IOW-40-199-4
Revision 0
December 1982
25.2640.0199

DUANE ARNOLD ENERGY CENTER
PLANT UNIQUE ANALYSIS REPORT
VOLUME 4
INTERNAL STRUCTURES ANALYSIS

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TITLE: Duane Arnold Energy Center
Plant Unique Analysis Report
Volume 4

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4-iv	0	APG	LSC	HHS
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4-1.1				HHS
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EFFECTIVE PAGE(S)	REV	PREPARED	ACCURACY CHECK	CRITERIA CHECK
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4-2.15	0	APG	VK	[illegible]					
4-2.16	↓	↓	↓	[illegible]					
4-2.17			LSC	VK					
4-2.18			LSC	↓					
4-2.19			LSC						
4-2.20			[illegible]						
4-2.21			LSC	[illegible]					
4-2.22			LSC	↓					
4-2.23			LSC						
4-2.24		KLO	APG						
4-2.25		↓	APG						
4-2.26		LSC	VK						
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ABSTRACT

The primary containment for the Duane Arnold Energy Center was designed, erected, pressure-tested, and ASME Code N-stamped during the early 1970's for the Iowa Electric Light and Power Company by the Chicago Bridge and Iron Company. Since that time new requirements have been generated. These requirements affect the design and operation of the primary containment system and are defined in the Nuclear Regulatory Commission's Safety Evaluation Report NUREG-0661. The requirements to be addressed include an assessment of additional containment design loads postulated to occur during a loss-of-coolant accident or a safety relief valve discharge event, as well as an assessment of the effects that these postulated events have on the operational characteristics of the containment system.

This plant unique analysis report documents the efforts undertaken to address and resolve each of the applicable NUREG-0661 requirements, and demonstrates, in accordance with NUREG-0661 acceptance criteria, that the design of the primary containment system is adequate and that original design safety margins have been restored. The report is composed of the following six volumes and Appendix.

- Volume 1 - GENERAL CRITERIA AND LOADS METHODOLOGY
- Volume 2 - SUPPRESSION CHAMBER ANALYSIS
- Volume 3 - VENT SYSTEM ANALYSIS
- Volume 4 - INTERNAL STRUCTURES ANALYSIS
- Volume 5 - SAFETY RELIEF VALVE DISCHARGE LINE PIPING ANALYSIS
- Volume 6 - TORUS ATTACHED PIPING AND SUPPRESSION CHAMBER PENETRATIONS ANALYSES
- Appendix A - DAEC RESPONSES TO CURRENT CONTAINMENT AND PIPING LICENSING ISSUES

Volume 4 documents the evaluation of the internal structures and has been prepared by NUTECH Engineers, Inc. (NUTECH), acting as an agent to the Iowa Electric Light and Power Company.

TABLE OF CONTENTS

LIST OF ACRONYMS

ADS	Automatic Depressurization System
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CO	Condensation Oscillation
DAEC	Duane Arnold Energy Center
DBA	Design Basis Accident
DBE	Design Basis Earthquake
DLF	Dynamic Load Factor
FSAR	Final Safety Analysis Report
IBA	Intermediate Break Accident
LDR	Load Definition Report
LOCA	Loss-of-Coolant Accident
MC	Midcylinder
MJ	Miter Joint
NOC	Normal Operating Conditions
NPS	Nominal Pipe Size
NRC	Nuclear Regulatory Commission
NVB	Non-Vent Bay
OBE	Operating Basis Earthquake
PUA	Plant Unique Analysis
PUAAG	Plant Unique Analysis Application Guide
PUAR	Plant Unique Analysis Report
PULD	Plant Unique Load Definition
QSTF	Quarter-Scale Test Facility
RSEL	Resultant-Static-Equivalent Load
SBA	Small Break Accident
SRV	Safety Relief Valve
SRVDL	Safety Relief Valve Discharge Line
SSE	Safe Shutdown Earthquake
VB	Vent Bay

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4-1.0 INTRODUCTION

In conjunction with Volume 1 of the Plant Unique Analysis Report (PUAR), this volume documents the efforts undertaken to address the requirements defined in NUREG-0661 which affect the Duane Arnold Energy Center suppression chamber internal structures. The internal structures PUAR is organized as follows.

- INTRODUCTION
  - Scope of Analysis
  - Summary and Conclusions
- INTERNAL STRUCTURES ANALYSIS (Catwalk, Monorail, Thermowells, Vacuum Breaker Electrical Conduits, and Vacuum Breaker Nitrogen Lines).
  - Component Description
  - Loads and Load Combinations
  - Analysis Acceptance Criteria
  - Methods of Analysis
  - Analysis Results

The INTRODUCTION section contains a general overview discussion of the internal structures evaluation. The INTERNAL STRUCTURES ANALYSIS section discusses the specific components, loads, criteria, methods, and results associated with the evaluation.

4-1.1 Scope of Analysis

The criteria presented in Volume 1 are used as the basis for all of the Duane Arnold Energy Center internal structures evaluations described in this volume. The internal structures evaluated include the catwalk, monorail, original thermowells, and vacuum breaker electrical conduits and nitrogen lines. The thermowells are part of the suppression chamber pressure boundary and are evaluated as safety-related components. The other internal structures are not required for the safe operation of the primary containment system during accident conditions. However, the evaluation includes a structural analysis of these internal structures to ensure that they do not fail and result in damage to safety-related components or diminish the integrity of the suppression chamber pressure boundary.

The internal structures are evaluated for the effects of LOCA and SRV discharge-related loads, as defined by the NRC's Safety Evaluation Report NUREG-0661 (Reference 1) and the "Mark I Containment Program Load Definition Report" (LDR) (Reference 2). The LOCA and SRV discharge loads used in this evaluation are formulated using the procedures discussed in Volume 1 of this report.

