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Report

on

Scale Model Tests of Main Steam Piping of AN1, USS Monitor

FR-1958

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Prepared by:

Irwin Vigness, Associate Physicist

T. E. Pardue, Jr. Physicist

Reviewed by:

Ross Gunn, Superintendent Mechanics and Electricity Division.

Approved by:

H. G. Bowen, Rear Admiral USN, Director

Distribution: BuShips (20)

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ABSTRACT

The end reactions of a main steam pipe system having nine points of constraint have been determined by the use of a scale model. The reaction forces and moments determined by this experimental method are found to differ considerably in many cases from calculated values. The piping system is of such complicated nature that these differences are not unreasonable.

INTRODUCTION

(a) Authorization

1. This problem was authorized by Bureau of Ships' letter AN1-4/S 48-10(354) of April 28, 1942.

(b) Statement of Problem.

2. The determination of end reactions of a three-dimensional piping system having several branches can be accomplished by the use of scale models as described in previous reports. [1,2,3]

3. In this problem the end reactions of a main steam piping system having nine points of constraint, have been determined. These reactions are compared with similar reactions calculated by the Philadelphia Navy Yard.

(c) Known Facts Bearing on the Problem.

4. It has been shown [1,2,3] that the use of model pipe systems is practical and, for models of reasonable stiffness, the major reactions can be measured to within 15% of calculated values. For complicated branched piping systems it is probable that results obtained by use of model systems are more easily obtained and less likely in error than calculated values.

5. Calculations of reactions for systems having many ends become cumbersome, and in many cases it is impractical to do the calculations for the system as a unit. With a scale model the reactions forces at all points can be determined to a degree of accuracy dependent on the exactness of the construction of the model and on the accuracy of measurements.

METHOD AND APPARATUS

(a) Construction of Scale Model

6. The full scale system (see plates 4 & 5) for which end reactions are to be determined consisted largely of straight sections and short turn bends. These bends are of heavier section than their corresponding tangents and the lengths of the bends constitute but a small part of the total lengths of piping in the system. Therefore in the model system the short turns were constructed of 1/8 inch pipe fittings with a few exceptions. These corners in the model can be regarded as rigid compared to the rest of the system. The rest of the system was constructed of rods except for the large radius bends of pipes d and e. It is not believed that these approximations in the model construction will affect the results to a degree as great as the experimental errors involved. The errors that are caused by these

approximations make the system more rigid than the exact model and therefore give end reactions that are a little too large.

7. There are three constraints at points other than the ends of the pipes, in the piping arrangement. These are shown O_{a2}, O_{b2} and O_d, on plates 1 through 5. The first two of these constraints allow only motion in the zx plane, and the last constraint allows only motion in the vertical (z) direction.

8. To eliminate the effects of friction in these constraints the pipes were moved in the constraints so that the reaction forces remained small and of constant value in the directions in which free motion was allowed for any proper motions of the ends of the piping system. All of the pipe ends were held in fixed directions except pipe C, this was allowed to rotate freely in the horizontal (xy) plane.

9. Equipment to measure the end reactions simultaneously at the nine points of constraint (six pipe ends and three directed motions) was not available. The test was therefore divided into three parts. In the first two parts of the test, pipe ends O_f and O_g were left free, as these pipes were small, but the motions of the manifold ends of these pipes caused by the system expansion was measured. For the first test force measuring heads were placed at O_a, O_{a2}, O_{b2}, O_c, and O_d while proper motion was applied to ends O_{b1} and O_e by rigid attachments to lathe rests (see plate 3). For the second test the heads at O_{a1} and O_c were interchanged with the sliding lathe rests at O_{b1} and O_e (See plate 1). For the third part of the test force measuring heads were attached to the ends O_f and O_g of the small pipes f and g. The pipe constraints O_{a2} and O_{b2} were made to prohibit motion in any direction and the ends O_f and O_g were made to move an amount equal to the algebraic sum of the observed motion at these points during the first two tests and the calculated motion due to expansion. The reaction caused by these deflections were assumed absorbed at ends O_{a2} and O_{b2}. In combining the reactions obtained in this test with those of the first two tests the forces in the x and z directions and the moment about the y axis were neglected because of their small values.

10. For convenience a fixed point of reference was taken on the center line of the ship 18 inches behind point A (see plate 5). This permitted measuring heads at points O_{a2} and O_{b2} to remain fixed. The deflections of the pipe and supports were taken from the calculations of the Philadelphia Navy Yard.[4]

11. A scale factor, or ratio of length between the model and full scale pipe, was taken as 1/11.2. The full scale pipe forces are then obtained by multiplying the model forces by

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

where $s = 1/11.2$

the subscripts a and m refer to the full scale and model values

$E_a = 24.5 \times 10^6$ = modulus of elasticity
$E_m = 29.0 \times 10^6$
I = moment of inertia (see tables 1 and 2)
ΔL_a = displacement of the ends of the full scale pipe
ΔL_m = displacement of the ends of the model pipe

The full scale moments are obtained by multiplying the model values by

$$\frac{E_a}{E_m} \frac{I_a}{I_m} s^2 \frac{\Delta L_a}{\Delta L_m} .$$

TABLE I.

