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Attachment:
No. 1, 15 pages

Report of Preliminary Investigation

FAILURE OF HANGER BOLTS ON SUPPRESSION CHAMBER SUCTION HEADER at Quad Cities Nuclear Station, Unit -2

Commonwealth Edison Company
Iowa-Illinois Gas and Electric Company
Rock Island, Illinois

Report No. DC-98

(Draft) June 19, 1972
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Prepared for: U. S. Atomic Energy Comm.
Directorate of Regulatory Operations
AEC Contract AT(11-1)-1658
Task "A"
PAR: 71-72 A

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NOTICE

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I Introduction:

At the request of AEC Regulatory Operations, Technical Assistance Br., the writer assisted Mr. L. L. Beratan, Senior Structural Engineer, RO-Hq. and Mr. E. Jordan, Reactor Inspector, RO-III, on June 6 and 7, 1972, in a review of the failed suction header hanger bolts on the Quad Cities suppression chamber.

The review consisted of a physical inspection and fact finding discussion with operating, construction, and design personnel at the Quad Cities plant; and a follow-up session with AEC personnel at Region -III in Glen Ellyn.

PARAMETER's investigation to date, which must be considered preliminary pending the availability of analysis and test data to be assembled by the licensee, includes a check on the flooded weight of the ring header and an estimate of the unit load under which the originally installed support bolts might have been expected to fail. Also included is an assessment of the proposed redesign for static loads.

Failure of four adjacent header support hangers by double shear of the clevis bolts was noted during tests of plant systems. Quad Cities, Unit -2, is a 809 MW(e)BWR being supplied by General Electric to Commonwealth Edison on a turnkey basis. Sargent and Lundy was the Architect-Engineer and United Engineers and Constructors, the general contractor for the plant. The plant is in its start-up phase.

The attendees at the inspection and meetings of June 6 and 7 at Quad Cities were:
(titles may be approximate or unknown)

Commonwealth Edison Company (CECO)

H. Hoyt, Operations
F. Palmer, Plant Superintendent
R. W. Thompson
B. Stephenson, Assistant Plant Superintendent

I Introduction: continued

General Electric Comapny (GE)

R. Leasburg, Project Manager
L. Hartley, Site Manager

Sargent & Lundy (S&L)

E. R. Weaver, Structural Engineer

Chicago Bridge & Iron (CB&I)

T. J. Ahl, Design Engineer/Analyst

AEC Regulatory Operations *

E. Jordan, Reactor Inspector, RO-III
L. L. Beratan, Senior Structural Engineer, RO-Hq.
R. A. Lofy, Consulting Engineer, PARAMETER, Inc.

* During the afternoon briefing session on June 7, the inspection team also met with the following RO-III personnel at Glen Ellyn:

B. H. Grier, Director, RO-III
G. Fiorelli, Senior Reactor Inspector, Operations
D. Hunnicutt, Senior Reactor Inspector, Start-up

Note: Detailed notes and calculations assembled in connection with preparation of this report are maintained on file for the AEC by PARAMETER, Inc. under Assignment No. DC-98.

II Summary of Findings:

1. The design of the bolted pipe hanger connection meets the stated gravity plus vertical seismic load requirement with a minimum margin based on its AISC rating.

Stated (CBI) design weight load:	8000 lbs.	
Weight plus .08g seismic load:	8640 lbs.	
AISC Rating of Bolt:	8840 lbs.	(Ref.-4)
(A-307, 3/4" Dia.)		(Sect.4-4)

The use of fully threaded bolts added no conservatism to the design.

2. Calculations by PARAMETER, Inc. (Attachment -1) verified the suction header flooded weight which resulted in the stated 8000 lb. load per hanger used in the design. The load of the 360°, 24" Dia. header and contained water was assumed to be uniformly supported by each of the four (4) nozzles connected to the torus plus twelve (12) hangers. The 8000 lb. load per support point (16 points) does not reflect any forces due to built-in distortion (preload) of the header or imposition of loads from piping connected to the header. The assumption of proportionate sharing of the total weight load between hangers and nozzles and the non-symmetry of the supports show the basic design (gravity) load alone to be non-conservative. (See Attachment -1)

3. Calculations by PARAMETER, Inc. (Attachment -1), based on root area double shear as was actually experienced, indicate that the hanger connection should have had an ultimate load carrying capability of approximately 24,000 lbs. (Attachment -1, p. 10). This value is based on a shear stress of 2/3 the minimum ultimate tensile strength of the material. The failure load of the material could have been lowered somewhat by the tapered (punched) holes in the structural members and poor fit-up.

   In the absence of material defects, the wide disparity between predicted failure load for an individual hanger, and the dead weight design load is great enough to point to the possibility of other imposed loads contributing to the failures. They could be one or a combination of the following:

II Summary of Findings: continued

a. Dynamic loads due to valve opening/ closing or pump starting/stopping on systems connected to the header.

b. Dynamic loads due to observed movement of the torus wall during steam relief valve blowdown into the suppression chamber.

c. Uneven loading of hangers due to initial installation and/or residual distortion of the header. These loads, particularly if the nozzles do not carry their share of the gravity load, could preload some hangers well beyond their nominal "balanced" design load.

d. Gravity loads from connected pipe not accounted for in the weight balance or not compensated for by hangers in the attached systems.

4. Measurements of actual static loads carried by individual hangers will establish conclusively whether the conditions described in 3c and 3d above exist. (The individual hanger loads could conveniently be checked when temporary bolts are replaced.) The total load carried by the twelve (12) hangers can also be used to verify the proportion of load shared by the nozzles.

5. A test program is being formulated by GE to measure movement of the torus and header during operation of the steam relief and safety injection systems and to monitor vibration. The results of these tests, in conjunction with the static load measurements described in Item -4 above should be useful in determining if there are strong dynamic loads on the header which could have been a major contributor to the failures.