The results of the structural evaluation for each load are used to evaluate load combinations for the internal structures, in accordance with the "Mark I Containment Program Plant Unique Analysis Application Guide" (PUAAG) (Reference 3). The evaluation results are conservatively compared with the acceptance limits specified by the PUAAG and the applicable sections of the ASME Code (Reference 4) to ensure that safety-related components are not adversely affected.

4-1.2 Summary and Conclusions

The evaluation documented in this volume is performed for the Duane Arnold Energy Center internal structures identified in Section 1-1.1. These structures include the catwalk, monorail, original thermowells, and vacuum breaker electrical conduits and nitrogen lines. The thermowells associated with the new SPTMS system and the internal spray headers along with their associated support bracketry will be discussed in Volume 6.

The LOCA and SRV discharge-related events defined in NUREG-0661 result in hydrodynamic loadings on the internal structures. The major loadings which affect the catwalk, monorail, thermowells, and the portions of vacuum breaker electrical conduits and nitrogen lines above the suppression pool include pool swell impact loads, froth impingement loads, and pool fallback loads. The major loadings which affect submerged portions of the catwalk support and the thermowells include submerged structure loadings. Conservative values for these loadings are developed using the methodology discussed in Section 1-4.0. Other loads, such as dead and seismic loads, have a lesser effect on the internal structures but are still considered in the evaluation.

The analysis results for these loadings are used to formulate the controlling event combinations which affect the internal structures, as discussed in Section 1-3.2. The results are compared to acceptance limits which ensure that the internal structures do not fail and result in damage to safety-related components. The evaluation results show that the stresses for all of the internal structure components are within acceptable limits. The intent of the NUREG-0661 requirements as they affect the internal structures is therefore considered to be met.

4-2.0 INTERNAL STRUCTURES ANALYSIS

An evaluation of each of the NUREG-0661 requirements which affect the design adequacy of the Duane Arnold Energy Center internal structures is presented in the sections which follow. The criteria used in the evaluation are contained in Volume 1 of this report.

The components of the internal structures which are examined are described in Section 4-2.1. The loads and load combinations which are evaluated are presented in Section 4-2.2. The acceptance limits to which the analysis results are compared are discussed and presented in Section 4-2.3. The analysis methodology used to evaluate the effects of these loads and load combinations is discussed in Section 4-2.4. The analysis results and the corresponding design margins are presented in Section 4-2.5.

4-2.1 Component Description

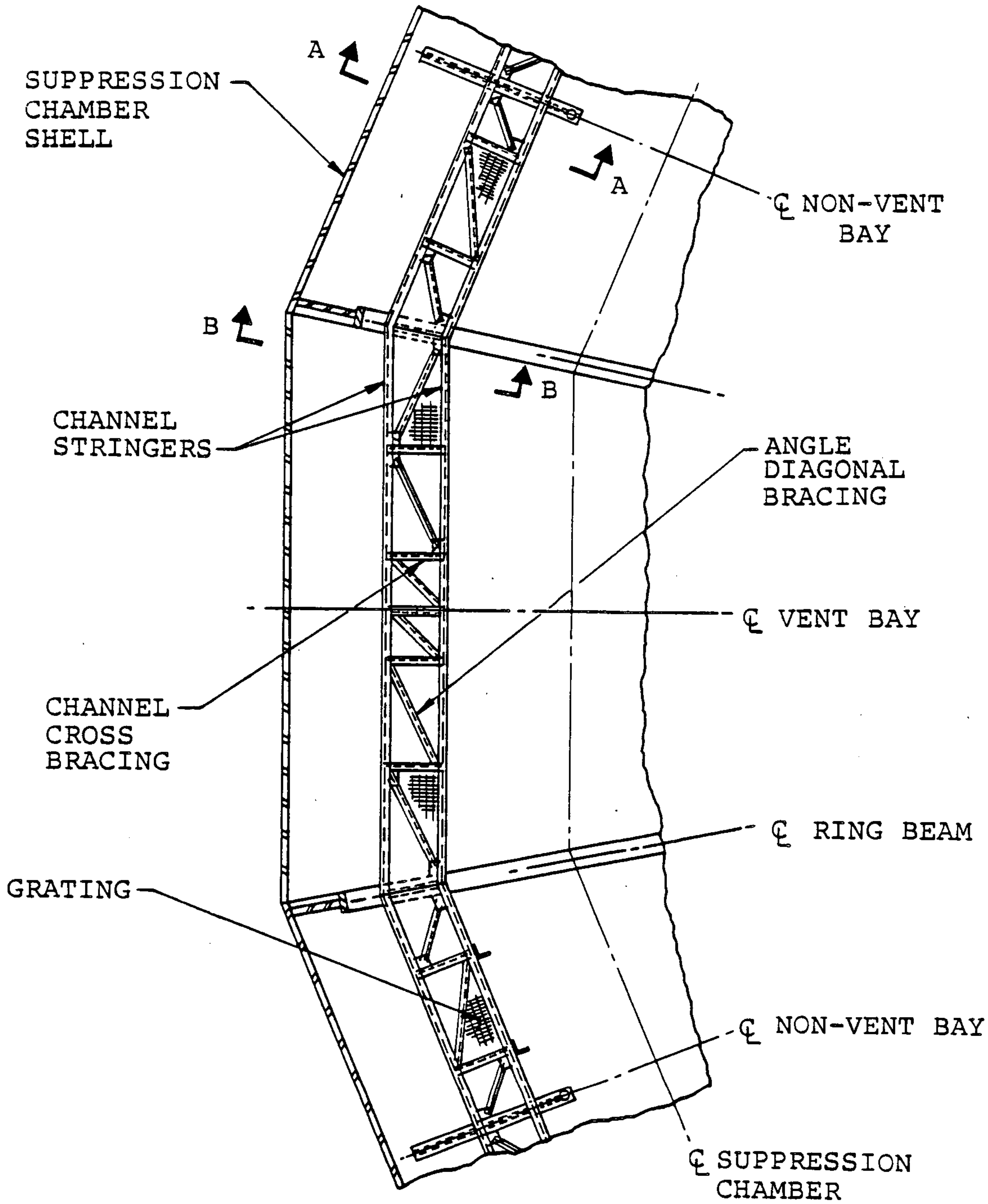
The internal structures which are evaluated include the catwalk, monorail, original thermowells, and vacuum breaker electrical conduits and nitrogen lines. These structures are described in Sections 4-2.1.1 through 4-2.1.3.

