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SUBJECT

Scale Model Tests of High-Temperature High Pressure Steam Piping

DV 9 (Class Vessel)

NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

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NAVY DEPARTMENT

Report

on

Scale Model Tests of High-Temperature High Pressure Steam Piping - CV9 Class Vessel

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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TABLE OF CONTENTS

APPENDICES

Appendix I - Model Test Data

ABSTRACT

Scale model tests of piping of ships of the CV9 Class have been made to determine the reaction forces and moments at various points on the piping system. Effects of horizontal tie rods at certain points have been determined.

SCALE MODEL TESTS OF HIGH TEMPERATURE HIGH PRESSURE STEAM PIPING - CV9 CLASS VESSEL

Introduction

A. Authorization

1. This problem was authorized by Bureau of Ships letter CV9Class/ S48-10(350) of 17 January 1943.

B. Statement of Problem

2. End reactions of steam piping of a CV9Class Vessel were required for several conditions of constraint. The points at which end reactions were to be determined are shown on plates 5 through 9, and are listed below.

a. No. 2 engine room and Nos. 3 and 4 fire rooms.
End reactions of the starboard and port side steam piping were to be measured both without and with constraint on the superheated branches from boilers 7 and 5, respectively. These constraints are described in paragraph 17, and their locations are shown in plates 6 and 8. In the following, Condition No. I will refer to the condition with no constraint, and Condition No. II will refer to the condition with this constraint, on the proper superheated branch.

Point A. - Connection of superheated steam branch to boiler No. 8 for conditions I and II, see plates 5a and 6a.

Point B. - Connection at superheated branch from starboard side main steam piping to No. 4 turbo-generator for conditions I and II, see plates 5a and 6a.

Point C. - Connection of superheated steam branch to boiler No. 7 for conditions I and II, see plates 5a and 6a.

Point L. - Connection of superheated steam branch from port side main steam piping to No. 4 turbo-generator for condition I, see plates 7a and 8a.

Point O. - Connection of superheated branch to boiler No. 6 for conditions I and II, see plates 7a and 8a.

Point Q. - Connection of superheated branch from main steam piping to No. 3 turbo-generator for condition I, see plate 7a.

Point P. - Connection of superheated branch to boiler No. 5 for conditions I and II, see plates 7a and 8a.

b. No. 1 engine room and Nos. 1 and 2 fire rooms

Point I. - Connection of superheated branch from main steam piping to No. 2 turbo-generator, see plate 9.

C. Statement of Method

3. These end reactions were obtained by the use of scale models. The method of scale models for the determination of end reactions in the case of three-dimensional piping systems having several branches has been described in previous reports 1,2,3.

Description of Piping Under Consideration

A. Main Steam Piping

4. The main steam piping in No. 2 engine room and Nos. 3 and 4 fire rooms consists of two piping systems connected by a 7 inch cross-over pipe. These systems are: (1) port side main steam piping from boilers Nos. 5 and 6 to Turbine Set No. 3 (plates 7 and 8), and (2) starboard side main steam piping from boilers Nos. 7 and 8 to Turbine Set No. 2 (plates 5 and 6).

5. In the determination of end reactions at various points of a piping system, one must first know the location of all points of constraint and the type of each constraint. In the main steam piping systems under investigation all piping is permitted to "float" in the vertical direction, with the exception of boiler, turbine, and turbo-generator connections. At two points the main steam piping is constrained by means of tie rods which prevent motion in the horizontal plane but allow vertical motion and all rotations. These points are on the pipe axis at bulkhead 131 (see plates 5a and 7a). At several other points the main piping is constrained by means of horizontal tie rods which prevent motion parallel to the rod, but allow displacements in the two perpendicular directions and all rotations. These points of constraint are labelled G, M, N, S in plates 5, 6, 7, 8.

6. The large number of points of constraint involved made it impractical to set up these two systems together and measure all of the desired reactions. Therefore, each system was set up separately and the reactions determined. To approximate the effect of the cross-over pipe it was included in both systems, as shown in plates 1 and 2.

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B. Auxiliary Steam Piping

7. The auxiliary piping investigated consists of superheated branches from the port and starboard main steam lines to turbo-generators Nos. 3 and 4, in Nos. 3 and 4 fire rooms; and of the superheated branch to turbo-generator No. 2, in No. 1 engine room.

8. The rigidity of the auxiliary piping is much less than that of the main steam piping and was neglected, therefore, when the reactions at points on the main steam piping were measured. To determine the reactions of the auxiliary piping, these were built as separate models of convenient size. The proper relative motions of the ends of these pipes were obtained by measuring the translations of the main steam piping at the point of connection of each auxiliary pipe. These translations were added to the thermal expansions of the auxiliary piping, and the reactions caused by the relative translations were measured. The effect of the rotations at the connection to the main steam line was assimilated by displacing the arms of the measuring head amounts proportional to the measured rotations. The additional reactions due to the rotations were thus obtained. the total reactions were then determined by adding the two sets of reactions.

9. This procedure was also followed in the case of the superheated branch to No. 2 turbo-generator in engine-room No. 1. It was assumed, to avoid building a model of the whole main piping system in engine-room No. 1 and fire rooms Nos. 1 and 2, that the deflections and rotations of the corresponding point of the cross-over pipe in engine-room No. 2 (point I') would be approximately the same as those of the point of the cross-over pipe in engine-room No. 1, to which the pipe is actually connected.

Construction of Scale Models

A. Selection of Model Tubing

10. The scale factor s, or ratio of axial dimensions of the model to those of the full scale pipe, is given by

$$s = \left(\frac{r_m}{r_a}\right)^2 \frac{t_a}{t_m}$$

where r_a = mean radius of full-scale pipe
r_m = mean radius of model pipe
t_a = wall thickness of full-scale pipe
t_m = wall thickness of model pipe

This condition should be satisfied for each pipe size which contains a bend.

11. A second condition which must be satisfied when the piping system is composed of several pipe sizes is that the ratio of the moment of inertia of a pipe in the full-scale system to that of the corresponding pipe in the model system should be maintained constant for all the pipe sizes. In the present model system, due to the use of standard sizes of tubing, these requirements were satisfied to within about 4 percent.

12. When the above conditions are satisfied, the full-scale pipe forces are obtained by multiplying those measured on the model by the factor K, where

$$K = \frac{E_a \; I_a}{E_m \; I_m} \; s^3 \frac{\Delta L_a}{\Delta L_m}$$

The full-scale moments are obtained by multiplying the moments measured on the model by the factor K/s.

here $E_a = 24.8 \times 10^6$ #/in^2 = Young's modulus for full-scale piping at operating temperature.
$E_m = 29.0 \times 10^6$ #/in^2 = Young's modulus for model tubing.
I_a = moment of inertia of full-scale pipe.
I_m = moment of inertia of corresponding model pipe.
s = scale factor, ratio of axial lengths of model to full-scale piping.
L_a = end displacement of full-scale pipe.
L_m = displacement of corresponding end of model system.

13. Dimensions of full-scale and model piping are given in the following tables:

Table I - Main and Auxiliary Steam Piping. Cross-sectional Dimensions and Moments of Inertia of Full-size Piping (see plates 5-9).

Pipe size in.	O. D. in.	Wall Thickness in.	I. D. in.	Moment of Inertia in.^{4}
3-1/2	4.00	.225	3.55	4.76
7	7.625	.429	6.767	63.3
8	8.625	.486	7.653	103.5
10	10.750	.605	9.54	249.0

[redacted]

Table II - Main Steam Piping. Cross-sectional Dimensions and Moments of Inertia of Model Tubing (see plates 1,3).

Full Scale Pipe Size in.	O. D. in.	Wall Thickness in.	I. D. in.	Moment of inertia in.4	Scale Factor s
7	.562	.022	.518	1.365×10^{-3}	1/9.4
8	.626	.0245	.577	2.15×10^{-3}	1/9.4
10	.755	.0365	.682	5.36×10^{-3}	1/9.4

Table III - Auxiliary Steam Piping. Cross-sectional Dimensions and Moments of Inertia for Model of Superheated Branch from Starboard Main Steam Piping to Turbo-Generator No.4

Full Scale Pipe Size in.	O. D. in.	Wall Thickness in.	I. D. in.	Moment of inertia in.4	Scale Factor s
3-1/2	0.756	.0362	.6836	5.36×10^{-3}	1/4.43

Table IV - Auxiliary Steam Piping. Cross-sectional Dimensions and Moment of Inertia for Models of (1) Superheated Branch from Port Side Main Steam Piping to No. 4 Turbo-Generator, (2) Superheated Branch from Port Side Main Steam Piping to No. 3 Turbo-Generator, and (3) Superheated Branch from Main Steam Piping to No. 2 Turbo-Generator.

Full Scale Pipe Size in.	O. D. in.	Wall Thickness in.	I. D. in.	Moment of inertia in.4	Scale Factor s
3-1/2	0.751	.0288	.694	4.27×10^{-3}	1/3.5

B. Construction of Constraints and Anchors - Starboard Side Main Steam Piping

14. Diagrams of this system are given in plates 5 and 6, and a photograph of the model set-up is given in plate 1.

15. The piping is considered to be rigidly anchored at points A and C, i.e., at connections to boilers 7 and 8 (motions of anchor points are considered). At bulkhead 131, tie rods prevent translation in the horizontal plane but allow vertical translation and all rotations. These constraints are assimilated at point D in the model by the device shown in plate 2. A metal plate is mounted on roller bearings inside a fixed housing which permits motion in one direction.

The model tubing passes through the plate and is fixed to it by means of a self-aligning ball bearing in the manner shown in plate 2.

16. The system is terminated at the main steam strainer (turbine set No. 2), point E on plates 1,5,6. At this point all horizontal translation is prevented while vertical translation and all rotations are permitted. The rotations of this point due to the thermal expansions of the turbine and turbine connections are not known, but since this point is a considerable distance from the points where reactions are to be measured, the effects of these rotations were assumed to be negligible. The vertical displacement given this end of the model set-up was taken as the thermal expansion of the piping from the turbine-set connection to the strainer, plus the given vertical motion of the turbine-set connection.

17. The reactions at points A, B, and C were desired without and with a horizontal tie rod placed at point G on the superheated branch from boiler No. 7 (conditions I and II respectively). This constraint was constructed as shown in plate 4, consisting of a horizontal rod connected to the model tubing and to the anchor by means of self-aligning ball bearings. This device prevents horizontal translation parallel to the rod, but permits translations in the two perpendicular directions, and all rotations.

18. The relative translations and rotations of point H (point of connection to the port side piping system) are not known. As the best approximation, it was assumed that the rotations at this point are negligible and that the only translations are those due to the thermal expansion across the ship between points F and H.

19. For the purpose of calculating end motions, the piping system was considered fixed at a point on the pipe axis 22" aft of bulkhead 131. This was merely an arbitrary reference point and its location in no way affects the results.

C. Construction of Constraints and Anchors - Port Side Main Steam Piping

20. Diagrams of this system are given in plates 7 and 8, and a photograph of the model set-up is given in plate 3.

21. As in the case of the starboard side main steam piping, the boiler connections (points O and P) were assumed to be rigid. The constraints at bulkhead 131 and at the main steam strainer (turbine set No. 3) were assumed to be identical with the corresponding constraints on the starboard side. The horizontal tie rods at points M, N, and S are identical to that shown in plate 4 and described above.

22. The rotations at point F were assumed to be negligible. The across-ship translation was taken to be equal to the thermal expansion between F and H. The vertical translation of F was assumed to be equal to that measured on the model of the starboard side main piping.

23. In calculating the end displacements, the pipe was considered fixed at a point on the pipe axis 22" aft of bulkhead 131 (see paragraph 19).

Results

24. Data obtained and calculations leading up to the results are given in Appendix I. A summary of results is included in Tables V through XI.

25. In the tables, forces and moments are those exerted by constraints on the pipes. Forces are given in pounds, moments in inch-pounds.

Table V - Starboard Side Main Steam Piping.
Condition No. I: no constraint on superheated branch from boiler 7
Condition No. II: with constraint on superheated branch from boiler 7

	Condition No. I		Condition No. II	
Reaction	Point A	Point C	Point A	Point C
F_x	+282	+403	+462	+364
F_y	-484	-1325	-785	-1618
F_z	-227	+215	-78	+272
Resultant	604	1405	944	1681
M_x	+80,000	+160,500	+72,700	+146,000
M_y	+47,700	- 11,800	+42,500	- 14,900
M_z	-29,300	-160,000	-16,800	-161,000
Resultant	97,600	226,500	85,900	217,200

Table VI - Superheated Steam Branch from Starboard Side Main Steam Piping to No. 4 Turbo-Generator, Without Constraint on Superheated Branch from Boiler No. 7 (Condition No. I).

	Point B			Point B'		
Reaction	Translations only	Rotations only	Sum	Translations only	Rotations only	Sum
F_x	+219.0	- 9	+210	-208.0	+ 9	-199
F_y	-128	+28	-100	+100	-28	+ 72
F_z	6	+24	+30	+21	-24	- 3
Resultant	253	38	234	232	38	212
M_x	700	-5,340	-4,640	+2570	+540	+3110
M_y	910	-6,870	-5,960	+3430	+1140	+4570
M_z	+19,270	+100	+19,370	-12,700	+460	-12240
Resultant	19,300	8,700	20,800	13,380	1340	13400

Table VII - Superheated Steam Branch from Starboard Main Steam Piping to No. 4 Turbo-Generator. With Constraint on Superheated Steam Branch from Boiler No. 7 (Condition No.II).

	Point B			Point B'		
Reaction	Translations only	Rotations only	Sum	Translations only	Rotations only	Sum
F_x	+185	0	+185	-205	0	-205
F_y	- 96	+ 3	- 93	+ 91	- 3	+ 88
F_z	- 4	-37	- 41	+ 25	+37	+ 62
Resultant	208	38	211	226	38	232
M_x	+ 910	+4,960	+5,770	+2,970	+1350	+3320
M_y	+1550	+5,360	+6,920	+4,040	+3110	+7150
M_z	+20,350	-3,614	16,736	-12,070	+4330	-7740
Resultant	20,400	8,150	18,700	13,100	5,500	11000

Table VIII - Port Side Main Steam Piping. Contition I: No constraint on Superheated Branch from Boiler No. 5. Condition II: With Constraint on Superheated Branch from Boiler No. 5.

Reaction	Condition I		Condition II	
	Point O	Point P.	Point O	Point P
F_x	- 1178	- 1171	- 865	+ 1420
F_y	- 872	- 1467	- 1105	- 2780
F_z	- 62	+ 521	+ 1	- 56.5
Resultant	1466	1947	1400	3140
M_x	+ 99,600	+168,500	+153,200	+338,000
M_y	-140,500	-133,100	-102,700	+239,700
M_z	+ 65,700	- 93,400	+ 76,800	-116,600
Resultant	184,200	233,800	200,000	471,000

Table IX - Superheated Branch from Port Side Main Steam Piping to No. 4 Turbo-Generator. Without Constraint on Superheated Branch from Boiler No. 5 (Condition I).

Reaction	Point L			Point L'		
	Translations only	Rotations only	Sum	Translations only	Rotations only	Sum
F_x	- 231	- 28	-259	+ 195	+ 28	+223
F_y	- 38	+ 14	- 24	+ 57	- 14	+ 43
F_z	- 100	+ 1	- 99	+ 82	- 1	+ 81
Resultant	254	31	278	221	31	241
M_x	+6,360	-1,203	+5,160	-5,440	+880	-4560
M_y	-5,400	-1,300	-6,700	+2,450	+520	+2970
M_z	-11,000	- 280	-11,280	+14,270	+1620	+15890
Resultant	13,760	1,800	14,100	15,470	1,910	16,760

Table X - Superheated Branch from Port Side Main Steam Piping to No. 3 Turbo-Generator. Without Constraint on Superheated Branch from Boiler No. 5 (Condition I).

	Point Q			Point Q'		
Reaction	Translation only	Rotation only	Sum	Translation only	Rotation only	Sum
F_x	-152	- 14	-166	+141	+ 14	+155
F_y	- 90	+ 2	- 88	+108	- 2	+106
F_z	- 48	+ 18	- 30	+ 40	- 18	+ 22
Resultant	183	23	190	182	23	189
M_x	+4870	-1220	+3650	+1730	-570	+1160
M_y	-4200	+ 580	-3600	-6050	+1980	-4070
M_z	-7970	- 960	-8930	+7780	790	+6990
Resultant	10,250	1,660	10,200	10,050	2,210	8,170

Table XI - Superheated Branch from Main Steam Piping to No. 2 Turbo-Generator.

	Point I			Point I'		
Reaction	Translation only	Rotation only	Sum	Translation only	Rotation only	Sum
F_x	-41	+ 30	- 11	+ 38	- 30	8
F_y	+420	- 18	+402	-472	+ 18	-454
F_z	+ 82	+ 33	+115	- 84	- 33	-117
Resultant	430	48.1	418	481	48.1	468
M_x	-2520	+1506	-1010	-2650	+1832	-820
My	+ 25	+3569	+3590	+4800	+ 219	+4580
Mz	-3840	-810	-4650	-35500	-157	-35340
Resultant	4600	3960	5,940	35,950	1855	35700

Discussion of Results

26. Tables V through X give end reactions for the points considered on the main steam piping and auxiliary steam piping in engine room No. 2 and fire rooms Nos. 3 and 4. The tables giving reactions for the auxiliary piping include results due to relative translations of the ends, rotation produced by the action of the main steam piping and a summation of these two results.

27. Table XI gives the results for the superheated steam branch from the main steam piping to No. 2 turbo-generator. Due to the method of obtaining the end-rotations for this pipe, the reactions caused by the rotations are known to be inaccurate, but the orders of magnitude are believed to be correct. However, as the resultant forces and moments caused by the rotations are less than 10 percent of the resultant forces and moments caused by translations, for this case, it is evident that these errors are of little importance.

28. For the auxiliary steam piping a check of the results may be obtained by transferring the reactions from one end to the other. Table XII gives a comparison of the results measured at the connection to the main steam lines with those obtained by transferring from the other end. The values agree to within a reasonable percentage.

Table XII - Measured Reactions of the Auxiliary Steam Piping at the Connections to the Main Steam Piping, Compared to Values Obtained by Transferring Reactions from Turbo-Generator Connections.

