E+03	3	1.28E+03	1.33E+03	-8.26E+02
3	3	1.83E+03	3.14E+02	8.26E+02	4	-1.83E+03	-3.14E+02	4.28E+02

MODULE SHIPPING SKID ANALYSIS FOR UPENDING CONDITION. (CONT.)

ASSUME ANGLE TAB AND SCREW MUST TAKE LOAD $\frac{P}{2} = 7000^{\#}$.





NOTE: 00# RESULTANT LOAD VECTOR ALSO IS AT 12° ANGLE INTO PAPER, I.E., 1380#

$$a = \frac{3.500}{6.000} = .583$$

$$k = \frac{2.750}{6.000} = .458$$

REF. A.I.S.C. MANUAL, 7th Ed., TABLE XIV, P. 4-68.

ALLOWABLE LOAD $P = CC_1 D\ell$ (FOR 2950# LOAD CONTRIBUTION)

WHERE $C_1 = 1.0$ FOR E70 ROD, AND $C = .64$ FROM TABLE XIV.

$\therefore P \simeq .64\,(1.0)(4)(6.0) = 15.36$ KIPS

F.S. ON ALLOWABLE $\frac{15.36}{2.75} = 5.58$ (CONTRIBUTION DUE TO 2750# LOAD BASED ON 21,000 PSI ALLOWABLE.)

CORRESPONDING STRESS IS $\frac{21000}{5.58} = 3760$ PSI

CHECK SHEAR STRESS CONTRIBUTION DUE TO 5890# SHEAR LOAD.

USE TABLE XV, P. 4-69, WHERE $a = \frac{1.5}{6.0} = .25$ AND $k = \frac{2.75}{6.0} = .458$

$P = CC_1 D\ell = .95\,(1.0)(4)(6.0) = 22.8$ KIPS

CORRESPONDING STRESS $\frac{5.89}{22.8}(21{,}000 \text{ PSI}) = 5425$ PSI

CHECK SHEAR STRESS CONTRIBUTION DUE TO LOAD COMPONENT 12° INTO PAPER:

$$f_v = \frac{\frac{3.50 - 2.75/2}{2.75}\,(1380^{\#})}{6.00''\,(.707)(1/4'')} = 1005 \text{ PSI}$$

RESULTANT SHEAR STRESS ON WELD IS

$$\left[(3760)^2 + (5425)^2 + 1005)^2 = 6675 \text{ PSI} \quad (< F_v = 21{,}000 \text{ PSI})$$

$$F.S. = \frac{21000}{6675} = 3.14$$

FOR 5:1 F.S. ON ULTIMATE STRENGTH OF LIFTING CABLE, USE CABLE WITH ULTIMATE STRENGTH F_u:

$$F_u = 5\left[\frac{6500^{\#}}{\cos 12°}\right] = 33{,}230^{\#}$$

MODULE SHIPPING SKID ANALYSIS FOR UPENDING CONDITION. (CONT.)

CHECK SHEAR STRESS ON 1.00" DIA. SCREW:

$$f_v = \frac{6500^{\#}}{(\pi/4)(1.00)^2} = 8275 \text{ PSI} \quad (< F_v = 34{,}000 \text{ PSI})$$

$$F.S. = \frac{34000}{8275} = 4.10$$

CHECK RIPOUT SHEAR STRESS ON 1/2" TAB:

$$f_v = \frac{6500^{\#}}{2(1.50'')(.500'')} = 4330 \text{ PSI} \quad (< F_v = 14{,}400 \text{ PSI})$$

$$F.S. = \frac{14{,}400}{4330} = 3.32$$

PROGRAMMED AND REMOTE SYSTEMS CORPORATION
3460 LEXINGTON AVE. NO., ST. PAUL, MINNESOTA 55112
AREA CODE 612 484-7261 TELEX #29-7473

SECTION 6.1

FUEL STORAGE SYSTEM DESIGN REPORT

PaR Job: 3091

DUANE ARNOLD ENERGY CENTER UNIT NO. 1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

SIMULATED MINIMUM COEFFICIENT OF FRICTION TEST

PREPARED BY [signature] DATE 1-24-78

CHECKED BY George L. Goblish DATE 1-24-78

REVISION NO. ______ DATE ______

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHK'D BY	APPV'D BY	DATE

FRICTION TEST REPORT

FOR YANKEE ATOMIC COMPANY

1.0 PURPOSE

To verify the minimum coefficient of friction for loading geometry, environments, and pressure as found on feet assemblies of spent fuel modules sliding on the floor liner plates of spent fuel pools.

The friction values were used in module design to determine maximum module displacements after a seismic event. These tests were done under ideal conditions with no considerations given to long term contact effects and corrosion effects. Therefore, they represent the minimum friction forces and do not attempt to define their maximums.

2.0 TEST SET-UP & DESCRIPTION

Picture 1 delineates the test set-up. Two 6" diameter x 1/2" thick 304 S.S. pads were bolted onto a middle sandwich plate. These pads are identical to the foot assembly pad as used on the module. The middle pad sandwich plate is connected to a 3" diameter hydraulic cylinder actuated by a hand pump. The pad assembly is in turn sandwiched between two stationary 1" thick 304 S.S. plates with standard hot rolled finish to simulate the pool liner. (See picture 2). The complete friction test assembly is located in the bottom of a shallow tub, capable of holding enough water such that the pad assembly can be totally submerged. The stationary plates are vertically loaded with a 5" diameter bench press.

The pad assembly is then slid between the sandwich by means of the other hydraulic cylinder. Both cylinders have pressure gages to measure the vertical and horizontal pulling force.

3.0 TEST PROCEDURE

For normal loads of 5000 to 40,000# increments, measure the horizontal static and kinetic sliding force under the following conditions:

1) Pad assembly with 32 micro-inch surface finsih
   a) Dry
   b) Wet (water)
2) Pad assembly with 250 micro-inch surface finish
   a) Wet

Note: because two sliding surfaces are used , the horizontal force is divided by two to obtain the sliding force by one surface. This force is then divided by the normal force to obtain the coefficient of friction.

4.0 RESULTS OF MEASURED DATA

TABLE I

Normal Force	Static Coefficient of Friction			Kinetic Coefficient of Friction		
	Dry 32√	Wet 32√	Wet 250√	Dry 32√	Wet 32√	Wet 250√
5,000	.19	.14	.09	.14	.13	.07
10,000	.25	.27	.22	.21	.23	.20
15,000	.26	.26	.25	.24	.24	.23
20,000	.27	.25	.24	.25	.23	.22
25,000	.25	.24	.23	.24	.23	.23
30,000	.29	.25	.23	.24	.25	.23
35,000			.24			.23
40,000			.23			.23

5.0 SUMMARY

Table I presents the coefficient of friction for the various conditions measured. The live and dead weight of four legged 10 x 10 module assembly is approximately 22,000 lbs. per pad. For normal pad forces between 15,000 to 30,000 lbs, the variation of measured friction coefficient is .23 - .29 for all conditions.

The following observations are made in reviewing the data.

1) For normal forces above 10,000# coefficients are fairly constant for a given conidition. Coefficients are always substantially lower for normal forces below 10,000# .
2) Wet values were 0-1% lower than dry values.
3) Kinetic values were 0-2% lower than static values.
4) Wet values for 250 micro-inch finishes were 0-2% lower than smoother pad surfaces with 32 micro-finishes.

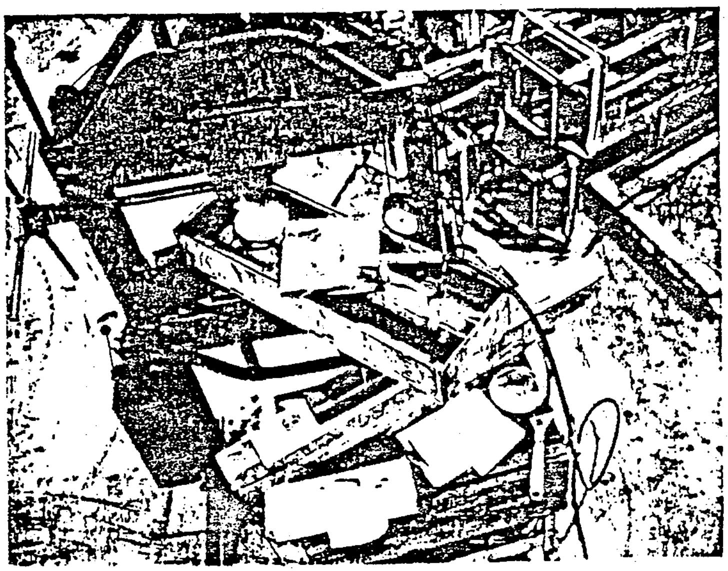
Very little difference was measured for kinetic and static friction, which may be attributed to the small pad velocities maintained with the hand pump on the actuating cylinder.

6.0 CONCLUSIONS

For nominal contact pressures minimum coefficient of friction measured were .23 -.29 for all conditions. Because these measured values do not show the effects of long term contact stress and corrosion, we believe these values represent the absolute minimum.

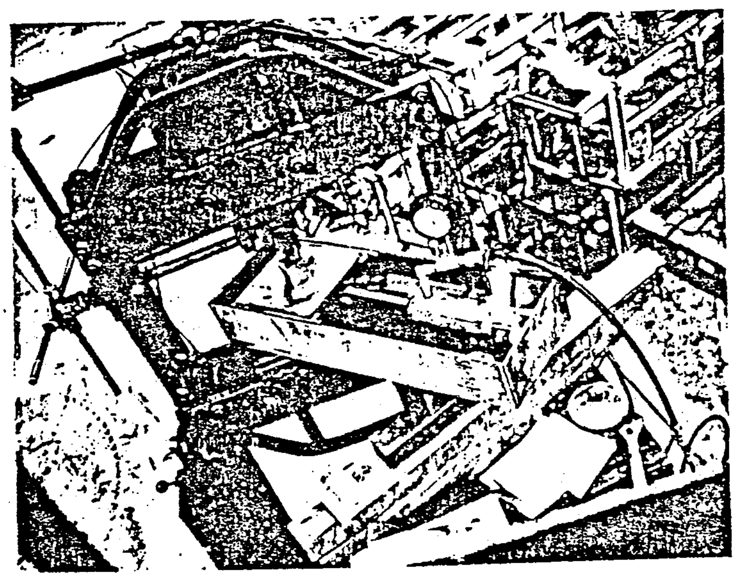
A coefficient of friction of .2 based on these tests was used in the seismic time history analysis to determine maximum module relative displacement. This value is 15% below a minimum measured value of .23 to account for measurement uncertanties.

7.0 PICTURES



PICTURE 1

PICTURE 2



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SECTION 6.2

FUEL STORAGE SYSTEM DESIGN REPORT

PaR Job: 3091

DUANE ARNOLD ENERGY CENTER UNIT NO. 1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

BOLT CLEARANCE TEST REPORT

PREPARED BY [signature] DATE 1-10-78

CHECKED BY George L. Hoblish DATE 1-24-78

REVISION NO. ________ DATE ________

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHK'D BY	APPV'D BY	DATE

TEST REPORT/BOLT CLEARANCE

PURPOSE: To determine the deflection and ultimate load capacity of bolted joints with different body clearances, seating torques and hole misalignment. The values were then compared against identical bolt patterns with a dowel pin press fitted in the middle of the bolt pattern.

TEST SET UP & PROCEDURE: Figure 2 delineates the test set-up. Here a typical two bolt pattern was mocked up and loaded in a 5" diameter bore bench press. The top surface of the plates was measured with a dial indicator. The plates were loaded in 100 psi increments of the bench and deflection measurements were taken at each load.

Four different conditions were tested:

1) The plates bolted together with two 3/4-10 bolt torqued to 600 in-# with body hole of .015" clearance. Body hole pattern .015" less the mating hole pattern so that it is a line to line fit on outside edges of the bolts- note theoretically all the load would be of the 1st bolt, in this case.
2) Same as (1) except body hole clearance .005" and hole patterns in line.
3) Same as (2) except a 1" dowel with a .0003-7" press fit was added to the middle of an inline bolt pattern, and body hole clearance of .015. The testing for this case was done by Twin City Testing. The test report is found in back of this repor

4) Same as (2) except bolts are only finger tight.

All materials were aluminum. Bolts were Standard 3/4-10-UC x 1 1/2" Hex Heads, alloy 2024-T4. Bolt threads were in the shear.

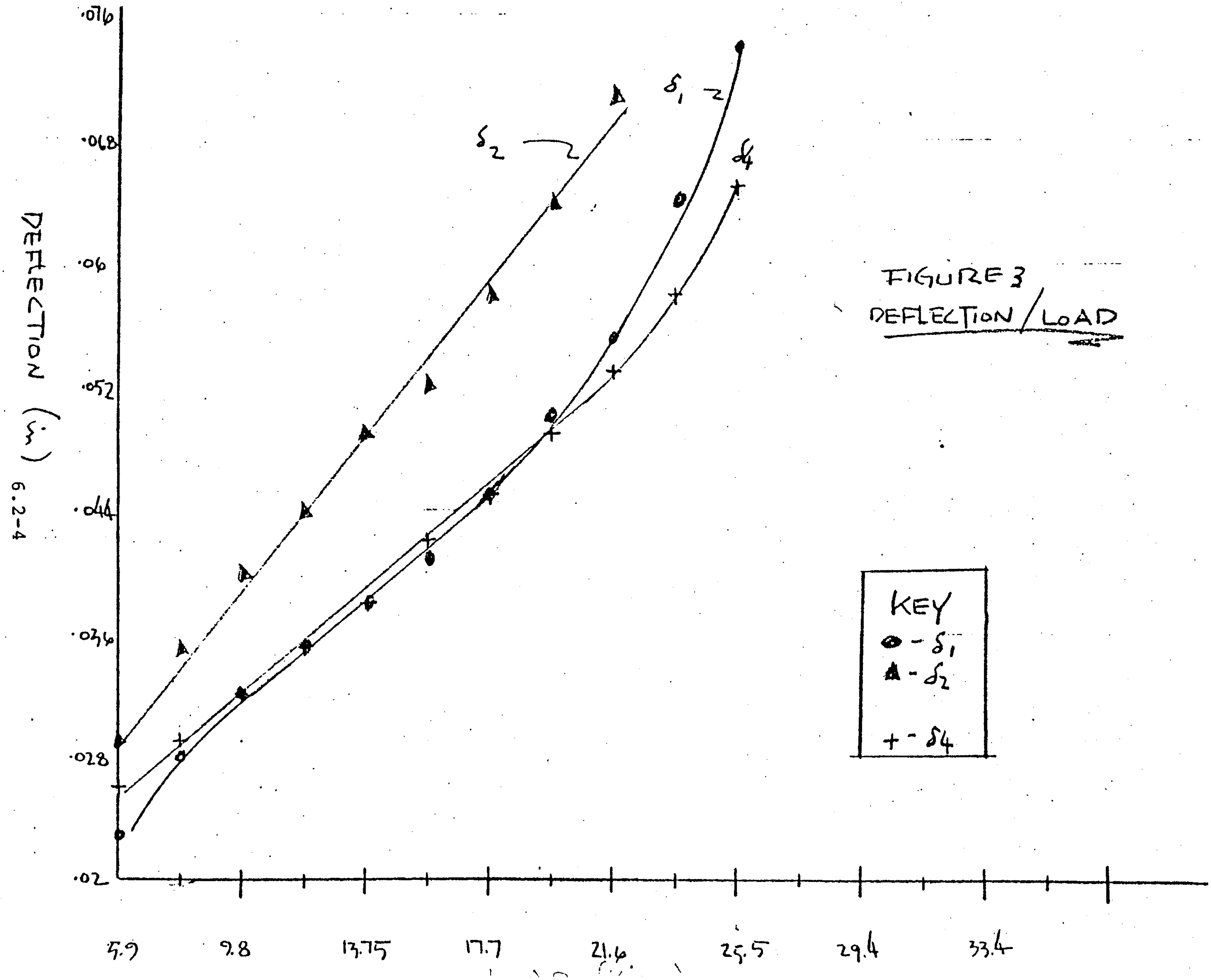
RESULTS: Table one summarizes the deflection -vs- load results for four cases. (Figure 3 presents these same results in a graphical form), for conditions 1,2, and 4. Figure 1 and Table 2 presents results for case 3.

On Figure 3, the results for trials 1,2, and 4 are approximately linear up to approximately 22 Kips. After the load the slope increases. This effect is accounted for by parallegramming of the bench press and should be ignored.

CONCLUSIONS: For Trials 1,2, and 4 bolt clearances, hole misalignment and seating torque had virtually no effect on ultimate failure load.

The failure load for these three cases were 25.15 ksi. The total effective shear area of the two 3/4 bolts is .668 in^2. The failure shear strength is then 25.51/.668 = 38.18 ksi.

For load case 3 the total shear area of the two bolts plus the 1" dowel pin is 1.453 in^2. The failure shear strength is then 52.75/1.453 = 36.29 ksi. This results in a 5% reduction in the shear strength due to the dowel pin and bolts not sharing the load proportionately.



BY .... DATE .... SUBJECT .... SHEET NO .... OF ....
CHKD. BY .... DATE .... JOB NO ....

TABLE ONE

DEFLECTION OF BOLTED JOINTS

Load Kips	Deflection S_1	S_2	S_4
5.89	.023	.029	.026
7.85	.028	.035	.029
9.81	.032	.040	.032
11.77	.035	.044	.035
13.74	.038	.049	.038
15.7	.041	.052	.042
17.66	.045	.058	.045
19.63	.050	.064	.049
21.59	.055	.071	.053
23.55	.064	.081	.058
25.51	.074	Failure	.065
27.48	Failure		Failure
29.44			
31.4			
33.36			
35.32			
37.29			

KEY

S_1 = .015 Body Clearance- Two Bolts Torqued 600 in-#/and hole Misalignment of .015"

S_2 = .005" Holes in Line- Two Bolts Torqued 600 in-#

S_3 = .015 Holes in Line- Two Bolts Torqued 600 in-# and 1" dowel pin with .0003-7 press fit

S_4 = .005 Clearance- Two Bolts Finger Tight

BY [signature] DATE 12/25/76 SUBJECT

CHKD. BY [signature] DATE 1/6/78

SHEET NO .... OF ....

JOB NO. ....