4-2.1.1 Catwalk

The catwalk, a platform-type structure approximately 3' wide, extends around the full circumference of the suppression chamber. The catwalk is located in the upper outside quadrant of each suppression chamber mitered cylinder.

The catwalk frame consists of two channel stringers (C10 x 15.3) which extend from miter joint to miter joint with intermittently spaced channel cross bracing (C10 x 15.3) and angle diagonal bracing (L3 x 3 x 1/2). The catwalk frame is supported at each ring beam and at one intermediate location in each of the non-vent bays. The ring beam supports consist of a vertical pipe column (6" diameter NPS) and a horizontal support beam member (stiffened WT5 X 16.5). The intermediate supports consist of a horizontal beam (W10 X 15) located directly beneath the catwalk. This beam is attached at one end to the suppression chamber shell and is suspended by a pipe hanger (4" diameter NPS) at the other end. The connection of the horizontal beam to the suppression chamber shell is designed to allow for free horizontal movement, while still providing vertical support. Figures 4-2.1-1 through 4-2.1-3 show the catwalk and its support configurations.

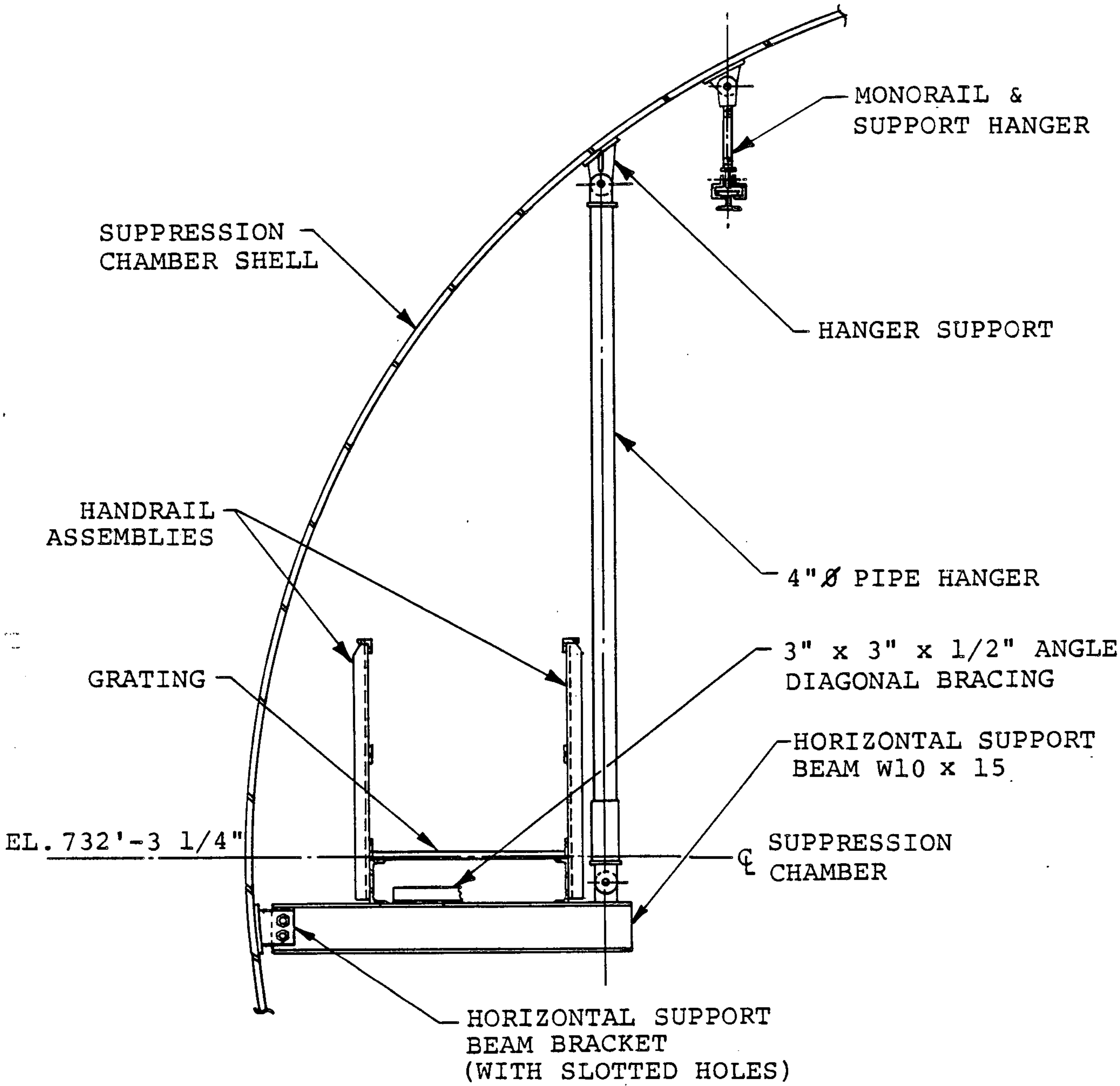
The catwalk platform is covered by grating which is welded to the catwalk frame. The catwalk frame is braced against lateral loads by the diagonal and cross bracing members located between the stringers.



