WISCONSIN PUBLIC SERVICE CORPORATION
KEWAUNEE NUCLEAR POWER PLANT

SAFETY EVALUATION OF STEAM GENERATOR SUPPORT PAD CONNECTIONS HAVING VASCOMAX BOLTS IN HELICOIL INSERTS

June 18, 1980

FLUOR POWER SERVICES, INC.

CHICAGO, ILLINOIS 60606

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PROJECT: 237127-030

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VASCOMAX BOLTS IN HELICOIL INSERTS

DATE: June 18, 1980

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A. V. Setlur

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1.0 SUMMARY

The main support pads at the steam generator (S.G.) base are attached to the upper plate of the steam generator leg by means of 1½ inch diameter Vascomax steel (18 percent Nickel Maraging Steel) bolts with Helicoil inserts. Maraging steels have been reported in NUREG 0577 as being susceptible to stress corrosion cracking under a combination of steady state stress and corrosive atmosphere (humidity or hydrogen). To address this concern, Wisconsin Public Service Corporation (WPS) performed visual and ultrasonic examination of these bolts on May 28-31, 1980, specifically to determine whether or not there was evidence of incipient cracking of these bolts.

The ultrasonic examination revealed that 33 out of a total of 48 bolts in the two steam generators were shorter than their original design lengths. A design review of the existing bolting arrangement was authorized by WPS.

The review consists of evaluation of mechanical properties of the pertinent materials, design loads, bolt thread engagement calculations, elastic analysis of the effective bolt patterns and compliance with the Kewaunee FSAR criteria.

The evaluation of the thread engagement length necessary to develop the full capacity of the bolt revealed the following:

a. Three of the four legs of each S.G. have all six bolts effective

b. Fourth leg of S.G. 1A and S.G. 1B have five and four effective bolts respectively.

Safety evaluation of the four and five bolt arrangements indicated that these patterns have the design capacity to satisfy the FSAR criteria under the governing "Faulted Load" condition. However, to improve the safety margins, the four bolt arrangement was upgraded to a 5 bolt pattern by interchanging the short Vascomax Bolt with one from a leg with full six effective bolts. This modification has resulted in three legs having five effective bolts and the remaining five legs with six effective bolts.

Under the Faulted Load condition, the highest stressed bolt in the most unfavorable non-symmetric five bolt arrangement develops a stress of 88 percent of the yield stress of the bolt material. Other five and six bolt arrangement develop lesser stress values.

Therefore, the present bolts in the steam generator legs have adequate load carrying capacity and the design satifies the FSAR criteria.

2.0 DESCRIPTION OF BOLTS

Each steam generator is supported by four pin-columns (Figs. 1A & B). Each pin column is pinned at the top and bottom by means of a pin clevis arrangement. A top clevis bracket is mounted to the underside of each of the four steam generator lower support pads. Each clevis bracket-support pad attachment is secured by means of six Vascomax high strength bolts. There are a total of 24 bolts holding down each steam generator to the pin-columns.

The high strength bolts are 1½ inch with a 12 UNF thread and a class 2A tolerance for external thread. The shank of the bolt is 6¼ inches long with a thread relief and smooth rounded fillets. The bolt has a hexagonal tightening head that projects beyond the rounded bolt head. The material for the bolts is 250 CVM Vascomax steel, supplied by Vanadium Alloys Steel Co. The mill test reports for the two heats used in the fabrication of these bolts are attached (Appendix B-1).

The steam generator support pads are drilled and tapped for 1½ inch 18-8 stainless steel Heli-Coil screwlock inserts. The inserts are 4½ inches long.

3.0 FINDINGS OF VISUAL AND ULTRASONIC EXAMINATION

To determine any evidence of stress corrosion cracking (NUREG 0577), a visual and ultrasonic examination was carried out for all 48 Vascomax bolts of the two steam generator supports. The findings are summarized below.

1. 33 of total 48 bolts are shorter than the designed length of 8 1/8 inches. The bolt lengths as measured by the ultrasonic examination are given in Figure 2.

2. One of the short length bolt is of Non-Vascomax material with conventional bolt head distinctly different from the special bolt head design of Vascomax Bolt.

3. All bolts except three have no washers. The washers are as identified in Figure 2.

4. The ultrasonic examination measured a legnth of 8.4 inches for the fabricated length of 8.125 inches. However, a 4.8 inches

long bolt by UT when pulled out and measured came out to be 4.75 inches.

5. There is no visual evidence that the bolts are pretensioned to the values specified on the design drawings. The tightening may at most represent a snug-tight condition with bolt stresses less than 2 KSI.