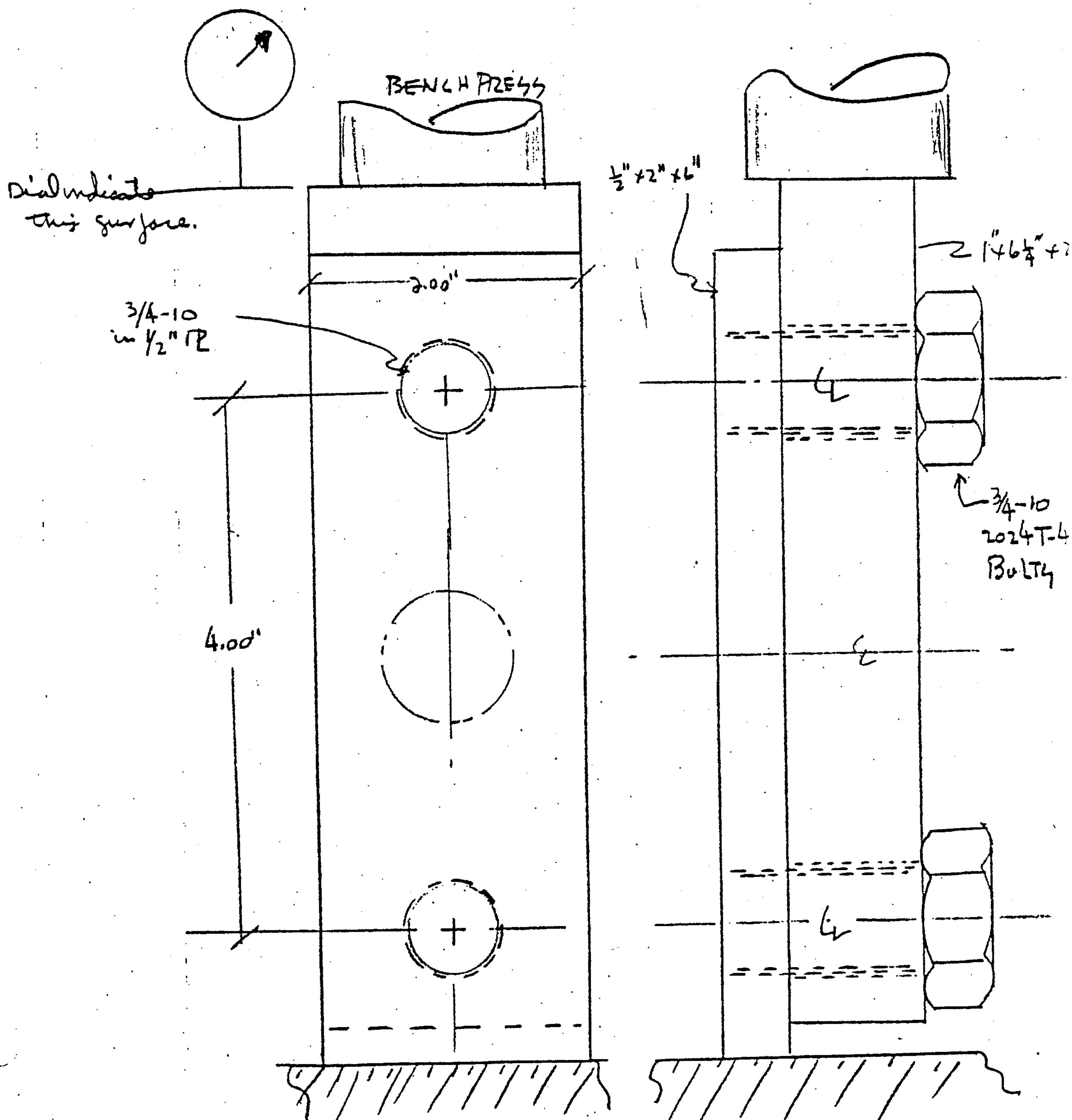


FIGURE 2 TEST SET UP

twin city testing
and engineering laboratory, inc.
662 CROMWELL AVENUE
ST. PAUL, MN 55114
PHONE 612/645-3601

REPORT OF: LOAD-DEFLECTION TEST OF SHEAR BLOCK

PROJECT:

DATE: December 23, 1976

REPORTED TO: Programmed & Remote Systems Corp
899 W Highway 96
St Paul, MN 55112
Attn: Mr Al Sturm

FURNISHED BY:

COPIES TO:

LABORATORY No. 14-2500

GENERAL:

On December 2, 1976, we received a shear block for load test. The shear block consisted of a 6 1/4" x 2" x 1" aluminum plate placed alongside a 6" x 2" x 1/2" aluminum plate and bolted together with two 3/4" diameter by 1 7/8" long aluminum bolts. A 1" diameter aluminum shear pin was also connected to the two aluminum plates midway between the two threaded bolts.

A load-deflection test was conducted on the shear block by applying a downward force to the 6" x 2" x 1/2" aluminum plate while oriented in a vertical position. Deflection measurements were recorded at regular load intervals using a dial indicator.

D-DEFLECTION TEST RESULTS: Table 2

Compressive Load, lb	Compressive Deflection, in.
0	0
1,000	0.0015
2,000	0.0025
3,000	0.0040
4,000	0.0055
5,000	0.0065
6,000	0.0080
7,000	0.0095
8,000	0.0110
9,000	0.0120
10,000	0.0135
11,000	0.0145
12,000	0.0160
13,000	0.0170
14,000	0.0185
15,000	0.0200
16,000	0.0215
17,000	0.0230
18,000	0.0245
19,000	0.0260

twin city testing
and engineering laboratory, inc.
662 CROMWELL AVENUE
ST. PAUL, MN 55114
PHONE 612/645-3601

REPORT OF: LOAD-DEFLECTION TEST OF SHEAR BLOCK

DATE: December 23, 1976

LABORATORY No. 14-2500

LOAD-DEFLECTION TEST RESULTS: (Cont.)

Compressive Load, lb	Compressive Deflection, in.
20,000	0.0270
21,000	0.0285
22,000	0.0300
23,000	0.0310
24,000	0.0325
25,000	0.0335
26,000	0.0350
27,000	0.0360
28,000	0.0375
29,000	0.0385
30,000	0.0400
31,000	0.0410
32,000	0.0425
33,000	0.0440
34,000	0.0450
35,000	0.0465
36,000	0.0480
37,000	0.0495
38,000	0.0510
39,000	0.0530
40,000	0.0545
41,000	0.0555
42,000	0.0575
43,000	0.0595
44,000	0.0615
45,000	0.0645
46,000	0.0675
47,000	0.0705
48,000	0.0735
49,000	0.0770
50,000	0.0815
51,000	0.0860
52,000	0.0905
52,750*	0.0980

twin city testing
and engineering laboratory, inc.
662 CROMWELL AVENUE
ST. PAUL, MN 55114
PHONE 612/645-3601

REPORT OF: LOAD-DEFLECTION TEST OF SHEAR BLOCK

DATE: December 23, 1976

LABORATORY No. 14-2500

LOAD-DEFLECTION TEST RESULTS: (Cont.)

* Shear fractures occurred in the two threaded bolts and the 1" diameter shear pin.

The load-deflection test results suggested that the shear block started to yield at approximately 36,000 lb. The load-deflection curve for the shear block is shown in Figure #1.

REMARKS:

This test was conducted under your Purchase Order Number L-12319-1.

The shear block is being returned to you under separate cover.

Twin City Testing and Engineering Laboratory, Inc.

By Richard Rilltis

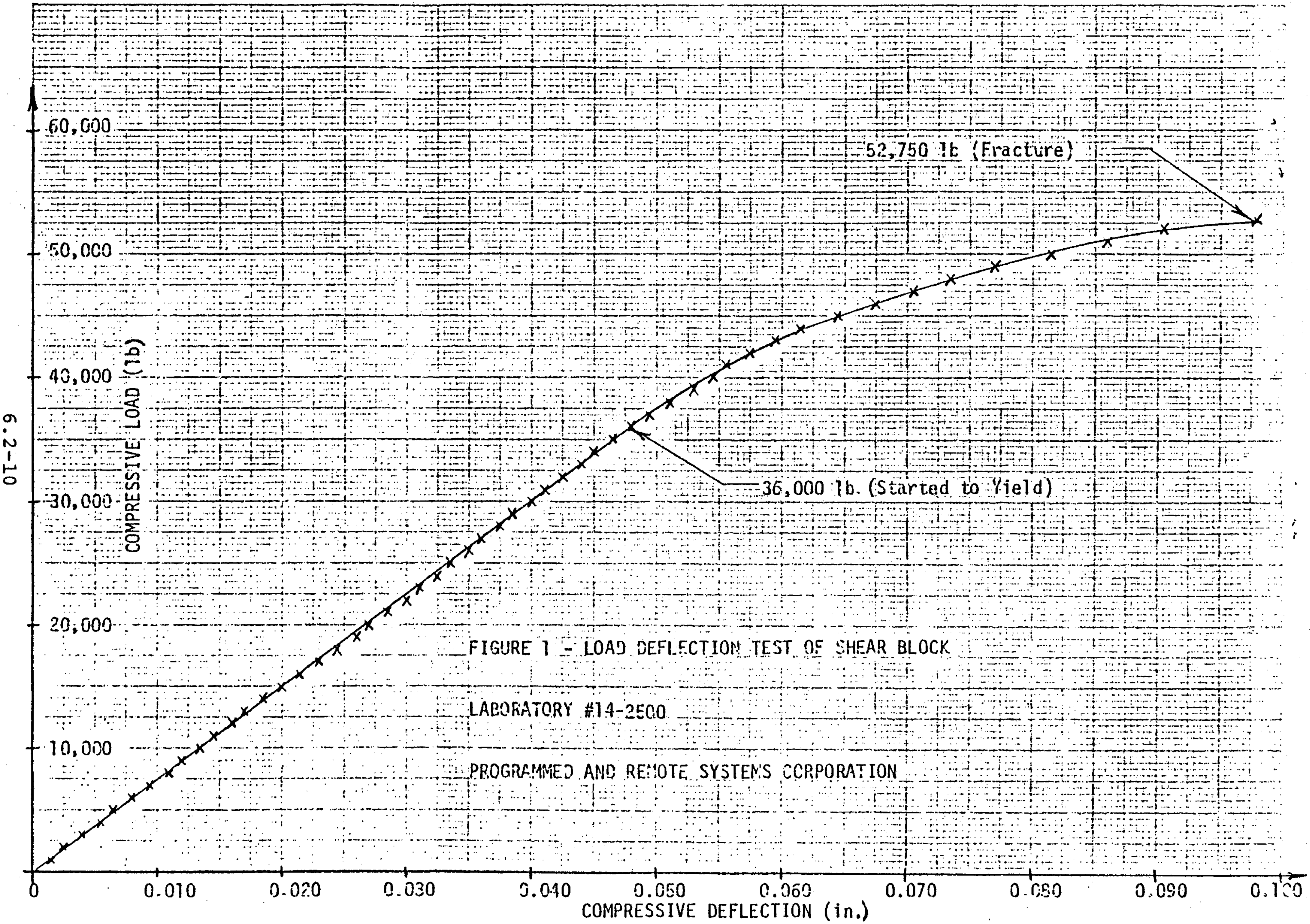


FIGURE 1 - LOAD DEFLECTION TEST OF SHEAR BLOCK

LABORATORY #14-2500

PROGRAMMED AND REMOTE SYSTEMS CORPORATION

PROGRAMMED AND REMOTE SYSTEMS CORPORATION
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AREA CODE 612 484-7261 TELEX #29-7473

SECTION 6.3

FUEL STORAGE SYSTEM DESIGN REPORT

PaR Job: 3091

DUANE ARNOLD ENERGY CENTER UNIT NO. 1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

SIMULATED DROPPED FUEL BUNDLE TEST

PREPARED BY [signature] DATE 1-10-78

CHECKED BY [signature] DATE 1-24-78

REVISION NO. 1 DATE 2-17-78

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHK'D BY	APPV'D BY	DATE
1	2-17-78	Deleted sentence para. 1 from word drop.	H. J. H.	[illegible signature]	2/10/78

DROP TEST REPORT

1.0 PURPOSE

To determine impact loads and verify top casting integrity resulting from a 18" fuel drop.

2.0 BACKGROUND

In Section 5.2 of the design report, a net impact energy for the 18" drop was calculated as 7802 in.-lb.. The spring rate at the corners of the module at the top casting were calculated at 1121 Kip/In.

In this test, a 10 x 7 top casting was used. It was supported on the four corners by load cells resting on wooden blocks. See Picture 1.

The wooden blocks were used so that the spring rate of the supports in the test approximately match that of the supporting structure of the module.

The bearing on the blocks was a 2.5" square plate or 6.25 $in.^2$. Two 4 x 4 blocks were stacked giving a total wood depth of 7". The spring rate "K" for the wooden supports is given by the following equation:

$K = AE/\ell$

Where $A = 6.25$ in.^{2}

$E = 1.5\ (10^6)$ psi for wood

$\ell = 7"$

Solving yields

$K = 6.25\ (1.5)(10^6)/7 = 1330$ Kip/In.

This spring rate is slightly higher than the calculated value of 1121 Kips/In., so it will tend to give slightly higher loads.

3.0 TEST SET UP

As mentioned previously, Pictures 1 and 2 delineate the test setup. The 10 x 7 casting was supported at the corners by load cells in series with wooden blocks to match the structural stiffness. Note: In the actual assembly, the top casting is supported along its entire periphery by the 1/2" side panels. So that bending stresses in the casting will be slightly higher for the tested geometry. A 2'x 2'x 2', 1100# concrete block with a 7" square x 2" LCS impact nose anchored to it under side was used to simulate the dropped fuel bundle. A four angle guiding structure surrounded the block for safety reasons. Metal binding tape connected the block lifting eye to an overhead crane hook. After the block was lifted to the desired drop height, the metal tape was cut and impact time histories were recorded using a light beam oscillograph. The oscillograph and load cells were supplied and monitored by Test Technology of Minneapolis, Minnesota. Equipment description and calibration record are on file at PaR.

To obtain a 7802 In.-Lb. impact energy for the 1100# block, the proper drop height is, d = 7802/1100 = 7.09".

4.0 PROCEDURE

Drop block 3.5" above casting, record force impact time histories, and note any visual damage. Repeat for a 7.09" drop Repeat once again for a 3.5" and 7.09" drop noting repeatability of results.

5.0 RESULTS

Plots 1 and 2 present the measured impact time histories for the 3.5" and 7.09" drop. The repetitious runs agree very closely and are not presented. These plots are the sum of all 4 load cells or the total impact force. Plot number 1 had a peak impact force of 17,000# and plot number 2 had a peak force of 25,000#.

Picture 3 and 4 depict the set up prior to the 3.5" and 7.09" drop. After all testing, only slight local deformations less 1/16" deep were noted at the impact interface.

6.0 CONCLUSIONS

For an elastic impact, the impact force "F" can be shown to be:

(1) $$F = \sqrt{2EK}$$

Where:

E = impact energy

K = spring rate

For a constant spring rate and mass, the following proportionally can be shown to exist:

(2) $$\frac{F_1}{F_2} = \sqrt{\frac{d_1}{d_2}}$$

Where d = drop height

For the 3.5" drop the measured force "F", is 17,000#. The predicted force "F_2", using equation (2) for the 7.09" drop would be:

$$F_2 = 17{,}000 \sqrt{\frac{7.09}{3.5}} = \underline{24{,}195\#}$$

Which is very close to the measured value of 25,000#.

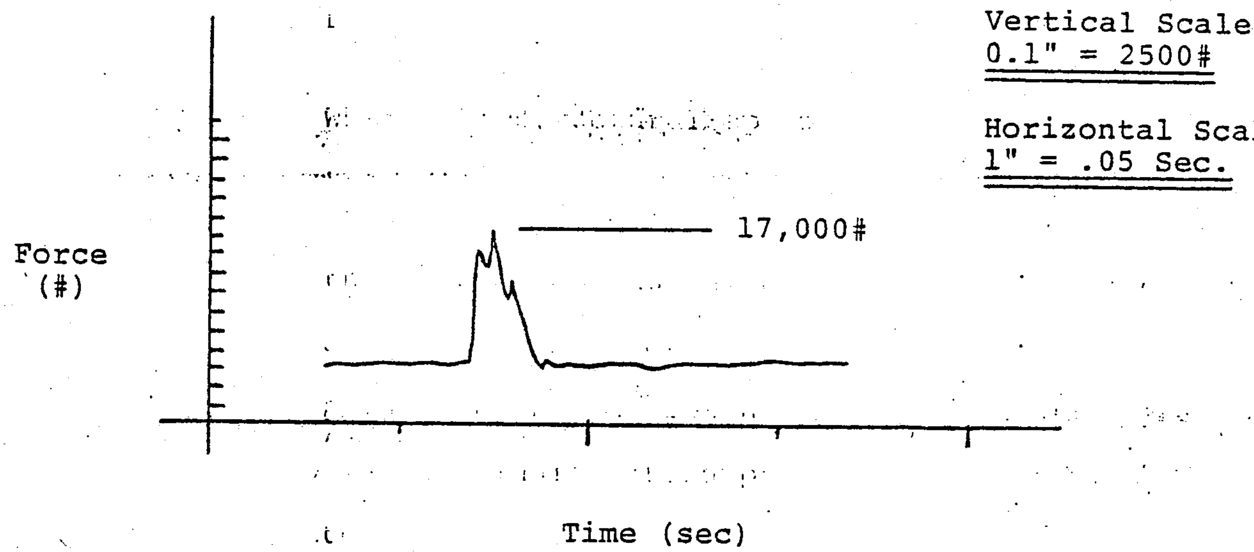
Measurements of impact forces for a drop condition on the corners of the module were not taken, however, an indication of the value of this force can be made by assuming a constant impact energy and applying the following proportionality existing in equation (1):

$$\frac{F_1}{F_2} = \sqrt{\frac{K_1}{K_2}}$$

Where K = structural spring rate

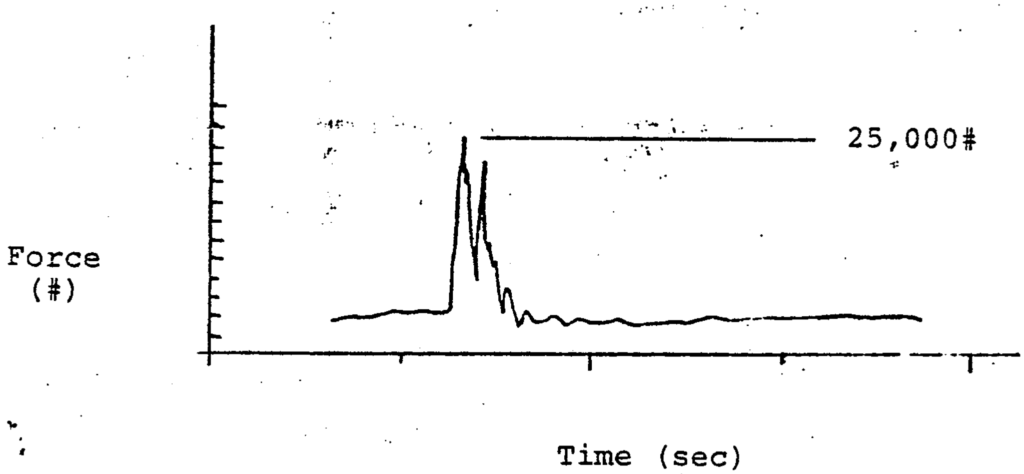
In Section 5.2, the spring rate due to a unit load in the middle of the module top was calculated as 822 Kips/In. The spring rate at the corners of the module was calculated to be 1121 Kip/In.. Using the measured 25,000# impact force for a drop in the middle, the approximate impact force for a drop in the corners is:

$$F_1 = 25,000 \sqrt{\frac{1121}{822}} = 29,181\#$$



PLOT NO. 1

Impact Energy = 3850 In/Lbs.