1. SEE FIGURE 4-2.1-2 FOR SECTION A-A.
2. SEE FIGURE 4-2.1-3 FOR SECTION B-B.

Figure 4-2.1-1

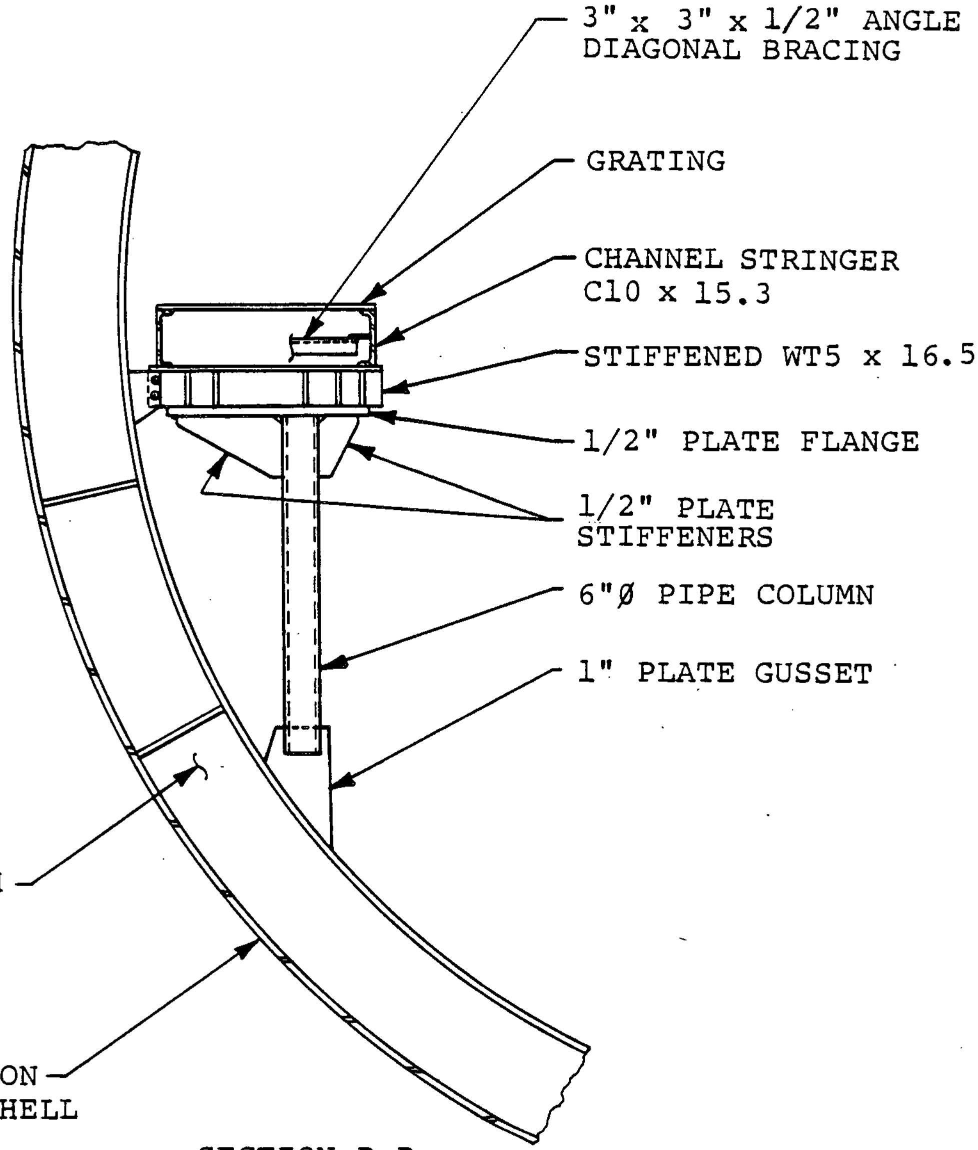
TYPICAL PLAN VIEW OF CATWALK



SECTION A-A
(From Figure 4-2.1-1)

Figure 4-2.1-2

CATWALK SUPPORT IN THE NON-VENT BAY



SECTION B-B
(From Figure 4-2.1-1)

1. HANDRAIL NOT SHOWN FOR CLARITY.

Figure 4-2.1-3

CATWALK SUPPORT AT RING BEAM

4-2.1.2 Monorail

The monorail consists of I-beam sections (S6 x 17.25) curved to a 55'-1" radius and connected end-to-end to form a continuous monorail beam around the circumference of the suppression chamber. The monorail is located in the upper outside quadrant of each suppression chamber mitered cylinder (Figure 4-2.1-2).

The monorail beam is supported at three locations in each bay. There is no support at the miter joint. The supports are equally spaced with one support in the center of each bay.

The monorail supports consist of a vertical support member and a pad plate on the suppression chamber shell. The vertical support consists of a 1-1/8" diameter hanger rod with a clevis on one end, and a forged eye nut and beam clamp on the other end. Figure 4-2.1-4 shows a typical monorail support.