4.0 EFFECTIVE THREAD ENGAGEMENT

To evaluate effectiveness of 33 short length bolts, the actual length of thread engagement is computed. The effective thread length, L_e is computed conservatively by the following equation:

$$L_e = L_t - (t_p + t_h) - e_{ut} - t_w$$

Where,

L_t = Length of bolt as measured by UT, in inches

t_p = Thickness of bolting plate = 2.0 inches

t_h = Thickness of bolt head comprised 1 inch shoulder and 7/8 inch Hexogonal head = 1.875 inches

$(t_p + t_h)$ = Is conservatively taken as 4.0 inches in order to account for any rounding-off at bolt ends.

e_{ut} = Correction for length variations measured by UT. This is conservatively taken as 0.3 inch

t_w = Thickness of washer, if any, in inches

The effective thread engagement lengths computed using the above formula are given in Figure 3.

5.0 TENSILE STRENGTH OF BOLT-HELI COIL ASSEMBLY

The required length of thread engagement in a Heli-Coil insert is computed from curves developed by Helicoil Products (Figure 4).

The curves indicate the tensile strength capacity of bolt-Heli Coil-parent material assembly for 1½-12 NF bolts for different lengths of Heli-Coil inserts. For developing the required bolt force (Vertical axis) in the parent material of known shear strength (Horizontal Axis), the insert length above the intersection point is selected in order to ensure the failure of bolt rather than the parent material. For example, a bolt force of 250 KIPS can be developed in 1.25 inches length Heli-Coil inserted in the parent material having 50 KSI shear strength.

The parent material of steam generator support pads is ASTM A216, grade WCC with a minimum tensile strength of 70 KSI. There is no reduction of strength at 600°F. (ASME Boiler & Pressure Vessel Code, Section III, Division 1. Appendices, Table I.3-1). The shear strength of the material may be estimated as 75 percent of the tensile strength but conservatively taken as 49(=0.7 x 70) KSI. The mill test reports for Vascomax Bolts (Appendix B-1) given a maximum tensile strength of 251 KSI. The reduction in strength at 600°F is small for Vascomax 250, which can be estimated as 2 percent. With a tensile area of 1.581 in.^{2} (1½-12NF), the ultimate capacity of the bolt is 389 (=.98x251x1.581) KIPS.

From Figure 4, the 389 KIP bolt capacity and 49 KSI shear strength requires 2.25 inches long Heli-Coil insert. A minimum thread engagement of 2.25 in. will ensure the development of ultimate bolt capacity, since

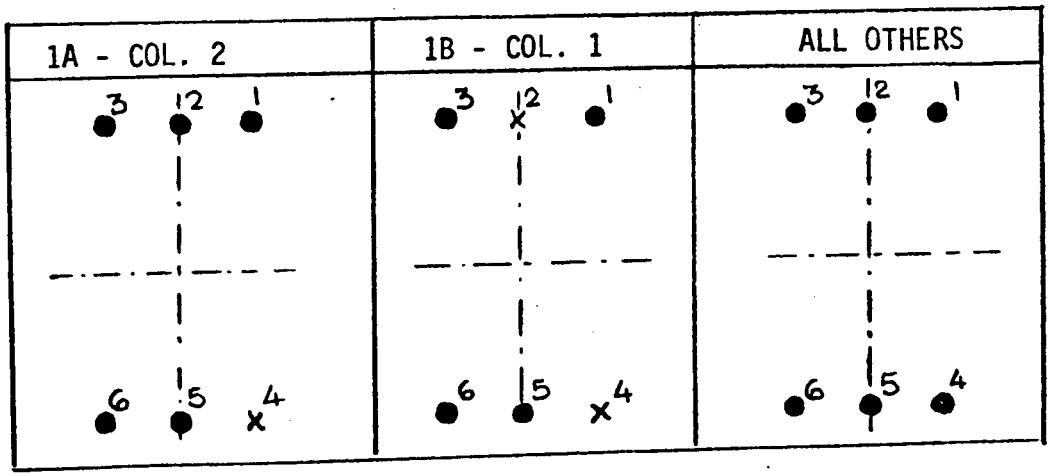
1) The bolt capacity is based on the strength reported in the mill test reports, and

2) The shear strength of parent material is conservatively estimated from the minimum ultimate strength of the material.

Also, smaller thread engagement lengths are adequate to develop bolt loads smaller than the ultimate capacity of the bolt.