II <u>Summary of Findings</u>: continued

6. A possible explanation of the timing of the failures, occurring during systems tests, in the presence of a grossly overloaded condition, is the breaking loose of the bolting friction, and loss of part of the load carrying capability of the hanger bolts from the vibrations reported to be associated with the tests.

7. The revised design will utilize a 1" Dia. A-325 steel bolt with the threads excluded from the shear plane. The AISC rating for this bolt in a tight structural connection is 34,000 lbs. A pair of revised hanger bars (3" x 1/2"), evaluated as an AISC clevis will have a safe working load of 15000 lbs. (Attachment -1, p. 13). Thus, the hanger bars become the weaker link in the revised design. Whether they are adequate will depend upon the individual hanger loads determined to exist from the possible dynamic or static effects described in Item -3 above.

8. In Reference -2, CB&I reports the approximate membrane stresses calculated in the header and torus wall in the failed ondition. Significant stresses are reported in the torus insert plate at the nozzle neck (25,200 psi.) and in the torus shell adjacent to the insert plate (26,700 psi.), both in a circumferential direction with respect to the torus. The reported calculated stresses result from the static load of the header between two nozzles with the intermediate three hangers missing. The theoretical deflection of the header associated with the reported stresses is 4". (The deflection of the header in its at-rest position after the bolt failure as measured was 5-3/4")

The stresses reported by CB&I may not be as high

II Summary of Findings: continued

as actually realized for a number of reasons:

a. The dynamic effect of the header dropping and coming to rest in its displaced position was apparently not considered.

b. The fourth failed hanger on the opposite side of the nozzle bounding the quadrant of three failed hangers was presumably not in the analytical model.

c. Dynamic and/or static loads imposed on the system which are still unknown were obviously not considered.

Because a 5-3/4" deflection was observed at the header mid-point after the hanger bolts failed, the 4" theoretical deflection and associated stresses would not appear to reflect an entirely conservative analysis. Other factors accounting for the difference between calculated and measured values of deflection, either positively or negatively, might include:

a. An initial upward deflection of this section of the header (preload) might have existed when installed.

b. Some restraint or additional load could have been received from connecting piping.

c. The fact that torsional deflection of the nozzles was not considered in the analysis (and thus did not contribute to the total calculated deflection).

d. The header could have taken some permanent set as a result of the stresses occurring at time of failure. Calculation of such stresses would require a dynamic analysis.

II Summary of Findings: continued

- Combined with negligible radial pressure stress, the circumferential membrane stress of 26,700 psi. reported by CB&I in Reference -2 results in a stress intensity of 26,700 psi. which exceeds slightly the 1.5S design limit (Ref. -6) of 26,250 psi. for local membrane stress intensity.

- Because bending stresses are not reported by CB&I for nozzle areas, evaluation of their results cannot be made at the present time.

9. CB&I reported (Ref. -2) as a result of their visual inspection, that there was no apparent yielding of the suppression chamber (torus) shell. In the writer's inspection, made after the header was returned to its original position, no permanent deformation was observed. Lack of any gross yielding, appropriate nondestructive testing, and evaluation of stresses as reported in Item -8 above would, in the author's opinion, support the position that the components are suitable for their normal service life.

10. During the discussion with Quad Cities operating personnel, the bolt failure was described by Mr. Palmer as having the appearance of the wearing through or experiencing a "hacksaw" effect due to motion. It is the author's opinion that "hacksawing", wear or fatigue were not significant factors in causing the failure. The total double shear of the bolt into three pieces indicates a gross overload with a follow-up capability.

III Discussion of Inspection:

The design of the 24" Dia. Header which supplies water to various safety injection and cooling systems from the suppression chamber torus section and its method of support was described by CB&I drawings, (Ref. -1, a. b. c.). The header is a continuous 360° mitered pipe assembly supported by twelve pipe hangers and four nozzles connecting to the torus at approximately equal spacing. Failure of three (3) vertical hangers in one quadrant between nozzles and one (1) adjacent hanger on the opposite side of the nozzle occurred by complete double shear and parting of the bolts at the clevis type connection. Remaining bolts which did not fail, showed varying degrees of thread deformation and offset. (See sketches of Attachment No. 1, p. 6).

The design of the ring header, as part of the suppression chamber system was completed by CB&I to S&L specifications. Mr. Ahl of CB&I stated that the nominal dead load for design of the hangars was 8000 lbs. to which static seismic factors of 0.08g vertical and 0.3g horizontal were applied. Dynamic effects of seismic activity or operating loads were not specified as such or considered by CB&I in their design. Thermal considerations are not a factor in hanging the header as it contains water at the same temperature as the torus.

It was determined in discussion that a dynamic analysis of the torus and header was performed by Blume and Associates for GE. It was not established whether the results of that analysis were directly inputed to the specifications to which CB&I was working. It was indicated that seismic snubbers were not required on this system on the basis of Blume's dynamic analysis. (The Dresden plant has snubbers which were specified on the basis of static analyses.)

The CB&I design was reported to be based on applied forces, moments, shear loads, and static seismic factors specified by S&L and CB&I's own determination of gravity loads. The methods of Welding Research Council Bulletin No. 107 (Bijlaard methods) were used to evaluate stresses

III Discussion of Inspection: continued

in the torus at both hanger and nozzle attachment points.

A metallurgical test of the failed bolts has been obtained (Ref. -3). It confirmed that they were A307 material (3/4"-IONC) as specified (Ref. -1a.).

The CB&I representative referenced the AISC Manual (Ref. -4) (Section -4 -4) in indicating that the allowable load for 3/4" Dia. A307 bolts in double shear is 8840 lbs. (This load rating would just about equal the stated static load per hanger including the vertical seismic factor).

Author's Note: The AISC rating for a bolted structural connection is based on a nominal (3/4") diameter. For A307 bolts, the Manual does not differentiate in its rating between the load carrying capability for shear through the body diameter versus shear through the threads. For the condition, threads in the shear plane, as was experienced at Quad Cities, there would be considerably less conservatism in the application than for the case of full shank diameter.