	Point B'		Point B'		Point L'		Point Q'		Point I'	
	Condition I		Condition II		Condition I		Condition I		Condition I	
Reaction	Measured at B'	Trans. from B	Measured at B'	Trans. from B	Measured at L'	Trans. from L	Measured at Q'	Trans. from Q	Measured at I'	Trans. from I
F_x	-199	- 210	-205	-185	+223	+259	+155	+166	+ 8	+ 11
F_y	+ 72	+100	+ 88	+ 93	+ 43	+ 24	+106	+ 88	-454	-402
F_z	- 3	- 30	+ 62	+ 41	+ 81	+ 99	+ 22	+ 30	-117	-115
Resultant	212	234	232	211	241	278	189	190	468	418
% Difference		+ 11		- 10		+ 15		0		- 12
M_x	+3110	+1320	+3320	+3590	-4560	-7070	+1160	+1290	- 802	+2970
M_y	+4570	+4010	+7150	+6980	+2970	+4550	-4070	-5180	+4580	+7280
M_z	-12240	-5970	-7740	-6030	+15890	+16800	+6990	+7230	-35340	-33100
Resultant	13400	7040	11050	9900	16790	18750	8170	8980	35680	34000
% Difference		- 47		- 10		+ 12		+ 10		- 5

Table XIII - Summary of Results Including Data Given in Previous NRL Report(3).

Pipe End	Condition	Piping System	F_x #	F_y #	F_z #	M_x in-#	M_y in-#	M_z in-#
A	I	Stbd.	+282	-484	-227	+80000	+47700	-29300
A	II	Stbd.	+462	-785	- 78	+72700	+42500	-16800
A	III	Stbd.	+332	-237	+1164	+72400	+67800	-26500
B	I	Stbd.	+210	-100	+ 30	-4640	-5960	+19370
B	II	Stbd.	+185	- 93	- 41	+5770	+6920	+16736
B	III	Stbd.	+238	-182	+ 8	+2450	- 168	+19500
C	I	Stbd.	+403	-1325	+215	+160500	-11800	-160000
C	II	Stbd.	+364	-1618	+272	+146000	-14900	-161000
C	III	Stbd.	+127	-1709	+532	+171000	-67000	-202000
L	I	Port	-259	- 24	- 99	+5160	-6700	-11280
O	I	Port	-1178	-872	- 62	+99600	-140500	+65700
	II	Port	- 865	-1105	+ 1	+153200	-102700	+76800
P	I	Port	-1171	-1467	+521	+168500	-133100	-93400
	II	Port	+1420	-2780	-565	+338000	+239700	-116100
Q	I	Port	-166	- 88	- 30	+3650	-3600	-8930
I		No. 1 Engine Room	- 11	+402	+115	-1010	+3590	-4650

Table XIII gives a summary of all the work that has been done at the Naval Research Laboratory on the piping of the CV9Class Vessel. In Table XIII the type of constraint is designated as follows:

Condition I: At bulkhead 131, piping is permitted to have only vertical translation. All rotations are permitted. For the starboard side piping, there is no constraint on the superheated branch from boiler No. 7. For the port side piping, there is no constraint on superheated branch from boiler No. 5 (see paragraph 2a).

Condition II: (1) At bulkhead 131, piping is permitted to have only vertical translation. All rotations are permitted.

(2) For the starboard side piping, there is a constraint on the superheated branch from boiler No. 7. For the port side piping, there is a constraint on superheated branch from boiler No. 5.

Condition III: Piping is anchored at bulkhead 131. There are no constraints on superheated branch from boiler No. 7. (The data for this condition was taken from the previous work[3].)

Bibliography

(1). Scale Model Tests for High-Pressure High-Temperature Steam Piping, First Partial Report. NRL Report No. O-1684.

(2). Scale Model Tests for High-Pressure High-Temperature Steam Piping, Second Partial Report. NRL Report No. O-1749.

(3). Scale Model Tests for High-Pressure High-Temperature Steam Piping, Third Partial Report, NRL Report No. O-1829.

APPENDIX I

Model Test Data

A. Starboard Side Main Steam Piping
Note: "Condition I" refers to tests made with no constraint on superheated branch from boiler No. 7. "Condition II" refers to tests made with constraint against horizontal motion caused by a tie rod on the superheated branch from boiler No. 7, in position shown in Plates 5 and 6 (see paragraph 2a).

Coordinate systems used are as follows3:

(x,y,z) = pipe coordinates; x = starboard, y = forward, z = up.
(x_r, y_r, z_r) = reference coordinates; arbitrary fixed axes.
(x', y', z') = measuring head coordinates.

1. Point A: Pipe connection to Boiler No. 8

End motions:

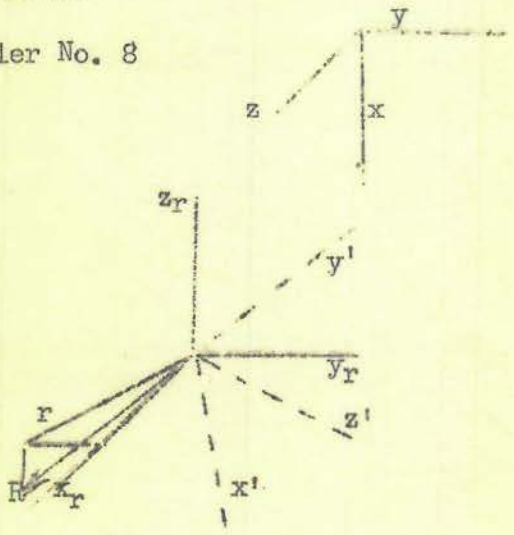
Δx = +.3682 in.
Δy = -.5847
Δz = +1.1016

Coordinates of pipe-end:

x' = o, y' = o, z' = 2.625 in.

Scale constants:

K = 288, K/s = 2144



Condition I

$R_{x'}$ = +1.293 lb.
$R_{y'}$ = - 9.14
$R_{z'}$ = - 2.342
$R_{x'y'}$ =+2.665
$R_{y'z'}$ =+8.68
$R_{z'x'}$ =+2.8

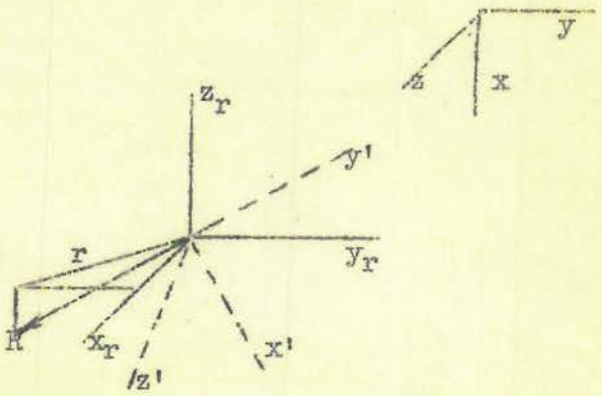
Condition II

$R_{x'}$ = + 0.824 lb.
$R_{y'}$ = - 10.23
$R_{z'}$ = - 3.2
$R_{x'y'}$ = +2.77
$R_{y'z'}$ = +8.4
$R_{z'x'}$ = +2.02

2. Point C: Pipe connection to Boiler No. 7.

End motions:

$\Delta x = + .3602$ in.
$\Delta y = - 2.600$
$\Delta z = + 1.1016$



Coordinates of pipe-end:

$x' = o$, $y' = o$, $z' = 2.625$ in.

Scale constants:

K = 228, K/s = 2144

Reactions:

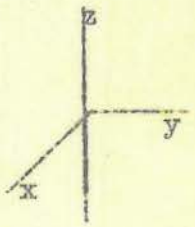
Condition I	Condition II
$R_{x'} = + 18.65$ lb.	$R_{x'} = + 18.25$ lb.
$R_{y'} = - 24.5$	$R_{y'} = - 25.02$
$R_{z'} = - 1.4$	$R_{z'} = - 1.67$
$R_{x'y'} = - 14.2$	$R_{x'y'} = - 14.37$
$R_{y'z'} = + 18.6$	$R_{y'z'} = + 17.87$
$R_{z'x'} = + 3.42$	$R_{z'x'} = + 3.18$

3. Point B': Superheated branch from starboard side main steam line to No. 4 turbo-generator, connection to valve at main steam line.

Condition I

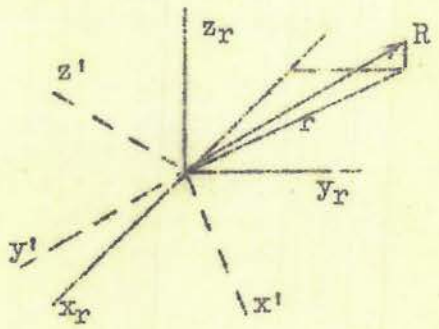
End Motions:

$\Delta x = -1.932$ in.
$\Delta y = +1.935$
$\Delta z = + .420$



Rotations:

$\phi_x = + .019$
$\phi_y = + .00125$
$\phi_z = + .019$



Coordinates of pipe-end:

$x' = o$, $y' = o$, $z' = 2.625$ in.

Scale constants:

K = 26.9, K/s = 119.0

Reactions at B'
(due to translations)

$R_{x'}$ = + 10.07 lb.
$R_{y'}$ = - 33.6
$R_{z'}$ = + 2.86
$R_{x'y'}$ = - 7.14
$R_{y'z'}$ = + 25.5
$R_{z'x'}$ = + 2.47

Reactions at B'
(due to rotations)

$R_{x'}$ = - .42 lb.
$R_{y'}$ = + 27.3
$R_{z'}$ = - 1.05
$R_{x'y'}$ = - 2.8
$R_{y'z'}$ = - 24.15
$R_{z'x'}$ = - 5.94

Condition II

End motions:

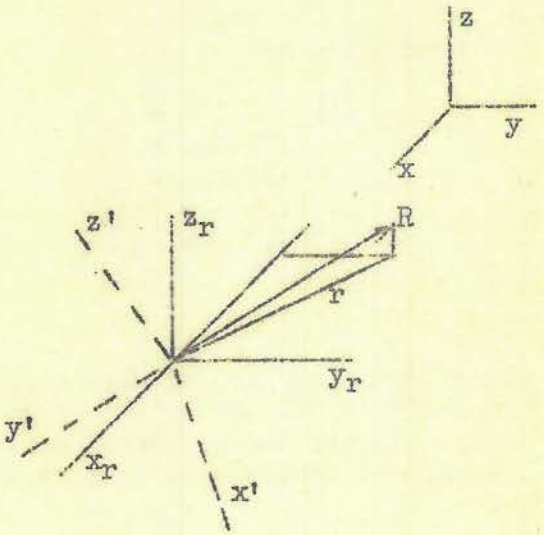
Δx = - 2.169 in.
Δy = + 1.921
Δz = + .453

Rotations:

ϕ_x = + .0166
ϕ_y = + .013
ϕ_z = + .0195

Coordinates of pipe-end:

x' = o, y' = o, z' = 2.625 in.



Scale constants:

K = 26.9, K/s = 119

Reactions at B'
(due to translations)

$R_{x'}$ = + 11.2 lb.
$R_{y'}$ = - 32.35
$R_{z'}$ = + 2.52
$R_{x'y'}$ = - 8.4
$R_{y'z'}$ = + 24.35
$R_{z'x'}$ = + 2.52

Reactions at B'
(due to rotations)

$R_{x'}$ = - 13.30 lb.
$R_{y'}$ = + 22.74
$R_{z'}$ = 0
$R_{x'y'}$ = - 7.0
$R_{y'z'}$ = - 22.4
$R_{z'x'}$ = - 16.10

4. Point B: Connection to No. 4 turbo-generator of superheated steam branch from starboard side main steam line.

End motions:

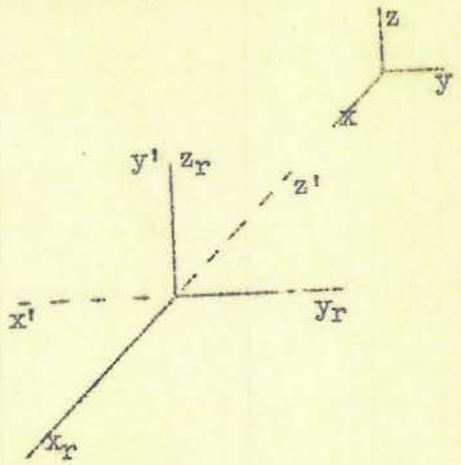
$\Delta x = 0$ in.
$\Delta y = 0$
$\Delta z = 0$

Coordinates of pipe-end:

$x' = 0$, $y' = 0$, $z' = 3.375$ in.

Scale constants:

K = 26.9, K/s = 119



Condition I
Reactions
(due to translations of B')

$R_{x'} = +41.4$ lb.
$R_{y'} = +1.89$
$R_{z'} = -7.7$
$R_{x'y'} = -1.18$
$R_{y'z'} = -1.68$
$R_{z'x'} = +35.55$

Condition II
Reactions
(due to translations of B')

$R_{x'} = +41.7$ lb.
$R_{y'} = +2.38$
$R_{z'} = -6.86$
$R_{x'y'} = -1.54$
$R_{y'z'} = -2.52$
$R_{z'x'} = +36.6$

B. Port Side Main Steam Piping
Note: "Condition I" refers to tests made with no constraint on superheated branch from boiler No. 5; "Condition II" refers to tests made with constraint against horizontal motion caused by tie rod on superheated branch from boiler No. 5, in position shown in Plates 7 and 8 (see paragraph 2a).

1. Point 0: Superheated branch connection to Boiler No. 6.

End motions:

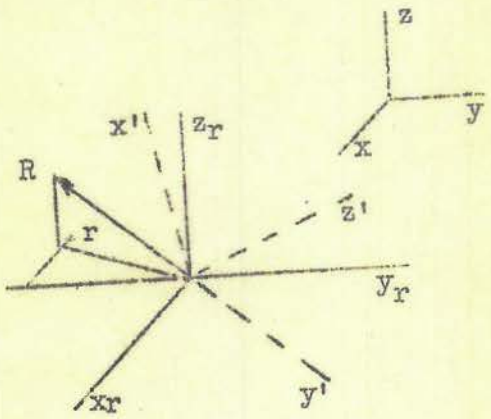
$\Delta x = -.3445$ in.
$\Delta y = -3.466$
$\Delta z = +1.100$

Coordinates of pipe-end:

$x' = 0$, $y' = 0$, $z' = 2.625$ in.

Scale constants:

K = 299, K/s = 2810



Appendix I

Reactions:

Condition I

$R_x' = -3.99$ lb.
$R_y' = -6.37$
$R_z' = +3.64$
$R_{x'y'} = -8.05$
$R_{y'z'} = +3.29$
$R_{z'x'} = -10.85$

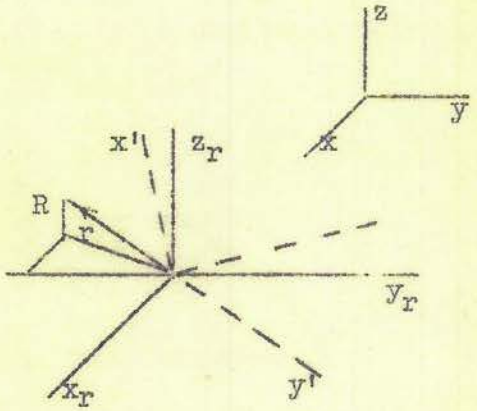
Condition II

$R_x' = +2.17$ lb.
$R_y' = -9.1$
$R_z' = +2.52$
$R_{x'y'} = -11.55$
$R_{y'z'} = +5.32$
$R_{z'x'} = -8.19$

2. Point P: Reactions at superheated branch, connection to boiler No. 5

End motions:

$\Delta x = -.3254$ in.
$\Delta y = -5.490$
$\Delta z = +1.100$



Coordinates of pipe-end:

$x' = o$, $y' = o$, $z' = 2.625$ in.

Scale constants:

K = 299, K/s = 2810

Reactions:
Condition I

$R_x' = +6.37$ lb.
$R_y' = 0$
$R_z' = +3.64$
$R_{x'y'} = -12.6$
$R_{y'z'} = -5.39$
$R_{z'x'} = -6.93$

Condition II

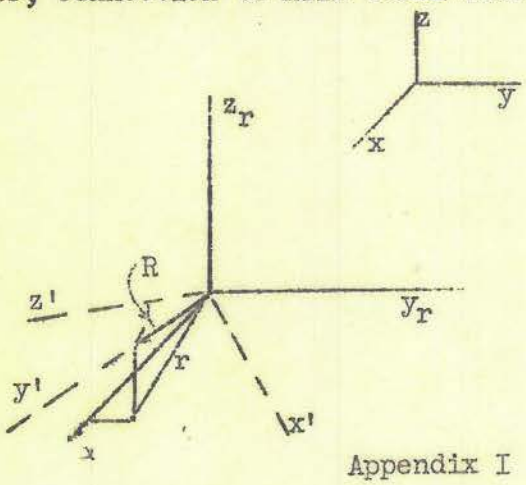
$R_x' = +39.9$ lb.
$R_y' = -8.96$
$R_z' = -5.32$
$R_{x'y'} = -23.1$
$R_{y'z'} = +0.14$
$R_{z'x'} = +18.75$

3. Point L': Superheated branch from port side main steam line to No. 4 turbo-generator, connection to main steam line.

Condition I

End motions:

$\Delta x = +0.7875$ in.
$\Delta y = +0.300$
$\Delta z = +.5595$



Rotations:

$\phi_x = + .0195$
$\phi_y = + .0235$
$\phi_z = + .097$

Coordinates of pipe-end:

$x' = o$, $y' = o$, $z' = +2.625$ in.

Scale Constants:

K = 44.9, K/s = 157.0

Reactions at L'
(due to translations at L')

$R_{x'} = + 12.45$ lb.
$R_{y'} = + 25.35$
$R_{z'} = + 0.35$
$R_{x'y'} = - 5.39$
$R_{y'z'} = - 20.60$
$R_{z'x'} = + 6.09$

Reactions at L'
(due to rotations at L')

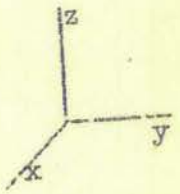
$R_{x'} = + 1.82$ lb.
$R_{y'} = + 2.69$
$R_{z'} = + 0.31$
$R_{x'y'} = - 0.67$
$R_{y'z'} = - 2.07$
$R_{z'x'} = + 1.16$

4. Point L: Superheated branch from port side main steam line to No. 4 turbo-generator, connection to turbo-generator.

Condition I

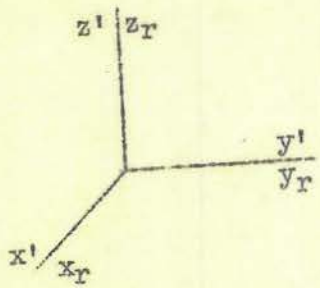
End motions:

$\Delta x = o$ in.
$\Delta y = o$
$\Delta z = o$



Coordinates of pipe-end:

$x' = o$, $y' = o$, $z' = 2.625$ in.



Reactions:
(due to translations at L')

$R_{x'} = - 0.7$ lb.
$R_{y'} = - 9.38$
$R_{z'} = - 2.24$
$R_{x'y'} = - 14.06$
$R_{y'z'} = + 8.54$
$R_{z'x'} = - 9.6$

5. Point Q': Superheated branch from port side main steam line to No. 3 turbo-generator, connection to superheated branch from boiler No. 5.