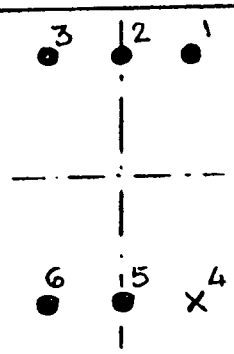
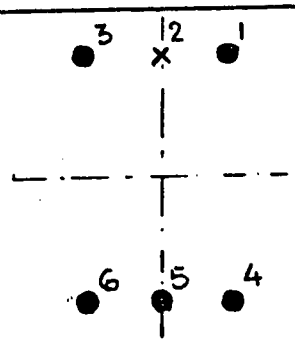
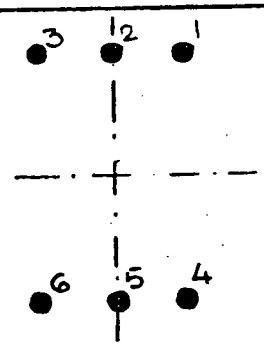
6.0 SUPPORT CONNECTION DETAILS WITH EFFECTIVE VASCOMAX BOLTS

All Vascomax Bolts which have effective thread engagement length greater than 2.25 inches are effective to carry the bolt load upto its ultimate capacity. It is seen from Figure 3. That the steam generator support column connection prior to the modifications had the effective Vascomax Bolts in the configurations shown below.



●EFFECTIVE VASCOMAX BOLT; X NON-EFFECTIVE BOLT

A preliminary analysis of non-symmetric 4 bolt configuration indicated that the safety criteria as stipulated in the FSAR (Table B. 7-4, Appendix B, volume 5) are met. However, in order to improve the margins of safety, bolt 2 in col. 4 of steam generator B was interchanged with bolt 2 in Column 1 of the same. The Steam generator support column connections presently, have the effective Vascomax Bolt arrangements as shown in the following table.

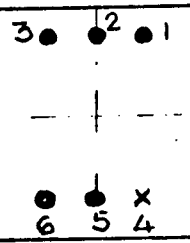
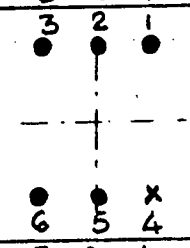
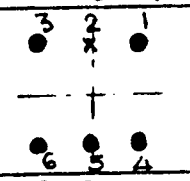
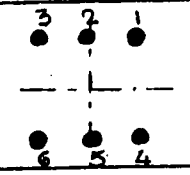
1A - COL. 2 & 1B - COL. 1	1B - COL. 4	ALL OTHERS
		

7.0 SAFETY EVALUATION

The existing 5 and 6 bolt configurations are analyzed based on elastic theory (Appendix-A) provides bolt forces in terms of applied axial load P, and moment, M, perpendicular to the axis of the pin for all three present bolt configurations.

The design loads on the steam generator columns are given in Appendix E of Westinghouse report No. SD 103 (Structural Analysis of Reactor Coolant Loop/Support System for NSP and WPS Nuclear Power Plants, February 1972). The Governing Faulted condition (Dead + Temp. + Pressure + DBE + cross-over leg break at pump suction) loads are given in Table 7.1. The corresponding bolt forces are readily obtained from the expressions derived in Appendix A. Under faulted condition, FSAR (Table B.7-4, Appendix B, volume 5) stipulates that the "permanent defection of supports limited to maintain supported equipment within faulted condition stress limits". A common approach to limit the deflections is to limit the stresses to yield. Thus, Table 7.1 examines the Faulted Condition bolt loads as a fraction of the yield strength of the bolt. The yield strength of Vascomax 250 at 600°F is 0.98 x 243.9 = 239 KSI (the mill test report value is reduced by 2 percent for temperature.)

TABLE 7.1 SAFETY ANALYSIS OF VASCOMAX BOLTS

COLUMN IDENTIFICATION	BOLT CONFIGURATION	FAULTED CONDITION LOADS		BOLT		BOLT FORCE / 239X1.581
		P KIPS	M K-IN.	NO.	FORCE KIPS	
1A-COLUMN 2		1077	143	1 2 3 5 6	306 186 86 330 231	0.81 0.49 0.23 0.87 0.61
1B-COLUMN 1		1073	190	1 2 3 5 6	312 187 90 332 235	0.82 0.49 0.24 0.88* 0.62
1B-COLUMN 4		1100	177	1,3 4,6 5	292 199 187	0.77 0.53 0.50
ALL OTHERS		1100 (MAX.)	177 (MAX.)	1,3 } 4,6 } 2,5	199 187	0.53 0.50

*MAXIMUM BOLT STRESS

8.0 CONCLUSIONS

Following are the conclusions of the review:

1. Out of 33 short Vascomax bolts, three bolts were found to have inadequate thread engagement length for developing the ultimate bolt capacity.

2. Three out of eight columns have 5 effective bolts and the remaining five columns have all 6 bolts effective.

3. The non-symmetric 5 bolt configuration resulted in a maximum bolt load equal to 88 percent of the yield strength under the Governing Faulted Condition (D + T + P $\pm$ DBE + A) loads.

Therefore, it is concluded that the existing Vascomax bolts in the steam generator legs have adequate load carrying capacity and the design satisfies the FSAR criteria.

FOR STEAM GENERATOR SUPPORT ADAPTER DETAILS,

SEE FIGURE 1B.