In spite of the use of low strength (A307) fully threaded bolts, considering the factor of safety implicit in the rating of bolted connections by AISC, one would expect the bolt in question to be able to sustain loads greater than the 8000 lb. design static load by a factor of 2 to 3.

When questioned as to his theory of failure, Mr. Ahl speculated that failure occurred due to poor initial fit-up and uneven loading of the hanger links. After failure of one bolt, the load transference to adjacent

III Discussion of Inspection: continued

hangers would promote their failure in sequence.

The proposed bolt fix was discussed. A325 bolts, 1" Dia. have been installed with holes in the hanger bars and clip assembly drilled and reamed to size. New bars (3" x 1/2") replace original bars (2-1/2" x 1/2"). Although no damage to horizontal restraints was noted, the 3/4" bolts will also be replaced with the 1" size. The 1" bolts presently in place, have some of the threads in the shear plane. These will be further substituted with A325 bolts to provide for full shank diameter in both shear planes. A rating of approximately 23,000 lbs. was said to be achieved with the present installation (1" partially threaded bolts). (This would assume that the hanger bars do not become limiting as clevis connections.)

Questions regarding field installation of the header assembly established that the pads supporting the header were field welded to the torus. It was indicated that the pad location was not necessarily matched to the header, but rather the fit-up of the header made by adjusting the hole distance in the links. This was evident in subsequent physical inspection of the link bars for the failed bolt connections which showed a variation in hole distance and overall length of about 3 inches.

Inspection of the 1/2" thick hanger bars revealed that most holes had been punched (versus being drilled), thus having a tapered inside diameter and were somewhat over the 13/16" specified diameter. The tapered hole would not present as uniform a bearing surface to the bolt as a constant diameter and could account for some degradation of the load carry capability of the bolts in shear. Some of the holes in the hanger bars were just rough burned, which could similarly lower the bolt strength. Two of the pairs of bars of the four on which bolts failed had such torch cut holes.

III Discussion of Inspection: continued

CB&I has performed an analysis of stresses which were imposed on the header and its points of attachment to the torus as a result of the hanger bolt failures. These were reported in Ref. -2. A three dimensional finite element analysis was used to obtain moments and forces in the header and at the nozzles connecting to the torus. The Bijlaard method was used to calculate nozzle and shell stresses. Stresses quoted are for the calculated deflection based on gravity loading. It was noted by the team, that the calculated deflection of 4" of the header under gravity load did not agree with the measured deflection of 5-3/4" before the header was replaced in its original position. The final analysis report is to address itself more specifically to the stress levels or other factors that might have been associated with the measured deflection.

Further analysis of the header is also to consider the effects of dynamic loads due to operation of plant systems which are to be identified and quantified in instrumented tests planned by GE. The analysis will also specify the seismic basis for the design. Stresses in the torus wall and pad connections will also be reported in the analysis to make a complete disposition of the effects of the hanger failure and substantiate the design for normal plant operation. It was decided by the team not to request CB&I's preliminary analysis report for review at this time as it did not include the above considerations.

A visual inspection of the torus by the writer revealed no observable deformation in the torus wall at the areas of reported local high stress.

IV <u>References</u>:

1. Reduced size prints of Chicago Bridge and Iron Company drawings (Ref. Contract No. 9-6771):
   a. No. 213, Rev. 1, Support Assembly for 24" Dia. Header.
   b. No. 216, Rev. 6, Shop Details, 24" Dia. Header for Suppression Chamber.
   c. No. 217, Rev. 5, Field Details for 24" Dia. Header for Suppression Chamber.

2. Telex No. 2531B6, T. J. Ahl, CB&I to E. Weaver, Sargent & Lundy, dated June 2, 1972 (Report of Stresses).

3. Test Results, Ring Header Support Bolts - Letter June 2, 1972, G. C. Kuhlman, Sargent & Lundy, to R. Leasburg, General Electric, with enclosures.

4. Manual of Steel Construction, Seventh Edition, American Institute of Steel Construction, Inc., 101 Park Avenue, New York.

5. The American Society of Mechanical Engineers, <u>Materials Specifications, Part A - Ferrous</u>, ASME Boiler and Pressure Vessel Code, Section II, 1971 Edition.

6. The American Society of Mechanical Engineers, <u>Rules for Construction of Nuclear Power Plant Components</u>, ASME Boiler and Pressure Vessel Code, Section III, 1971 Edition.

V Attachments:

ATTACHMENT NO. 1
TO REPORT DC-93

JUNE 19, 1972

ANALYSIS OF SUPPORT BARS AND BOLTS OF 24" SUCTION HEADER FOR SUPPRESSION CHAMBER

QUAD CITIES NUCLEAR STATION - UNIT 2

PREPARED FOR : U. S. ATOMIC ENERGY COMM., DIRECTORATE OF REGULATORY OPERATIONS
AEC CONTRACT AT(11-1) -1658 TASK "A"
PA.I: 71-71 A

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REV.	DATE	BY
0	6-19-72	W. FOLEY
1	6-22-72	W. FOLEY

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INTRODUCTION

THE PURPOSE OF THIS ATTACHMENT IS FOURFOLD, AS FOLLOWS:

1. TO CALCULATE STATIC LOADS APPLIED TO FOUR (4) SUPPRESSION CHAMBER NOZZLES AND TWELVE (12) HANGERS BY FLOODED WEIGHT OF 24" Φ HEADER

2. TO EVALUATE STRESSES OF ORIGINAL HANGER BARS AND BOLTS CAUSED BY STATIC FLOODED WEIGHT OF HEADER

3. TO EVALUATE STRESSES OF REVISED HANGER BARS AND BOLTS CAUSED BY STATIC FLOODED WEIGHT OF HEADER

4. TO EVALUATE EFFECT OF UNEVEN SPACING OF SUPPORTS.

THE SCOPE OF THIS ATTACHMENT IS DESCRIBED BY THE TABLE OF CONTENTS ON PAGE 2 AS WELL AS BY THE ABOVE STATEMENT OF PURPOSE.