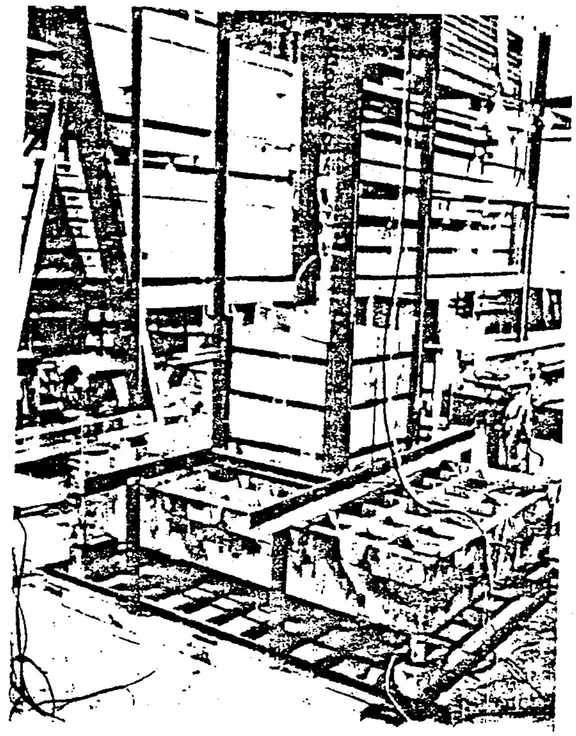


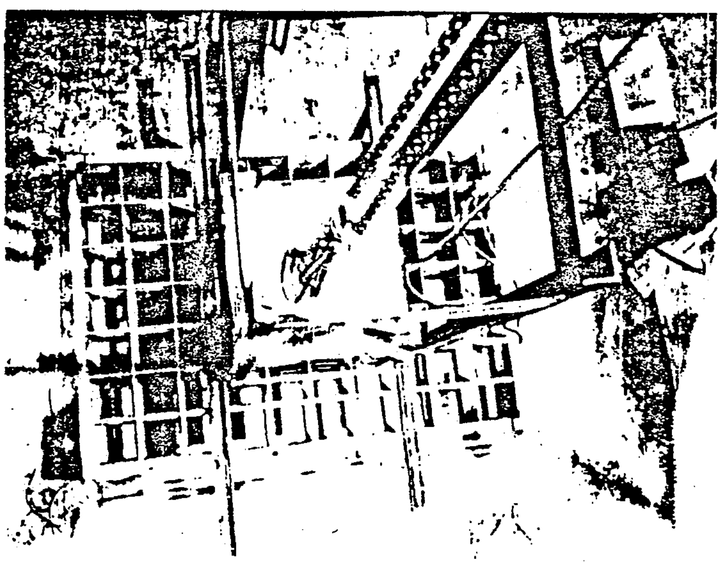
PLOT NO. 2

Impact Energy = 7802 In/Lbs.

FORCE IMPACT TIME HISTORIES

Picture #1
Test-Setup Side View

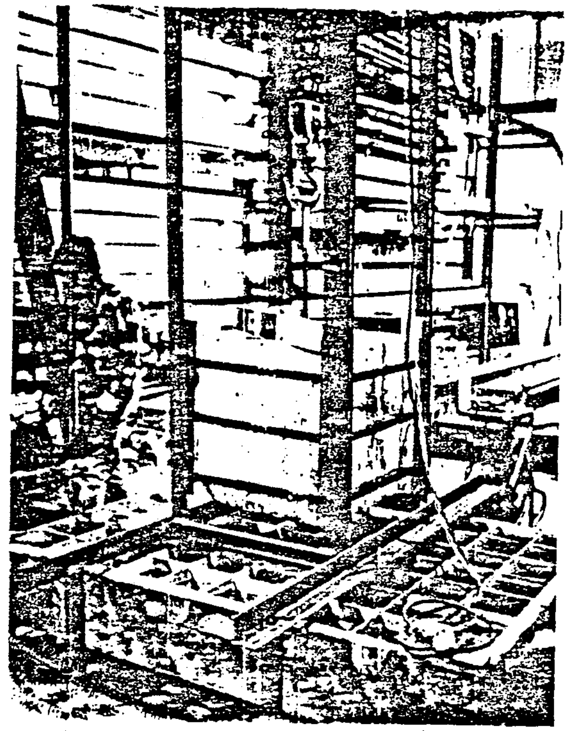


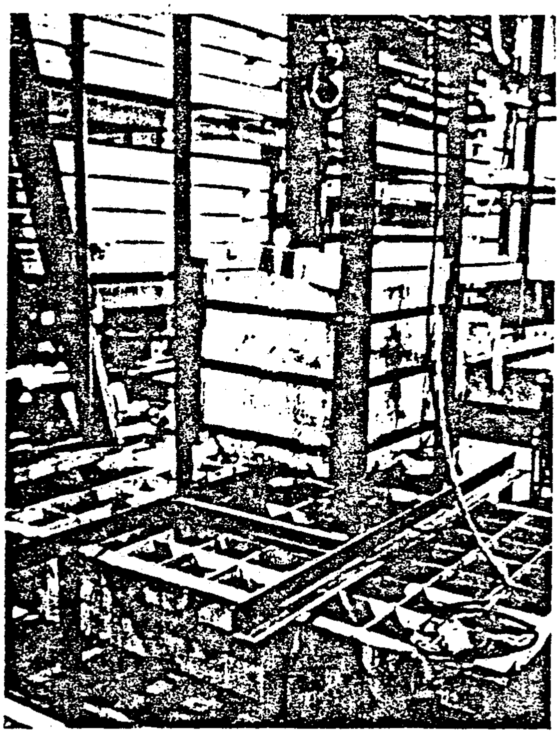


Picture #2
Test-Setup Aerial View

Picture #3

Test Setup Prior to the 3.6" drop.





Picture #4

7" Drop

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APPENDIX A.1

FUEL STORAGE SYSTEM DESIGN REPORT

PaR Job No. 3091

DESIGN CALCULATIONS

For

DUANE ARNOLD ENERGY CENTER UNIT NO.1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

BEAM SECTION PROPERTIES, MODULE DEAD WEIGHT ESTIMATE AND SEISMIC MASS INPUT

PREPARED BY George P. Hoblish DATE 11-14-77

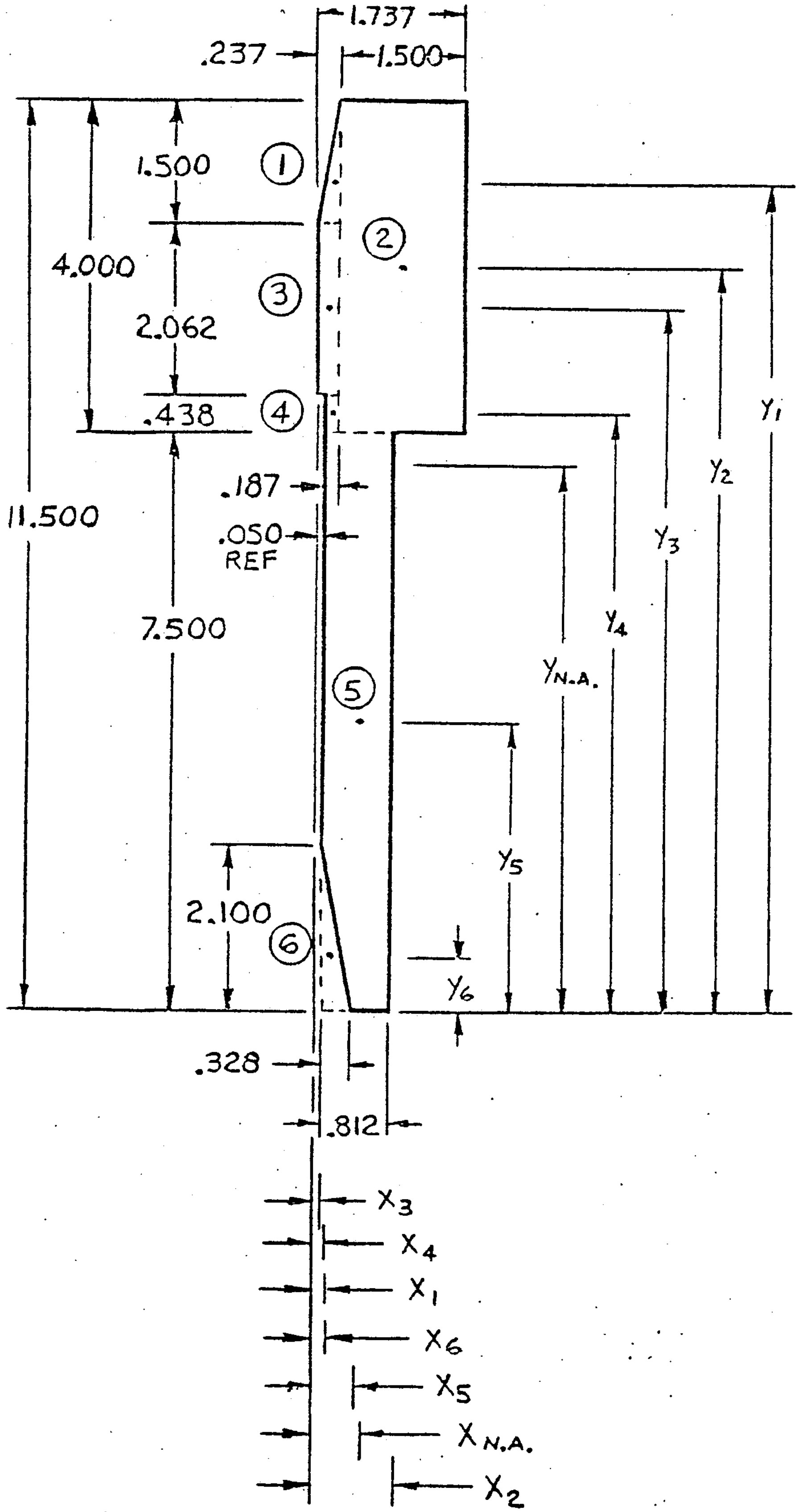
CHECKED BY [signature] DATE 12-15-77

REVISION NO. 1 DATE 2-17-78

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHK'D BY	APP'D BY	DATE
1	2-17-78	Revised Sheets A.1.24 & A.1.25 Renumbered sheet A.1.26	H.L.H.	[illegible]	2/17/78

DETERMINE MOMENT OF INERTIA I OF TOP GRID OUTER SECTION :
USE THE FOLLOWING APPROXIMATE CONFIGURATION, (1) + (2) + (3) + (4) + (5) - (6).



BY G. GOBLISH DATE 11-3-77 SUBJECT SECTION PROPERTY CALCULATIONS SHEET NO ...... OF ......
CHKD. BY [signature] DATE 11/15/77 TOP GRID OUTER SECTION JOB NO. 3091

DETERMINE I_{ny} AND S_y FOR TOP GRID OUTER SECTION.

SECTION	SIZE (b×d)	DISTANCE Y	AREA A (IN^2)	M_y=AY (IN^3)	$I_y = AY^2 = MY$ (IN^4)	I_g (IN^4)
1 ◺	.237" × 1.500"	10.500"	.178	1.869	19.625	.022
2 ▭	1.500" × 4.000"	9.500"	6.000	57.000	541.500	8.000
3 ▭	.237" × 2.062"	8.969"	.488	4.377	39.256	.173
4 ▭	.187" × .438"	7.719"	.082	.633	4.886	.001
5 ▭	.812" × 7.000"	3.750"	6.090	22.838	85.641	28.547
-6 ◺	.328" × 2.100"	.700"	-.344	-.241	-.169	-.084
		TOTAL*:	12.494	86.476	690.739	36.659

$$I_{ny} = I_y + I_g - \frac{M_y^2}{A}$$

$$= 690.739 + 36.659 - \frac{(86.476)^2}{12.494} = 128.863 \text{ IN}^4$$

$$y_{N.A.} = \frac{M_y}{A} = \frac{86.476}{12.494} = 6.921''$$

$$S_{y\,MIN} = \frac{I_{ny}}{C_{MAX}} = \frac{128.863}{6.921} = 18.618 \text{ IN}^3$$

DETERMINE I_{nx} AND S_x FOR TOP GRID OUTER SECTION.

SECTION	SIZE (b×d)	DISTANCE X	AREA A (IN^2)	M_x=AX (IN^3)	$I_x=AX^2=MX$ (IN^4)	I_g (IN^4)
1 △	.237" × 1.500"	.158"	.178	.028	.004	.001
2 ▭	1.500" × 4.000"	.987"	6.000	5.922	5.845	1.125
3 ▭	.237" × 2.062"	.118"	.488	.058	.007	.002
4 ▭	.187" × .438"	.143"	.082	.012	.002	.000
5 ▭	.812" × 7.500"	.456"	6.090	2.777	1.266	.335
-6 △	.328" × 2.100"	.159"	-.344	-.055	-.009	-.002
		TOTAL*:	12.494	8.742	7.115	1.461

$$I_{nx} = I_x + I_g - \frac{M_x^2}{A}$$

$$= 7.115 + 1.461 - \frac{(8.742)^2}{12.494} = 2.459 \ IN^4$$

$$X_{N.A.} = \frac{M_x}{A} = \frac{8.742}{12.494} = .700''$$

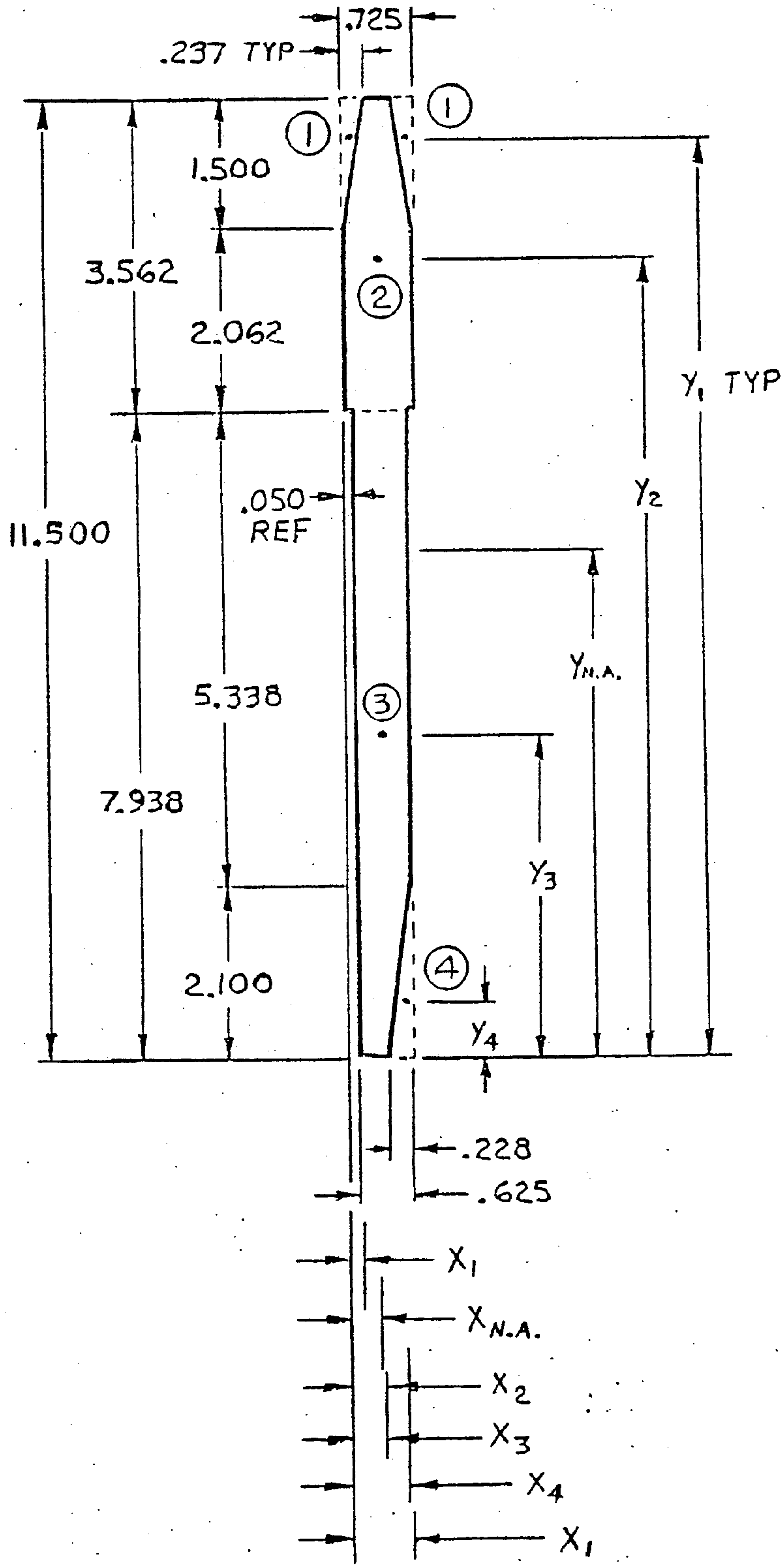
$$S_{x\,MIN} = \frac{I_{nx}}{C_{MAX}} = \frac{2.459}{1.737 - .700} = 2.371 \ IN^3$$

DETERMINE TORSIONAL MOMENT OF INERTIA J FOR TOP GRID OUTER SECTION. USE CASE 18 METHOD DESCRIBED IN FORMULAS FOR STRESS & STRAIN BY R.J. ROARK & W.C. YOUNG, TABLE 20, P. 294, 5th Ed, 1975.

$$J = \frac{1}{3} U t^3$$ WHERE $U \equiv$ LENGTH OF MEDIAN LINE
$t \equiv$ AVERAGE THICKNESS OF SECTION

$$= \frac{1}{3}(11.500)\left(\frac{12.494}{11.500}\right)^3 = 4.916 \ IN^4$$

DETERMINE MOMENT OF INERTIA I OF TOP GRID INNER SECTION:
USE THE FOLLOWING APPROXIMATE CONFIGURATION, (2) - 2(1) + (3) - (4).*



DETERMINE I_{ny} AND S_y FOR TOP GRID INNER SECTION.

SECTION	SIZE (b x d)	DISTANCE y	AREA A (IN²)	$M_y = Ay$ (IN³)	$I_y = Ay^2 = My$ (IN⁴)	I_g (IN⁴)
-1 Δ	.237" x 1.500"	11.000"	-2(.178)	-2(1.958)	-2(21.538)	-2(.022)
2 ▭	.725" x 3.562"	9.719"	2.582	25.095	243.893	2.730
3 ▭	.625" x 7.938"	3.969"	4.961	19.690	78.150	26.052
-4 Δ	.228" x 2.100"	.700"	-.239	-.167	-.117	-.059
		TOTAL*:	6.948	40.702	278.850	28.679

$$I_{ny} = I_y + I_g - \frac{M_y^2}{A}$$

$$= 278.850 + 28.679 - \frac{(40.702)^2}{6.948} = 69.093 \text{ IN}^4$$

$$y_{N.A.} = \frac{M_y}{A} = \frac{40.702}{6.948} = 5.858''$$

$$S_{y\,MIN} = \frac{I_{ny}}{c_{MAX}} = \frac{69.093}{5.858} = 11.795 \text{ IN}^3$$

DETERMINE I_{nx} AND S_x FOR TOP GRID INNER SECTION.