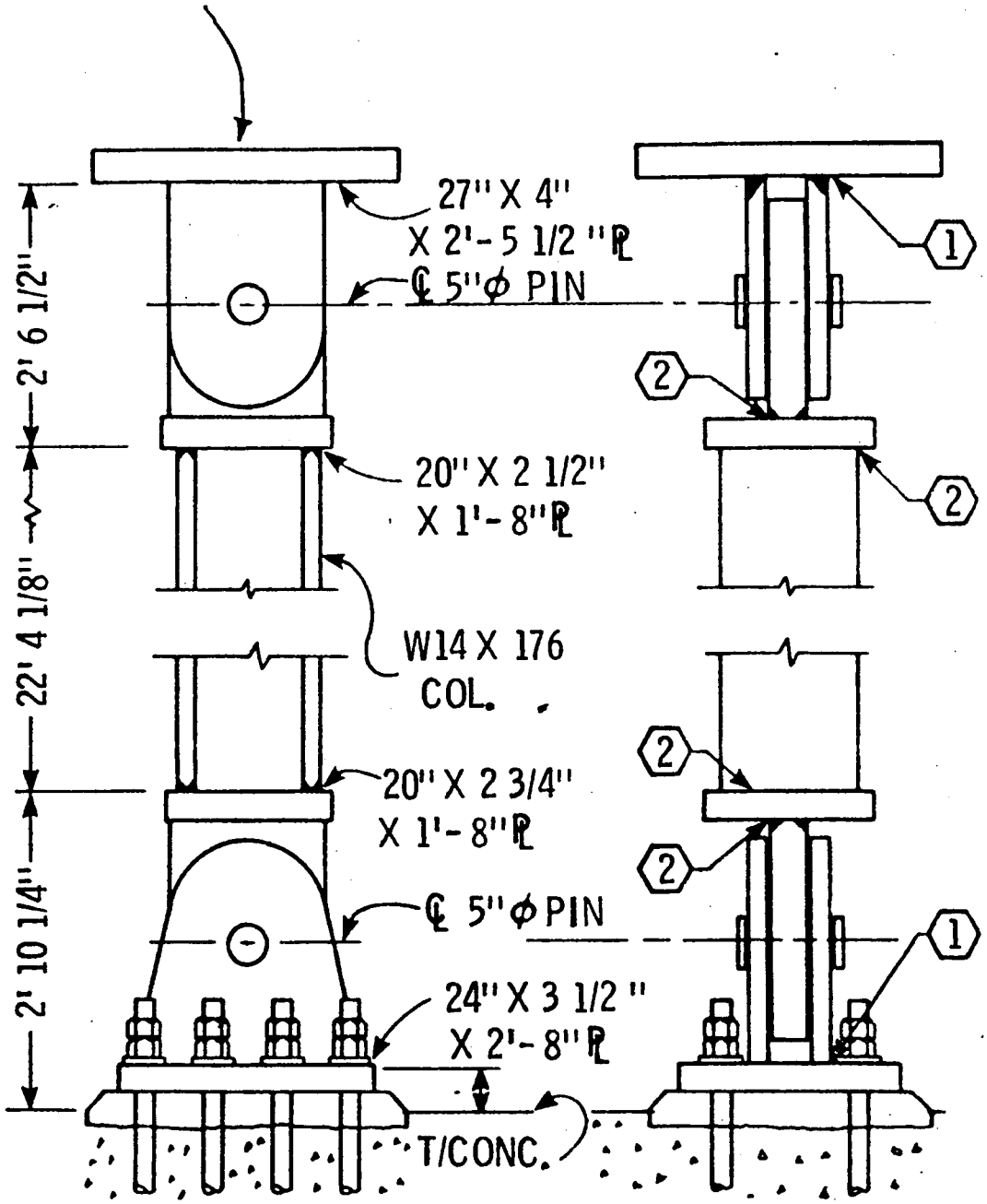
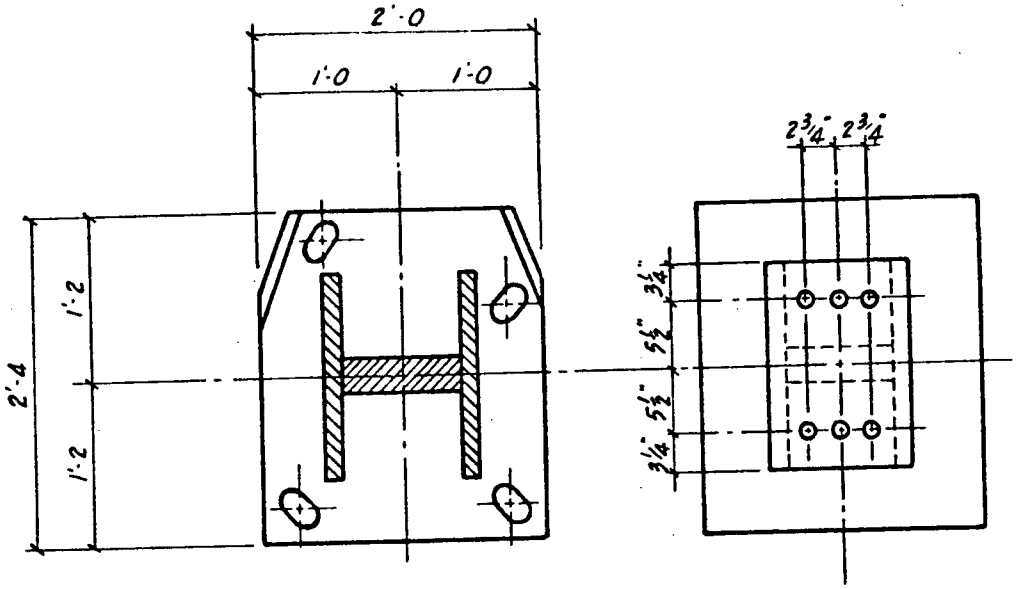