REFERENCES LISTED IN REPORT NO. DC-98 ARE USED AND ARE DENOTED BY BRACKETED NUMBERS, THAT IS, "[1a]" (SAY).

BECAUSE FITUP DIFFICULTIES APPEAR TO MAKE SHARING OF TOTAL HEADER WEIGHT BY THE FOUR NOZZLES UNCERTAIN, THE EFFECT ON HANGER LOADS OF REMOVING THE NOZZLES IS EVALUATED.

CONCLUSIONS

1. THE FLOODED HEADER WEIGHT OF ABOUT 8000 POUNDS AVERAGE PER SUPPORT REPORTED BY CB&I IS VERIFIED BY THE WEIGHT ESTIMATE ON PAGES 8 AND 9.

2. THE SHEAR STRESS OF 9067 PSI CALCULATED ON PAGE 10 FOR THE ORIGINAL BOLT UNDER GRAVITY LOADING IS VERY CLOSE TO THE AISC [4] ALLOWABLE OF 10000 PSI.

3. ON THE BASIS OF MINIMUM SPECIFIED MATERIAL STRENGTH, THE LOAD REQUIRED TO FAIL THE ORIGINAL BOLT IN DOUBLE SHEAR IS 24160 POUNDS. AS SHOWN ON PAGE 10, THE RATIO OF FAILURE LOAD TO GRAVITY LOAD IS 3.01. IT SEEMS CERTAIN THAT THE FAILED BOLTS MUST HAVE BEEN SUBJECTED TO A LOAD GREATLY IN EXCESS OF THE FLOODED HEADER WEIGHT OF 8000 POUNDS AVERAGE PER SUPPORT

4. AS SHOWN BY THE CALCULATION ON PAGE 11, THE 5102 PSI SHEAR STRESS OF THE REVISED BOLT FOR GRAVITY LOADING IS WELL WITHIN THE AISC [4] ALLOWABLE OF 22000 PSI WITH THREADING EXCLUDED FROM SHEAR PLANES, AS PLANNED.

5. AS CALCULATED ON PAGE 12, THE 4007 PSI TENSILE STRESS CAUSED BY GRAVITY LOADING OF THE REVISED BAR AT THE NET SECTION IS WELL WITHIN THE AISC [4] ALLOWABLE OF 16200 PSI.

CONCLUSIONS, CONT'D

6. AS CALCULATED ON PAGE 12, THE 16030 PSI BEARING STRESS OF THE REVISED PLATE IS ABOUT ONE-HALF OF THE AISC [4] ALLOWABLE OF 32400 PSI.

7. COMPARISON ON PAGE 13 WITH A STANDARD CLEVIS SHOWS THAT THE SAFE WORKING LOAD OF A PAIR OF REVISED BARS IS 15000 POUNDS, WHICH IS NOT QUITE TWICE AS GREAT AS THE GRAVITY LOADING OF 8000 POUNDS AVERAGE PER SUPPORT.

   STANDARD CLEVISES ARE DESIGNED WITH A 5:1 FACTOR OF SAFETY BASED ON ULTIMATE TENSILE STRENGTH.

   THE PURPOSE OF THE CALCULATION ON PAGE 13 IS TO TAKE INTO ACCOUNT BENDING AND SHEAR STRESSES OF THE CROWN OF THE REVISED BAR.

8. REVIEW OF CONCLUSIONS 4, 6 AND 7 INDICATES THAT LOAD CAPACITY OF THE REVISED DESIGN IS LIMITED BY BARS AND PLATES, NOT BY BOLTS.

9. REFERRING TO PAGES 9 & 15, LET US ESTIMATE SUPPORT REACTIONS CAUSED BY UNLOADING NOZZLES.

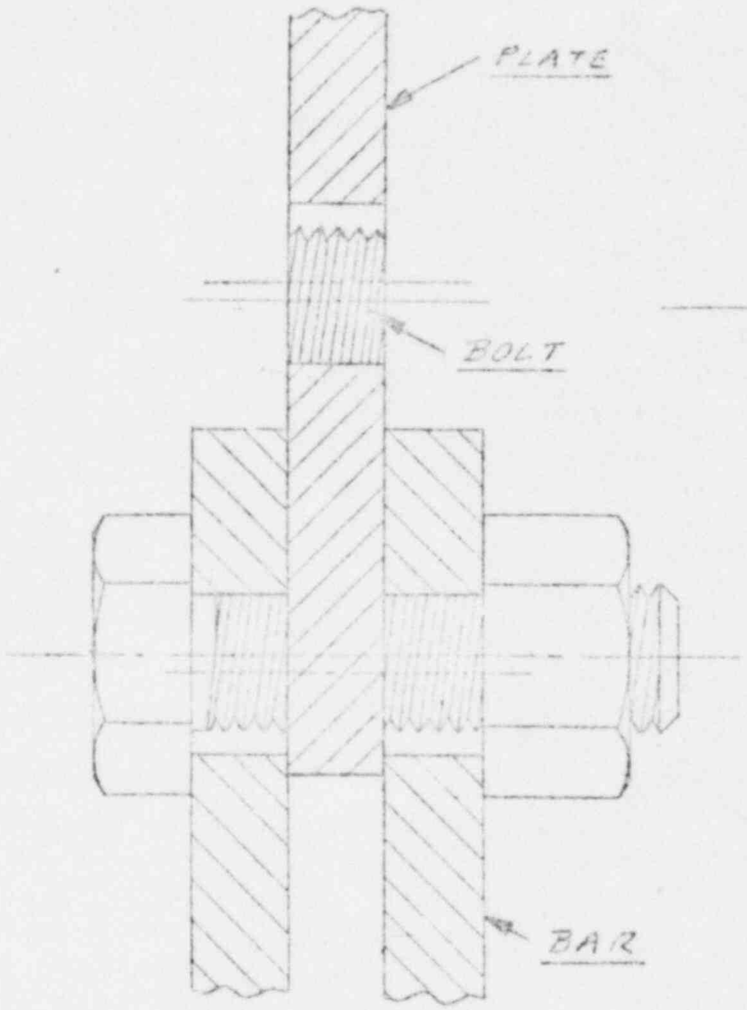
$$(V_G)_{CASE\ 6} = 1.519\ V_G = \underline{12175\ LB}$$