Condition I

End motions:

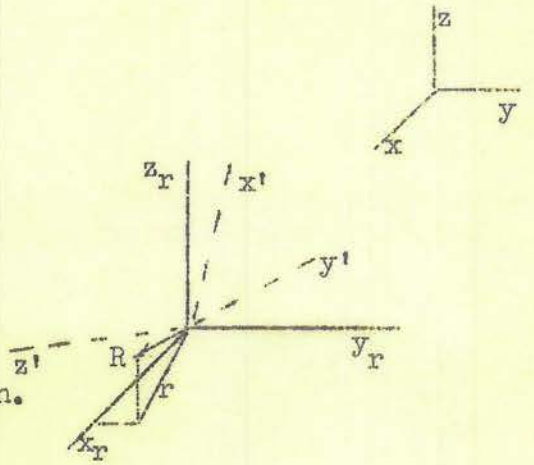
$\Delta x = + 1.920$ in.
$\Delta y = + 0.157$
$\Delta z = + 1.176$

Rotations:

$\phi_x = + .0091$
$\phi_y = + .0222$
$\phi_z = - .00557$

Coordinates of pipe-end:

$x' = o, y' = o, z' = 2.625$ in.



Scale constants:

K = 62.5, K/s = 219

Reactions
(due to translations at Q')

$R_{x'} = - 11.34$ lb.
$R_{y'} = - 9.08$
$R_{z'} = - 1.54$
$R_{x'y'} = + 5.60$
$R_{y'z'} = + 6.72$
$R_{z'x'} = - 5.04$

Reactions
(due to rotations at Q')

$R_{x'} = + 1.89$ lb.
$R_{y'} = + .37$
$R_{z'} = + .035$
$R_{x'y'} = - 1.81$
$R_{y'z'} = - .61$
$R_{z'x'} = + .37$

6. Point Q: Superheated steam branch from port side main steam line to No. 3 turbo-generator, pipe connection to No. 3 turbo-generator.

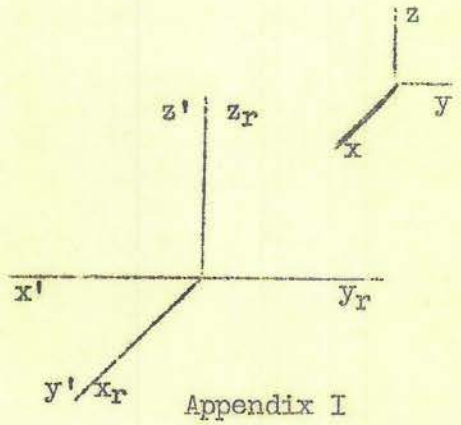
Condition I

End motions:

$\Delta x = \Delta y = \Delta z = o$ in.

Coordinates of pipe-end:

$x' = o, y' = o, z' = 2.625$ in.



Scale constants:

K = 62.5, K/s = 219

Reactions:
(due to translations at Q')

$R_{x'} = +\ 13.85$ lb.
$R_{y'} = -\ 7.54$
$R_{z'} = -\ 0.77$
$R_{x'y'} = -\ 7.28$
$R_{y'z'} = +\ 5.11$
$R_{z'x'} = +\ 5.18$

7. Point I': Superheated steam branch from No. 2 turbo-generator to main steam line, connection to main steam line.

Condition I

End motions:

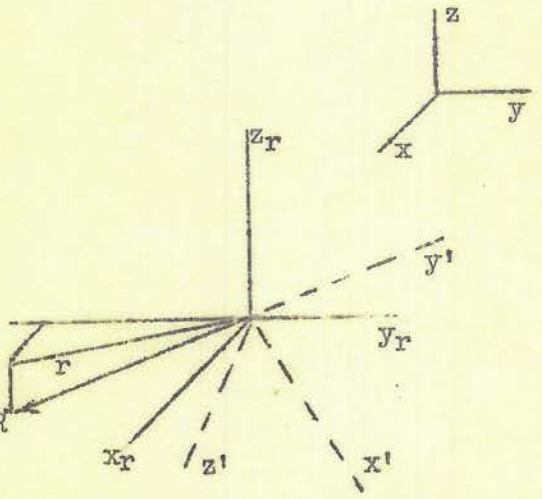
$\Delta x = +\ 0.157$ in.
$\Delta y = -\ 3.039$
$\Delta z = -\ 0.538$

Rotations:

$\phi_x = +\ .018$
$\phi_y = -\ .00865$
$\phi_z = -\ .00278$

Coordinates of pipe-end:

x' = o, y' = o, z' = 2.625 in.



Scale constants:

K = 98, K/s = 343

Reactions
(due to translations at I')

$R_{x'} = +\ 0.56$ lb.
$R_{y'} = -\ 28.75$
$R_{z'} = +\ 0.14$
$R_{x'y'} = -\ 1.4$
$R_{y'z'} = +\ 23.85$
$R_{z'x'} = -\ 0.84$

Reactions
(due to rotations at I')

$R_{x'} = +\ 1.40$ lb.
$R_{y'} = -\ .108$
$R_{z'} = -\ .162$
$R_{x'y'} = -\ .108$
$R_{y'z'} = +\ .081$
$R_{z'x'} = +\ .943$

8. Point I: Superheated steam branch from No. 2 turbo-generator to main steam line, pipe connection to No. 2 turbo-generator.

Condition I

End motions:

$\Delta x = \Delta y = \Delta z = 0$ in.

Coordinates of pipe-end:

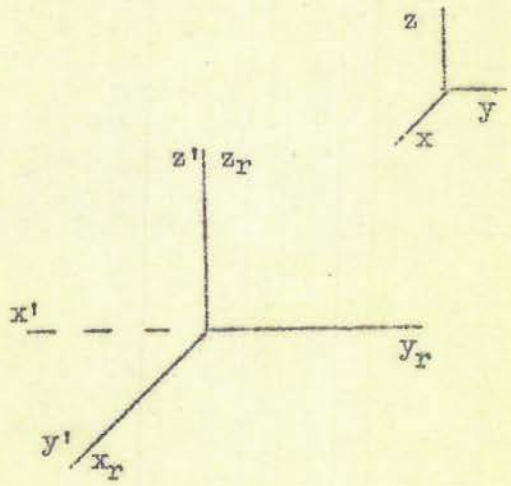
$x' = 0$, $y' = 0$, $z' = 2.625$ in.

Scale constants:

K = 98, K/s = 343

Reactions:
(due to translations at I')

$R_{x'} = -5.74$ lb.
$R_{y'} = -0.63$
$R_{z'} = +0.84$
$R_{x'y'} = -2.24$
$R_{y'z'} = +0.21$
$R_{z'x'} = -3.71$