FIG. 1A. COLUMN ENDS OF THE KEWAUNEE STEAM GENERATOR SUPPORT STRUCTURE



SECTION 7-7

SECTION 6-6

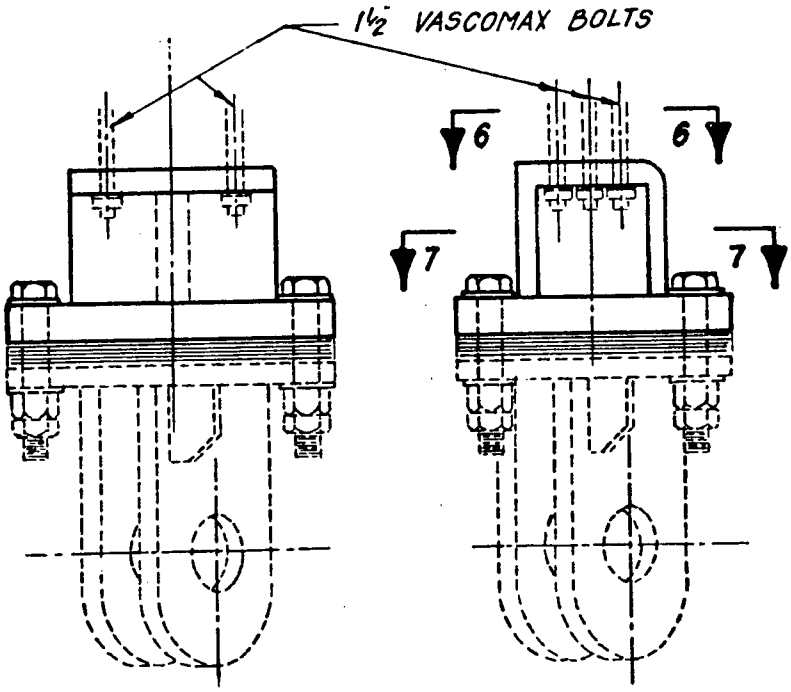
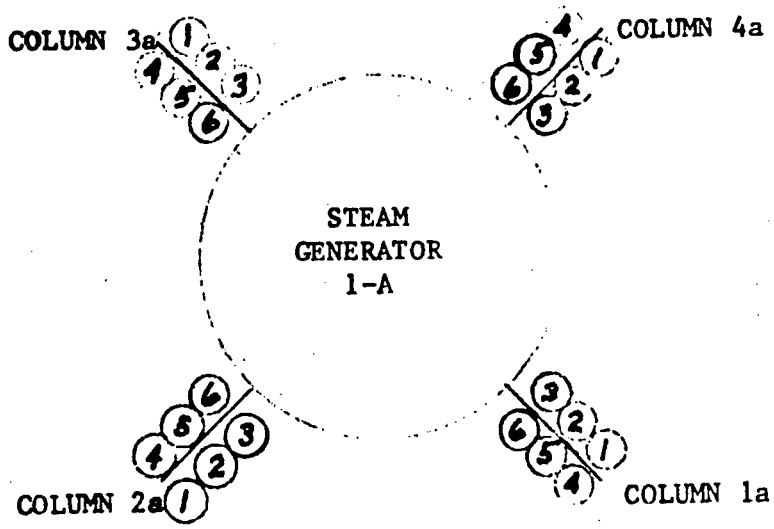