$$(V_D)_{CASE\ 6} = 1.519\ V_D = \underline{13148\ LB}$$

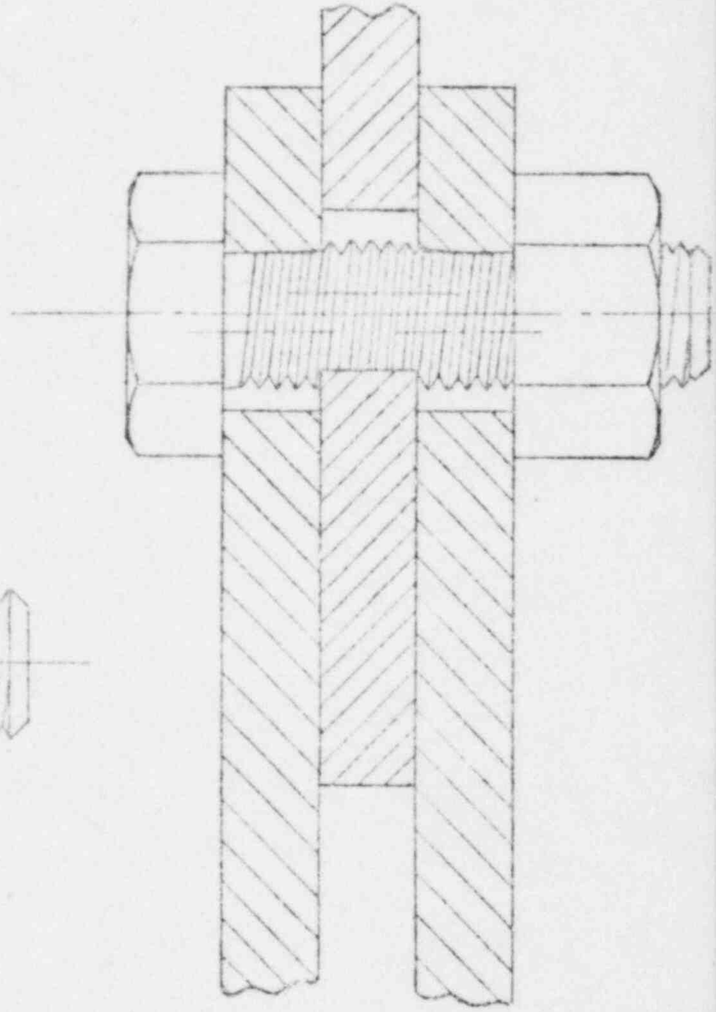
P. 11

8840 (ORIGINAL) & 34558 (REVISED) $\frac{LB}{BOLT}$ ARE ALLOWED.

SKETCHES OF FAILED SUPPORT BOLTS



COMPLETE FAILURE



PARTIAL FAILURE

ALTHOUGH NOT SHOWN, SOME BENDING OF THE BOLTS DID OCCUR.

NOTE THAT THREADS ARE CRUSHED AT BEARING SURFACES.

SCALE: FULL SIZE

Header Supports
Materials and Allowable Stresses

Bolts Per AISC Manual, Section 1.5.2.1 Page 5-20 [4]

Bolt Material		A307	A325	
Tension	F_t	1. 20 ksi	2. 40 ksi	
Shear	F_v	10 ksi	3. 15 ksi 4. 22 ksi	
Ultimate in Tension (min)	F_u	60 ksi	120 ksi	[5]

1. On tensile stress area
2. On nominal bolt area
3. With shear planes in threaded section
4. With threaded section excluded from shear planes.

Han[illegible] Ro[illegible] [illegible]): SA 36 Steel

F_y = 36 ksi

$F_t = 0.6 F_y = 21.6$ ksi

$F_t = 0.45 F_y = 16.2$ ksi [illegible] see [illegible] [4]

F_u = 58 ksi min. to 80 ksi max.

[illegible]

W_p = PIPE WEIGHT = $\pi L t (D-t)(.283)$ [illegible] DIMENSIONS IN INCHES.