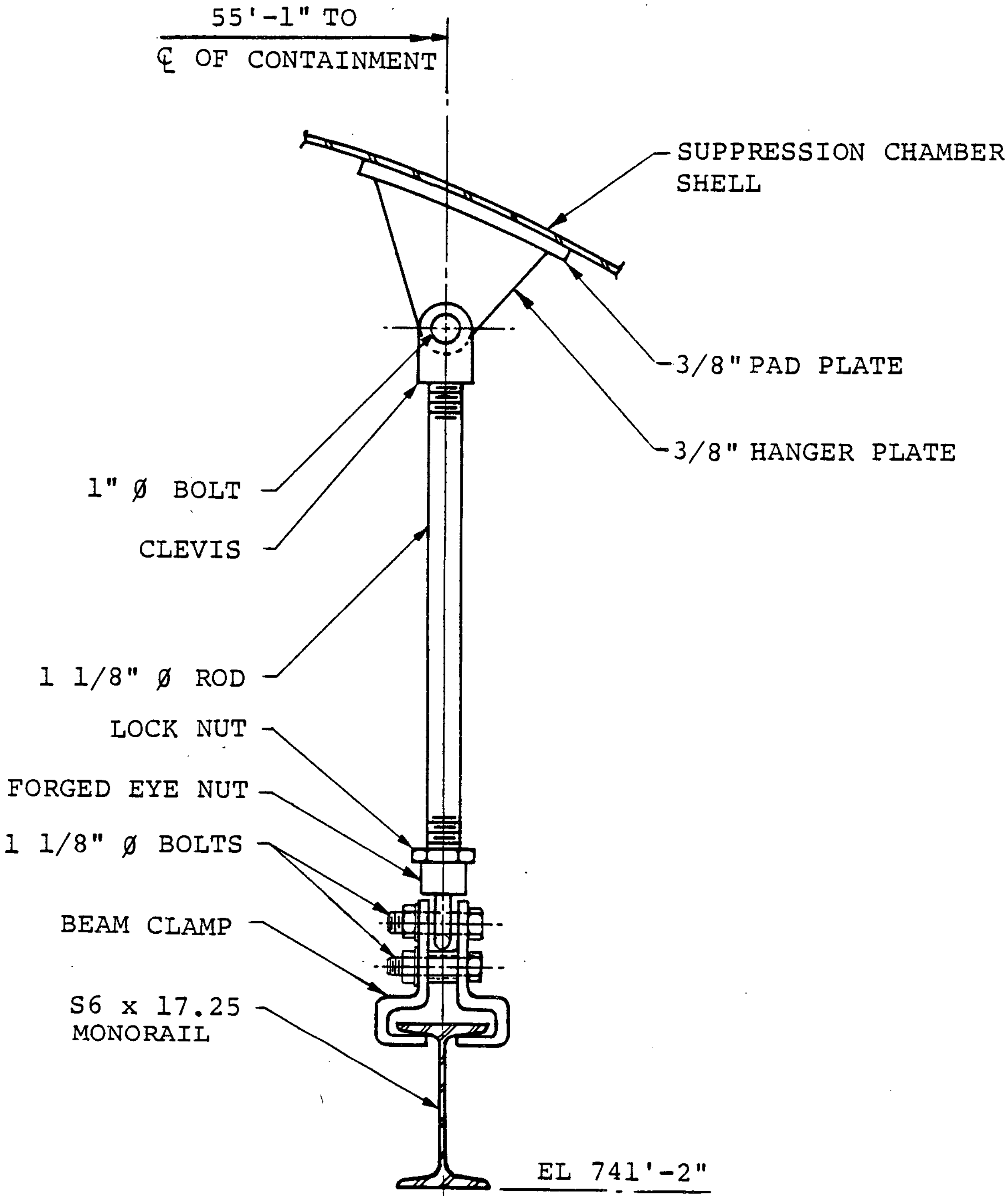


Figure 4-2.1-4

TYPICAL MONORAIL SUPPORT

4-2.1.3 Thermowells and Vacuum Breaker Electrical Conduits and Nitrogen Lines

The two thermowells, located inside the suppression chamber, were a part of the containment temperature monitoring system. These thermowells remain physically in place but have been deactivated and functionally replaced by new ones. The original thermowells are mounted from outside and project inside the suppression chamber at two locations. Figure 4-2.1-5 shows the approximate location of the two original thermowells.

The vacuum breaker nitrogen lines provide nitrogen for the activation of the suppression chamber vacuum breakers. The 2" diameter nitrogen lines run on the inboard side of the catwalk platform feeding each vacuum breaker through a 3/8" diameter feeder line. The feeder lines are supported on the catwalk handrail post. Figure 4-2.1-5 shows the routing for the suppression chamber nitrogen lines.

The vacuum breaker electrical conduits provide power and circuitry for solenoids and instrumentation located inside the suppression chamber vacuum breakers. The instrumentation is used to monitor the vacuum breaker valve in the open and closed positions. The wiring for the vacuum breaker electrical system is routed to each of the vacuum breakers inside 4", 3", 2", 1-1/2", and 1" diameter rigid steel conduits from one suppression chamber penetration location (Figure 4-2.1-6). The vacuum breaker electrical conduits are supported by the catwalk at regular intervals along their length.