FIGURE 1-B STEAM GENERATOR SUPPORT ADAPTER DETAIL

BOLT #	LENGTH IN.
[illegible]	7.2
2	7.2
3	7.4
4	7.0
5	8.4
6	7.6

BOLT #	LENGTH IN.
1	7.0
2	8.4
3	7.4
4	8.4
5	8.4
6	7.1

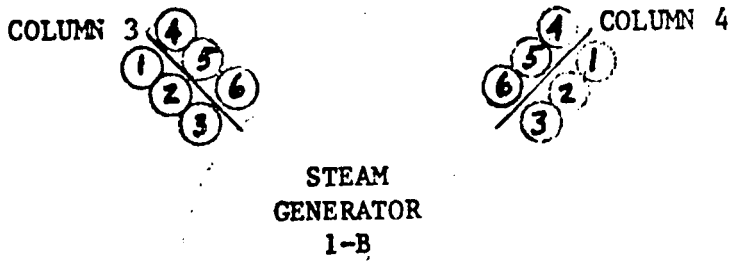


1	8.4
2	8.4
3	8.4
4	5.4
5	7.0
6	7.2

1	6.8	
2	7.8	
3	8.4	
4	8.4	1 1/4" WASHER
5	7.8	
6	7.2	

1	7.2
2	7.2
[illegible]	7.0
[illegible]	8.4
5	7.2
6	7.2

1	8.4	
2	7.2	
3	8.4	5/8" WASHER
4	7.2	
5	7.1	
6	8.4	



1	7.0
2	7.2
3	7.1
4	8.4
5	7.2
6	8.4

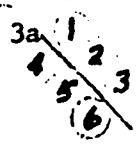
1	7.2	
2	4.8	
3	7.2	
4	4.8*	1 1/4" WASHER
5	7.1	
6	7.1	