SECTION	SIZE (b x d)	DISTANCE X	AREA A (IN^2)	$M_x = AX$ (IN^3)	$I_x = AX^2 = MX$ (IN^4)	I_g (IN^4)
-1 Δ	.237" x 1.500"	.079 .646	-2(.178)	-.014 -.115	-.001 -.074	-2(.001)
2 ▭	.725" x 3.562"	.362	2.582	.935	.338	.113
3 ▭	.625" x 7.938"	.362	4.961	1.796	.650	.162
-4 Δ	.228" x 2.100"	.599	-.239	-.143	-.086	-.001
		TOTAL*:	6.948	2.459	.827	.272

$$I_{nx} = I_x + I_g - \frac{M_x^2}{A}$$

$$= .827 + .272 - \frac{(2.459)^2}{6.948} = .229 \ IN^4$$

$$X_{N.A.} = \frac{M_x}{A} = \frac{2.459}{6.948} = .354''$$

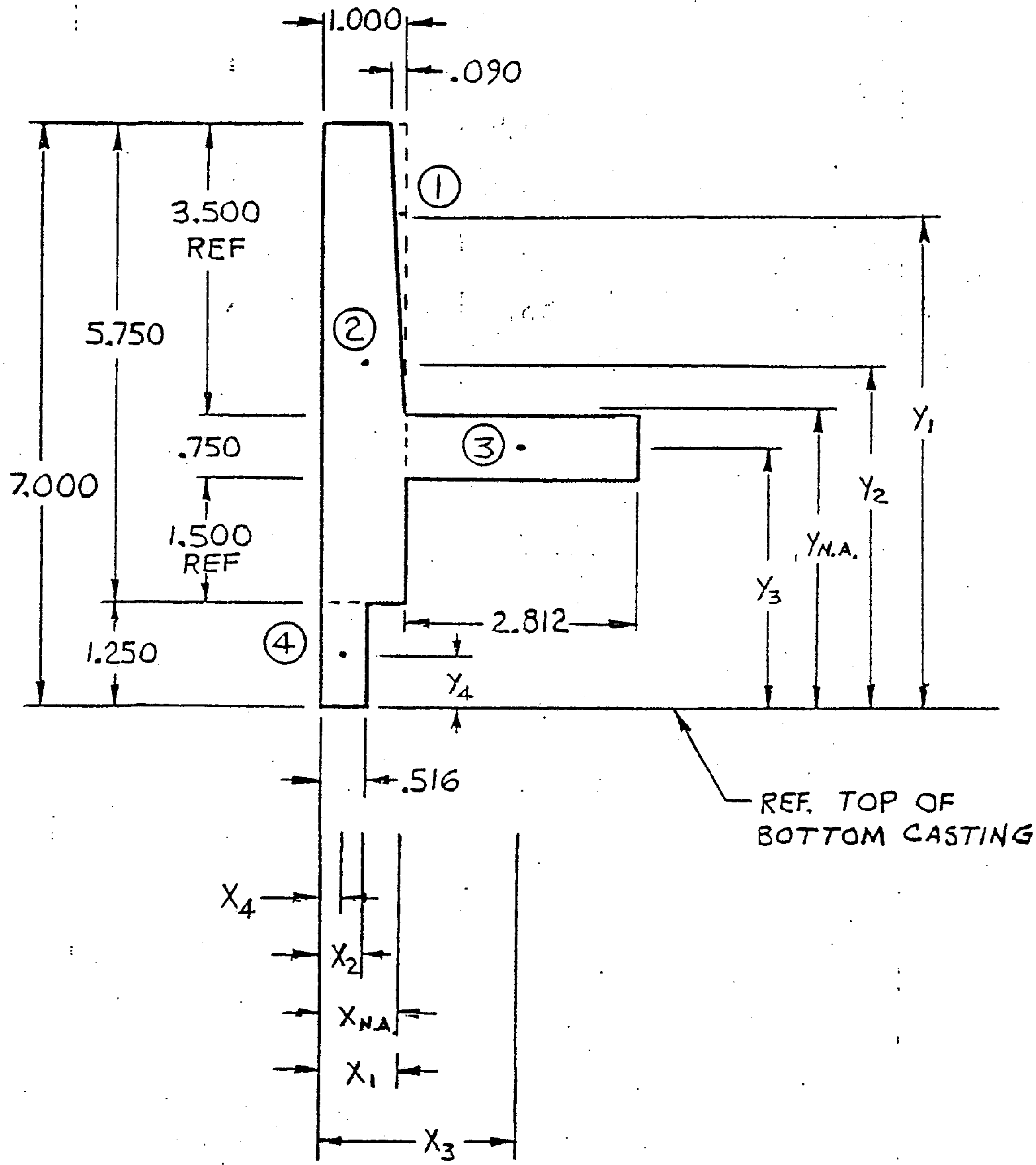
$$S_{x\,MIN} = \frac{I_{nx}}{c_{MAX}} = \frac{.229}{.725 - .354} = .616 \ IN^3$$

DETERMINE TORSIONAL MOMENT OF INERTIA J FOR TOP GRID INNER SECTION. USE CASE 18 METHOD DESCRIBED IN <u>FORMULAS FOR STRESS & STRAIN</u> BY R.J. ROARK & W.C. YOUNG, TABLE 20, P.294, 5th Ed., 1975.

$$J = \frac{1}{3} U t^3$$ WHERE $U \equiv$ LENGTH OF MEDIAN LINE
$t \equiv$ AVERAGE THICKNESS OF SECTION

$$= \frac{1}{3}(11.500)\left(\frac{6.948}{11.500}\right)^3 = .845 \ IN^4$$

DETERMINE MOMENT OF INERTIA I OF BOTTOM GRID OUTER SECTION:
USE THE FOLLOWING APPROXIMATE CONFIGURATION, ② − ① + ③ + ④.*



DETERMINE I_{ny} AND S_y FOR BOTTOM GRID OUTER SECTION.

SECTION	SIZE (b × d)	DISTANCE y	AREA A (IN^2)	$M_y = Ay$ (IN^3)	$I_y = Ay^2 = My$ (IN^4)	I_g (IN^4)
-1 △	.090" × 3.500"	5.833"	-.158	-.921	-5.373	-.107
2 □	1.000" × 5.750"	4.125"	5.750	23.719	97.840	15.842
3 □	2.812" × .750"	3.125"	2.109	6.591	20.596	.099
4 □	.516" × 1.250"	.625"	.645	.403	.252	.084
		TOTAL*:	8.346	29.792	113.315	15.918

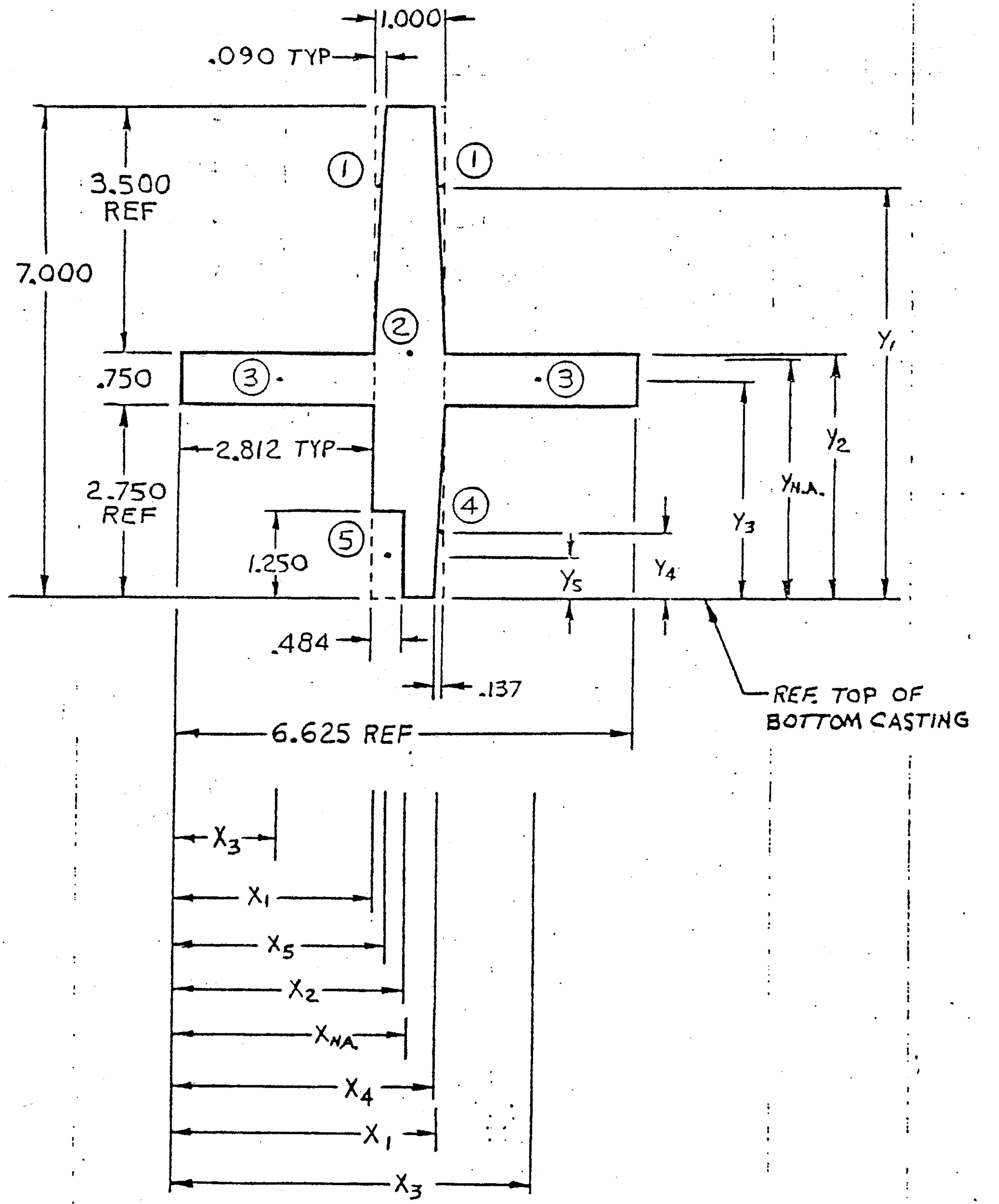
$$I_{ny} = I_y + I_g - \frac{M_y^2}{A}$$

$$= 113.315 + 15.918 - \frac{(29.792)^2}{8.346} = 22.887 \text{ IN}^4$$

$$y_{N.A.} = \frac{M_y}{A} = \frac{29.792}{8.346} = 3.570''$$

$$S_{y\,MIN} = \frac{I_{ny}}{c_{MAX}} = \frac{22.887}{3.570} = 6.411 \text{ IN}^3$$

DETERMINE MOMENT OF INERTIA I OF BOTTOM GRID INNER SECTION: USE THE FOLLOWING APPROXIMATE CONFIGURATION, (2) - 2(1) + 2(3) - (4) - (5).*



DETERMINE I_{ny} AND S_y FOR BOTTOM GRID INNER SECTION.

SECTION	SIZE (b×d)	DISTANCE y	AREA A (IN^2)	M = Ay (IN^3)	$I_y = Ay^2 = My$ (IN^4)	I_g (IN^4)
-1 △	.090"×3.500"	5.833"	-2(.158)	-2(.921)	-2(5.373)	-2(.107)
2 ▭	1.000"×7.000"	3.500"	7.000	24.500	85.750	28.583
3 ▭	2.812"×.750"	3.125"	2(2.109)	2(6.591)	2(20.596)	2(.099)
-4 △	.137"×2.750"	.917"	-.188	-.172	-.027	-.079
-5 ▭	.484"×1.250"	.625"	-.605	-.378	-.236	-.079
		TOTAL*:	10.109	35.290	115.933	28.409

$$I_{ny} = I_y + I_g - \frac{M^2}{A}$$

$$= 115.933 + 28.409 - \frac{(35.290)^2}{10.109} = 21.147\ IN^4$$

$$y_{N.A.} = \frac{M}{A} = \frac{35.290}{10.109} = 3.491''$$

$$S_{y\,MIN} = \frac{I_{ny}}{c_{MAX}} = \frac{21.147}{7.000 - 3.491} = 6.027\ IN^3$$

DETERMINE I_{nx} AND S_x FOR BOTTOM GRID OUTER SECTION.

SECTION	SIZE (b x d)	DISTANCE X	AREA A (IN^2)	$M_x = AX$ (IN^3)	$I_x = AX^2 = MX$ (IN^4)	I_g (IN^4)
-1 △	.090" × 3.500"	.970	-.158	-.153	-.149	-.000
2 □	1.000" × 5.750"	.500	5.750	2.875	1.438	.479
3 □	2.812" × .750"	2.406	2.109	5.074	12.209	1.390
4 □	.516" × 1.250"	.258	.645	.166	.043	.014
	TOTAL*:		8.346	7.962	13.541	1.883

$$I_{nx} = I_x + I_g - \frac{M_x^2}{A}$$

$$= 13.541 + 1.883 - \frac{(7.962)^2}{8.346} = 7.828 \ IN^4$$

$$X_{N.A.} = \frac{M_x}{A} = \frac{7.962}{8.346} = .954''$$

$$S_{X_{MIN}} = \frac{I_{nx}}{c_{MAX}} = \frac{7.828}{3.812 - .954} = 2.739 \ IN^3$$

DETERMINE TORSIONAL MOMENT OF INERTIA FOR BOTTOM GRID OUTER SECTION. USE CASE 18 METHOD DESCRIBED IN FORMULAS FOR STRESS & STRAIN BY R.J. ROARK & W.C. YOUNG, TABLE 20, P. 294, 5th Ed., 1975.

$J = \frac{1}{3} U t^3$ WHERE $U \equiv$ LENGTH OF MEDIAN LINE
$t \equiv$ AVERAGE THICKNESS OF SECTION

$$= \frac{1}{3}(7.000)\left(\frac{8.346}{7.000}\right)^3 = 3.955 \ IN^4$$

DETERMINE I_{nx} AND S_X FOR BOTTOM GRID INNER SECTION.

SECTION	SIZE (b x d)	DISTANCE X	AREA A (IN^2)	$M_x = AX$ (IN^3)	$I_X = AX^2 = MX$ (IN^4)	I_g (IN^4)
-1 △	.090" x 3.500"	2.842 3.783	-2(.158)	-.449 -.598	-1.276 -2.261	-2(.000)
2 ▭	1.000" x 7.000"	3.312	7.000	23.184	76.785	.583
3 ▭	2.812" x .750"	1.406 5.219	2(2.109)	2.965 11.007	4.169 57.445	2(1.390)
-4 △	.137" x 2.750"	3.767	-.188	-.708	-2.668	-.000
-5 ▭	.484" x 1.250"	3.054	-.605	-1.848	-5.643	-.012
		TOTAL:*	10.109	33.553	126.551	3.351

$$I_{nx} = I_X + I_g - \frac{M_x^2}{A}$$

$$= 126.551 + 3.351 - \frac{(33.553)^2}{10.109} = 18.536 \text{ IN}^4$$

$$X_{N.A.} = \frac{M_x}{A} = \frac{33.553}{10.109} = 3.319''$$

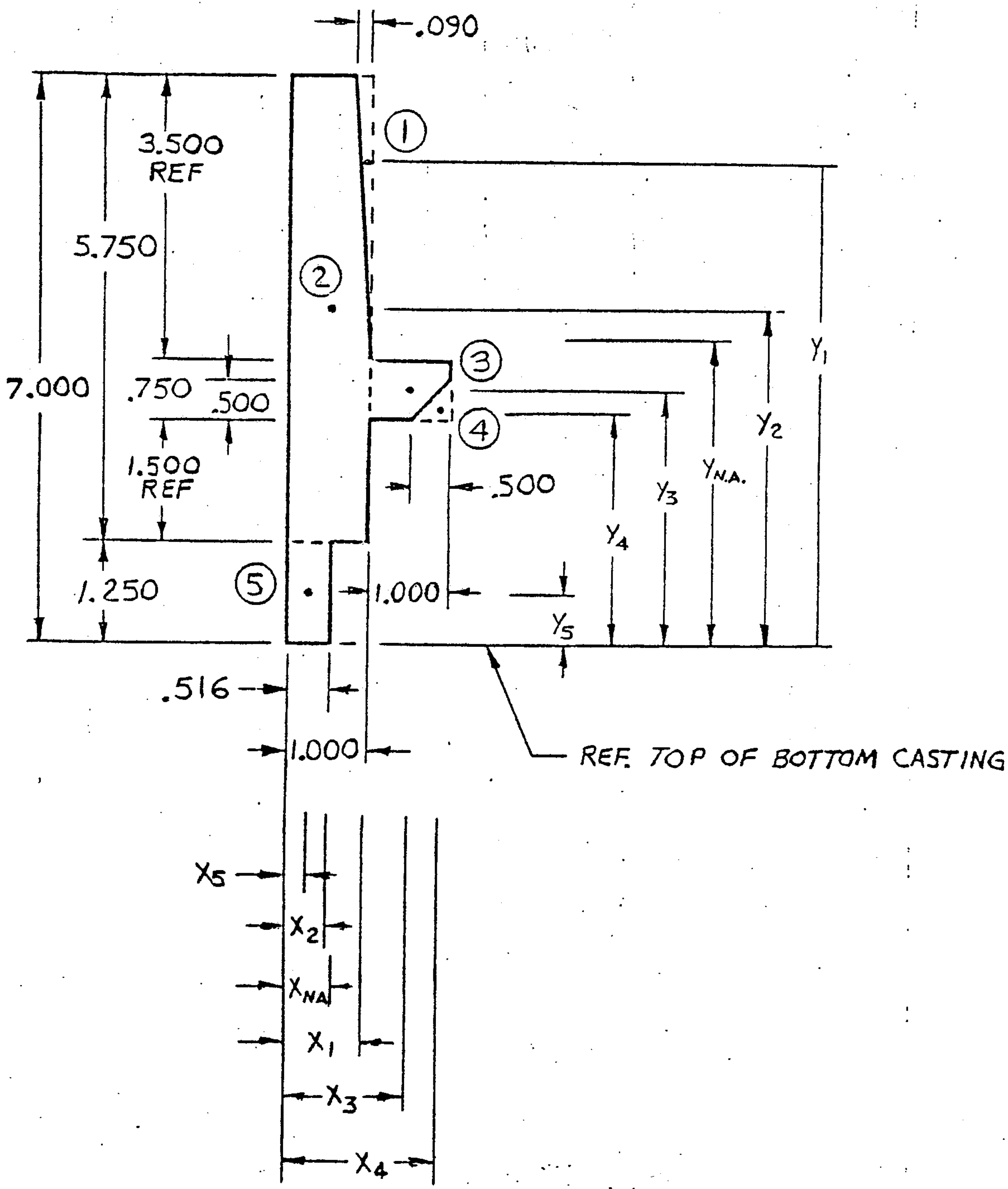
$$S_{X_{MIN}} = \frac{I_{nx}}{c_{MAX}} = \frac{18.536}{6.625 - 3.319} \quad 5.607 \text{ IN}^3$$

DETERMINE TORSIONAL MOMENT OF INERTIA J FOR BOTTOM GRID INNER SECTION. USE CASE 18 METHOD DESCRIBED IN <u>FORMULAS FOR STRESS & STRAIN</u> BY R.J. ROARK & W.C. YOUNG, TABLE 20, P. 294, 5th Ed., 1975.

$J = \frac{1}{3} U t^3$ WHERE $U \equiv$ LENGTH OF MEDIAN LINE
$t \equiv$ AVERAGE THICKNESS OF SECTION

$$= \frac{1}{3}(7.000)\left(\frac{10.109}{7.000}\right)^3 = 7.028 \text{ IN}^4$$

DETERMINE MOMENT OF INERTIA I OF BOTTOM GRID OUTER SECTION:
USE THE FOLLOWING APPROXIMATE CORNER CONFIGURATION,
(2) - (1) + (3) - (4) + (5).*



DETERMINE I_{ny} AND S_y FOR BOTTOM GRID OUTER SECTION (CORNER).