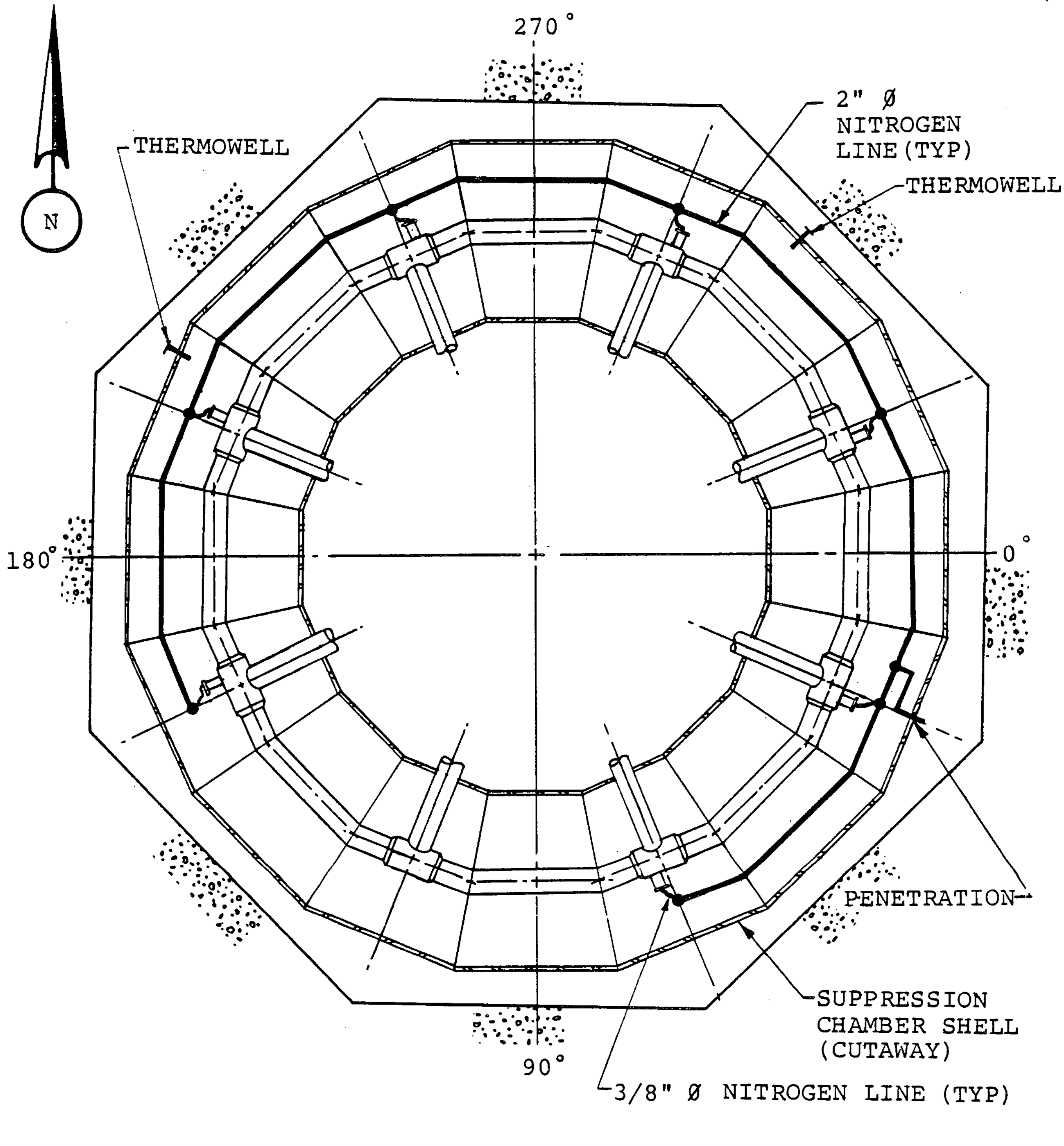


Figure 4-2.1-5

THERMOWELLS AND VACUUM BREAKER NITROGEN LINE ROUTING - PLAN VIEW

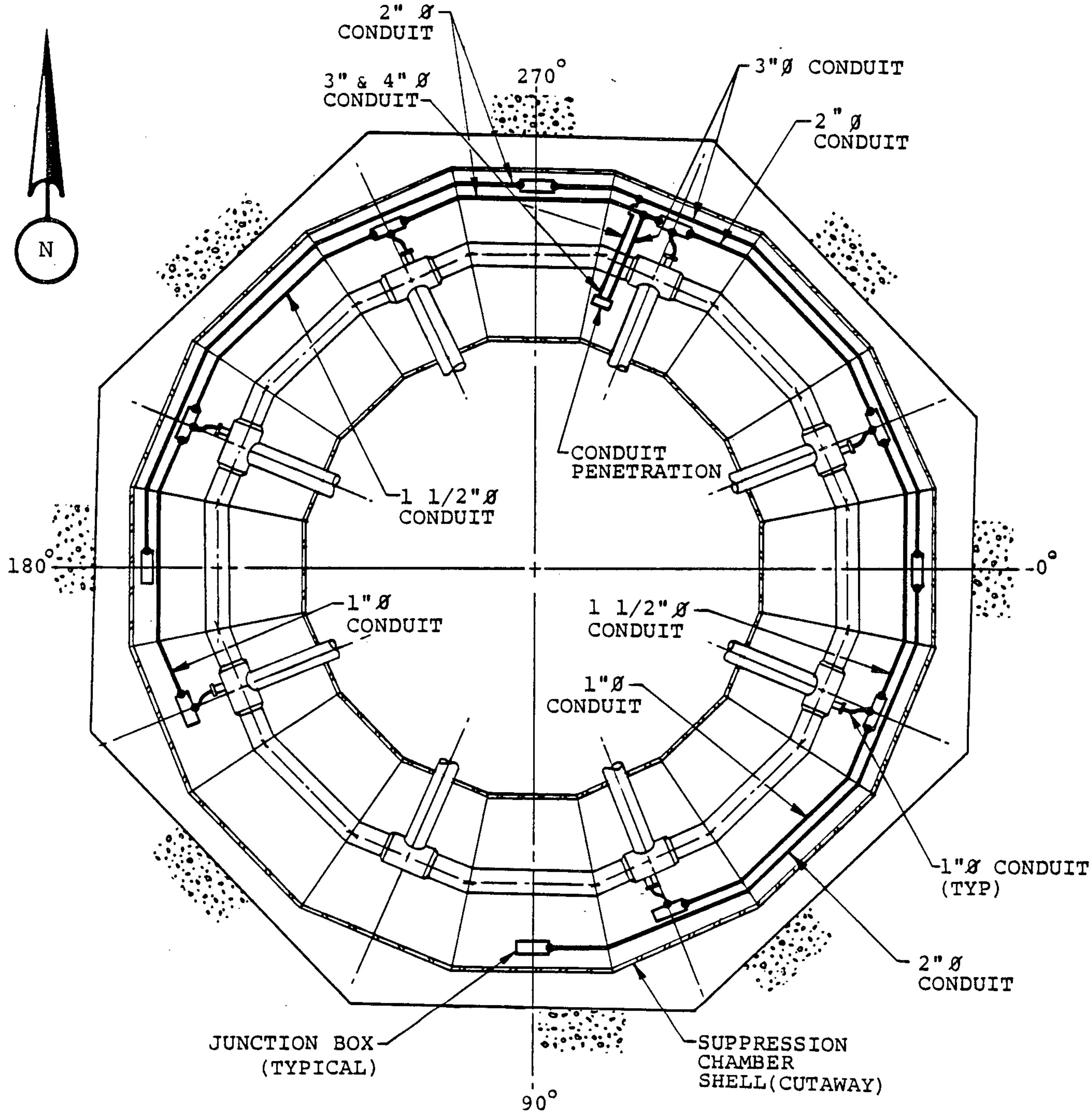


Figure 4-2.1-6

VACUUM BREAKER ELECTRICAL CONDUIT ROUTING - PLAN VIEW

4-2.2 Loads and Load Combinations

The loads for which the Duane Arnold Energy Center internal structures are evaluated are defined in NUREG-0661 on a generic basis for all Mark I plants. The methodology used to develop plant unique loads, for each applicable load defined in NUREG-0661, is discussed in Section 1-4.0. The results of applying the methodology to develop specific values for each of the controlling loads are discussed and presented in Section 4-2.2.1.