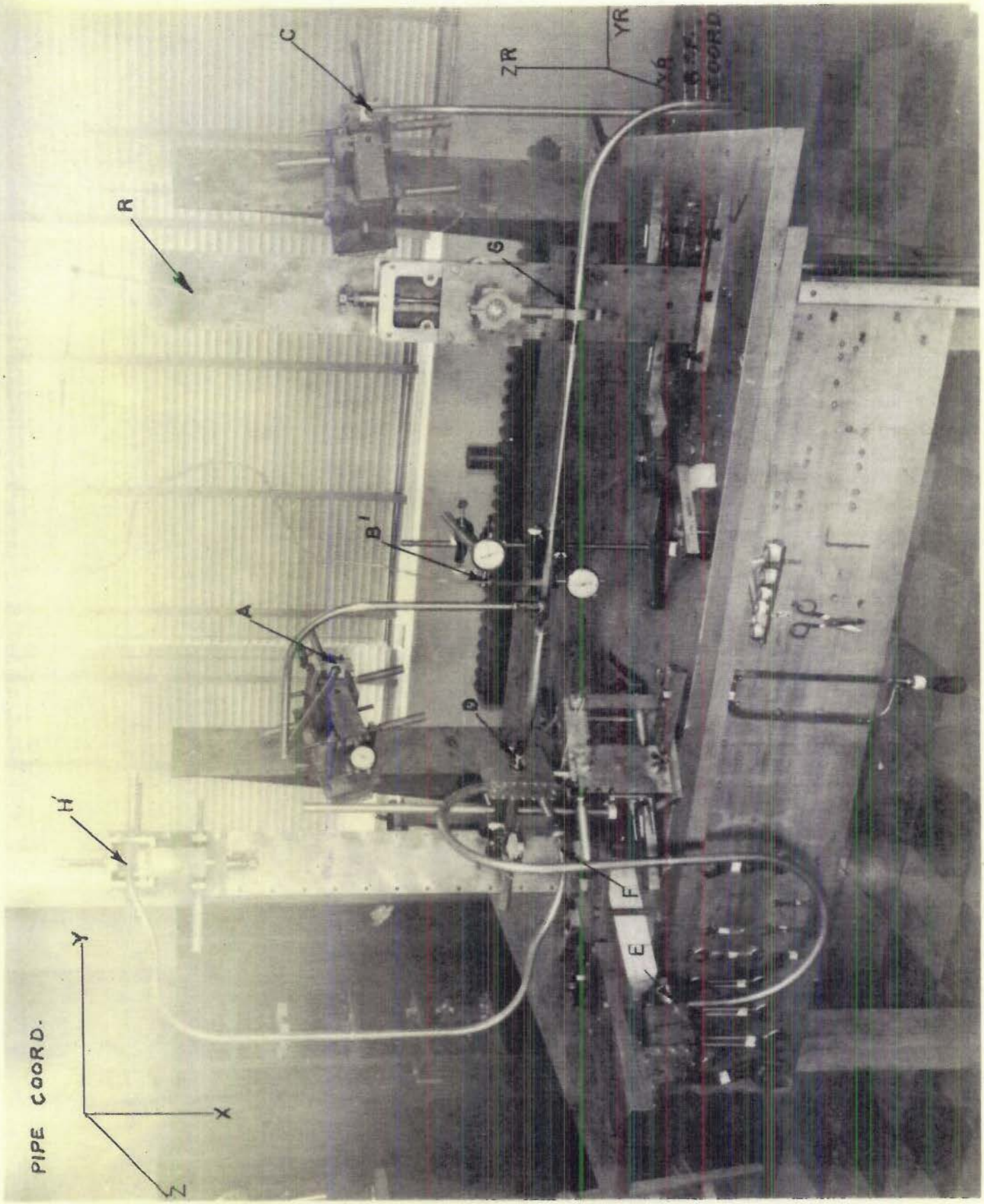


PLATE I

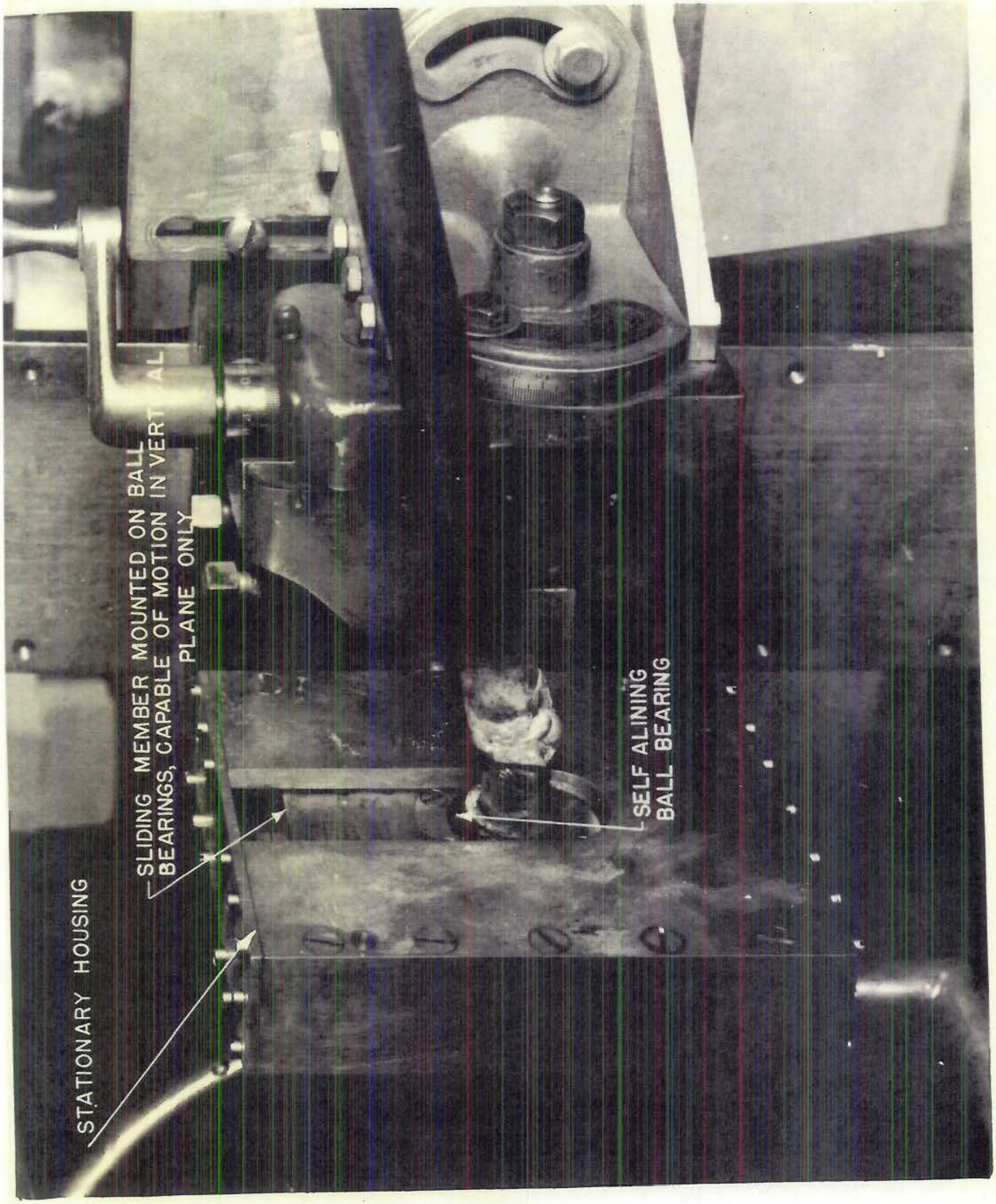


PLATE 2

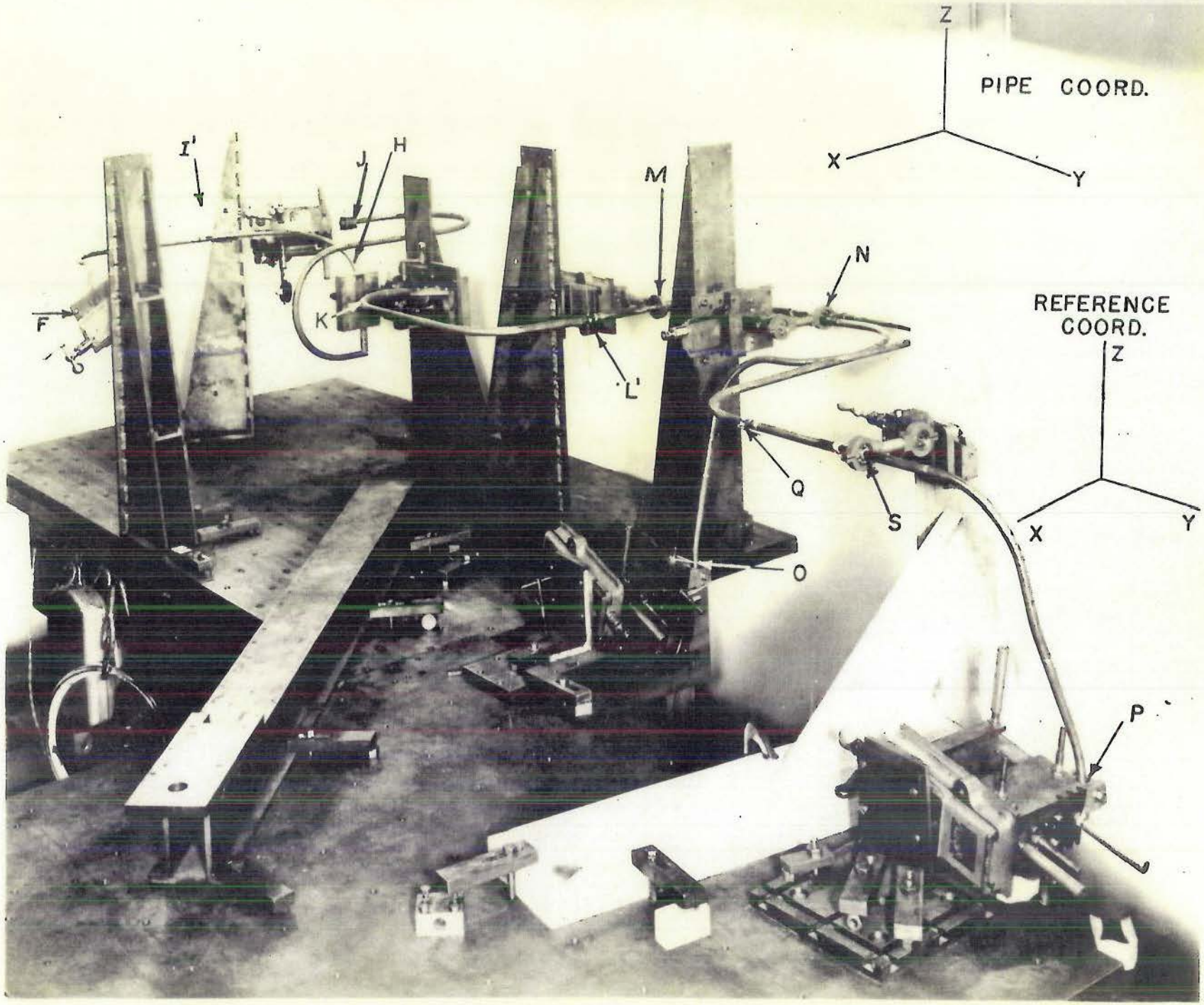


PLATE 3

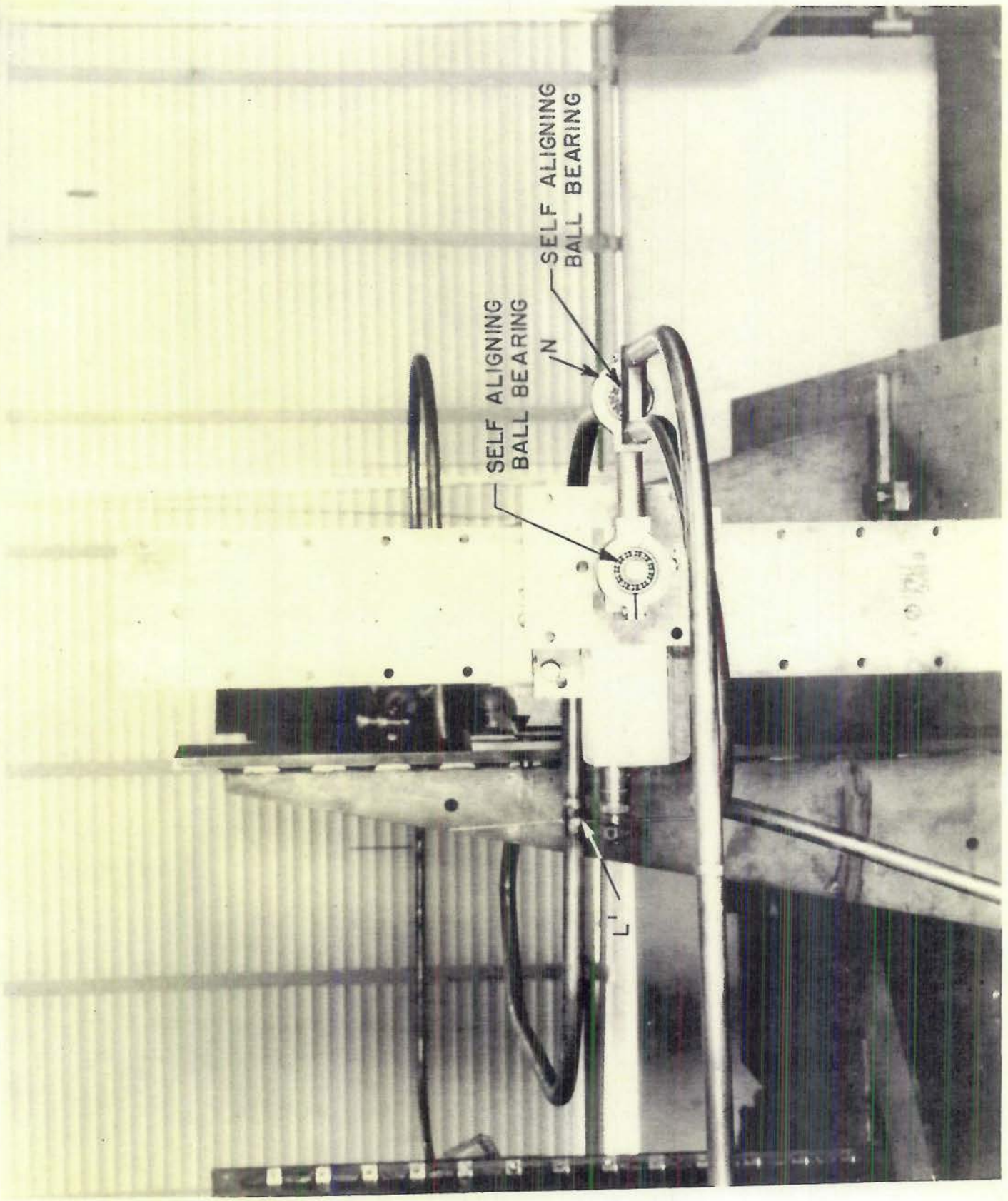
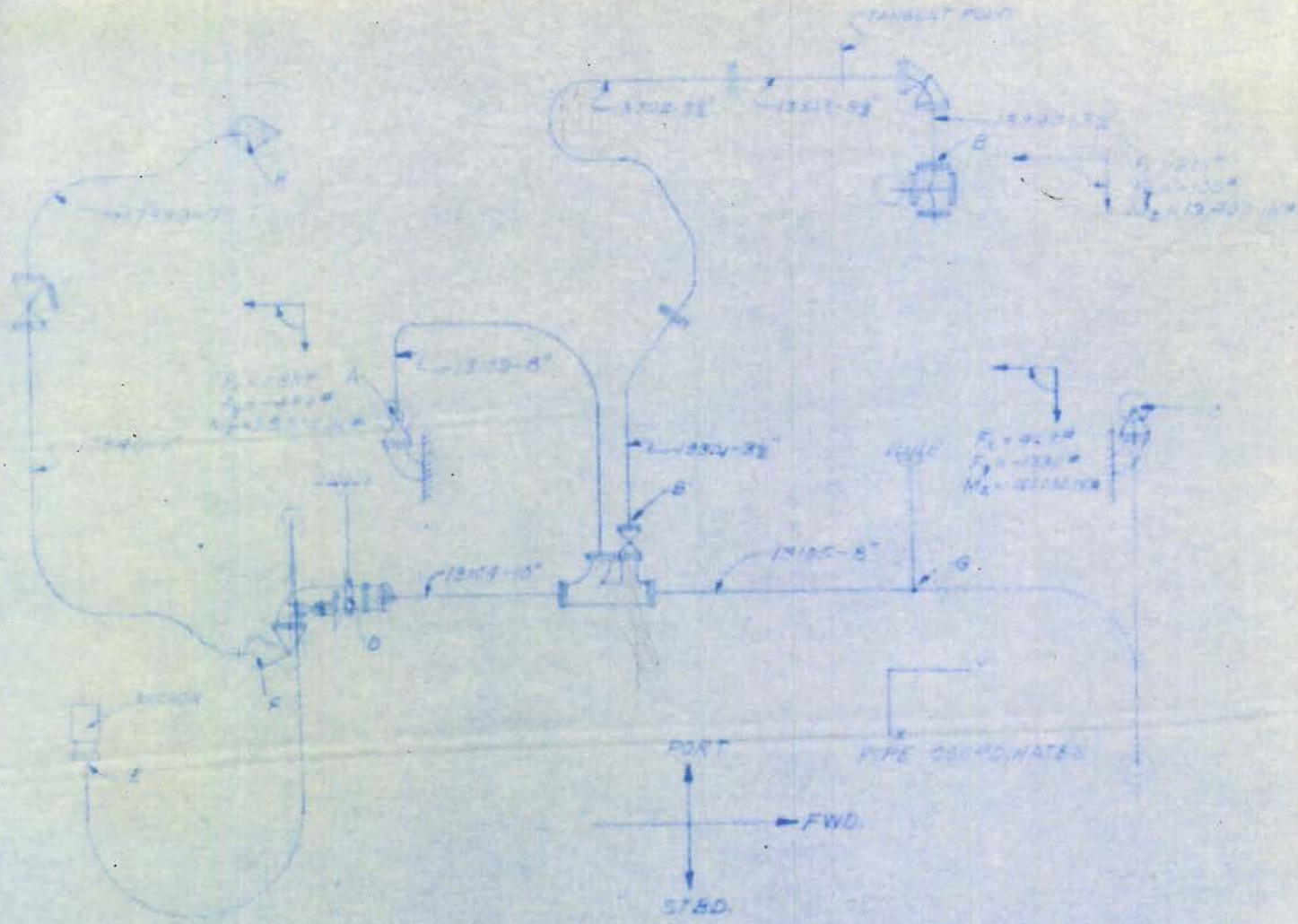
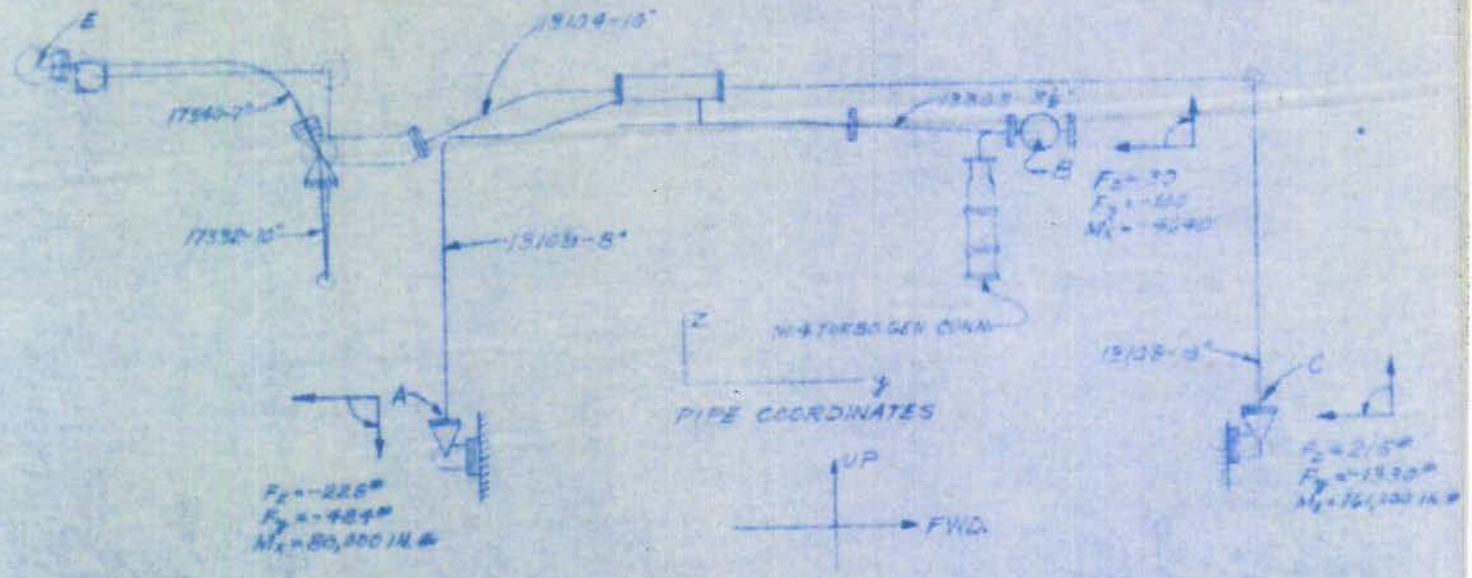


PLATE 4

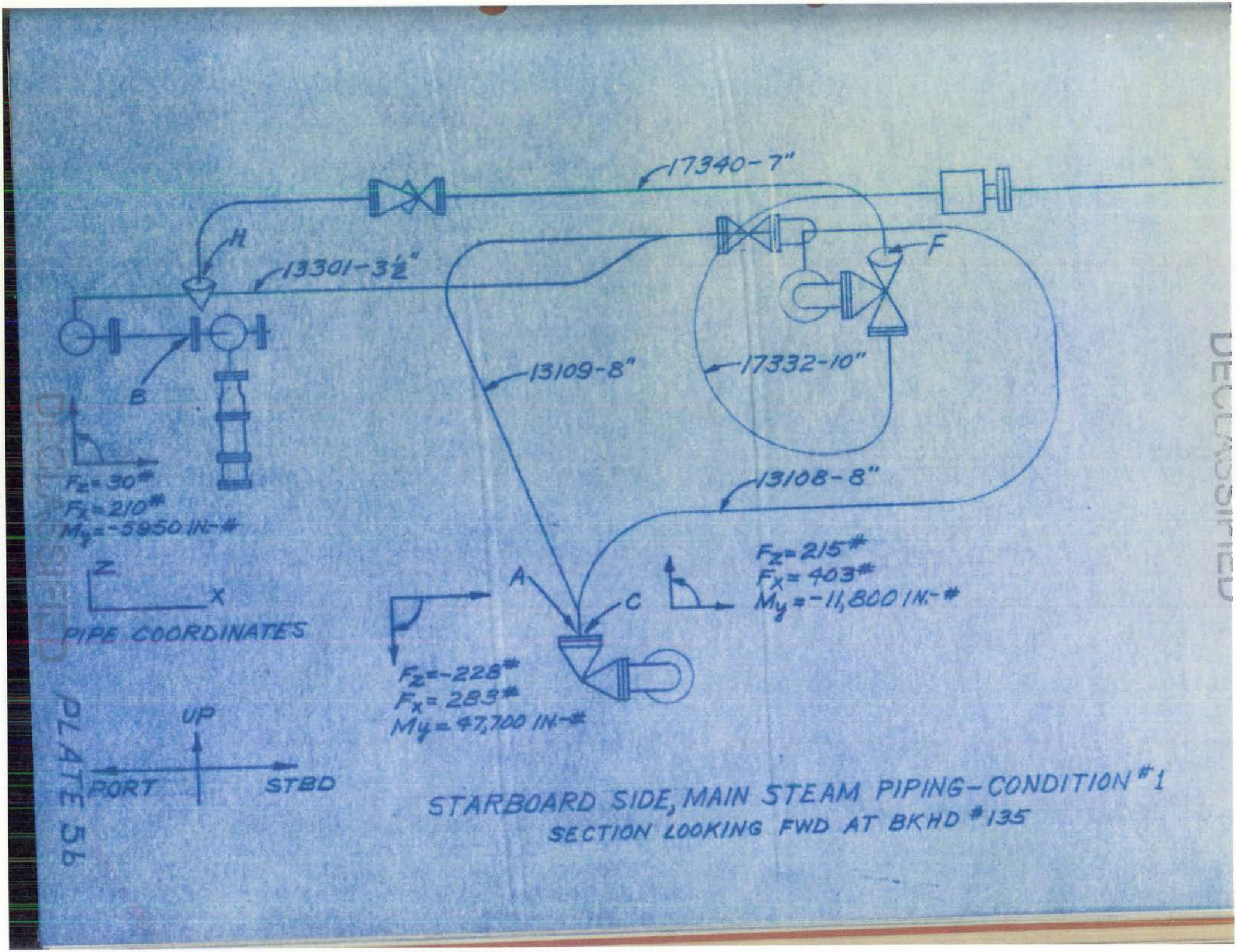


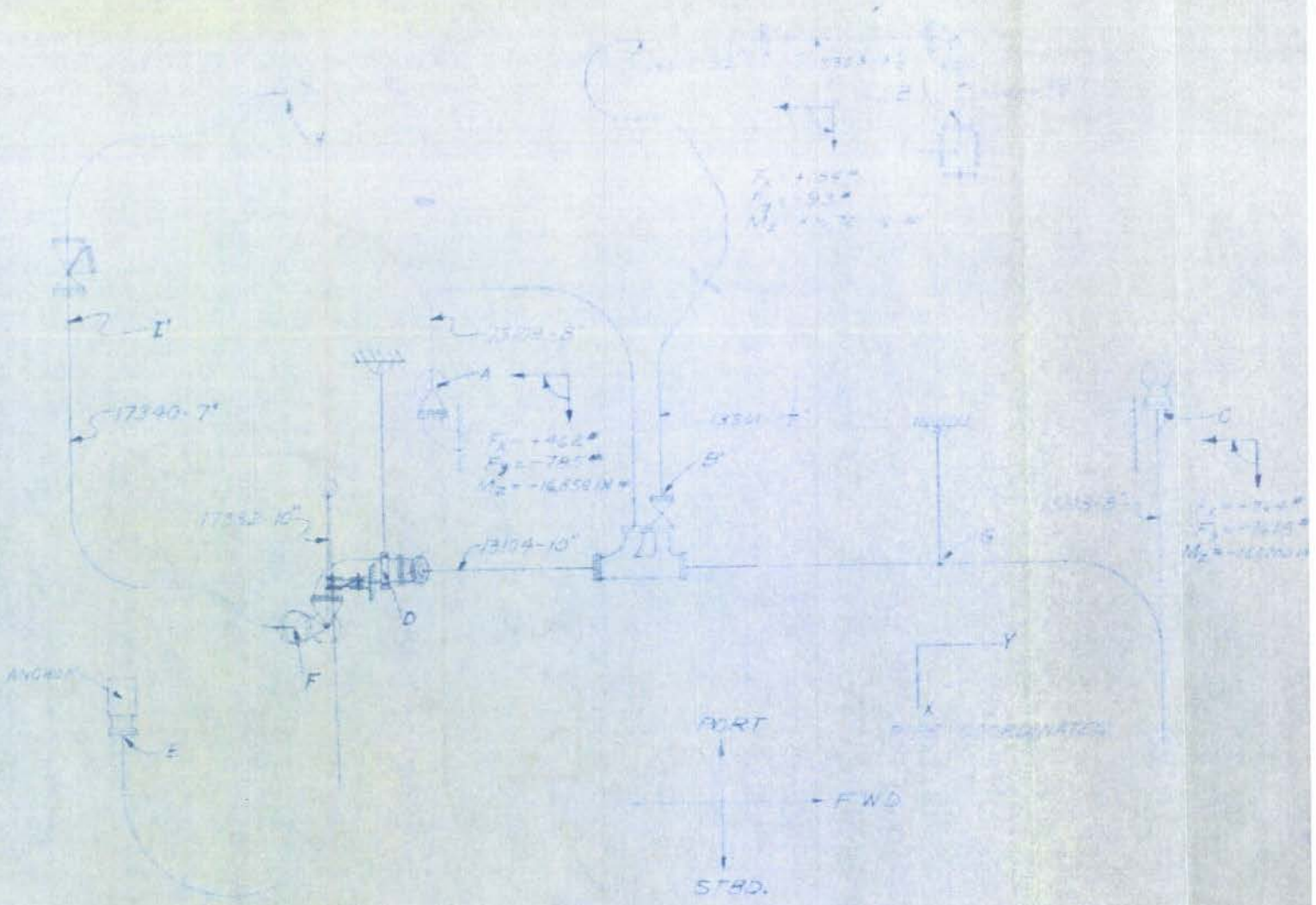
STARBOARD SIDE, MAIN STEAM PIPING - CONDITION #1



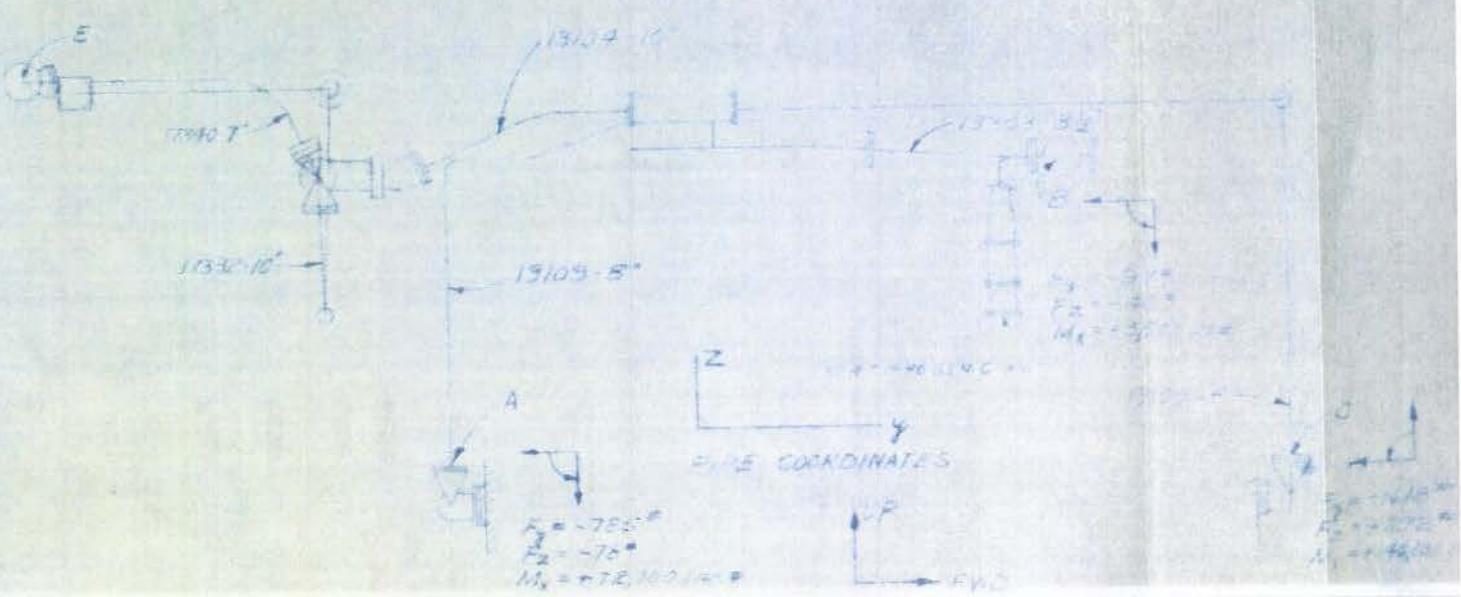
STARBOARD SIDE, MAIN STEAM PIPING - CONDITION #1
ELEVATION LOOKING TO PORT

PLATE 5a


17340-7"
H
13301-3½"
F
B
13109-8"
17332-10"
13108-8"
F_z = 30#
F_x = 210#
M_y = -5950 IN-#
Z
X
PIPE COORDINATES
A
C
F_z = 215#
F_x = 403#
M_y = -11,800 IN-#
F_z = -228#
F_x = 283#
M_y = 47,700 IN-#
UP
PORT
STBD
PLATE 5b
STARBOARD SIDE, MAIN STEAM PIPING - CONDITION #1
SECTION LOOKING FWD AT BKHD #135
DECLASSIFIED
DECLASSIFIED