[illegible] 24" O.D. × [illegible] WALL PIPE ; FOR 24 O.D. × 3/4 WALL PIPE

W_p = 7.9[illegible] L W_p = 18.5[illegible]2 L

W_w = WATER WEIGHT = $\frac{\pi}{4} L (D-2t)^2 (.036)$

W_w = 15.[illegible] L W_w = 14.3[illegible] L

[illegible]	[illegible]	O.D. D	THICK. t	LENGTH L	PIPE WT. W_p	WATER WT. W_w
[illegible] A	[illegible]	24	[illegible]	12 [illegible] + 7.8 [illegible]		
[illegible]	[illegible]			+ 7.6 = 25.56	2217.7	4303.4
	[illegible]		3/4	[illegible] = 30	559.1	515.3
	[illegible]	18	[illegible]	K: 4 [illegible] = 54.[illegible]	319.5	457.5
[illegible]					3095.3	5276.2
[illegible] B	[illegible]	24	[illegible]	13 [illegible] + 7.6 [illegible]		
[illegible]	[illegible]			= 29.56	2343.8	4547.9
[illegible]	[illegible]	2[illegible]	3/4	3 [illegible] 45.0	620.1	572.6
	[illegible]	20	[illegible]	[illegible] 17.0	111.2	178.1
[illegible]					3[illegible]5.1	5298.6
[illegible]					12300.4	2[illegible] 4
[illegible] C	[illegible]		[illegible]	[illegible]		
[illegible]	[illegible]			= 29.56	2343.8	4547.9
[illegible] TOTAL (4)					4375.2	18191.6
[illegible] D	[illegible]		[illegible]	[illegible]		
([illegible])	[illegible]			= 29.56	23[illegible].3	4553.6
TOTAL (3)					75[illegible]	14560.8
[illegible] E	[illegible]		[illegible]	[illegible] + 6.6		
[illegible]	[illegible]			= 2[illegible]	[illegible]	36[illegible].0
	[illegible]		[illegible]	[illegible] = 80.7[illegible]	1258.3	1156.3
	[illegible]		[illegible]	[illegible]	[illegible]	97.0
					35[illegible]	5612.3
[illegible]					7[illegible]	1139[illegible].6

HEADER WEIGHT (CONT)

HEADER SECTION	ITEM	O.D. D	THK. t	LENGTH L	PIPE WT. W_p	WATER WT. W_w
216-F (1 reqd.)	PIPE 4, 14, 15	24	3/8	281.56 (SEE 216-A)	2217.7	4303.4
	PIPE E	24	3/4	36	558.1	515.3
	NOZ 16	8 5/8	.277	K-4-2 5/8 = 52.625	104.1	93.2
TOTAL (1)					2879.9	4911.9
216-G (1 reqd.)	PIPES 4, 15	24	3/8	13'-2 25/32 + 2'-6 = 188.78	1486.9	2885.3
	PIPE 12	24	3/4	10'-8 25/32 = 128.78	1996.5	1843.3
	NOZ 18	24	3/8	60	472.6	917.0
	NOZ 21	18	3/8	K-4'-6 3/8 = 54.38	319.5	457.5
TOTAL (1)					4275.5	6103.1
HEADER TOTALS					46610.0	81622.6
FLOODED HEADER TOTAL					128,232.6	

LET US CHECK WHETHER THE TOTAL WEIGHT OF 128,232 LB CALCULATED ABOVE AGREES WITH THE AVERAGE LOAD OF 8000 LB/SUPPORT STATED BY CB&I

AVERAGE VERTICAL LOAD PER SUPPORT, GRAVITY ONLY

12 HANGER PINS TO SUPPORT
4 NOZZLE " " " } 16 SUPPORTS, APPROX. EQUALLY SPACED.

LOAD/SUPPORT = $V_G = \frac{128232.6}{16} = $ 8015 LB., FLOODED (CHECKS WITH CB&I)

DESIGN LOAD/SUPPORT, INCLUDING 0.08 G SEISMIC FACTOR

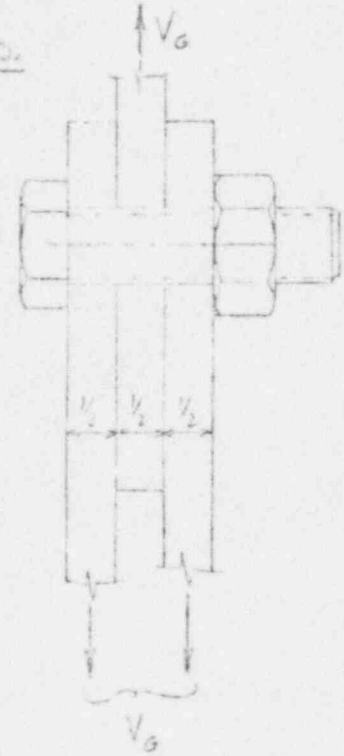
$V_D = 1.08\ V_G = $ 8656 LB.

REFERRING TO PAGE 15, LET US MODIFY THE ABOVE AVERAGE LOADS TO ACCOUNT FOR UNEVEN SPACING.

$(V_G)_{MAX} = 1.019\ V_G = $ 8167 LB/SUPPORT

$(V_D)_{MAX} = 1.019\ V_D = $ 8820 LB/SUPPORT

SHEAR STRESS OF ORIGINAL BOLT
IN 3/4-10 BOLT, FULL LENGTH THREAD.
FOR GRAVITY LOADING



SHANK AREA = 0.442 IN.^{2}

$A_V = 2(.442) = 0.884$ IN.^{2} (DOUBLE SHEAR).

$\tau_G = \frac{V_G}{A_V} = \frac{8015}{0.884}$ ← AVERAGE, PAGE 9

$= 9067$ PSI $< F_V = 10,000$ PSI FOR A-307 BOLTS.

NOTE THAT ALLOWABLE STRESS OF 10,000 PSI IS BASED ON UNTHREADED BODY AREA, PER ¶ 1.5.21, PAGE 5-20 [4].

LOAD REQUIRED TO CAUSE FAILURE OF ORIGINAL BOLT
IN DOUBLE SHEAR

$(F_U)_{SHEAR} = \frac{2}{3}(F_U)_{TENSION} = \frac{2}{3}(60,000) = 40,000$ PSI.

$V_{FAILURE} = A_V (F_U)_{SHEAR} = 0.604(40,000)$

$= 24,160$ LB.