The controlling load combinations which affect the internal structures are formulated by using the event combinations and event sequencing defined in NUREG-0661 and discussed in Sections 1-3.2 and 1-4.3. The controlling load combinations are discussed and presented in Section 4-2.2.2.

4-2.2.1 Loads

The loads acting on the internal structures are categorized as follows.

1. Dead Loads
   - 1a. Weight of Steel
2. Seismic Loads
   - 2a. OBE
   - 2b. SSE
3. Pool Swell Loads
   - 3a. Pool Swell Impact and Drag
   - 3b. Froth Impingement and Froth Fallback
   - 3c. Pool Fallback
   - 3d. LOCA Air Clearing Submerged Structure
4. Condensation Oscillation (CO) Loads
   - 4a. DBA CO Submerged Structure
   - 4b. IBA CO Submerged Structure
5. Chugging Loads
   - 5a. Pre-Chug Submerged Structure
   - 5b. Post-Chug Submerged Structure
6. Safety Relief Valve Discharge Loads
   - 6a. SRV Discharge Air Clearing Submerged Structure
7. Suppression Chamber Interaction Loads
   - 7a. Suppression Chamber Structure Motions

The above loads include the effects of associated temperatures and pressures. Table 4-2.2-1 shows the specific internal structures which are affected by each of the above loads. The methodology used to develop values for each of these loadings is discussed in Section 1-4.0. The resulting magnitudes and characteristics of each loading are similar to those described in Volumes 2 and 3 of this report.

Table 4-2.2-1

INTERNAL STRUCTURES

COMPONENT LOADING IDENTIFICATION

LOAD DESIGNATION: CATEGORY	LOAD DESIGNATION: CASE NUMBER	PUAR VOLUME SECTION REFERENCE	CATWALK	MONORAIL	VACUUM BREAKER NITROGEN LINES	THERMOWELLS	VACUUM BREAKER ELECTRICAL CONDUITS
DEAD	1a	1-3.0	X	X	X	X	X
SEISMIC	2a	1-3.0	X	X	X	X	X
	2b	1-3.0	X	X	X	X	X
POOL SWELL LOADS	3a	1-4.1.4.2	X		X		X
	3b	1-4.1.4.3	X	X	X		X
	3c	1-4.1.4.4	X		X		X
	3d	1-4.1.5 1-4.1.6	X(1)			X	
CONDENSATION OSCILLATION	4a	1-4.1.7.3	X(1)			X	
	4b	1-4.1.7.3	X(1)			X	
CHUGGING	5a	1-4.1.8.3	X(1)			X	
	5b	1-4.1.8.3	X(1)			X	
SRV DISCHARGE	6a	1-4.2.4	X(1)			X	
SUPPRESSION CHAMBER INTERACTION	7a	2-2.2.1	X	X	X	X	X

(1) APPLIES TO SUPPORT COLUMNS ONLY.

4-2.2.2 Load Combinations

The loadings which affect each of the internal structures are presented in Section 4-2.2.1. The general NUREG-0661 criteria for grouping these loads into event combinations are discussed in Section 1-3.2. Since the majority of the internal structures are located above the suppression pool, the event combinations which produce controlling stresses are those which contain pool swell loads. These include the DBA 18 and DBA 25 combinations as shown in Table 4-2.2-2. The catwalk, monorail, and vacuum breaker electrical conduits and nitrogen lines located above the suppression pool are therefore evaluated for the DBA 18 and DBA 25 event combinations.

The submerged portion of the catwalk supports and thermowells are subjected to LOCA air clearing, condensation oscillation, chugging, and SRV discharge submerged structure loads identified in Section 4-2.2.1. These submerged structure loadings are specified to occur during various event combinations. The DBA 18 and DBA 25 combinations contain only LOCA air clearing or SRV discharge submerged structure loadings. A bounding combination of the submerged structure loads is used to envelop the possible event combinations affecting the submerged portion of the catwalk supports and thermowells.

Table 4-2.2-2

INTERNAL STRUCTURES CONTROLLING
LOAD COMBINATIONS AND SERVICE LEVELS

LOAD DESIGNATION (1)	EVENT	DBA	
	NUREG-0661 COMBINATION NUMBER	18	25
DEAD		1a	1a
SEISMIC	OBE	2a	
	SSE		2b
POOL SWELL LOADS		3a-3d (2)	3a-3d (2)
SRV DISCHARGE			6a (2)
SUPPRESSION CHAMBER INTERACTION		7a	7a

SERVICE LEVEL AT WHICH STRESSES ARE EVALUATED	ATTACHMENT WELDS TO SUPPRESSION CHAMBER	B	C
	INTERNAL STRUCTURES	D	D

(1) REFERENCE PUAR SECTION 4-2.2.1.

(2) SUBMERGED STRUCTURE LOADINGS ONLY APPLY TO THE CATWALK SUPPORT COLUMNS AND THERMOWELLS.