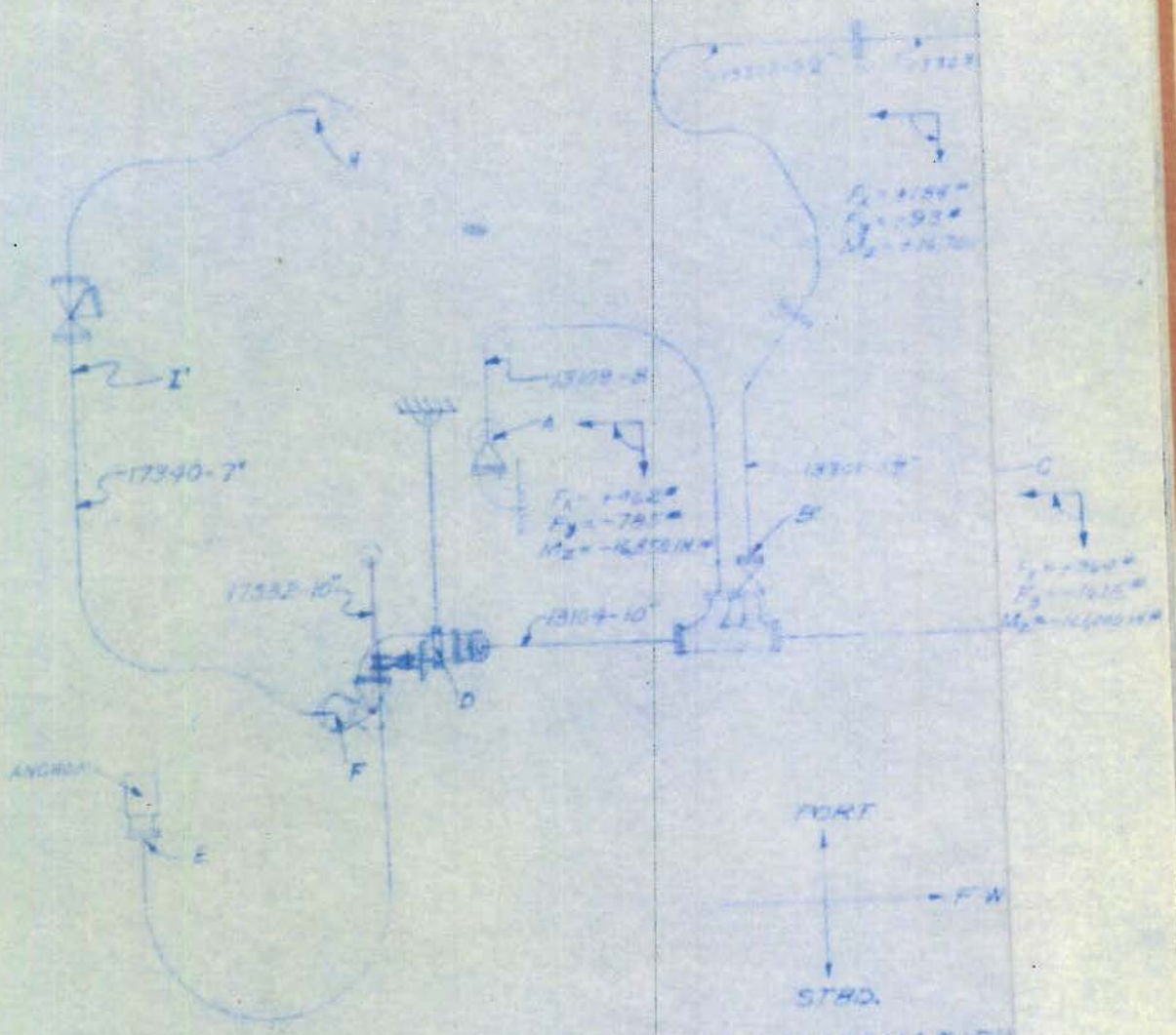


STARBOARD SIDE, MAIN STEAM PIPING-CONDITION #2

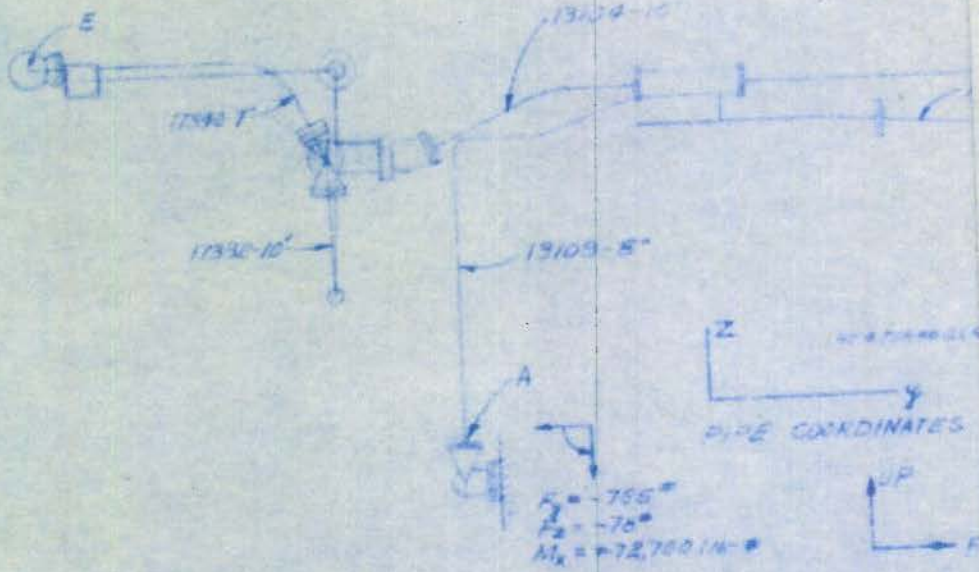


STARBOARD SIDE, MAIN STEAM PIPING-CONDITION #2
ELEVATION

PLATE 60

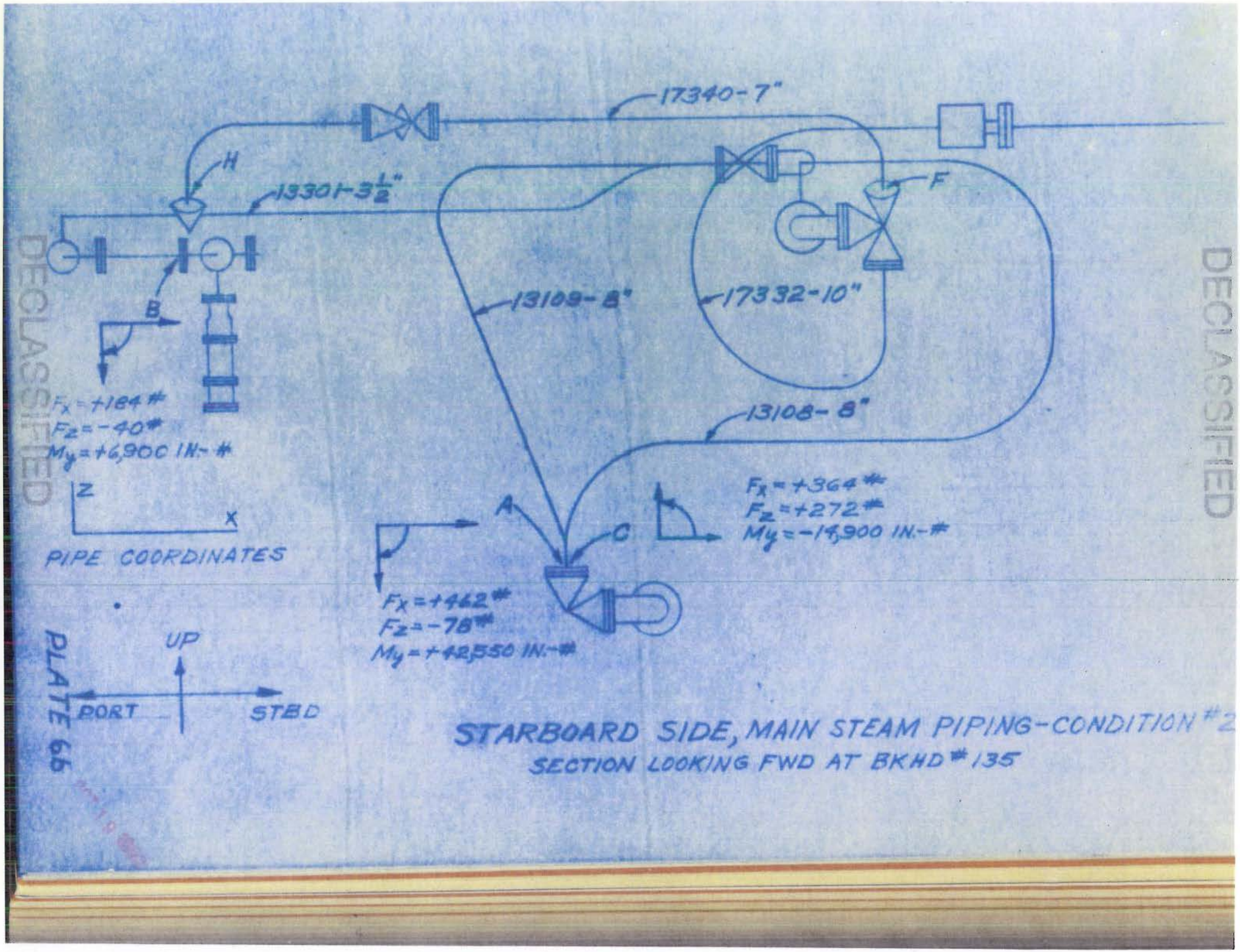


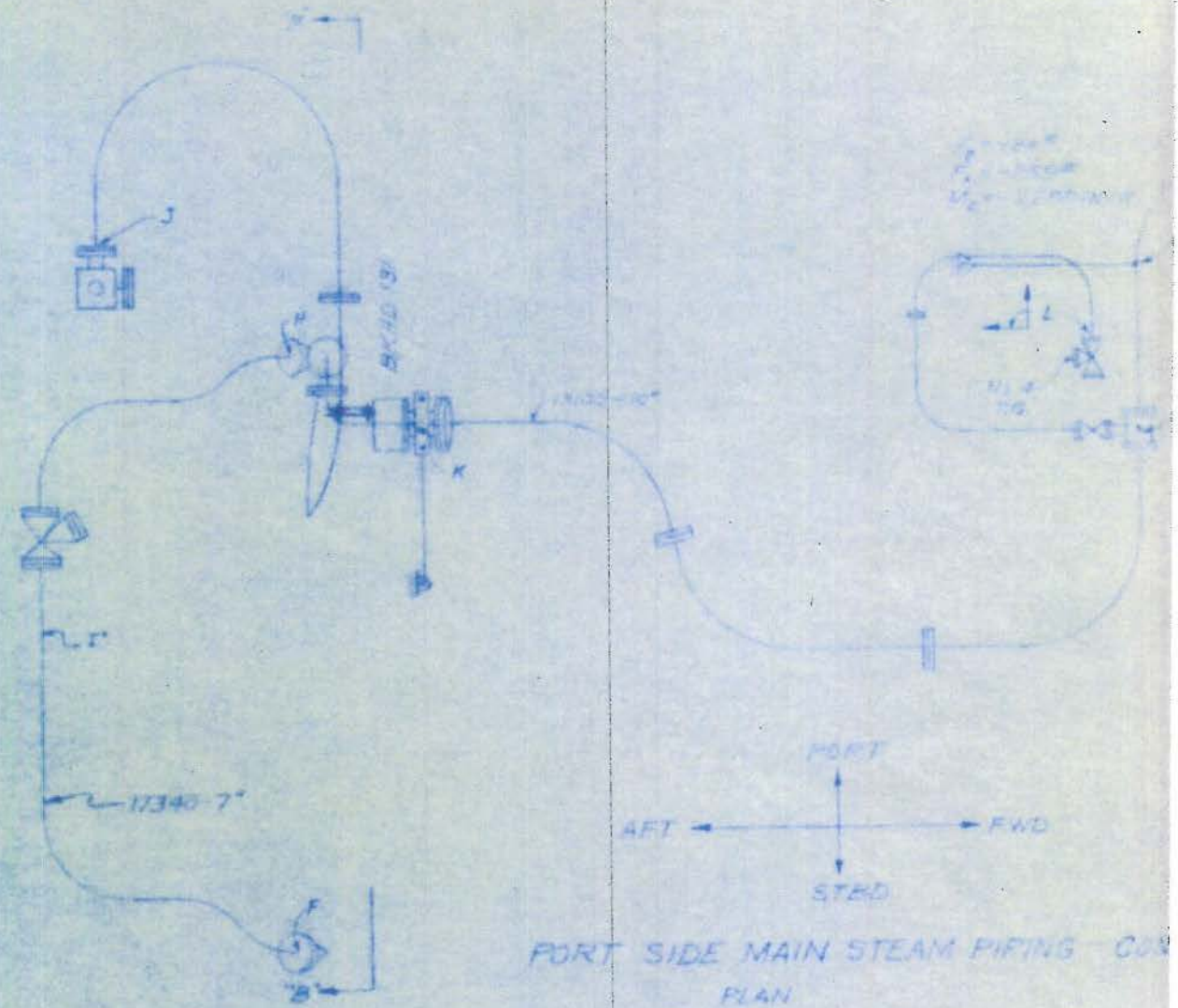
STARBOARD SIDE, MAIN STEAM PIPING



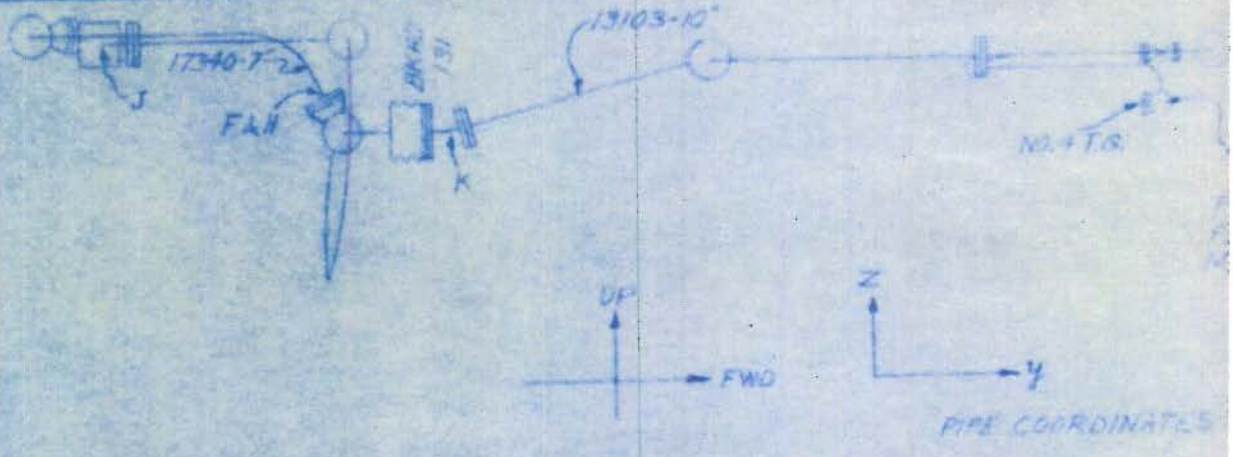
STARBOARD SIDE, MAIN STEAM PIPING
ELEVATION

PLATE 60


17340-7"
H
13301-3½"
F
B
13109-8"
17332-10"
13108-8"
Fx = +184 #
Fz = -40 #
My = +6,900 IN.-#
Z
X
PIPE COORDINATES
A
C
Fx = +364 #
Fz = +272 #
My = -14,900 IN.-#
Fx = +462 #
Fz = -78 #
My = +42,550 IN.-#
UP
PORT
STBD
PLATE 66
STARBOARD SIDE, MAIN STEAM PIPING - CONDITION #2
SECTION LOOKING FWD AT BKHD #135
DECLASSIFIED
DECLASSIFIED