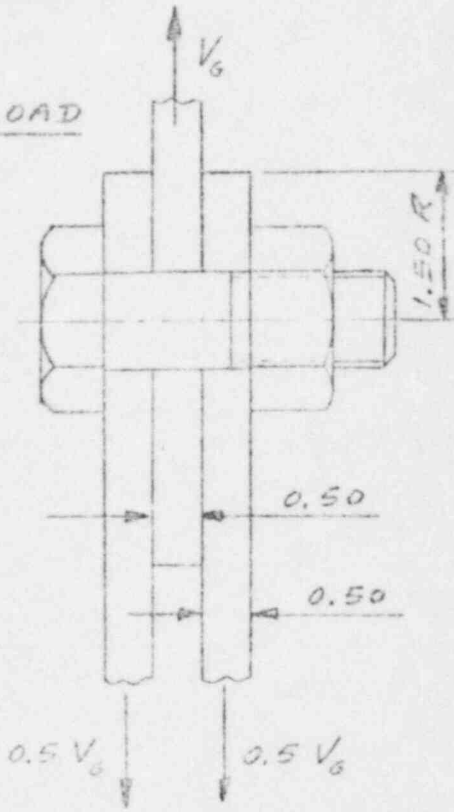
WHERE A_V = 2 × ROOT AREA
= 2 × 0.302
= 0.604 IN.^{2}

COMPARISON OF GRAVITY AND FAILURE LOADS
ON BASIS OF DOUBLE SHEAR OF ORIGINAL BOLTS

$\frac{V_{FAILURE}}{V_{GRAVITY}} = \frac{24160}{8015}$

$= 3.01$

SHEAR STRESS IN SHANK (FULL D.A.)
OF REVISED BOLT FOR GRAVITY LOAD



1"-8 BOLT OF A-325 STEEL
IN REAMED HOLE

THREADS ARE EXCLUDED
FROM SHEAR PLANES.

REVISED BARS ARE $3" \times \frac{1}{2}"$

SHANK AREA = 0.7854 IN.^{2}

$$\tau_G = \frac{V_G}{A_V} = \frac{8015}{2 \times 0.7854}$$

$= \underline{5102 \text{ PSI}}$

$< F_V$ = 22000 PSI WHEN THREADING IS <u>EXCLUDED</u> FROM SHEAR PLANES

$< F_V$ = 15000 PSI WHEN THREADING IS <u>NOT EXCLUDED</u> FROM SHEAR PLANES

PAGE 5-20 [4]

CALCULATING ALLOWABLE LOADS FOR THE TWO FOREGOING CONDITIONS,

$P = F_V A = 1.5708\ F_V$

= <u>34558 LB</u>, THREADING <u>EXCLUDED</u>
= <u>23562 LB</u>, THREADING <u>NOT EXCLUDED</u>

IN ACCORDANCE WITH TABLE 3, PAGE 5-195 [4], MINIMUM BOLT PRELOAD SHOULD BE 51000 LB.

TENSION AT NET SECTION OF REVISED BAR FOR GRAVITY LOADING

$$A = 0.50\,(3.00 - 1.00) = 1.000 \text{ IN.}^2\text{, PER BAR}$$

$$f_t = \frac{0.5 V_G}{A} = \frac{0.5 \times 8015}{1.000}$$

$$= \underline{4007 \text{ PSI}} < F_t = 0.45 F_y$$

$$= 16200 \text{ PSI}$$

TENSION AT GROSS SECTION OF REVISED BAR FOR GRAVITY LOADING

$$A = 0.50 \times 3.00 = 1.500 \text{ IN.}^2$$

$$f_t = \frac{0.5 V_G}{A} = \frac{0.5 \times 8015}{1.500}$$

$$= \underline{2672 \text{ PSI}} < F_t = 0.60 F_y$$

$$= 21600 \text{ PSI}$$

BEARING STRESS OF REVISED PLATE FOR GRAVITY LOADING

$$F_p = 0.90 F_y = 0.90 \times 36000$$

$$= 32400 \text{ PSI}$$ PAGE 5-19, ¶ 1.5.1.5.1 [4]

$$f_p = \frac{V_G}{A} = \frac{8015}{0.50 \times 1.00}$$

$$= \underline{16030} \text{ PSI} < F_p = 32400$$

COMPARISON OF REVISED BAR AND STANDARD CLEVIS

PAGE 4-126 [9]

NOTE THAT A 1" Ø PIN CAN BE USED WITH THE FOLLOWING STANDARD CLEVISES:

CLEVIS NO.	SAFE WORKING LOAD, POUNDS	NET AREA AT PIN HOLE, IN.^{2}
$2\frac{1}{2}$	7500	0.9375
3	15000	2.00
$3\frac{1}{2}$	18000	2.50

COMPARING TENSILE STRESSES CAUSED BY SAFE WORKING LOAD,

CLEVIS NO.	TENSILE STRESS IN NET AREA, PSI	TENSILE STRESS IN GROSS AREA
$2\frac{1}{2}$	8000	9600
3	7500	10000
$3\frac{1}{2}$	7200	10286