4-2.3 Analysis Acceptance Criteria

Table 4-2.2-2 shows the service level assignments applied to the internal structures and to their attachment welds to the suppression chamber. All internal structures are designated as Service Level E components and as such, are not required to meet ASME Code acceptance limits. However, in order to employ a consistent set of design criteria which ensures that failure will not occur, the internal structures are conservatively evaluated for the Service Level D acceptance limits contained in the ASME Code, Section III, Subsection NF. All the suppression chamber attachment welds to internal structures are evaluated in accordance with the requirements for Class MC components contained in the ASME Code, Section III, Subsection NE. The corresponding allowable stresses for the DBA 18 and DBA 25 combinations for the internal structures are presented in Section 4-2.5.

4-2.4 Methods of Analysis

The loadings for which the internal structures are evaluated are identified in Section 4-2.2.1.

The analysis of the catwalk is performed using a beam model which includes the stringers, cross and diagonal bracing, hangers, and associated catwalk components. An equivalent static analysis is performed for all of the catwalk loadings except suppression chamber motions. Suppression chamber support motions are analyzed dynamically using the damping values per Regulatory Guide 1.61 (Reference 5). The reaction loads in the catwalk hangers and supports are used to evaluate local stresses in the suppression chamber shell.

The analysis of the monorail is performed using a beam model which includes the monorail and its supports. An equivalent static analysis is performed for all monorail loadings. The reaction loads in the monorail supports are used to evaluate local stresses in the suppression chamber shell.

The thermowells, vacuum breaker electrical conduits and supports, and vacuum breaker nitrogen lines and their supports are evaluated using manual calculations. The reaction loads at the attachments and penetrations to the suppression chamber are used to evaluate local stresses in the suppression chamber shell.

4-2.5 Analysis Results

The geometry, loads, load combinations, acceptance criteria, and analysis methods used in the evaluation of the internal structures were presented in the preceding sections. Table 4-2.5-1 shows the resulting maximum stresses for the catwalk, monorail, thermowells, and vacuum breaker electrical conduits and nitrogen lines for the controlling load combinations.

Table 4-2.5-1

INTERNAL STRUCTURES STRESSES FOR CONTROLLING LOAD COMBINATIONS

COMPONENT	MATERIAL	MATERIAL PROPERTIES (ksi) (1)	STRESS TYPE	LOAD COMBINATION STRESSES (ksi) DBA 18 OR 25		
				CALC. STRESS	ALLOWABLE STRESS (SERVICE LEVEL D)	CALC./ALLOW. (2)
CATWALK STRINGER	ASTM A36	S_y = 32.1 S_u = 58.0	COMPRESSIVE	1.5	19.6	1.06 (3)
			WEAK AXIS BENDING	2.1	48.2	
			STRONG AXIS BENDING	36.3	38.5	
CATWALK VERTICAL HANGER SUPPORT PIPE	ASTM A106 GR B	S_y = 31.2 S_u = 60.0	COMPRESSIVE	1.8 (4)	13.2 (4)	0.77
			BENDING	11.9 (4)	18.7 (4)	
CATWALK SUPPORT COLUMN AT RING BEAM	ASTM A106 GR B	S_y = 31.2 S_u = 60.0	COMPRESSIVE	3.8	23.0	0.40
			BENDING	8.9	37.4	
MONORAIL BEAM	ASTM A36	S_y = 32.1 S_u = 58.0	TENSILE	12.3	38.5	0.48
			STRONG AXIS BENDING	4.7	28.6	
MONORAIL SUPPORT	ASTM A36	S_y = 32.1 S_u = 58.0	COMPRESSIVE	4.7	29.2	0.16
VACUUM BREAKER NITROGEN LINES	ASTM A376 TP 304	S_y = 23.0 S_u = 67.0	BENDING	32.1	37.0	0.87
THERMOWELLS	ASTM A105 GR 2	S_y = 32.1 S_u = 70.0	BENDING	8.9	19.3 (SERVICE LEVEL B)	0.46
VACUUM BREAKER ELECTRICAL CONDUITS	ASTM A120	S_y = 22.3 S_u = 45.0	BENDING	15.4	26.8	0.57

(1) MATERIAL PROPERTIES ARE TAKEN AT 281°F.

(2) VALUES SHOWN OBTAINED FROM BEAM INTERACTION EQUATION.

(3) RATIO BASED ON SERVICE LEVEL D ALLOWABLES. STRESSES, CALCULATED USING LINEAR ELASTIC ANALYSIS, MEET THE REQUIREMENTS OF SERVICE LEVEL E.

(4) NORMAL OPERATING LOAD COMBINATION 2 GOVERNS FOR THIS COMPONENT. ALLOWABLE STRESSES ARE BASED ON SERVICE LEVEL B.

4-2.5.1 Closure

The values of the loads used to evaluate the internal structures are conservative estimates of the loads postulated to occur during an actual LOCA or SRV discharge event. The event combinations for which the internal structures are evaluated envelop the actual events expected to occur during a LOCA or SRV discharge event.

The acceptance limits to which the evaluation results are compared are more restrictive than those required by NUREG-0661. Use of these acceptance limits ensures that the internal structure components will not fail and cause damage to safety-related components in the suppression chamber.

As is evident from the analysis results presented, stresses in the internal structure components are within conservative acceptance limits. The intent of the NUREG-0661 criteria as it relates to the design adequacy of the Duane Arnold Energy Center internal structures is therefore considered to be met.

4-3.0 LIST OF REFERENCES

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2. "Mark I Containment Program Load Definition Report," General Electric Company, NEDO-21888, Revision 2, November 1981, including Errata and Addenda No. 1, April 1982.

3. "Mark I Containment Program Structural Acceptance Criteria Plant Unique Analysis Application Guide," Task Number 3.1.3, General Electric Company, NEDO-24583-1, October 1979.

4. ASME Boiler and Pressure Vessel Code, Section III, Division 1, 1977 Edition with Addenda up to and including Winter 1978.

5. "Damping Values for Seismic Design of Nuclear Power Plants," U.S. Atomic Energy Commission, Regulatory Guide 1.61, October 1973.