SECTION	SIZE (b x d)	DISTANCE y	AREA A (IN^2)	$M_y = Ay$ (IN^3)	$I_y = Ay^2 = M_y y$ (IN^4)	I_g (IN^4)
-1 △	.090" x 3.500"	5.833"	-.158	-.921	-5.373	-.107
2 □	1.000" x 5.750"	4.125"	5.750	23.719	97.840	15.842
3 □	1.000" x .750"	3.125"	.750	2.344	7.325	.035
-4 △	.500" x .500"	2.917"	-.125	-.365	-1.064	-.002
5 □	.516" x 1.250"	.625"	.645	.403	.252	.084
		TOTAL*:	6.862	25.180	98.980	15.852

$$I_{ny} = I_y + I_g - \frac{M_y^2}{A}$$

$$= 98.980 + 15.852 - \frac{(25.180)^2}{6.862} = 22.434 \; IN^4$$

$$y_{N.A.} = \frac{M_y}{A} = \frac{25.180}{6.862} = 3.670''$$

$$S_{y_{MIN}} = \frac{I_{ny}}{c_{MAX}} = \frac{22.434}{3.670} = 6.113 \; IN^3$$

DETERMINE I_{nx} AND S_x FOR BOTTOM GRID OUTER SECTION (CORNER).

SECTION	SIZE (b x d)	DISTANCE X	AREA A (IN^2)	M = AX (IN^3)	$I_x = AX^2 = MX$ (IN^4)	I_g (IN^4)
-1 △	.090" × 3.500"	.970	-.158	-.153	-.149	-.000
2 □	1.000" × 5.750"	.500	5.750	2.875	1.438	.479
3 □	1.000" × .750"	1.500	.750	1.125	1.688	.062
-4 △	.500" × .500"	1.833	-.125	-.229	-.420	-.002
5 □	.516" × 1.250"	.258	.645	.166	.043	.014
		TOTAL*:	6.862	3.784	2.600	.553

$$I_{nx} = I_X + I_g - \frac{M_x^2}{A}$$

$$= 2.600 + .553 - \frac{(3.784)^2}{6.862} = 1.066 \ IN^4$$

$$X_{N.A.} = \frac{M_x}{A} = \frac{3.784}{6.862} = .551''$$

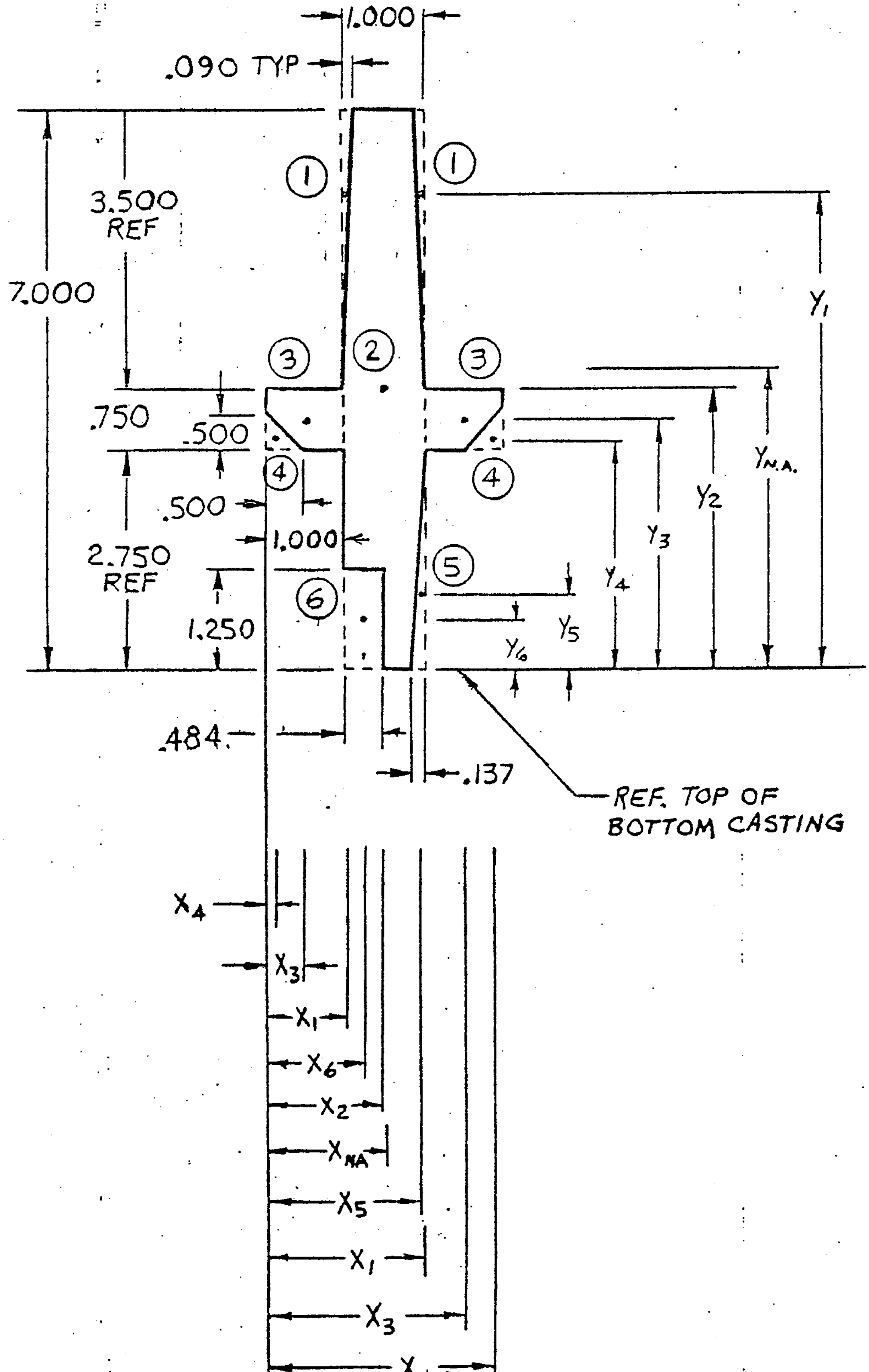
$$S_{X\,MIN} = \frac{I_{nx}}{C_{MAX}} = \frac{1.066}{2.000 - .551} = .736 \ IN^3$$

DETERMINE TORSIONAL MOMENT OF INERTIA J FOR BOTTOM GRID OUTER SECTION - CORNER. USE CASE 18 METHOD DESCRIBED IN FORMULAS FOR STRESS & STRAIN BY R.J. ROARK & W.C. YOUNG, TABLE 20, P. 294, 5th. Ed, 1975.

$J = \frac{1}{3}Ut^3$ WHERE $U \equiv$ LENGTH OF MEDIAN LINE
$t \equiv$ AVERAGE THICKNESS OF SECTION

$$= \frac{1}{3}(7.000)\left(\frac{6.862}{7.000}\right)^3 = 2.198$$

DETERMINE MOMENT OF INERTIA I OF BOTTOM GRID INNER SECTION:
USE THE FOLLOWING APPROXIMATE CORNER CONFIGURATION,
(2) - 2(1) + 2(3) - 2(4) - (5) - (6).*



DETERMINE I_{ny} AND S_y FOR BOTTOM GRID INNER SECTION (CORNER).

SECTION	SIZE (b x d)	DISTANCE y	AREA A (IN^2)	M_y=Ay (IN^3)	I_y = Ay^2=My (IN^4)	I_g (IN^4)
-1 △	.090" x 3.500"	5.833"	-2(.158)	-2(.921)	-2(5.373)	-2(.107)
2 ▭	1.000" x 7.000"	3.500"	7.000	24.500	85.750	28.583
3 ▭	1.000" x .750"	3.125"	2(.750)	2(2.344)	2(7.325)	2(.035)
-4 △	.500" x .500"	2.917"	-2(.125)	-2(.365)	-2(1.064)	-2(.002)
-5 △	.137" x 2.750"	.917"	-.188	-.172	-.027	-.079
-6 ▭	.484" x 1.250"	.625"	-.605	-.378	-.236	-.079
		TOTAL:*	7.141	26.066	87.263	28.277

$$I_{ny} = I_y + I_g - \frac{M_y^2}{A}$$

$$= 87.263 + 28.277 - \frac{(26.066)^2}{7.141} = 20.394 \ IN^4$$

$$y_{N.A.} = \frac{M_y}{A} = \frac{26.066}{7.141} = 3.650''$$

$$S_{y_{MIN}} = \frac{I_{ny}}{c_{MAX}} = \frac{20.394}{3.650} = 5.587 \ IN^3$$

DETERMINE I_{nx} AND S_X FOR BOTTOM GRID INNER SECTION (CORNER).

SECTION	SIZE (b×d)	DISTANCE X	AREA A (IN²)	M = AX (IN³)	$I_X = AX^2 = MX$ (IN⁴)	I_g (IN⁴)
-1 △	.090"×3.500"	1.030 1.970	-2(.158)	-.163 -.311	-.168 -.613	-2(.000)
2 ▭	1.000"×7.000"	1.500	7.000	10.500	15.750	.583
3 ▭	1.000"×.750"	.500 2.500	2(.750)	.375 1.875	.188 4.688	2(.062)
-4 △	.500"×.500"	.167 2.833	-2(.125)	-.021 -.354	-.003 -1.003	-2(.002)
-5 △	.137"×2.750"	1.954	-.188	-.367	-.718	-.000
-6 ▭	.484"×1.250"	1.242	-.605	-.751	-.933	-.012
		TOTAL:*	7.141	10.783	17.188	.691

$$I_{nx} = I_X + I_g - \frac{M_x^2}{A}$$

$$= 17.188 + .691 - \frac{(10.783)^2}{7.141} = 1.597 \text{ IN}^4$$

$$X_{N.A.} = \frac{M_x}{A} = \frac{10.783}{7.141} = 1.510''$$

$$S_{X_{MIN}} = \frac{I_{nx}}{c_{MAX}} = \frac{1.597}{1.510} = 1.057 \text{ IN}^3$$

DETERMINE TORSIONAL MOMENT OF INERTIA J FOR TOP GRID INNER SECTION – CORNER. USE CASE 18 METHOD DESCRIBED IN FORMULAS FOR STRESS & STRAIN BY R.J. ROARK & W.C. YOUNG, TABLE 20, P. 294, 5th Ed., 1975.

$$J = \frac{1}{3}Ut^3$$ WHERE $U \equiv$ LENGTH OF MEDIAN LINE; $t \equiv$ AVERAGE THICKNESS OF SECTION

$$= \frac{1}{3}(7.000)\left(\frac{7.141}{7.000}\right)^3 = 2.477 \text{ IN}^4$$

ESTIMATE WEIGHT OF TOP GRID MACHINING (FOR 11 x 11 MODULE)
DENSITY FOR ALUMINUM $\rho = .098\ \#/IN^3$. WEIGHT = ρ x VOL.

ITEM	QTY	DESCRIPTION	(IN^2) AREA	(IN) LENGTH OR THK.	(IN^3) TOTAL VOL.	(#) TOTAL WT.
1A	4	TOP GRID OUTER SECTION	12.494	73.875	3692	362
1B	4	.875" SQ. x 4.000" CORNER SECTION	.766	4.000	12	1
2A	20	TOP GRID INNER SECTION	6.948	73.875	10266	1006
-2B	100	LESS $\frac{6.636}{11.000}$ = .603" AVG. TH. INTERSECTION	6.948	.603	- 419	- 41
		TOTAL:			13551	1328

APPROXIMATE PER CAVITY WEIGHT OF TOP GRID IS

$$\frac{1328\#}{(11)(11)} = 10.98\ \#/\text{CAVITY}$$

ESTIMATE WEIGHT OF BOTTOM GRID MACHINING (FOR 11 X 11 MODULE)
DENSITY FOR ALUMINUM $\rho = .098\ \#/IN^3$. WEIGHT $= \rho \times$ VOL.

ITEM	QTY	DESCRIPTION	(IN^2) AREA	(IN) LENGTH OR THK.	(IN^3) TOTAL VOL.	(#) TOTAL WT.
1A	2	BOTTOM GRID OUTER SECTION	8.346	73.875	1233	121
1B	2	" " " "	8.346	71.875	1200	117
-1C	4	LESS 2.812" SQ. x .750" INTERSECTION	7.907	.750	- 24	- 2
2A	20	BOTTOM GRID INNER SECTION	10.109	71.875	14532	1424
-2B	100	LESS $\frac{10.109}{7.000}$ = 1.444 AVG. TH. INTERSECTION	10.109	1.444	- 1460	- 143
-3	121	LESS 3.625" DIA. HOLE OPENINGS	10.321	.750	- 937	- 92
-4A	4	LESS MISSING PLATE NEAR FOOT	3.500	5.625	- 79	- 8
4B	4	3.000" x 7.625" SQ. FOOT	58.140	3.000	698	68
4C	4	3.000" x 6.000" DIA. FOOT	28.274	3.000	339	33
-4D	4	LESS 3.625" DIA. FOOT HOLE	10.321	3.750	- 155	- 15
-4E	4	LESS 4.625" DIA HOLE OPENING	16.800	2.250	- 151	- 15
				TOTAL :	15196	1488

APPROXIMATE PER CAVITY WEIGHT OF BOTTOM GRID IS

$$\frac{1488\#}{(11)(11)} = 12.30\ \#/\text{CAVITY}$$

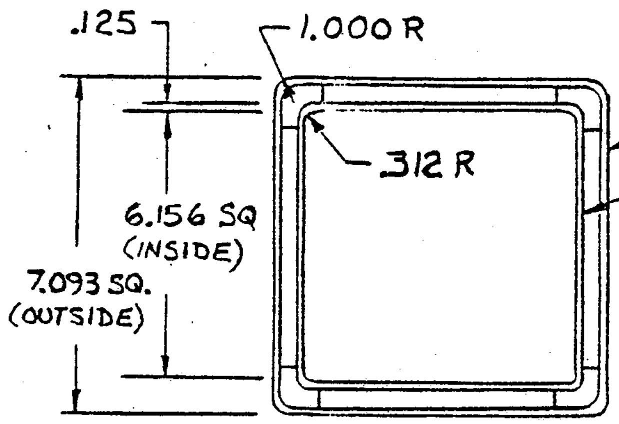
WEIGHT SUMMARY FOR 11 x 11 SPENT FUEL MODULE. DENSITY $\rho = .098\ ^{\#}/_{IN^3}$.

ITEM	QTY	DESCRIPTION	(IN^2) AREA	(IN) LENGTH OR THK.	(IN^3) TOTAL VOL.	(#) TOTAL WT
1	61	INNER TUBE – 6.406" SQ. x 1/8" WALL (D-22655-C REF.)	3.060	157.750	29446	2886
2	61	OUTER TUBE – 7.093" SQ. x 1/8" WALL (D-22656-C REF.)	3.283	153.687	30778	3016
3	244	BORAL SHEET – 5.250" WIDE x .115" TH. (D-22659-B REF.)	.604	152.000	22400	2195
4	1	TOP GRID MACHINING (SEE SHEET .)			13551	1328
5	1	BOTTOM GRID MACHINING (SEE SHEET .)			15196	1488
6	4	SIDE PANEL – 72.875" x .500" TH. (D-22660-C REF.)	36.437	168.375	24540	2405
7	4	SIDE ANGLE – 3.00" x 3.00" x .250" TH. (D-22663-C REF.)	1.344	155.125	834	82
8	4	FOOT ASSEMBLY				150
9		HARDWARE				125
					TOTAL:	13675

APPROXIMATE MODULE WEIGHT PER CAVITY IS

$$\frac{13675^{\#}}{(11)(11)} = 113.0\ ^{\#}/_{CAVITY}$$

ESTIMATE WEIGHT OF MODULE ENTRAPPED WATER: REF. 11 x 11 MODULE. TYPICAL CAVITY DETAIL IS SHOWN. REFER TO P&R DWG. A-2255G-E, SH. 2, CAVITY DETAIL, AND TO G.E. DWG. 829E293.



OUTER TUBE LENGTH 153.687"
OUTSIDE AREA = 49.452 IN²
INNER TUBE LENGTH 157.750"
OUTSIDE AREA = 40.874 IN²
INSIDE AREA = 37.814 IN²

THERE ARE (64) 1/2" DIA. RODS PER FUEL ASSY.
APPROX. LENGTH 160.00

V_T ≡ TOTAL VOLUME OF 11 x 11 MODULE CUBE 73.875 SQ. x 157.75 HIGH	860924
V_{RACK} { LESS VOLUME BOTTOM GRID MACHINING (SEE SHEET A.1-22)	− 15196
LESS VOLUME TOP GRID MACHINING (SEE SHEET A.1-21)	− 13551
LESS VOLUME OF 61 CANS 61 [(TOTAL OUTSIDE AREA OUTER TUBE − TOTAL INSIDE AREA) 153.687 + (OUTSIDE AREA OF INNER TUBE − TOTAL INSIDE AREA)(157.75 − 153.687)]	−109864
V_{FUEL} ≡ LESS VOLUME OF FUEL ASSY RODS $121 (64)(\pi/4)(.500)^2 (160.00)$	−243285
TOTAL RESULTANT VOL. OF ENTRAPPED WATER:	479028 IN³

PER CAVITY ENTRAPPED WATER VOLUME AND WEIGHT IS

$$V = \frac{479028}{(11)(11)} = 3959 \ IN^3$$

$$W = \rho_{WATER} V = .036 \ \#/IN^3 (3959 \ IN^3) = 143 \ \# \ WATER/CAV.$$

$V_{RACK} = 138,611 \ IN^3$, AND DISPLACED WATER BY RACK $= \frac{138611(.036)}{(11)(11)} = 41.2\#$

WET WEIGHT OF RACK $= 113\# - 41.2\# = 71.8 \#/CAV.$

WET WEIGHT OF FUEL $= 745 - \left(\frac{243285}{(11)(11)}\right)(.036) = 672\#$

The following summarizes the various mass inputs/per cavity

Dry Module Mass	113#	Wet Module Mass	72#
Dry Fuel Mass	745#	Wet Fuel Mass	672#
Added Water Mass	143#		
		Total Vert. Mass	744#/Cavity
Total Horizontal Mass	1001#/Cavity		

Dry Module Mass	113#
Dry Fuel Mass	745#
Total Vertical Mass	858#

Note: These masses are less than the values used for the seismic and dropped bundle stress analysis that are given in Page 5.3-6

Horizonatl Mass $= \frac{1001}{1062} = .981$

Vertical Mass $\frac{858}{880} = .975$

Wet Weight $\frac{744}{750} = .992$

PROGRAMMED AND REMOTE SYSTEMS CORPORATION
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AREA CODE 612 484-7261 TELEX #29-7473

APPENDIX A.2

FUEL STORAGE SYSTEM DESIGN REPORT

PaR Job No. 3091

DUANE ARNOLD ENERGY CENTER UNIT NO.1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

TABLES OF ALLOWABLE STRESSES FOR ALUMINUM STRUCTURES

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHK'D BY	APPRV'D BY	DATE

For intermediate joints of continuous angles, the effective net area shall be the gross sectional area less deductions for holes.

5.1.8 Grip of Rivets and Bolts. If the grip (total thickness of metal being fastened) of rivets or bolts carrying calculated stress exceeds four and one-half times the diameter, the allowable load per rivet or bolt shall be reduced. The reduced allowable load shall be the normal allowable load divided by $[1/2+G/(9D)]$ in which G is the grip and D is the nominal diameter of the rivet or bolt. If the grip of the rivet exceeds six times the diameter, special care shall be taken to insure that holes will be filled completely.