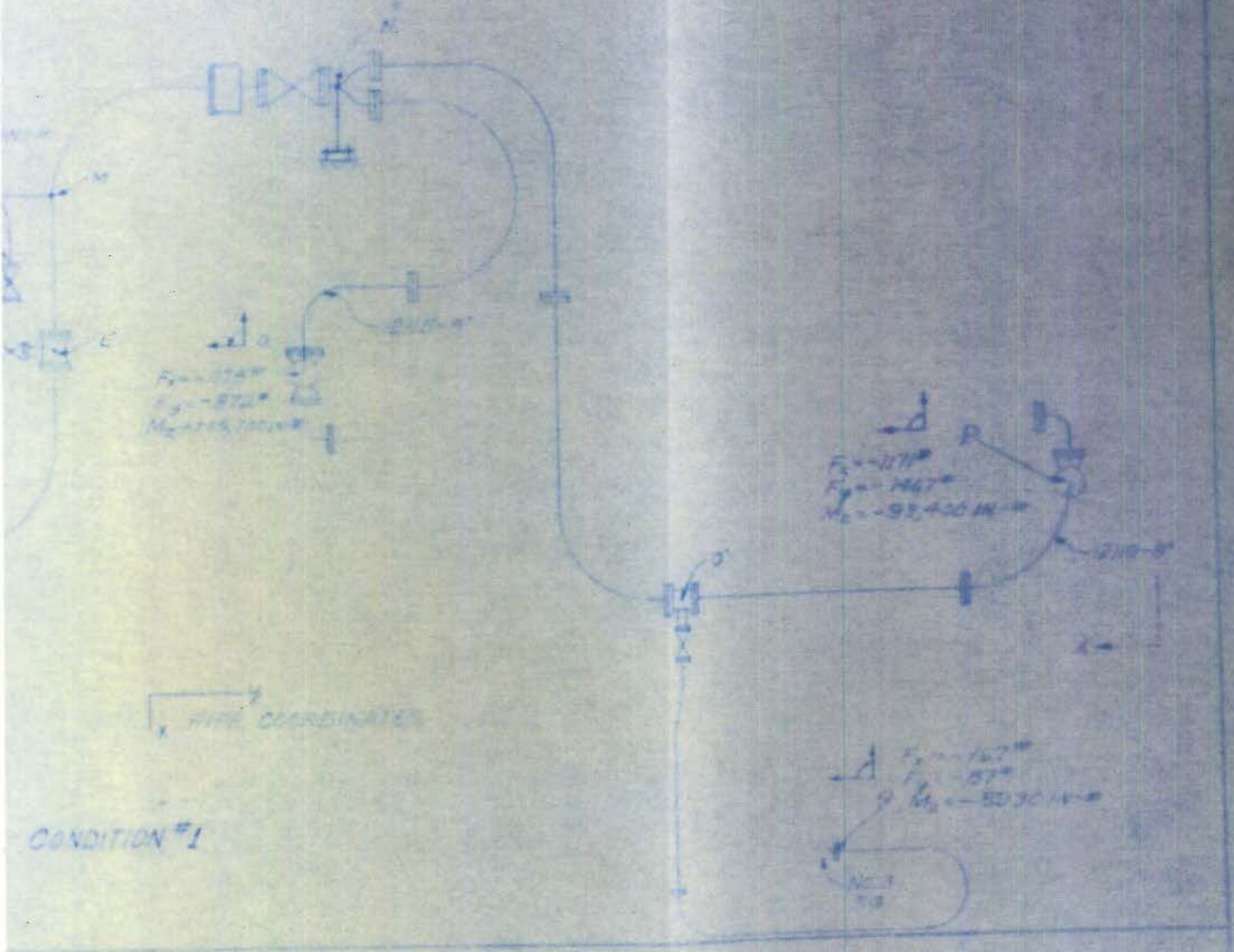


PORT SIDE MAIN STEAM PIPING
PLAN



PIPE COORDINATES

PORTSIDE MAIN STEAM PIPING
ELEVATION LOOKING TO PORT



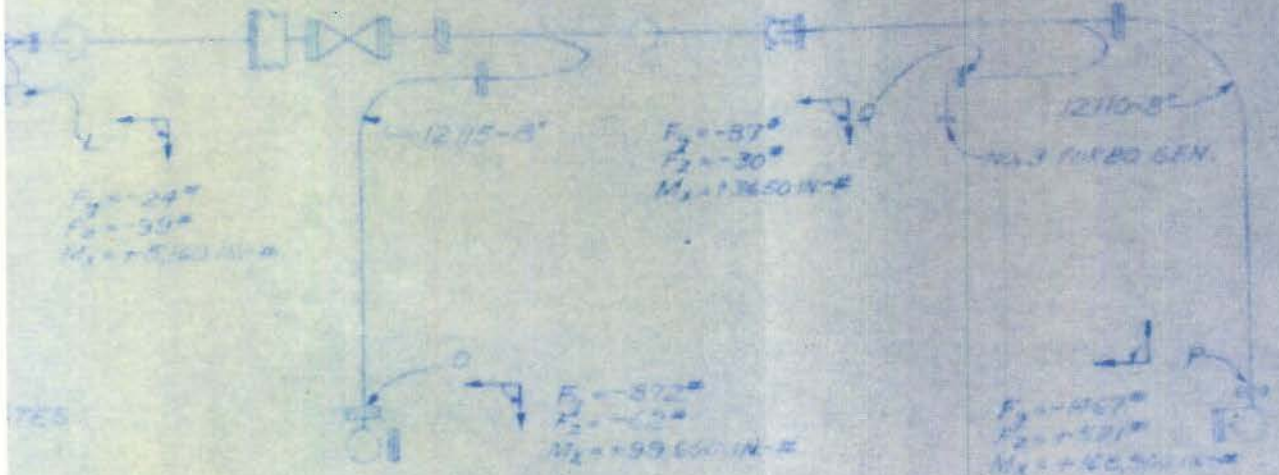
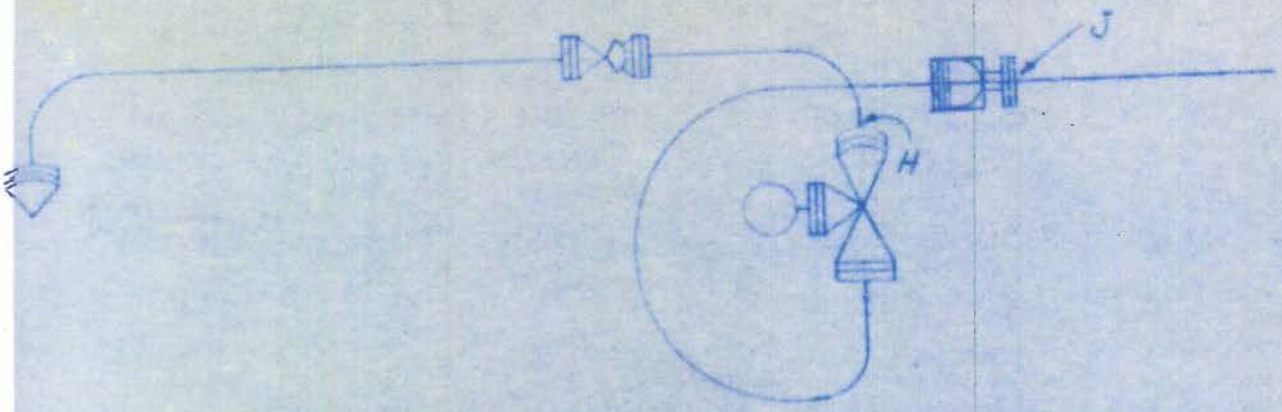
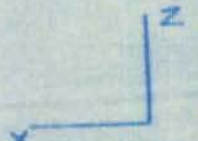


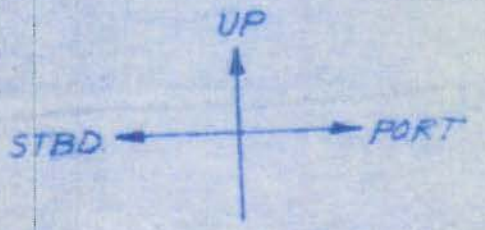
PLATE 7a



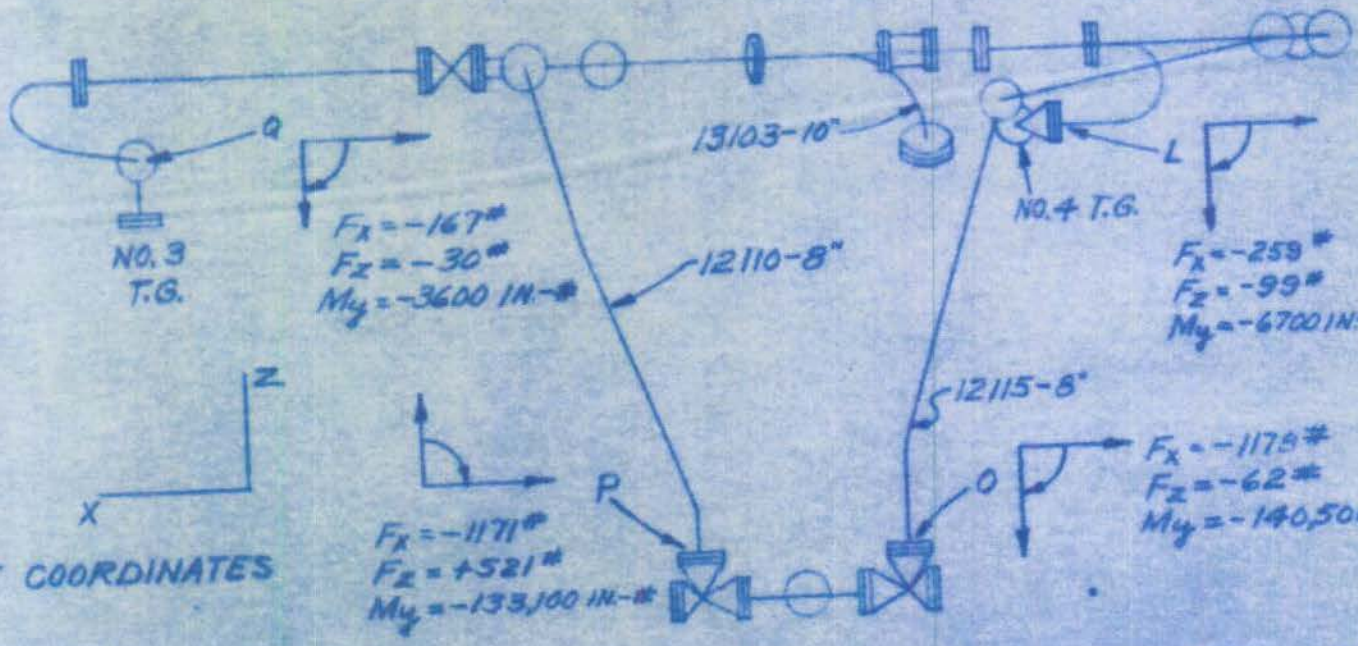
SECTION "B-B"



PIPE COORDINATES



PORT SIDE MAIN STEAM PIPING
ELEVATION LOOKING AFT FROM BKHD 131

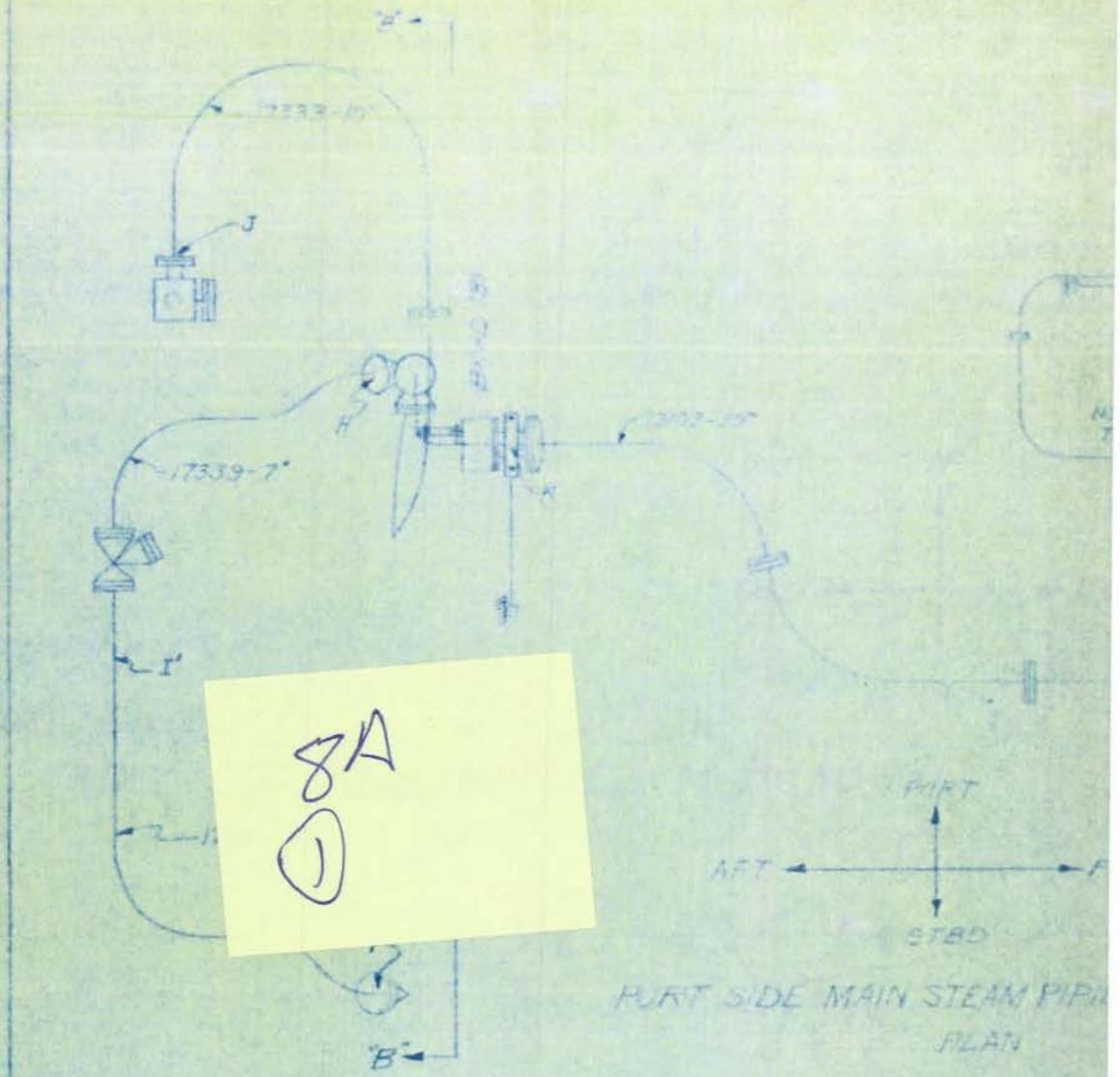


E COORDINATES

PORT SIDE MAIN STEAM PIPING
ELEVATION LOOKING AFT FROM BKHD III TO 131-CONDITION #1

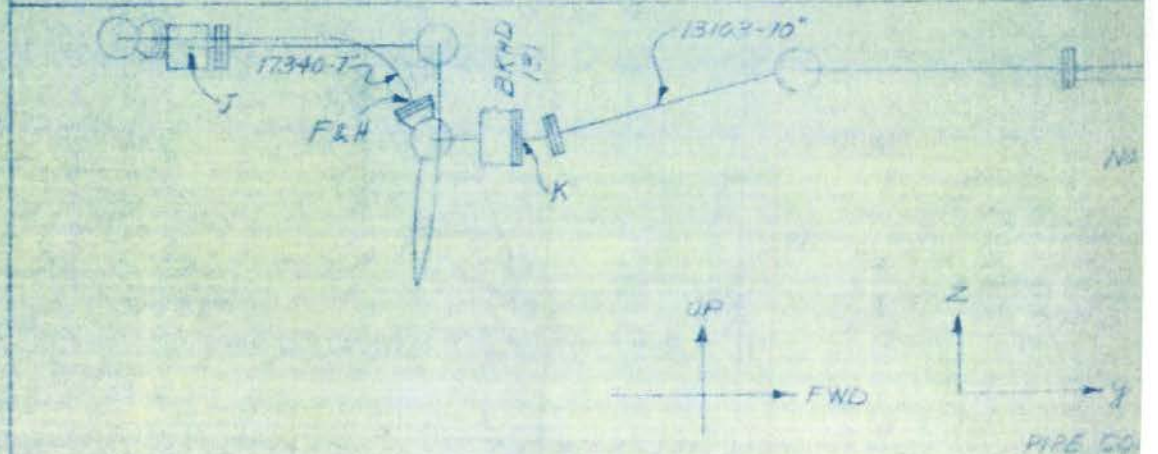
PLATE 76

VIEW "A-A"