* NON-VASCOMAX BOLT

FIG. 2 BOLT LENGTHS AS REPORTED BY ULTRASONIC EXAMINATION

BOLT #	EFFECTIVE THREAD LENGTH (IN.)
1	2.9
2	2.9
3	3.1
4	2.7
5	4.1
6	3.3

COLUMN 3a



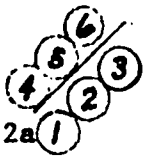
COLUMN 4a

BOLT #	EFFECTIVE THREAD LENGTH (IN.)
1	2.7
2	4.1
3	3.1
4	4.1
5	4.1
6	2.8

STEAM GENERATOR 1-A

1	4.1
2	4.1
3	4.1
4	1.1
5	2.7
6	2.9

COLUMN 2a

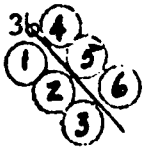


COLUMN 1a

1	2.5
2	3.5
3	4.1
4	2.8
5	3.5
6	2.9

1	2.9
2	2.9
3	2.7
4	4.1
5	2.9
6	2.9

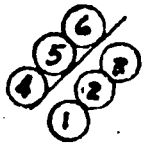
COLUMN 3b



COLUMN 4b

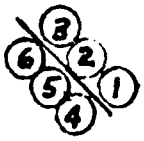
1	4.1
2	2.9
3	3.4
4	2.9
5	2.8
6	4.1

STEAM GENERATOR 1-B



COLUMN 2b

1	2.7
2	2.9
3	2.8
4	4.1
5	2.9
6	4.1



COLUMN 1b

1	2.9	
2	0.5	
3	2.9	
4	—	NON-VAS MAX BC
5	2.8	
6	2.8	

FIG. 3. EFFECTIVE THREAD ENGAGEMENT LENGTH

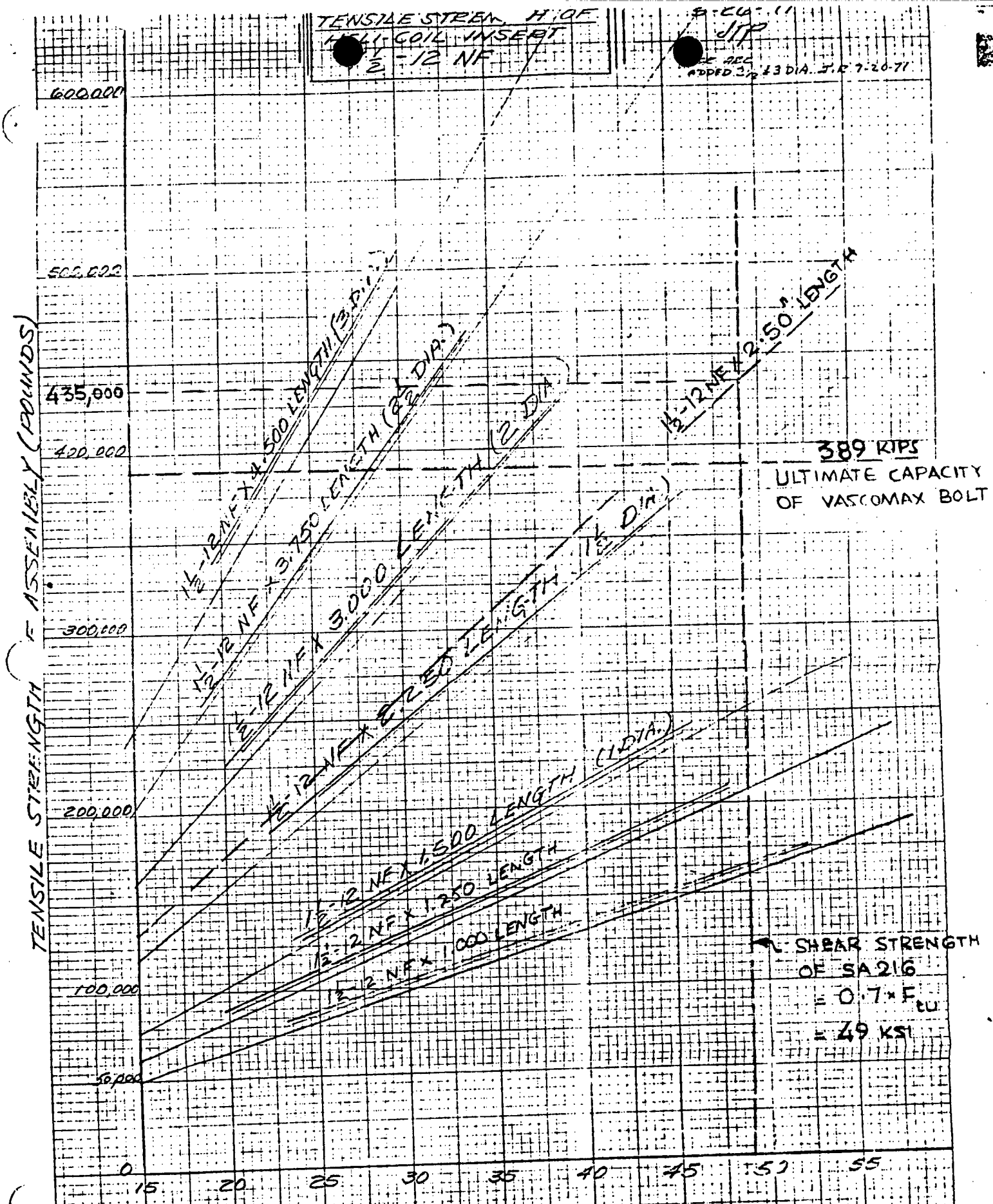


FIGURE 4 SHEAR STRENGTH OF PARENT MATERIAL IN THOUSANDS OF PSI

(DATA SHEET OBTAINED FROM HELI-COIL PRODUCTS, CONN.)

APPENDIX - A

COMPUTATION OF BOLT FORCES

COMPUTATION OF BOLT FORCES

A.1 TENSION LOAD

Under the action of a tensile load, P, along the axis of the column (center line of the 6 bolt assembly), the individual bolt forces are computed based on the following assumptions:

1. The adapter top plate connecting the steam generator support pad with the column is rigid and remains in a plane.

2. The bolts cannot transfer any moment to the supporting column.

The bolt force, F., in any bolt is given by the expression:

$$F_i = P\left[\frac{1}{N} + \frac{e_x(x_i I_x - y_i I_{xY}) - e_Y(x_i I_{xY} - y_i I_Y)}{I_x I_Y - I_{xY}^2}\right]$$

Where,

N - Number of bolts

e_x, e_Y - Distances of center point of pin from the centroid of the bdt group along centroidal X and Y axes respectively.

x_i, y_i - Distances of the bolt, "i", measured from the centroidal axes.

$$I_x = \sum y_i^2 \quad ; \quad I_Y = \sum x_i^2 \quad ; \quad I_{xY} = \sum x_i y_i$$

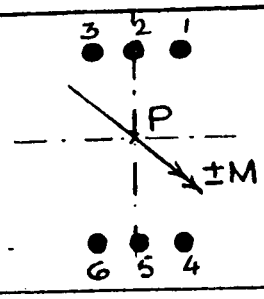
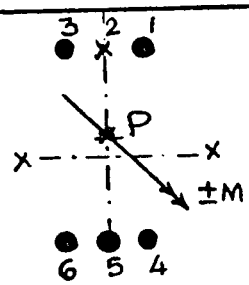
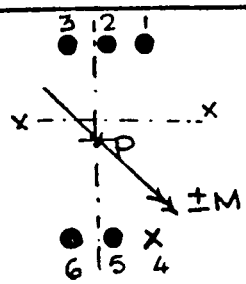
A.2 MOMENT ABOUT AXIS PERPENDICULAR TO PIN.

The bolt forces associated with a moment, M (K-IN) about the axis perpendicular to pin is computed from

$$F_i = \frac{M}{\sqrt{2}}\left[\pm \frac{y_i}{I_x} \pm \frac{x_i}{I_Y}\right]$$

Table A1 gives the bolt forces in terms of axial force P and moment M for the three bolt configurations of interest.