CROSS-SECTIONAL DIMENSIONS AND MOMENT OF INERTIA OF FULL SIZE PIPE

Pipe	Pipe size in.	Outside Diameter in.	Wall Thickness in.	Inside Diameter in.	Moment of Inertia $in.^4$
f & g	2-1/2	2.875	.119	2.637	0.982
a, b_1, c.	5	5.563	.23	5.103	13.7
d & e	6	6.625	.273	6.079	27.79
b_2	8	8.625	.5	7.625	106.2

TABLE 2.

CROSS-SECTIONAL DIMENSIONS AND MOMENT OF INERTIA OF MODEL PIPE

Pipe	Pipe Size in.	Outside Diameter in.	Wall Thickness in.	Inside Diameter in.	Moment of Inertia $in.^4$
f & g		.192			0.0684×10^{-3}
a, b_1, c		.373			0.953×10^{-3}
d & e		.445			1.932×10^{-3}
d & e		.563	.0325	.498	1.925×10^{-3}
b_2		.622			7.39×10^{-3}

RESULTS

12. Data obtained and calculations leading up to the results are included in Appendix I. A summary of the results are included in Table 3, 4 and 5.

TABLE 3.

COMPARISON OF END REACTIONS OF MAIN STEAM PIPING OF THE AN1-4 AS DETERMINED BY CALCULATIONS[4] AND BY SCALE MODEL TESTS. FORCES ARE IN POUNDS, MOMENTS ARE IN INCH-POUNDS

REACTION	PIPE END					
	O_{a_1}		O_{a_2}		O_{b_1}	
	Calculated	NRL	Calculated	NRL	Calculated	NRL
Fx	+ 282	+298	+282	+298	+5	+68.2
Fy	+ 125	+51.5	+209	+458	+209	+111.8
F_z	+ 213	+84.3	+213	+84.3	+218	+92.1
Resultant	374.8	315.0	410.5	551.5	302	160.1
Mx	-202	+2095	0	+3,033	-4,920	-3.885
My	+28,074	+23450	-11,494	-11,858	+9,654	+4,760
Mz	+15,402	-11,400	-5460	-20,820	+10,746	+73.4
Resultant	32,000	26,000	12,700	24,180	15,250	6,140

TABLE 4.

COMPARISON OF ENDS REACTIONS OF MAIN STEAM PIPING OF THE AN1-4 AS DETERMINED BY CALCULATION[4] AND BY SCALE MODEL TESTS. FORCES ARE IN POUNDS AND MOMENTS IN INCH-POUNDS.

REACTION	PIPE END					
	O_{b2}		O_c		O_d	
	Calculated	NRL	Calculated	NRL	Calculated	NRL
Fx	+5	+68.2	+59	+79.6	-345	-271
Fy	-362	-379	+259	+334	-106	-150
Fz	+218	+92.1			-235	-117
Resultant	422.5	396	265	341.0	430.5	331
Mx	0	+315	0	-5250*		+200
My	-47	+1850	0	+2515*		+14,932
Mz	-1218	-1515	0	0	+18,564	+20,736
Resultant	1,219	2,411		5,820.0	18,564	25,530

*Pipe end was not free to rotate except in xy plane.

TABLE 5

COMPARISON OF END REACTIONS OF MAIN STEAM PIPING OF THE AN1-4 AS DETERMINED BY CALCULATIONS[4] AND BY SCALE MODEL TESTS. FORCES ARE IN POUNDS MOMENTS IN INCH-POUNDS.

REACTION	PIPE ENDS					
	O_e		O_c		O_g	
	Calculated	NRL	Calculated	NRL	Calculated	NRL
Fx	-296.6	-101	+40	+21.6	-2	+19.7
Fy	+581.0	+256	-97	-95.0	-122	-119.5
Fz	-235	-117		-9.2		+12.1
Resultant	693	299	104.8	97.9	122	121.8
Mx	-22,235	-12,040		+4,160		+4,439
My	-3825	-5,630		-1,017		+340
Mz	+2317	+1,836	+5,370	+2,735	+3,381	+3,145
Resultant	22,600	13,420	5370	5,084	3,381	5,448

CHECK OF RESULTS

13. Tables 3 through 5 of the preceding section are not susceptible to direct check as the forces and moments are not all external reactions. In order to obtain results equivalent to those calculated the values of reactions at points O_{a2}, O_{b2}, and O_d were made as the reaction of only one side of a pipe against the support, where as the reactions measured are the reactions of two terminating pipes at each of these points. Table 6 below gives the total reactions measured at all constraint points obtained by scale model tests.