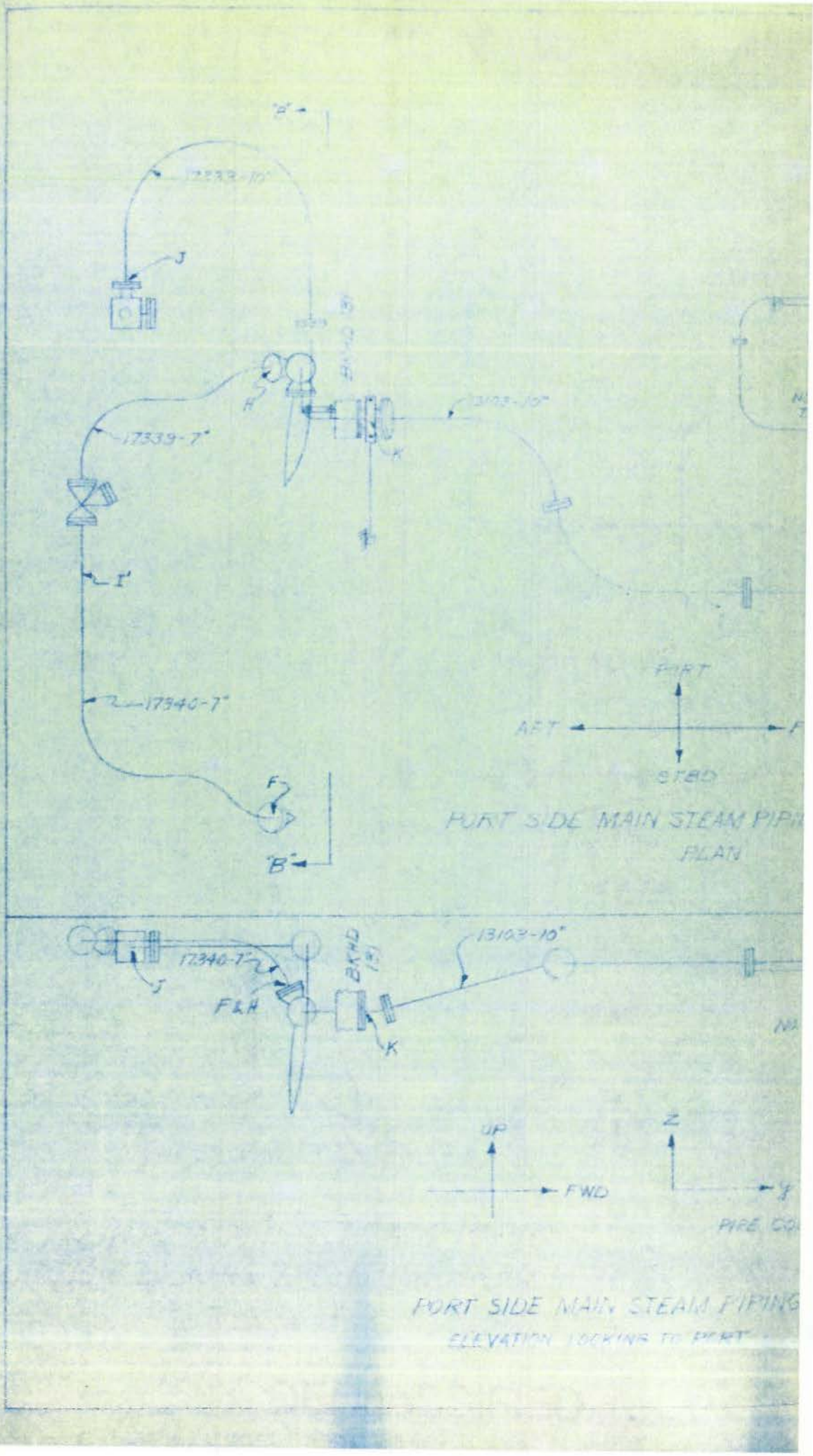


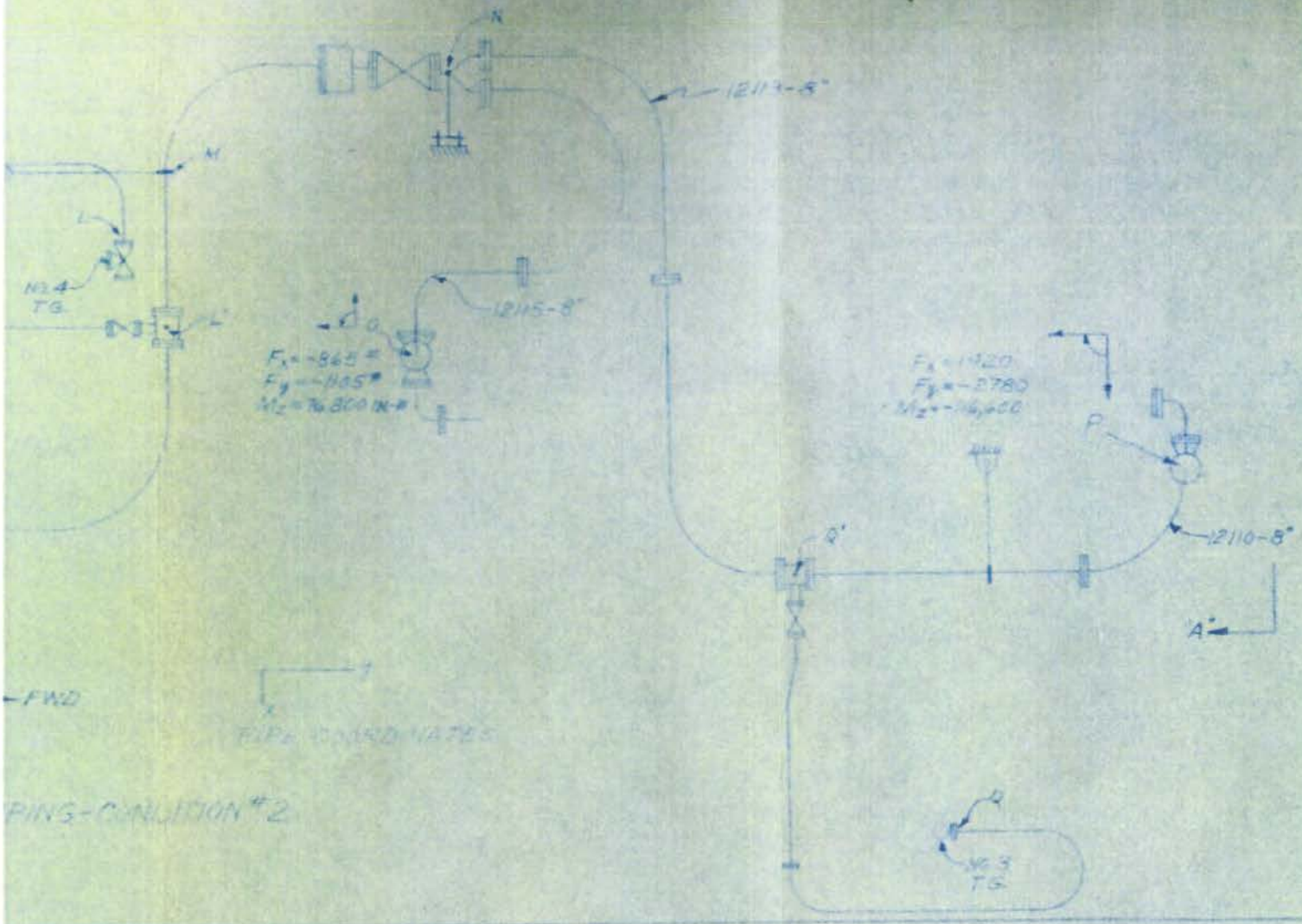
8A
(1)

PORT SIDE MAIN STEAM PIPI
PLAN



PORT SIDE MAIN STEAM PIPING
ELEVATION LOOKING TO


"A"
17339-10"
J
H
17339-7"
I
17340-7"
"B"
K
AFT
PORT
STBD
PORT SIDE MAIN STEAM PIPI
PLAN
17340-7"
J
F&H
K
13103-10"
UP
FWD
Z
Y
PIPE CO
PORT SIDE MAIN STEAM PIPING
ELEVATION LOOKING TO PORT



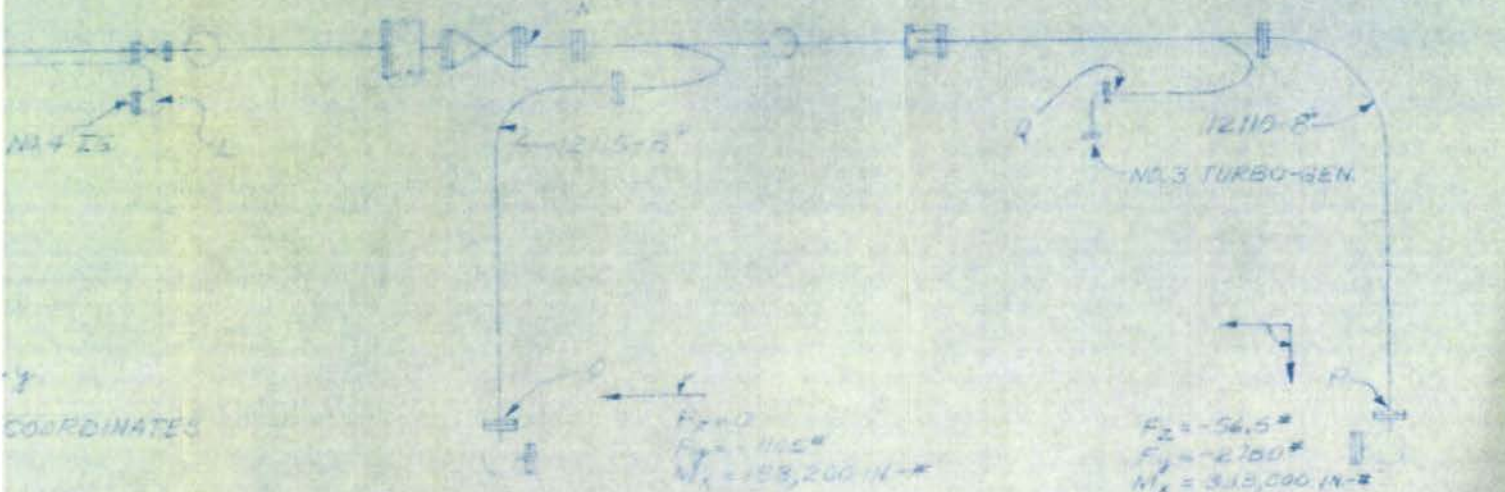
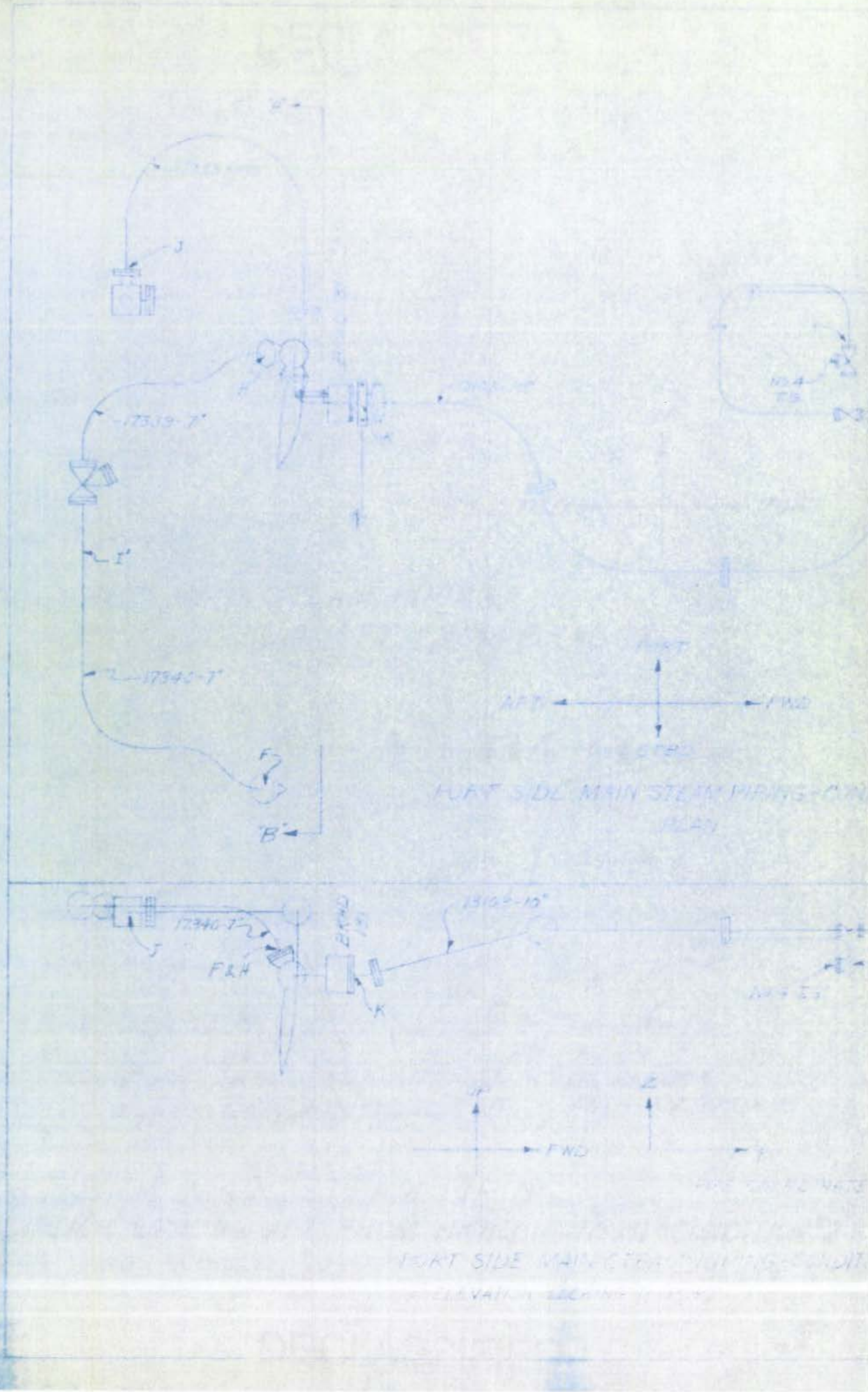
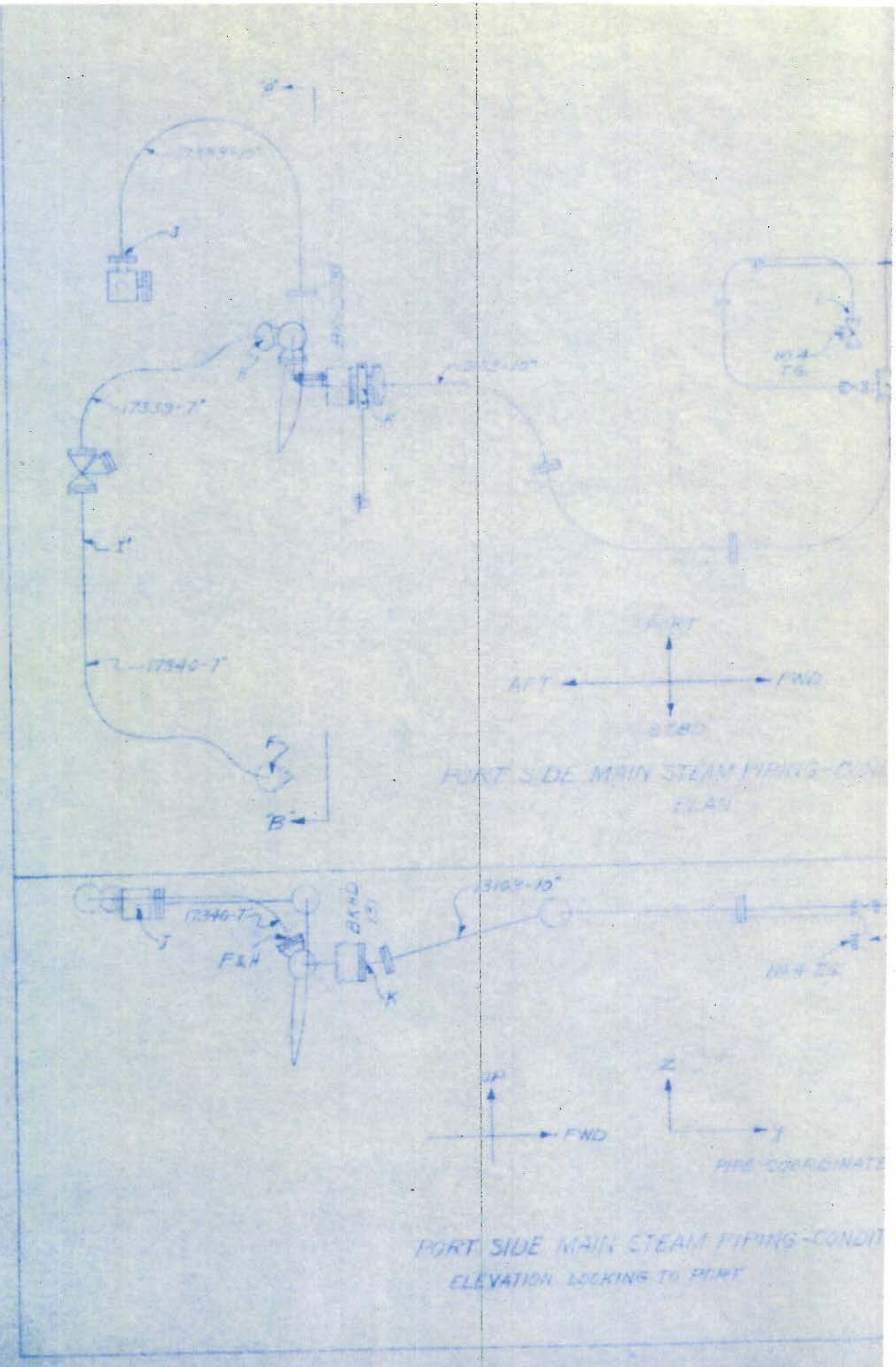