TABLE A-1 BOLT FORCES

BOLT CONFIGURATION			
N	6	5	5
E_x (IN.)	0	0	0.55
E_y (IN.)	0	1.1	-1.1
I_x (IN^2)	181.5	145.2	145.2
I_y (IN^2)	30.25	30.25	21.175
I_{xy} (IN^2)	-	0	18.15
F_1 (KIPS)	.167P + .086M	.25P + .096M	.267P + .132M
F_2 (KIPS)	.167P + .021M	-	.167P + .041M
F_3 (KIPS)	.167P + .086M	.25P + .096M	.067P + .095M
F_4 (KIPS)	.167P + .086M	.167P + .086M	-
F_5 (KIPS)	.167P + .021M	.167P + .021M	.3P + .051M
F_6 (KIPS)	.167P + .086M	.167P + .086M	.2P + .106M

TELEDYNE VASCO
LATROBE, PA. 15650

4PP. B1

ANALYSIS REPORT

Customer: Welding & Steel Fabrication Co.
7 Hackett Drive
Tonawanda, New York 14150

SITE QUALITY CONTROL FILE
P.S.&E.-QCS

Your Order No. 34705

Our Order No. V-312695

Brand: CVM VascoMax 250 MB 250 CVM & Astm-A-370 with exceptions & ASTM-A-388

SIZE	BARS	WEIGHT	HEAT No.	DATE SHIPPED
2-3/4" Round	1	182	2448-A	6-4-71

Tensile Strength, psi	250,000
Yield Strength, psi	243,300
0.2% Offset	
Reduction of Area %	62.4
Elongation %	11.5
Hardness	48.8 Rc
Grain Size	6.9
Impacts - Ft/Lbs -	38.5
	35.3
	37.4

Report #U1-2292

Ultrasonic Inspection - OK
Orbit Industries, Cleveland, Ohio

Aging Time & Temperature - 900° - 3 hours
Magnetic Particle Inspection - F/S = 0/0
JK Rating:

	A Thin	A Heavy	B Thin	B Heavy	C Thin	C Heavy	D Thin	D Heavy	E Thin	E Heavy
T	0	0	0	0	0	0	0	0	1	1/2
B	0	0	0	0	0	0	0	0	1	1-1/2

Analysis

Heat No.	C	Si	Mn	S	P	W	Cr	V	Mo	Co	Ni
2448-A	.014	.02	.01	.005	.006				4.81	7.87	18.18

Heat No.	Al	Ti	B	Zr	Ca
2448-A	.07	.37	.001	.010	.05 (added)

Sworn and subscribed to before me
this 9 day of June 1971
Arthur S. Bridge
My Commission Expires Mar 23, 1974
Derry Township, Westmoreland County

Certified Correct
H. V. Cunliffe

TELEDYNE VASCO

LATROBE, PA. 15650

SITE QUALITY CONTROL FILE
P.S.&E.-QCS

APP. B.

ANALYSIS REPORT

QC FILE K284
MAY 25 1971
OFFICE FILE

Customer: Welding & Steel Fabrication Co., Inc.
7 Hackett Drive
Tonawanda, New York 14150

Your Order No. 34705

Our Order No. V 312693

Brand: CVM VascoMax 250 MB-250, ASTM A-370, ASTM A-388

SIZE	BARS	WEIGHT	HEAT No.	DATE SHIPPED
2-3/4" round	6	1307#	2452-A	May 10, 1971

Longitudinal Tensile Results: #16-3

Tensile Strength, psi	251,000
Yield Strength, psi 0.2% Offset	245,900
Reduction of Area %	62.0
Elongation %	12.0

Hardness - 49.3 Rc
Grain Size - 6.3
Impacts - Ft/Lbs - 41.6
- 46.2
- 46.4

Ultrasonic Inspection - O.K.
Orbit Industries, Cleveland, Ohio
Report #U1-1897

Aging Time & Temperature - 900° - 3 hours
Magnetic Particle Inspection - F/S + 0/0
JK Rating:

	A Thin	A Heavy	B Thin	B Heavy	C Thin	C Heavy	D Thin	D Heavy	E Thin	E Heavy
T	0	0	0	0	0	0	0	0	1-1/2	1-1/2
B	0	0	0	0	0	0	0	0	1	1/2

Analysis

Heat No.	C	Si	Mn	S	P	W	Cr	V	Mo	Co	Ni
2452-A	.011	.01	.02	.006	.006	—	—	—	4.81	7.98	18.28

Heat No.	Al	Ti	B	Zr	Ca
2452-A	.14	.35	.002	.010	.05 (added)

Sworn and subscribed to before me
this 10 day of May 1971

Esther S. Bridge
ESTHER S. BRIDGE, Notary Public
My Commission Expires Mar 23, 1974
Derry Township, Westmoreland County

Certified Correct

J. H. McCauliffe