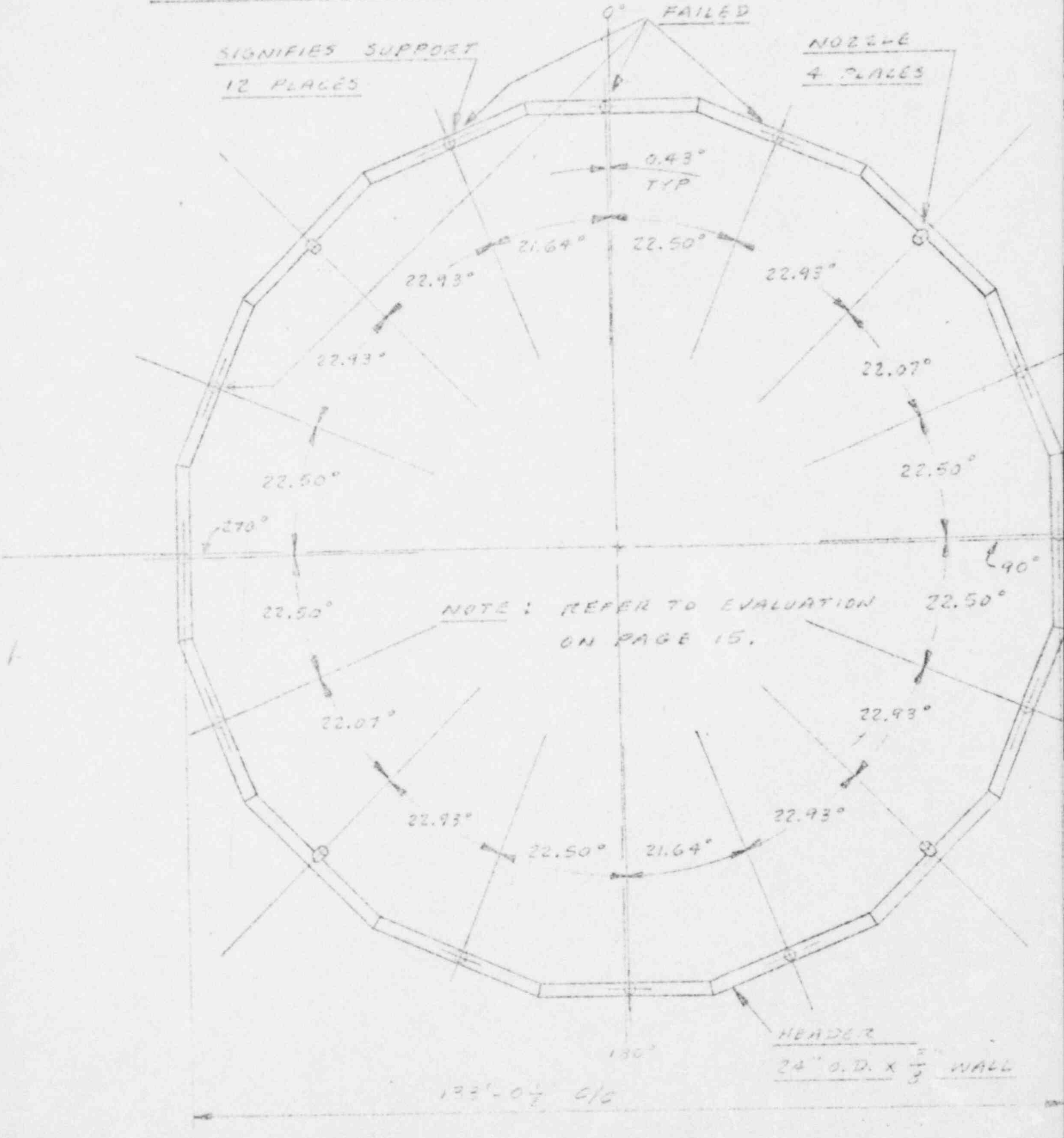
EVALUATING PAIR OF REVISED BARS ON BASIS OF CLEVIS NO. 3,

SAFE WORKING LOAD = 7500 × 1.000 × 2
= 15000 LB

THIS LOAD IS BASED ON THE SAFE WORKING STRESS OF 7500 PSI ON THE NET SECTION AT THE PIN HOLE OF A NO. 3 CLEVIS WITH A 1" DIA. PIN.

BY DATE SUBJECT SHEET NO 14 OF
CHKD BY DATE ATTACHMENT . 1 JOB NO
PARAMETER 71-12A TO REPORT DL-42

SKETCH OF SUPPORT SPACING [1b,1c]

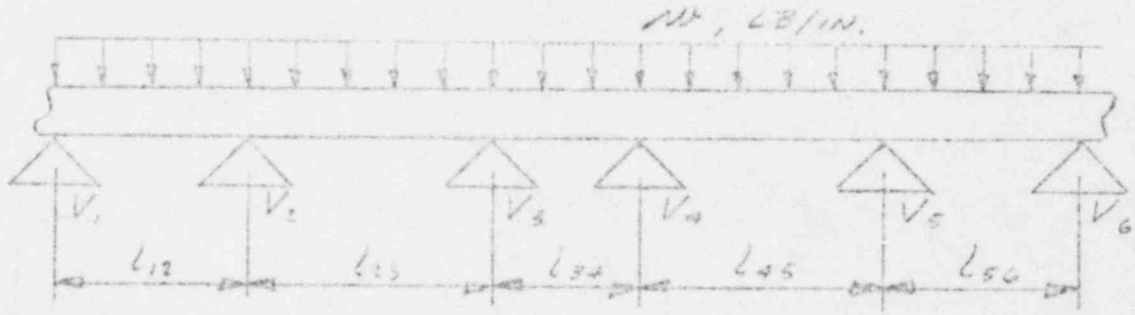


SCALE: 0.05" = 1'-0"

EVALUATION OF UNEVEN SPACING OF SUPPORTS

ANGULAR SPACING OF HANGER AND NOZZLE SUPPORTS IS SHOWN BY THE SKETCH OF SUPPORT SPACING ON PAGE 14.

LET US MAKE AN APPROXIMATE CALCULATION OF THE EFFECT OF UNEVEN SPACING ON SUPPORT LOADS, MODELING THE HEADER AS SIXTEEN (16) UNIFORMLY LOADED SIMPLE BEAMS WITH STRAIGHT SPANS EQUAL TO THE NOMINAL ARCS.



$$V_{i,i+1} = 0.5\,w\,(l_{i-1,i} + l_{i,i+1})$$

CASE	ANGULAR SPACING DEG		ARC SPACING IN.		REACTION %
1	$\alpha_{i-1,i}$	$\alpha_{i,i+1}$	$l_{i-1,i}$	$l_{i,i+1}$	V_i
2	21.64	22.50	95.97	99.78	98.1
3	22.07	22.50	97.87	99.78	99.0
4	22.50	22.50	99.78	99.78	100.0
5	22.93	22.93	101.69	101.69	101.9
6	45.86	22.50	203.38	99.78	151.9

NOTE: 1) CASE 4 IS RATED "PAR" OF 100% BECAUSE IT REPRESENTS "IDEAL" UNIFORM SPACING.

2) FOR CASE 6, NOZZLES ARE UNLOADED.