5.1.9 Spacing of Rivets and Bolts. Minimum distance of rivet centers shall be 3 times the nominal rivet diameter; minimum distance of bolt centers shall be 2½ times the nominal bolt diameter. In built-up compression members the pitch in the direction of stress shall be such that the allowable stress on the individual outside sheets and shapes, treated as columns having a length equal to the rivet or bolt pitch exceeds the calculated stress. The gage at right angles to the direction of stress shall be such that the allowable stress in the outside sheets, calculated from Section 3.4.9 exceeds the calculated stress. In this case the width b in Section 3.4.9 may be taken as 0.8*s* where "*s*" is the gage in inches.

TABLE 5.1.1a
ALLOWABLE BEARING STRESSES FOR BUILDING TYPE STRUCTURES

(F_{by} From Table 3.3.1a Divided By 1.65 Factor of Safety or F_{bu} Divided By 1.2 × 1.95)

Alloy And Temper	Allowable Bearing Stress* ksi
1100-H12	11.0
-H14	12.5
2014-T6 Sheet	53
-T651 Plate	54
-T6,T6510,T6511 Extrusions	49
-T6, T651 Rolled Bar, Drawn Tube	53
Alclad 2014-T6 Sheet (up to 0.039)*	53.4
-T6, T651 Sheet, Plate	55.2
3003-H12	11.5
-H14	15
-H16	19
-H18	21
Alclad 3003-H12	11
-H14	14.5
-H16	18
-H18	19
3004-H32	22
-H34	24
-H36	27
Alclad 3004-H32	21
-H34	23
-H14	24
-H16	27
5005-H12	13.5
-H14	15
-H32	12
-H34	14.5
5050-H32	16
-H34	19
5052-H32	24
-H34	27
5083-H111	25
-H321 (0.188 to 1.500)*	32
-H321 (1.501 to 3.000)*	30
-H323	35
-H343	40
5086-H111	22
-H112 (0.188 to 0.499)*	19
-H112 (0.500 to 3.000)*	17.0
-H32	29
-H34	35
5454-H111	19
-H112	14.5
-H32	27
-H34	30
5456-H111	27
-H112	23
-H321 (0.188 to 1.250)*	34
-H321 (1.251 to 1.500)*	32
-H321 (1.501 to 3.000)*	30
-H323	37
-H343	42
6061-T6, T651 Sheet & Plate	35
-T6, T651, T6510, T6511 Other Products	34
6063-T5 (up to 0.500)*	16
-T5 (Over 0.500)*	14.5
-T6	24

*Thickness in inches to which the allowable stress applies. Where not listed, bearing stress applies to all thicknesses.

TABLE 5.1.1b
ALLOWABLE STRESSES FOR RIVETS FOR BUILDING TYPE STRUCTURES

Designation Before Driving	Driving Procedure	Designation After Driving	Minimum Expected Shear Strength ksi	Allowable Shear Stress on Effective Area ksi
1100-H14	Cold, as received	1100-F	9.5	4
2017-T4	Cold, as received	2017-T3	34	14.5
2117-T4	Cold, as received	2117-T3	29	12
5056-H32	Cold, as received	5056-H321	26	11
6053-T61	Cold, as received	6053-T61	20	8.5
6061-T4	Hot, 990° to 1,050°F	6061-T43	21	9
6061-T6	Cold, as received	6061-T6	26	11†

† Also applies to 6061-T6 Pins.
* Minimum expected shear strength divided by 2.34. See Table 3.3.3.

ALLOWABLE STRESSES FOR BOLTS FOR BUILDING TYPE STRUCTURES

Alloy And Temper	Minimum Expected Shear Strength ksi	Allowable* Shear Stress on Effective Area ksi	Allowable Tensile Stress on Root Area ksi
2024-T4	37	16	26
6061-T6	27	12	18
7075-T73	40	17	28

*Values apply to either turned bolts or unfinished bolts in holes not more than 1/16 in. oversized.

5.1.10 Stitch Rivets and Bolts. Where two or more web plates are in contact, there shall be stitch rivets or bolts to make them act in unison. In compression members, the pitch and gage of such rivets or bolts shall be determined as outlined in Section 5.1.9. In tension members, the maximum pitch or gage of such rivets or bolts shall not exceed a distance, in inches, equal to $(3 + 20t)$ in which t is the thickness of the outside plates, in inches.

5.1.11 Edge Distance of Rivets or Bolts. The distance from the center of rivet or bolt under computed stress to the edge of the sheet or shape toward which the pressure is directed shall be twice the nominal diameter of the rivet or bolt. When a shorter edge distance is used, the allowable bearing stress as shown in Table 5.1.1a shall be reduced by the ratio: actual edge distance/twice rivet or bolt diameter (See Section 3.4.5). The edge distance shall not be less than 1.5 times the rivet or bolt diameter to sheared, sawed, rolled or planed edges.

5.1.12 Blind Rivets. Blind rivets may be used onl when the grip lengths and rivet-hole tolerances ar as recommended by the respective manufacturers

5.1.13 Hollow-End Rivets. If hollow-end rivets wit solid cross sections for a portion of the length are use the strength of these rivets may be taken equal to th strength of solid rivets of the same material, provide that the bottom of the cavity is at least 25 percent o the rivet diameter from the plane of shear, as measure toward the hollow-end, and further provided that the are used in locations where they will not be subjecte to appreciable tensile stresses.

5.1.14 Steel Rivets. Steel rivets shall not be used i aluminum structures unless the aluminum is to b joined to steel or where corrosion resistance of th structure is not a requirement, or where the structure i to be protected against corrosion (See Section 6.6.1)

TABLE 3.3.4b
FORMULAS FOR BUCKLING CONSTANTS
For Products Whose Temper Designation Begins With -T5, -T6, -T7, -T8, or -T9

Type of Member and Stress	Intercept, ksi	Slope, ksi	Intersection
Compression in Columns and Beam Flanges	$B_c = F_{cy}\left[1 + \left(\frac{F_{cy}}{2250}\right)^{1/2}\right]$	$D_c = \frac{B_c}{10}\left(\frac{B_c}{E}\right)^{1/2}$	$C_c = 0.41\frac{B_c}{D_c}$
Compression in Flat Plates	$B_p = F_{cy}\left[1 + \frac{(F_{cy})^{1/3}}{11.4}\right]$	$D_p = \frac{B_p}{10}\left(\frac{B_p}{E}\right)^{1/2}$	$C_p = 0.41\frac{B_p}{D_p}$
Compression in Round Tubes Under Axial End Load	$B_t = F_{cy}\left[1 + \frac{(F_{cy})^{1/5}}{8.7}\right]$	$D_t = \frac{B_t}{4.5}\left(\frac{B_t}{E}\right)^{1/3}$	C_t *
Compressive Bending Stress in Solid Rectangular Bars	$B_b = 1.3F_{cy}\left[1 + \frac{(F_{cy})^{1/3}}{7}\right]$	$D_b = \frac{B_b}{20}\left(\frac{6B_b}{E}\right)^{1/2}$	$C_b = \frac{2B_b}{3D_b}$
Compressive Bending Stress in Round Tubes	$B_{tb} = 1.5F_y\left[1 + \frac{(F_y)^{1/5}}{8.7}\right]$	$D_{tb} = \frac{B_{tb}}{2.7}\left(\frac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \left(\frac{B_{tb} - B_t}{D_{tb} - D_t}\right)^2$
Shear Stress in Flat Plates	$B_s = F_{sy}\left[1 + \frac{(F_{sy})^{1/3}}{9.3}\right]$	$D_s = \frac{B_s}{10}\left(\frac{B_s}{E}\right)^{1/2}$	$C_s = 0.41\frac{B_s}{D_s}$
Crippling of Flat Plates in Compression	$k_1 = 0.35$	$k_2 = 2.27$	
Crippling of Flat Plates in Bending	$k_1 = 0.50$	$k_2 = 2.04$	

* C_t can be found from a plot of the curves of allowable stress based on elastic and inelastic buckling or by a trial and error solution.

TABLE 3.3.5
VALUES OF COEFFICIENTS k_t and k_c*

Alloy and Temper	Non-welded or Regions Farther Than 1.0 in. From a Weld k_t	Non-welded or Regions Farther Than 1.0 in. From a Weld k_c	Regions Within 1.0 in. of a Weld k_t	Regions Within 1.0 in. of a Weld k_c†
2014-T6, -T651‡	1.25	1.12	—	—
Alclad 2014-T6, -T651	1.25	1.12	—	—
6061-T6, -T651‡	1.0	1.12	1.0	1.0
6063-T5, -T6, -T83	1.0	1.12	1.0	1.0
All Others Listed in Table 3.3.1	1.0	1.10	1.0	1.0
6351-T5	1.0	1.12	1.0	1.0

* These coefficients are used in the formulas in Table 3.3.6.
† If the weld yield strength exceeds 0.9 of the parent metal yield strength, the allowable compressive stress within 1.0 in. of a weld should be taken equal to the allowable stress for non-welded material.
‡ Values also apply to -T6510, -T6511 extrusion tempers.

Methods of Rounding Off Numbers in Tables 3.3.6 to 3.3.27

The allowable stresses in Specifications 1-6 and for slenderness ≦ S_1 in Specifications 7-21 are obtained by rounding off stresses below 5 ksi to the nearest 0.1 ksi; stresses between 5 and 15 ksi to the nearest 0.5 ksi; and stresses over 15 ksi to the nearest 1.0 ksi. To obtain allowable stresses for slenderness between S_1 and S_2, the constant is rounded off to the nearest 0.1 ksi. The coefficient of the slenderness ratio is rounded off according to the rule: for numbers between 2×10^n and $2 \times 10^{n+1}$, round off to nearest 0.1×10^n, where n is any positive or negative integer. This same rule is applied to the coefficients in the expressions for allowable stresses for slenderness ≧ S_2.

Slenderness limits S_1 and S_2 are based on the rounded off expressions for allowable stress obtained as described above. Values of S_1 and S_2 between 10 and 250 are rounded off to the nearest 1.0. Smaller values are rounded off to the nearest 0.1, and larger values to the nearest 10. If S_2 is not more than 5 per cent larger than S_1, the allowable stress for slenderness between S_1 and S_2 is taken to be the same as the allowable stress for slenderness ≦ S_1. In this case there is no value for S_1 and the value of S_2 is recalculated by equating the allowable stress for slenderness less than S_1 to the allowable stress for slenderness ≧ S_2, using rounded off values.

General Formulas for Determining Allowable Stresses

Type of Stress	Type of Member or Component	No.	ksi
TENSION, axial, net section	Any tension member:	1	F_{ty}/n_y or $F_{tu}/(k_t n_u)$
TENSION IN BEAMS, extreme fiber, net section	Rectangular tubes, structural shapes bent about strong axis	2	F_{ty}/n_y or $F_{tu}/(k_t n_u)$
	Round or oval tubes	3	$1.17F_{ty}/n_y$ or $1.24F_{tu}/(k_t n_u)$
	Rectangular bars, plates, shapes bent about weak axis	4	$1.30F_{ty}/n_y$ or $1.42F_{tu}/(k_t n_u)$
BEARING	On rivets and bolts	5	F_{by}/n_y or $F_{bu}/(1.2n_u)$
	On flat surfaces and pins	6	$F_{by}/(1.5n_y)$ or $F_{bu}/(1.8n_u)$

Type of Stress	Type of Member or Component	No.	Allowable Stress, ksi, Slenderness ≤ S_1	Slenderness Limit, S_1	Allowable Stress, ksi Slenderness Between S_1 and S_2	Slenderness Limit, S_2	Allowable Stress, ksi Slenderness ≥ S_2
COMPRESSION IN COLUMNS, axial, gross section	All columns	7	$\frac{F_{cy}}{k_c n_y}$	$\frac{L}{r}=\frac{B_c-\frac{n_u F_{cy}}{k_c n_y}}{D_c}$	$\frac{1}{n_u}\left(B_c-D_c\frac{L}{r}\right)$	$\frac{L}{r}=C_c$	$\frac{\pi^2 E}{n_u (L/r)^2}$
COMPRESSION IN COMPONENTS OF COLUMNS, gross section	Outstanding flanges and legs	8	$\frac{F_{cy}}{k_c n_y}$	$\frac{b}{t}=\frac{B_p-\frac{n_u F_{cy}}{k_c n_y}}{5.1D_p}$	$\frac{1}{n_u}\left(B_p-5.1D_p\frac{b}{t}\right)$	$\frac{b}{t}=\frac{C_p}{5.1}$	$\frac{\pi^2 E}{n_u (5.1b/t)^2}$
	Flat plates with both edges supported	9	$\frac{F_{cy}}{k_c n_y}$	$\frac{b}{t}=\frac{B_p-\frac{n_u F_{cy}}{k_c n_y}}{1.6D_p}$	$\frac{1}{n_u}\left(B_p-1.6D_p\frac{b}{t}\right)$	$\frac{b}{t}=\frac{k_1 B_p}{1.6D_p}$	$\frac{k_2\sqrt{B_p E}}{n_u (1.6b/t)}$
	Curved plates supported on both edges, walls of round or oval tubes	10	$\frac{F_{cy}}{k_c n_y}$	$\frac{R}{t}=\left(\frac{B_t-\frac{n_u F_{cy}}{k_c n_y}}{D_t}\right)^2$	$\frac{1}{n_u}\left(B_t-D_t\sqrt{\frac{R}{t}}\right)$	$\frac{R}{t}=C_t$	$\frac{\pi^2 E}{16n_u\left(\frac{R}{t}\right)\left(1+\frac{\sqrt{R/t}}{35}\right)^2}$
COMPRESSION IN BEAMS, extreme fiber, gross section	Single web beams bent about strong axis	11	$\frac{F_{cy}}{n_y}$	$\frac{L_b}{r_y}=\frac{1.2(B_c-F_{cy})}{D_c}$	$\frac{1}{n_y}\left(B_c-\frac{D_c L_b}{1.2r_y}\right)$	$\frac{L_b}{r_y}=1.2C_c$	$\frac{\pi^2 E}{n_y (L_b/1.2r_y)^2}$
	Round or oval tubes	12	$\frac{1.17F_{cy}}{n_y}$	$\frac{R_b}{t}=\left(\frac{B_{tb}-1.17F_{cy}}{D_{tb}}\right)^2$	$\frac{1}{n_y}\left(B_{tb}-D_{tb}\sqrt{\frac{R_b}{t}}\right)$	$\frac{R_b}{t}=\left(\frac{\frac{n_u}{n_y}B_{tb}-B_t}{\frac{n_u}{n_y}D_{tb}-D_t}\right)^2$	Same as Section 10 (See 3.4.12)
	Solid rectangular beams	13	$\frac{1.3F_{cy}}{n_y}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}}=\frac{B_b-1.3F_{cy}}{2.3D_b}$	$\frac{1}{n_y}\left(B_b-2.3D_b\frac{d}{t}\sqrt{\frac{L_b}{d}}\right)$	$\frac{d}{t}\sqrt{\frac{L_b}{d}}=\frac{C_b}{2.3}$	$\frac{\pi^2 E}{5.29n_y (d/t)^2 (L_b/d)}$
	Rectangular tubes and box sections	14	$\frac{F_{cy}}{n_y}$	$\frac{L_b S_c}{I_y}=\left(\frac{B_c-F_{cy}}{1.6D_c}\right)^2$	$\frac{1}{n_y}\left(B_c-1.6D_c\sqrt{\frac{L_b S_c}{I_y}}\right)$	$\frac{L_b S_c}{I_y}=\left(\frac{C_c}{1.6}\right)^2$	$\frac{\pi^2 E}{2.56n_y (L_b S_c/I_y)}$
COMPRESSION IN COMPONENTS OF BEAMS, (component under uniform compression), gross section	Outstanding flanges	15	$\frac{F_{cy}}{n_y}$	$\frac{b}{t}=\frac{B_p-F_{cy}}{5.1D_p}$	$\frac{1}{n_y}\left(B_p-5.1D_p\frac{b}{t}\right)$	$\frac{b}{t}=\frac{k_1 B_p}{5.1D_p}$	$\frac{k_2\sqrt{B_p E}}{n_y (5.1b/t)}$
	Flat plates with both edges supported	16	$\frac{F_{cy}}{n_y}$	$\frac{b}{t}=\frac{B_p-F_{cy}}{1.6D_p}$	$\frac{1}{n_y}\left(B_p-1.6D_p\frac{b}{t}\right)$	$\frac{b}{t}=\frac{k_1 B_p}{1.6D_p}$	$\frac{k_2\sqrt{B_p E}}{n_y (1.6b/t)}$
COMPRESSION IN COMPONENTS OF BEAMS, (component under bending in own plane), gross section	Flat plates with compression edge free, tension edge supported	17	$\frac{1.3F_{cy}}{n_y}$	$\frac{b}{t}=\frac{B_b-1.3F_{cy}}{3.5D_b}$	$\frac{1}{n_y}\left(B_b-3.5D_b\frac{b}{t}\right)$	$\frac{b}{t}=\frac{C_b}{3.5}$	$\frac{\pi^2 E}{n_y (3.5b/t)^2}$
	Flat plates with both edges supported	18	$\frac{1.3F_{cy}}{n_y}$	$\frac{h}{t}=\frac{B_b-1.3F_{cy}}{0.67D_b}$	$\frac{1}{n_y}\left(B_b-0.67D_b\frac{h}{t}\right)$	$\frac{h}{t}=\frac{k_1 B_b}{0.67D_b}$	$\frac{k_2\sqrt{B_b E}}{n_y (0.67h/t)}$
	Flat plates with horizontal stiffener, both edges supported	19	$\frac{1.3F_{cy}}{n_y}$	$\frac{h}{t}=\frac{B_b-1.3F_{cy}}{0.29D_b}$	$\frac{1}{n_y}\left(B_b-0.29D_b\frac{h}{t}\right)$	$\frac{h}{t}=\frac{k_1 B_b}{0.29D_b}$	$\frac{k_2\sqrt{B_b E}}{n_y (0.29h/t)}$
SHEAR IN WEBS, gross section	Unstiffened flat webs	20	$\frac{F_{sy}}{n_y}$	$\frac{h}{t}=\frac{B_s-F_{sy}}{1.25D_s}$	$\frac{1}{n_y}\left(B_s-1.25D_s\frac{h}{t}\right)$	$\frac{h}{t}=\frac{C_s}{1.25}$	$\frac{\pi^2 E}{n_y (1.25h/t)^2}$
	Stiffened flat webs $a_e = a_1/\sqrt{1+0.7(a_1/a_2)^2}$	21	$\frac{F_{sy}}{n_y}$	$\frac{a_e}{t}=\frac{B_s-\frac{n_a F_{sy}}{n_y}}{1.25D_s}$	$\frac{1}{n_a}\left(B_s-1.25D_s\frac{a_e}{t}\right)$	$\frac{a_e}{t}=\frac{C_s}{1.25}$	$\frac{\pi^2 E}{n_a (1.25a_e/t)^2}$

ROGRAMMED
ND
EMOTE SYSTEMS CORPORATION
3460 LEXINGTON AVE. NO., ST. PAUL, MINNESOTA 55112
AREA CODE 612 484-7261 TELEX #29-7473