PLATE 6a



J
-17339-7"
I"
-17345-7"
B
PORT
AFT
FWD
PORT SIDE MAIN STEAM PIPING-CON
PLAN
17340-7"
J
F&H
K
FWD



PORT
AFT
FWD
STBD
UP
FWD
PIPE COORDINATE
PORT SIDE MAIN STEAM PIPING-CONDIT
ELEVATION LOOKING TO PORT

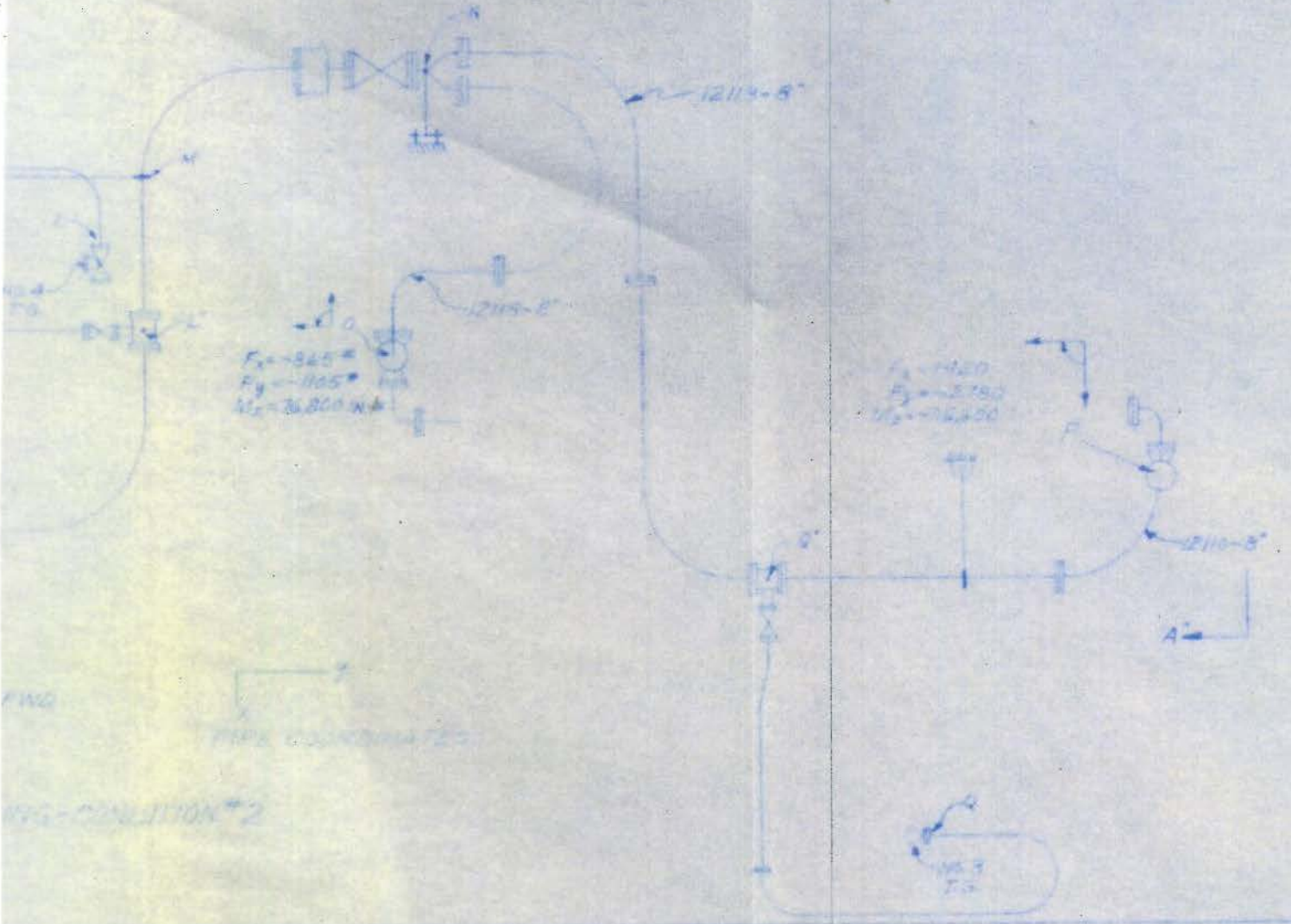
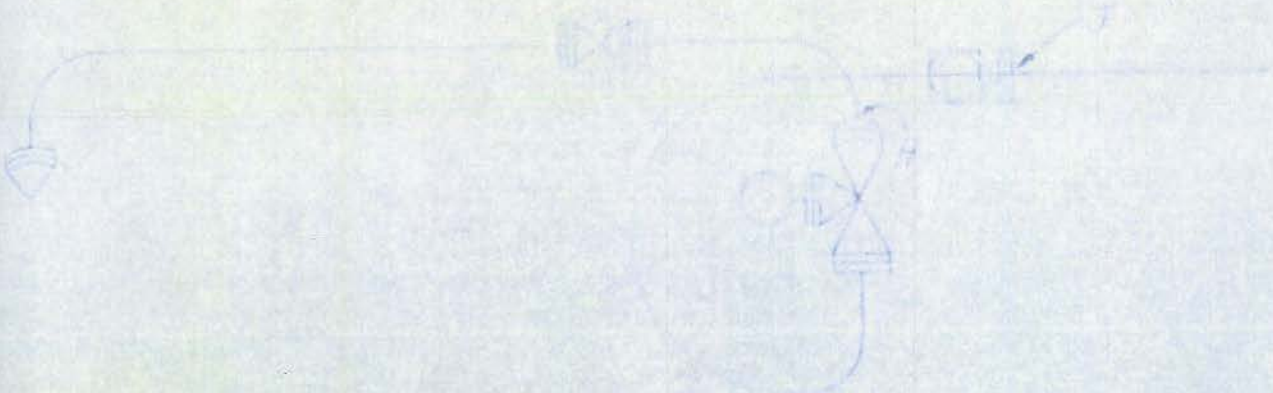
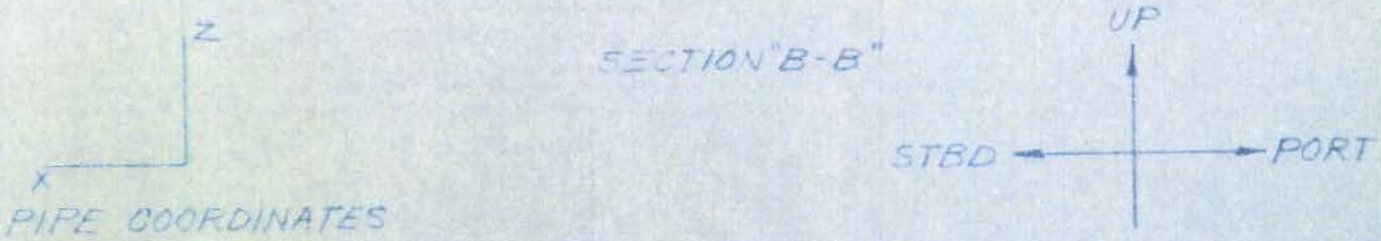
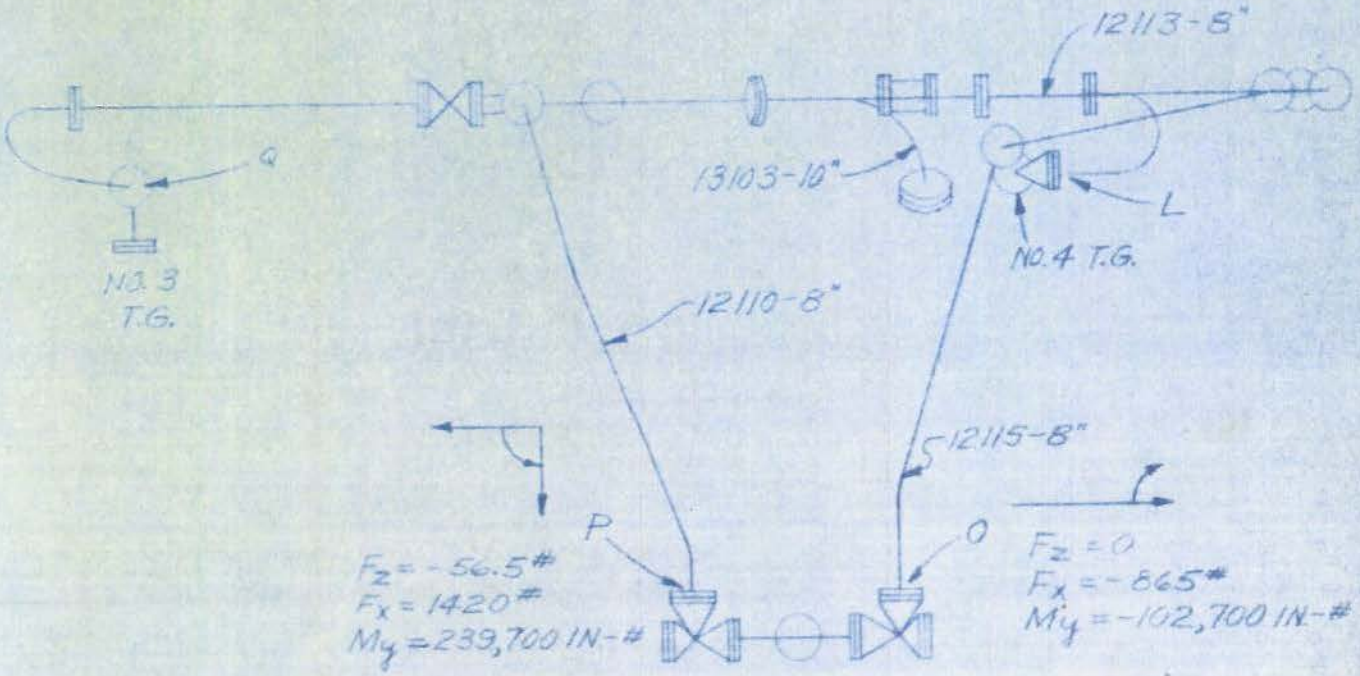


PLATE 8a





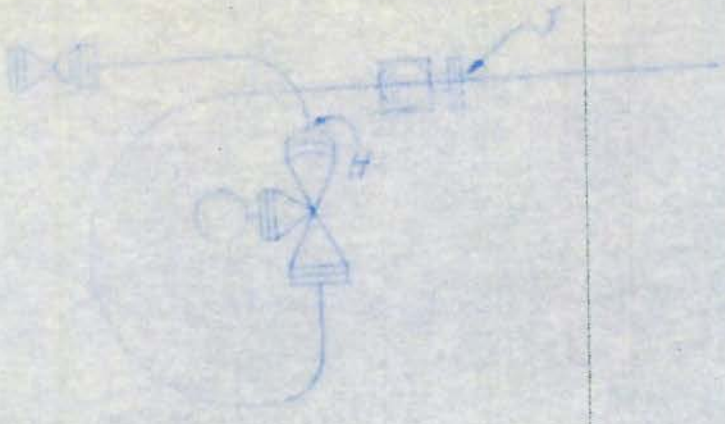
PORT SIDE MAIN STEAM PIPING
ELEVATION LOOKING AFT FROM BKHD 131



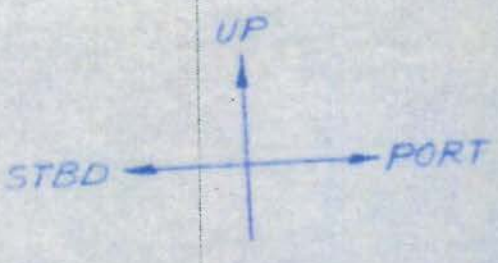
PORT SIDE MAIN STEAM PIPING
ELEVATION LOOKING AFT FROM BKHD 111 TO 131 - CONDITION #2

VIEW "A-A"

PLATE 86

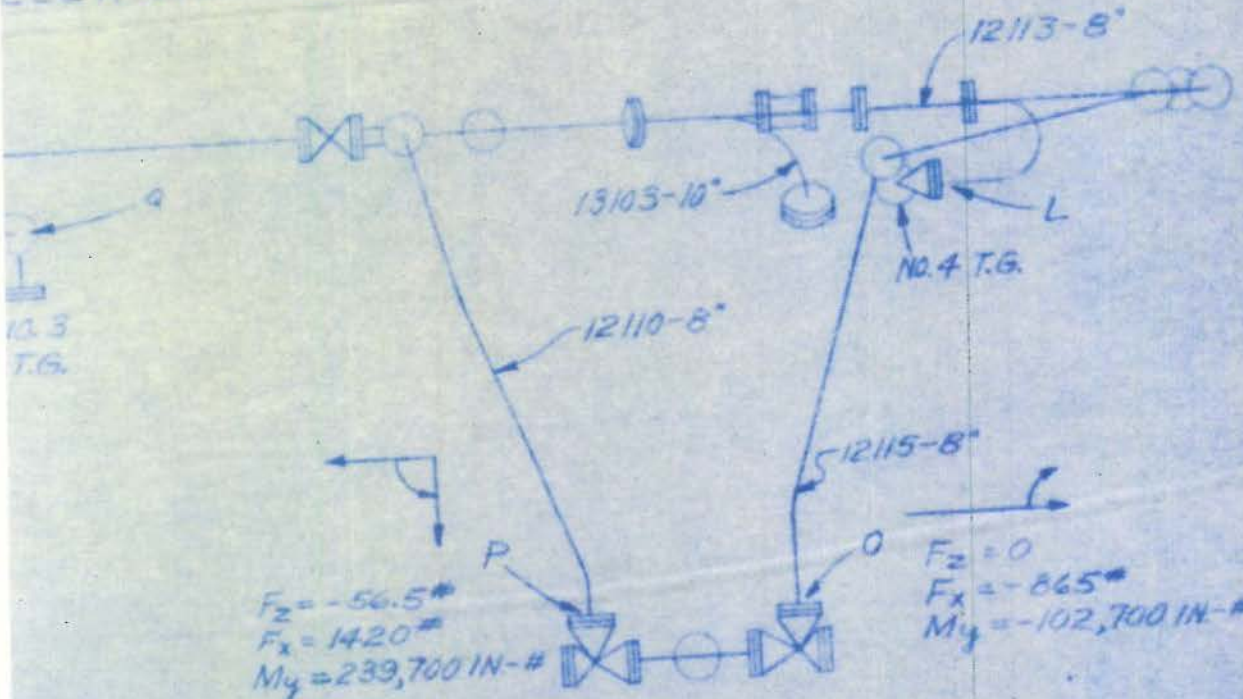


SECTION "B-B"



COORDINATES

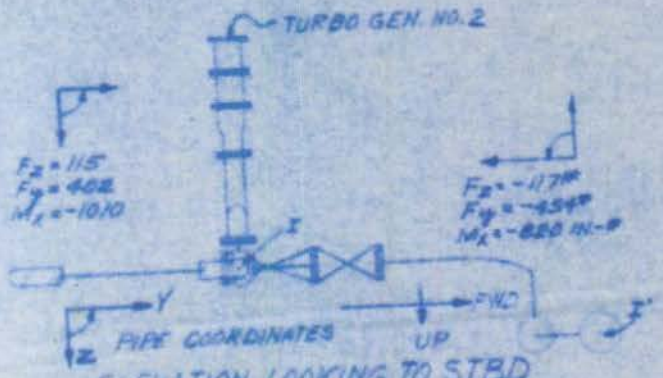
PORT SIDE MAIN STEAM PIPING
ELEVATION LOOKING AFT FROM BKHD 131



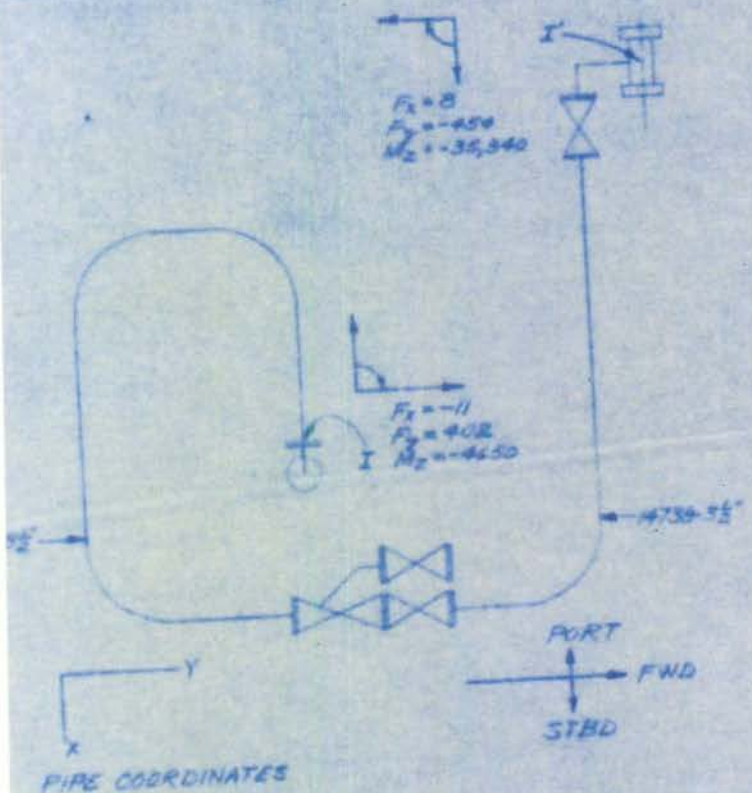
PORT SIDE MAIN STEAM PIPING
ELEVATION LOOKING AFT FROM BKHD 111 TO 131 - CONDITION #2

VIEW "A-A"

PLATE 86



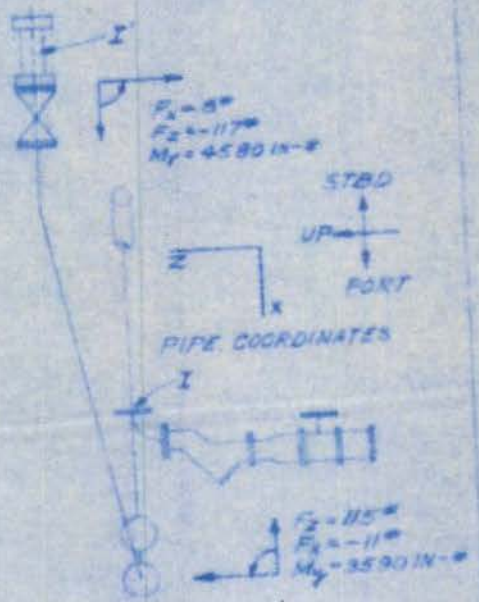
ELEVATION LOOKING TO STBD



SUPERHEATED STEAM BRANCH
FROM TURBO-GEN. NO.2 TO MAIN STEAM LINE

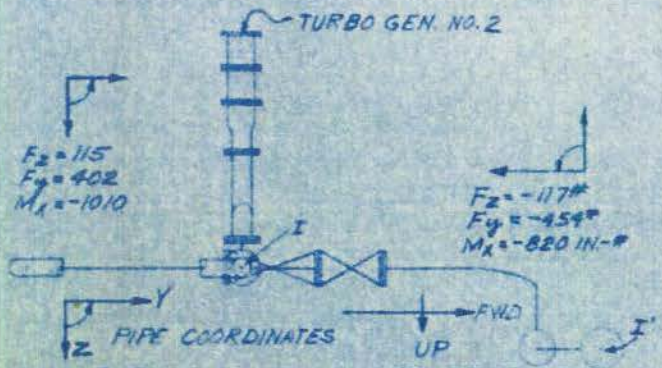
CONDITION NO. 1

PLAN

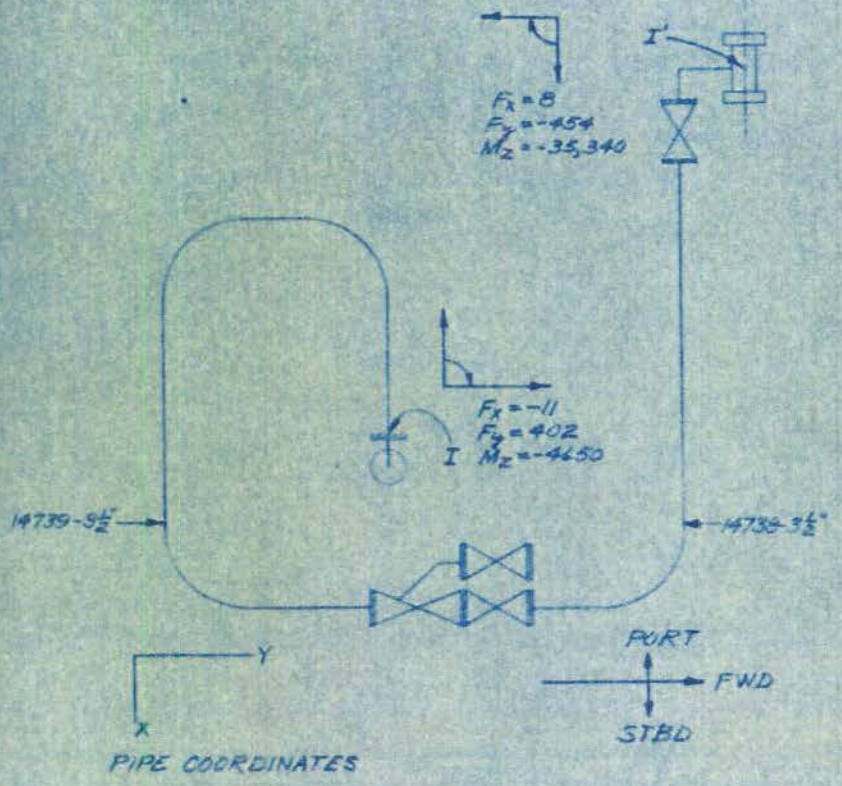


ELEVATION LOOKING AFT
FROM BLKHD #103

PLATE 9a



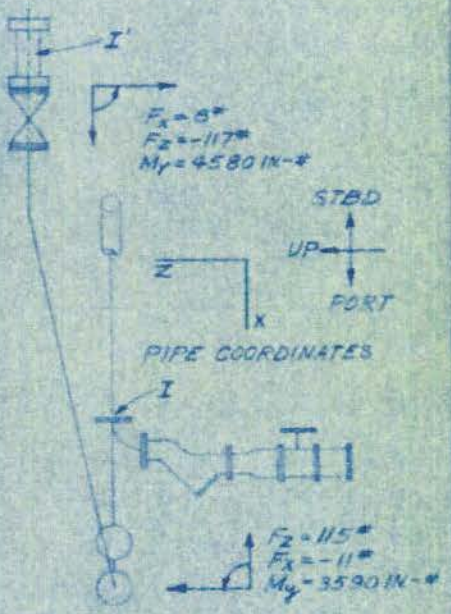
ELEVATION LOOKING TO STBD



SUPERHEATED STEAM BRANCH
FROM TURBO-GEN NO.2 TO MAIN STEAM LINE

CONDITION NO.1

PLAN



ELEVATION LOOKING AFT
FROM BLKHD #103

PLATE 9a