APPENDIX A.3

FUEL STORAGE SYSTEM DESIGN REPORT

PaR Job No. 3091

DUANE ARNOLD ENERGY CENTER UNIT NO. 1

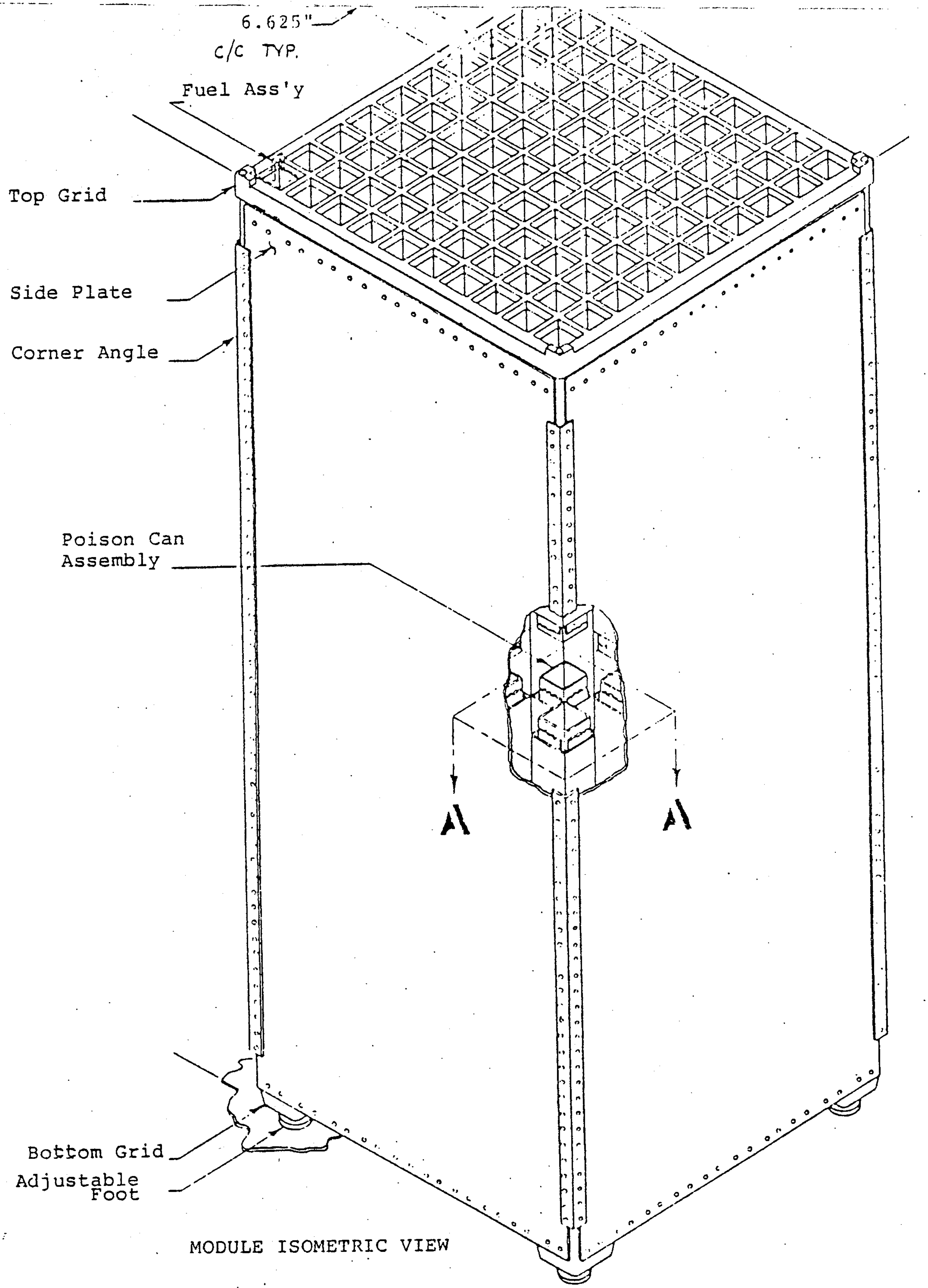
Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

MODULE ISOMETRIC

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHK'D BY	APPV'D BY	DATE



MODULE ISOMETRIC VIEW

Figure 3b

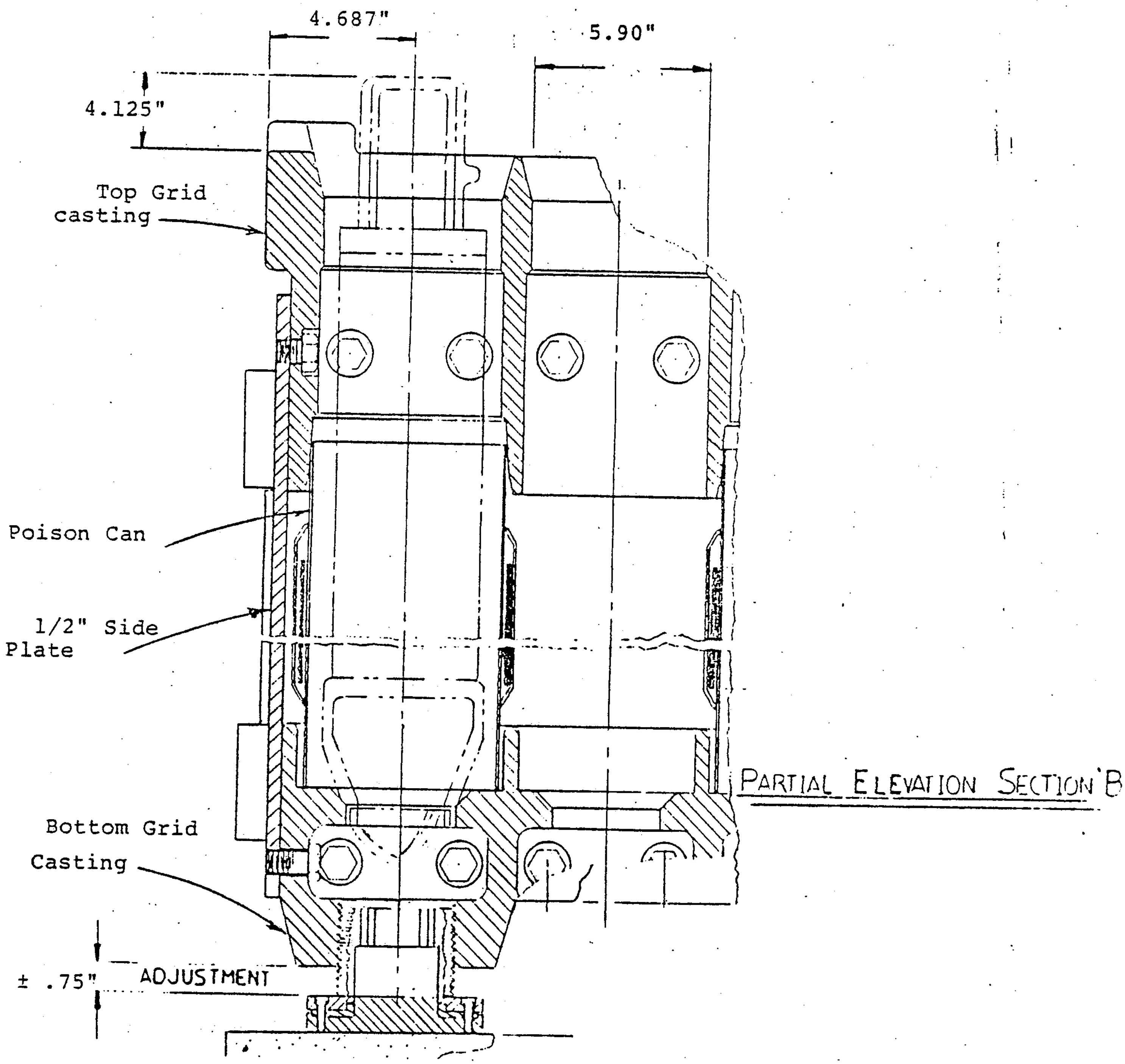

4.687"
5.90"
4.125"
Top Grid casting
Poison Can
1/2" Side Plate
PARTIAL ELEVATION SECTION 'B
Bottom Grid Casting
± .75"
ADJUSTMENT

Figure 3-c-1

APPENDIX A.4

FUEL STORAGE SYSTEM DESIGN REPORT

DUANE ARNOLD ENERGY CENTER UNIT I

IOWA ELECTRIC LIGHT & POWER COMPANY

PaR Job No. 3091

Design Calculations

BEAM SECTION PROPERTIES

&

ALLOWABLE STRESSES

PREPARED BY David L. Pederson DATE 1-17-78

APPROVED BY R. Barry Whitaker DATE 1/19/78

REVISION NO.__________ DATE__________

ENVIRONMENTAL SERVICES, INC.
P.O. BOX 35244
MINNEAPOLIS, MINNESOTA 55435
(612) 854-8414

SERIAL NO.__________

ENVIRONMENTAL SERVICES, INC.

DISTRIBUTION RECORD

SERIAL NO.	ORGANIZATION	DATE
R150-A.4	PaR Systems Corporation	

ENVIRONMENTAL SERVICES, INC.

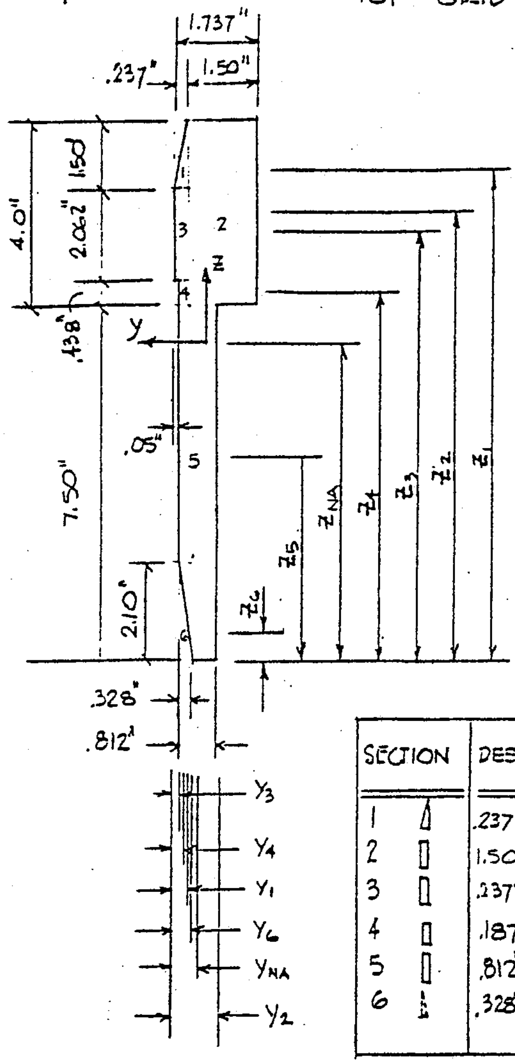
REVISION RECORD

REVISION NO.	DESCRIPTION	APPROVED	DATE	CHECKED	DATE

tsi
MINNEAPOLIS
MINN. 55435
(612) 854-8414

1

TOP GRID OUTER SECTION



$A_x = A_y = A_z = 12.494\ IN^2$

$I_x = 1/3\ 11.50 \left(\frac{12.494}{11.50}\right)^3 = 4.916\ IN^4$

$I_y = 128.862\ IN^4$

$I_z = 2.459\ IN^4$

$S_y = 18.618\ IN^3$

$S_z = 2.368\ IN^3$

$Y_y = \sqrt{128.862/12.494} = 3.212\ IN$

$Y_z = \sqrt{2.459/12.494} = .444\ IN$

SECTION	DESCRIPTION	y_n	A_n	$M_n = Ay$	$\bar{I}_{zn} = Ay^2$	I_g
1	.237" x 1.50"	.158	.178	.028	.004	.001
2	1.50" x 4.0"	.987	6.000	5.922	5.845	1.125
3	.237" x 2.062"	.119	.488	.058	.007	.002
4	.187" x .438"	.144	.082	.012	.002	-
5	.812" x 7.50"	.456	6.09	2.777	1.266	.335
6	.328" x 2.10	.159	-.344	-.055	-.009	-.002
			12.494	8.742	7.115	1.461

$I_z = \bar{I}_{zn} + I_g - \frac{M^2}{A}$ $y_{NA} = 8.742/12.494 = 0.699"$

$I_z = 7.115 + 1.461 - \frac{8.742^2}{12.494} = 2.459\ IN^4$ $S_z = 2.459/1.038 = 2.368\ IN^3$

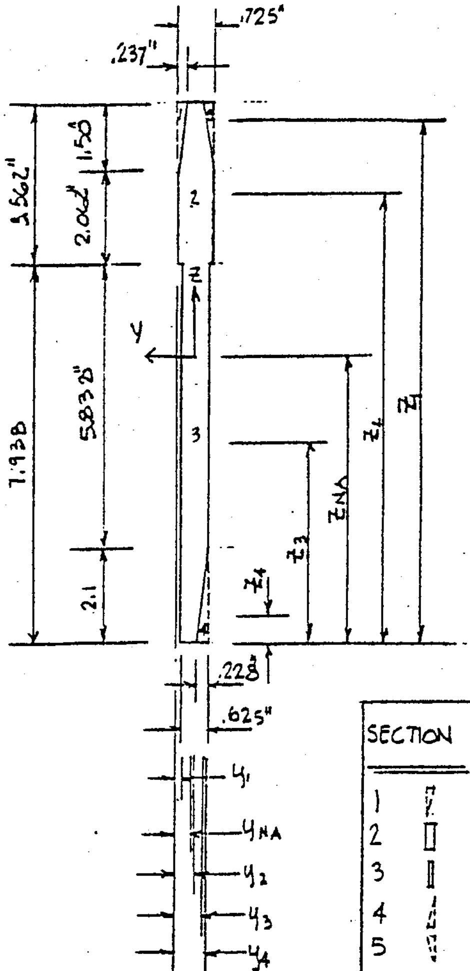
SECTION	DESCRIPTION	z_n	A	$M = Az$	$\bar{I}_y = Az^2$	I_g
1	.237" x 1.50"	10.50	.178	1.869	19.625	.022
2	1.50" x 4.0"	9.50	6.000	57.000	541.500	8.000
3	.237" x 2.062"	8.969	.488	4.377	39.256	.173
4	.187 x .438"	7.719	.082	.633	4.885	.001
5	.812" x 7.50"	3.750	6.09	22.838	85.641	28.547
6	.328" x 2.10"	.700	-.344	-.241	-.169	-.084
			12.494	86.476	690.738	36.659

$I_y = \bar{I}_{yn} + I_g - \frac{M^2}{A}$ $Z_{NA} = 86.476/12.494 = 6.921"$

$I_y = 690.738 + 36.659 - \frac{86.476^2}{12.494} = 128.862\ IN^4$

$S_y = 128.862/6.921 = 18.618\ IN^3$

2 TOP GRID - INNER SECTION



$A_x = A_y = A_z = 6.948\ IN^2$

$I_x = \frac{1}{3}\ 11.5\ (\frac{6.948}{11.50})^3 = 0.846\ IN^4$

$I_y = 69.105\ IN^4$

$I_z = 0.229\ IN^4$

$S_y = 11.796\ IN^4$

$S_z\quad 0.617\ IN^3$

$r_y = \sqrt{69.105/6.948} = 3.154\ IN$

$r_z = \sqrt{.229/6.948} = .182\ IN$

SECTION	DESCRIPTION	y_n	A_n	$M_n = Ay$	$\bar{I}_{zn} = Ay^2$	I_g
1	.237" x 1.50"	.079	-.178	-.014	-.001	-.001
2	.725" x 3.562"	.363	2.582	.936	.339	.113
3	.625" x 7.938"	.363	4.961	1.798	.652	.161
4	.228" x 2.10"	.599	-.239	-.143	-.086	-.001
5	.237" x 1.50"	.646	-.178	-.115	-.074	-.001
			6.948	2.462	.83	.271

$I_z = \bar{I}_{zn} + I_g - \frac{M^2}{A}$ $y_{NA} = 2.462/6.948 = 0.354"$

$I_z = .83 + .271 - \frac{2.462^2}{6.948} = 0.229\ IN^4$ $S_z = .229/.371 = .617\ IN^3$

SECTION	DESCRIPTION	Z_n	A_n	$M_n = Az$	$\bar{I}_y = Az^2$	I_g
1	.237" x 1.50"	11.00	-.178	-1.958	-21.538	-.022
2	.725" x 3.562"	9.719	2.582	25.094	243.893	2.730
3	.625" x 7.938"	3.969	4.961	19.690	78.150	26.051
4	.228" x 2.10"	.70	-.239	-.167	-.117	-.058
5	.237 x 1.50"	11.00	-.178	-1.958	-21.538	-.022
			6.948	40.701	278.85	28.679

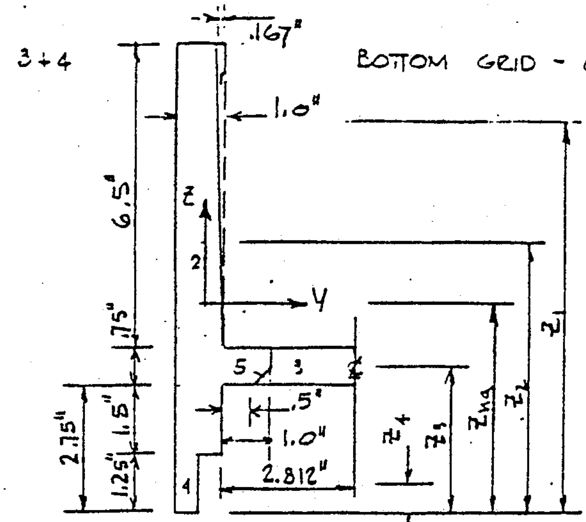
$I_y = \bar{I}_{yn} + I_g - \frac{M^2}{A}$ $Z_{NA} = 40.701/6.948 = 5.858"$

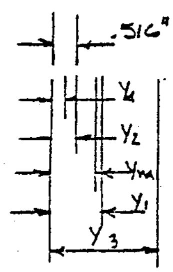
$I_y = 278.85 + 28.679 - \frac{40.701^2}{6.948} = 69.105\ IN^4$

$S_y = 69.105/5.858 = 11.796\ IN^3$

3+4

BOTTOM GRID - OUTER SECTION NEAR LEG





SECTION PROPERTIES ARE AVERAGE OR EFFECTIVE VALUES OF SECTIONS A+B

$A_x = \frac{1}{2}(10.962 + 9.478) = 10.22\ IN^2$

$A_y = \frac{1}{2}[.75(2.0 + 3.812)] = 2.180\ IN^2$

$A_z = 8.75 + .645 - .542 = 8.853\ IN^2$

$I_x = \frac{1}{3}\, 10.0 \left[\frac{10.22}{10.0}\right]^3 = 3.558\ IN^4$

$I_{y\,eff} = \frac{1}{2}[72.792 + 68.146] = 70.469\ IN^4$

$r_y = \sqrt{70.469/10.22} = 2.63\ IN$

$I_{z\,eff} = 5.450\ IN^4$

$r_z = \sqrt{5.450/10.22} = .73\ IN$

$S_y = 13.841\ IN^3$ $S_z = 2.862\ IN^3$

I_{z1} WITH NO HOLE - SECTION A-A

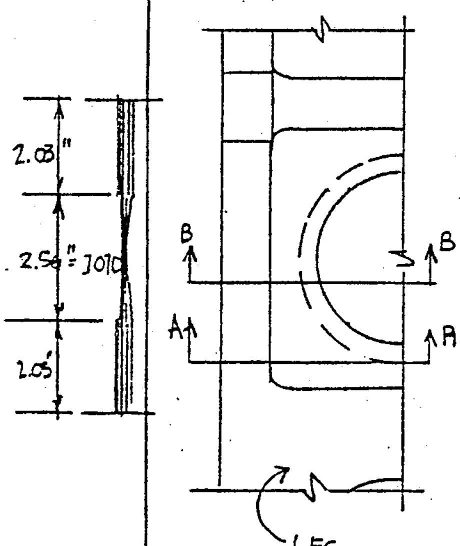
SECTION	DESCRIPTION	Y_n	A_n	$M_n = Ay$	$\bar{I}_{zn} = Ay^2$	I_{gz}
1	.167" x 6.5"	.944	-.542	-.512	-.484	-.001
2	1.0" x 8.75"	.500	8.750	4.375	2.188	.729
3	2.812 x .75"	2.406	2.109	5.074	12.209	1.390
4	.516" x 1.25"	.258	.645	.166	.043	.014
			10.962	9.103	13.956	2.132

$I_{z1} = \bar{I}_{zn} + I_{gz} - M^2/A$

$y_{na} = 9.103/10.962 = .830\ IN$

$I_{z1} = 13.956 + 2.132 - 9.103^2/10.962 = 8.529\ IN^4$

$S_{z1} = 8.529/2.982 = 2.862\ IN^3$



I_{z2} AT CENTER WITH HOLE - SECTION A-A

SECTION	DESCRIPTION	Y_n	A_n	$M_n = Ay$	$\bar{I}_{zn} = Ay^2$	I_{gz}
1	.167" x 6.5"	.944	-.542	-.512	-.484	-.001
2	1.0" x 8.75"	.500	8.750	4.375	2.188	.729
3	1.0" x .75"	1.50	.750	1.125	1.688	.063
4	.516" x 1.25"	.258	.645	.166	.043	.014
5	.50 x .50"	1.833	-.125	-.229	-.420	-.002
			9.478	4.925	3.015	.803

$y_{na} = 4.925/9.478 = .520\ IN$

$I_{z2} = 3.010 + .803 - 4.925^2/9.478 = 1.259\ IN^4$

$S_{z2} = 1.259/1.480 = .851\ IN^3$

3+4 CONTINUED

I_{y1} WITH NO HOLE - SECTION A-A

SECTION	DESCRIPTION	z_n	A_n	$M_n = Az$	$\bar{I}_{yn} = Az^2$	I_{gy}
1	.167" x 6.5"	7.833	-.542	-4.245	-33.256	-1.274
2	1.0" x 8.75"	5.625	8.750	49.219	276.856	55.827
3	2.812" x .75"	3.125	2.109	6.591	20.596	.099
4	.516 x 1.25"	.625	.645	.403	.252	.084
			10.962	51.971	264.451	54.736

$I_{y1} = \bar{I}_{yn} + I_{gy} - M^2/A$ $\quad z = 51.971/10.962 = 4.741$

$I_{y1} = 264.451 + 54.736 - 51.971^2/10.962 = 72.792 \text{ IN}^4$

$S_{y1} = 72.792/5.259 = 13.841 \text{ IN}^3$

I_{y2} AT CENTER WITH HOLE - SECTION B-B

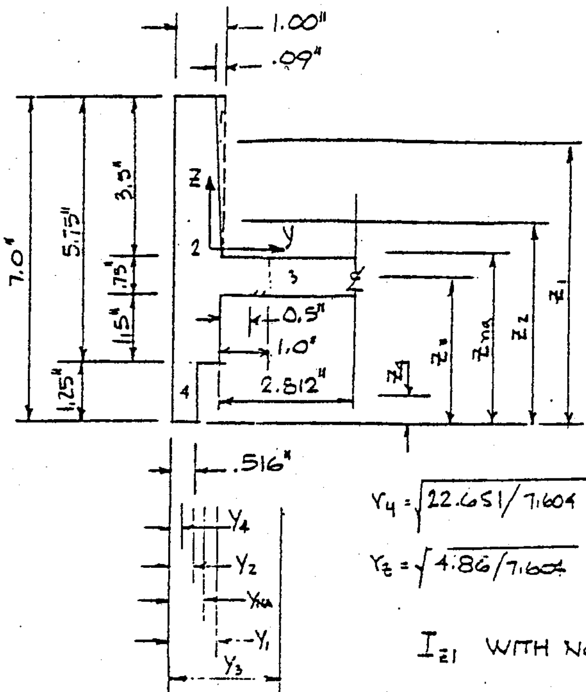
SECTION	DESCRIPTION	z_n	A_n	$M_n = Az$	$\bar{I}_{yn} = Az^2$	I_{gy}
1	.167 x 6.5"	7.833	-.542	-4.245	-33.255	-1.274
2	1.0" x 8.75"	5.625	8.750	49.219	276.856	55.827
3	1.0" x .75"	3.125	.750	2.343	7.324	.035
4	.516" x 1.25"	.625	.645	.406	.254	.084
5	.50" x .50"	2.917	-.125	-.364	-1.063	-.002
			9.478	47.359	250.116	54.670

$z = 47.359/9.478 = 4.997 \text{ IN}$

$I_{y2} = 250.116 + 54.670 - 47.359^2/9.478 = 68.146 \text{ IN}^4$

$S_{y2} = 68.146/5.003 = 13.621 \text{ IN}^3$

5 BOTTOM GRID – OUTER SECTION



SECTION PROPERTIES ARE AVERAGE OR EFFECTIVE VALUES OF SECTIONS A+B

$A_x = 1/2(8.346+6.862) = 7.604\ IN^2$

$A_y = 1/2[.75(2.0+3.812)] = 2.180\ IN^2$

$A_z = 8.346 - 2.109 = 6.237\ IN^2$

$I_x = 1/3\ 7.0\left[\frac{7.604}{7.0}\right]^3 = 2.991\ IN^4$

$I_{y\,eff} = 1/2[22.878+22.425] = 22.651\ IN^4$

$I_{z\,eff} = 4.86\ IN^4$

$S_y = 6.259\ IN^3$ $S_z = 2.739\ IN^3$

$r_y = \sqrt{22.651/7.604} = 1.73\ IN$

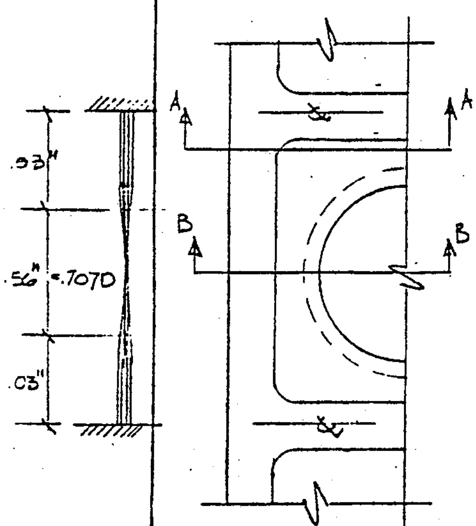
$r_z = \sqrt{4.86/7.604} = .766\ IN$

I_{z1} WITH NO HOLE – SECTION A-A

SECTION	DESCRIPTION	y_n	A_n	$M_n = Ay$	$\bar{I}_{zn} = Ay^2$	I_{gz}
1	.09" x 3.5"	0.97	-.158	-.153	-.148	-
2	1.0" x 5.75"	0.50	5.750	2.875	1.438	.479
3	2.812" x .75"	2.406	2.109	5.074	12.209	1.390
4	.516" x 1.25"	.258	.645	.166	.043	.014
			8.346	7.962	13.542	1.883

$I_{z_1} = \bar{I}_{zn} + I_{gz} - M^2/A$ $y_{na} = 7.962/8.346 = .954"$

$I_{z_1} = 13.542+1.883-7.962^2/8.346 = 7.829\ IN^4$ $S_{z_1} = 7.829/2.858 = 2.739\ IN^3$



I_{z2} AT CENTER WITH HOLE – SECTION B-B

SECTION	DESCRIPTION	y_n	A_n	$M_n = Ay$	$\bar{I}_{zn} = Ay^2$	I_{gz}
1	.09" x 3.5"	0.97	-.158	-.153	-.148	-
2	1.0" x 5.75"	0.50	5.750	2.875	1.438	.479
3	1.0" x 0.75"	1.50	.750	1.125	1.688	.063
4	.516" x 1.25"	.258	.645	.166	.043	.014
5	.50" x .50"	1.833	-.125	-.229	-.420	-.002
			6.862	3.784	2.601	.554

$I_{z2} = \bar{I}_{zn} + I_{gz} - M^2/A$ $y_{na} = 3.784/6.862 = .551"$

$I_{z2} = 2.601+.554-3.784^2/6.862 = 1.068\ IN^4$

$I_{z(EFF)} = 4.86\ IN^4$

5 CONTINUED

I_{y1} WITH NO HOLE - SECTION A-A

SECTION	DESCRIPTION	z_n	A_n	$M_n = Az$	$I_{yn} = Az^2$	I_{gy}
1	.09" X 3.5"	5.833	-.158	-.922	-5.376	-.107
2	1.0" x 5.75"	4.125	5.750	23.718	97.839	15.842
3	2.812" x .75"	3.125	2.109	6.591	20.596	.099
4	.516" x 1.25"	.625	.645	.406	.254	.084
			8.346	29.793	113.313	15.918

$I_{y1} = \bar{I}_{yn} + I_{gy} - M^2/A$ $\bar{z} = 29.793/8.346 = 3.570"$

$S_{y3n7} = 1.669$

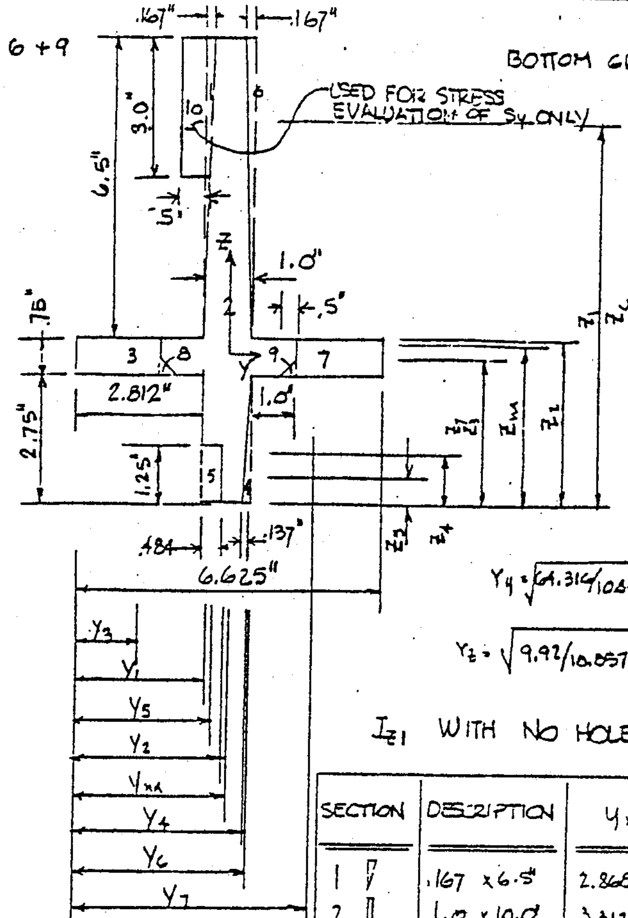
$I_{y1} = 113.313 + 15.918 - 29.793^2/8.346 = 22.878 IN^4$ $S_{y1} = \frac{22.878}{3.57} = 6.408 IN^3$

I_{y2} AT CENTER WITH HOLE - SECTION B-B

SECTION	DESCRIPTION	z_n	A_n	$M_n = Az$	$\bar{I}_{yn} = Az^2$	I_g
1	.09" x 3.5"	5.833	-.158	-.922	-5.376	-.107
2	1.0" x 5.75"	4.125	5.750	23.718	97.839	15.842
3	1.0" x 0.75"	3.125	.750	2.343	7.324	.035
4	.516" x 1.25"	.625	.645	.406	.254	.084
5	.50" x .50"	2.917	-.125	-.364	-1.063	-.002
			6.862	25.181	98.978	15.852

$I_{y2} = \bar{I}_{yn} + I_{gy} - M^2/A$ $\bar{z} = 25.181/6.862 = 3.67"$

$I_{y2} = 98.978 + 15.852 - 25.181^2/6.862 = 22.425 IN^4$ $S_{y2} = \frac{22.425}{3.67} = 6.110$



BOTTOM GRID - INNER SECTION (WITH GUSSET)

SECTION PROPERTIES ARE AVERAGE OR EFFECTIVE VALUES OF SECTIONS A+B

$A_x = 1/2\,(12.341 + 9.373) = 10.857\ IN^2$

$A_y = 1/2\,[.75\,(3.0 + 6.625)] = 3.609\ IN^2$

$A_z = 10.0 - .542 - .542 - .188 - .605 = 8.123\ IN^2$

$I_x = 1/3\ 10.0\left[\frac{10.857}{10.}\right]^3 = 4\ 265\ IN^4$

$I_{y\,(AVG)} = 1/2\,[67.583 + 61.049] = 64.316\ IN^4$

$Y_y = \sqrt{64.316/10.857} = 2.44$

$I_{z\,(eff)} = 9.92\ IN^4$

$Y_z = \sqrt{9.92/10.857} = .96$

$S_y = 18.851$ $S_z = 3.318\ IN^3$ (5.62)

I_{z1} WITH NO HOLE - SECTION A-A

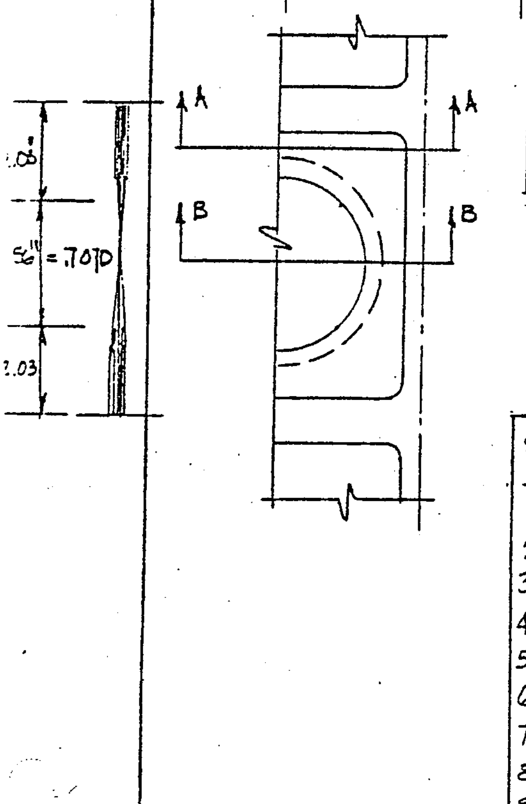
SECTION	DESCRIPTION	y_n	A_n	$M = Ay$	$I_{zn} = Ay^2$	I_{gz}
1	.167 x 6.5"	2.868	-0.542	-1.554	-4.457	-.001
2	1.0 x 10.0	3.312	10.000	33.120	109.693	0.833
3	0.75" x 2.812"	1.406	2.109	2.965	4.169	1.387
4	.137 x 2.75"	3.766	-0.188	-0.708	-2.667	-
5	.484 x 1.25"	3.054	-0.605	-1.848	-5.643	-.012
6	.167 x 6.5"	3.756	-0.542	-2.036	-7.646	-.001
7	0.75" x 2.812"	5.218	2.109	11.005	57.423	1.387
			12.341	40.944	150.872	3.593

$I_{z1} = I_{zn} + I_{gz} - M^2/A$

$I_{z1} = 150.872 + 3.593 - \frac{40.944^2}{12.341} = 18.624\ IN^4$

$y_{NA} = 40.944/12.341 = 3.318"$

$S_{z1} = 18.624/3.318 = 5.614\ IN^3$



I_{z2} AT CENTER WITH HOLE - SECTION B-B

SECTION	DESCRIPTION	y_n	A_n	$M = Ay$	$I_{zn} = Ay^2$	I_{gz}
1	.167" x 6.5"	2.868	-0.542	-1.554	-4.457	-.001
2	1.0" x 10.0"	3.312	10.000	33.120	109.693	0.833
3	0.75 x 1.0"	2.312	.750	1.734	4.009	.063
4	.137" x 2.75"	3.766	-0.188	-0.708	-2.667	-
5	.484" x 1.25"	3.054	-0.605	-1.848	-5.643	-.012
6	.167" x 6.5"	3.756	-0.542	-2.036	-7.646	-.001
7	0.75" x 1.0"	4.312	.75	3.234	13.945	.063
8	.50" x .50"	1.979	-.125	-0.247	-0.490	-.002
9	.50" x .50"	4.645	-.125	-.581	-2.697	-.002
			9.373	31.114	104.047	.941

$I_{z2} = 104.047 + .941 - 31.114^2/9.373 = 1.704\ IN^4$

$y_{NA} = 31.114/9.373 = 3.320"$

$S_{z2} = 1.704/1.508 = 1.130\ IN^3$

6+9 (CONTINUED)

I_{y1} WITH NO HOLE - SECTION A-A

SECTION	DESCRIPTION	Z_n	A_n	$M_z = Az$	$I_{yn} = Az^2$	I_{gy}
1	.167" x 6.5"	7.833	-0.542	-4.245	-33.255	-1.274
2	1.0" x 10.0"	5.000	10.000	50.0	250.000	83.333
3	0.75" x 2.812"	3.125	2.109	6.591	20.596	.099
4	.137" x 2.75"	.916	-0.188	-.172	-0.158	-.079
5	.484" x 1.25"	.625	-0.605	-.378	-0.236	-.079
6	.167" x 6.5"	7.833	-0.542	-4.245	-33.255	-1.274
7	0.75" x 2.812"	3.125	2.109	6.591	20.596	.099
10**	0.59" x 3.0"	8.567	1.769	15.155	129.833	1.315**
			14.110	69.297	354.121	82.140

$I_{y1} = I_{yn} + I_{gy} - M^2/A$ $\bar{z}_1 = 69.297/14.110 = 4.911$

$I_{y1} = 354.121 + 82.140 - 69.297^2/14.11 = 95.929 \text{ IN}^4$

$S_{y1} = 95.929/5.089 = 18.851 \text{ IN}^3$

I_{y2} AT CENTER WITH HOLE - SECTION B-B

SECTION	DESCRIPTION	Z_n	A_n	$M_z = Az$	$I_{yn} = Az^2$	I_{gy}
1	.167" x 6.5"	7.833	-0.542	-4.245	-33.255	-1.274
2	1.0" x 10.0"	5.000	10.000	50.000	250.000	83.333
3	0.75" x 1.0"	3.125	0.750	2.344	7.325	.035
4	.137 x 2.75"	.916	-0.188	-.172	-0.158	-.079
5	.484 x 1.25"	.625	-0.605	-0.378	-0.236	-.079
6	.167" x 6.5"	7.833	-0.542	-4.245	-33.255	-1.274
7	0.75" x 1.0"	3.125	0.750	2.344	7.325	.035
8	.50" x 0.50"	2.917	-.125	-.365	-1.065	-.002
9	.50" x .50"	2.917	-.125	-.365	-1.065	-.002
			9.373	44.918	195.66	80.693

$\bar{z}_2 = 44.918/9.373 = 4.792 \text{ IN}$

$I_{y2} = 195.616 + 80.693 - 44.918^2/9.373 = 61.049$

$S_{y2} = 61.049/5.208 = 11.722 \text{ IN}^3$

** SECTION AT LEG HAS ADDITIONAL MATERIAL WHICH IS USED FOR EVALUATING SECTION MODULUS AND STRESS AT JUNCTION OF GUSSET AND LEG.