TABLE 6

EXTERNAL REACTIONS OF PIPING SYSTEM AT POINTS OF CONSTRAINT, UNITS ARE IN POUNDS OR INCH-POUNDS

	VALUE OF REACTION AT POINT								
Reaction	O_{a_1}	O_{a_2}	O_{b_1}	O_{b_2}	O_c	O_d	O_e	O_f	O_g
Fx	+298	0	+68.2	+ 0	+79.6	-372	-101	+21.6	+19.7
Fy	+51.5	+407	+111.8	-491	+334	-406	+262	-95.0	-119.5
Fz	+84.3	0	+92.1	0	0	0	-117	-9.2	+12.1
Mx	+2095	-642	-3885	+4,020	-5,250	-1960	-12,040	+4,160	+4,439
My	+23,450	0	+4760	0	+2,515	-15,630	-5,630	-1017	-340
Mz	-11,400	-10,530	+73.4	-5568	0	+17,070	+1,836	+2,735	+3,145

14. The sum of the positive forces should equal the sum of the negative forces for each component, and thesum of the positive moments should equal the sum of the negative moments at any given point. This latter check is not as simple as that of the forces as the moment at any point is also a function of the forces and their distances from the point. The moments are summed up about a point on the axis of the ship, 18 inches back of point A. These checks give the following results:

Force Check (Units are pounds)

Fx	-Fx	Fy	-Fy	Fz	-Fz
487	473	1167	1112	188	126

Moment Check (Units are inch-pounds)

Mx	-Mx	My	-My	Mz	-Mz
5260	38302	29050	24540	136400	160640

These checks are considered satisfactory. The large error of the Mx moment does not greatly affect the resultant moment.

DISCUSSION OF RESULTS

15. The tables 3, 4, and 5 in the foregoing section contain comparison of the resultant forces and moments as well as their components in the coordinate directions. Most emphasis should be placed on the resultants. Large percentage differences in the smaller components are of little significance. The model test values for all pipe ends except O_{a2}, O_{b2}, and O_d are obtained from direct measuring head readings at, or very near, a pipe end considered. These results of major reactions should be correct within about 15 or 20 percent. The model test values obtained at constraints O_{a2}, O_{b2}, and O_d are obtained from the corresponding measuring head and a transfer of forces and moments from the opposite pipe ends, which are O_{a1}, O_{b1}, and O_e respectively. Because of differences involved this increases the probable error for O_{a2}, O_{b2} and O_d. All of the major components of reactions for these heads are believed to be correct within about 25 percent with the possible exception of the My reaction of the O_d end (table 4). As this moment appeared unreasonably high at first glance a separate test was made to give a rough check value. The zx rotation of O_d, due to its relative vertical displacement with respect to the manifold, was measured. With ends O_{d2}, O_{b2} fixed and with O_e free, the measuring head at O_d was rotated in the zx plane a given amount. It was found that the moment necessary to cause this zx rotation of O_d equivalent to that caused by its displacement with respect to the manifold was 6800 inch-pounds in full scale terms. It is believed that a correct value lies between 6800 inch-pound and 14900 inch-pounds as given in the table. (Value of My for pipe end

O_d shown in table 4).

16. The calculated and the scale model values of end reactions agree as well as can be expected considering the nature of the problem and the approximations necessary in both cases. The stresses resulting from the end reactions are not considered in this report, but it appears that they remain within accepted limits.

REFERENCES

1. Scale Model tests for High-Pressure High-temperature Steam piping, First Partial Report, NRL Report No. O-1684.

2. Scale Model test 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

4. Stress Analysis Main Steam Piping AN1-SK-S48-356 Navy Yard, Philadelphia, Pa. 12 January 1942.

APPENDIX I - PRINCIPAL DATA

The principal data and methods, used in obtaining the results of the report body, are included in this appendix. These include:

1. Reactions as determined directly from the force measuring head.

2. Determination of forces and moments in the coordinate system determined by the measuring head orientation.

3. Transfering of the forces and moments from the measuring head to the point of pipe support. These determine the actual model forces at the ends of the pipes.

4. Multiplication of forces and moments by proper scale factors to get the full scale forces and moments.

5. In the cases of heads at O_{a_2}, O_{b_2}, and O_d to subtract the forces and moments transferred from O_{a_1}, O_b and O_e respectively, from the reactions measured at the heads.

Table 1 below gives the directly measured reactions for the different measuring heads. The apparatus set-up had to be dismounted to a large degree between runs 1 and 2 and again between runs 4 and 5. Runs 1, 4 and 5 were taken with the set-up illustrated on Plate 1. Runs 2 and 3 were taken with the set-up illustrated on Plate 3. Nomenclature and methods followed are given in detail in reference 3.

TABLE I

Forces in Pounds Obtained from Measuring Heads; In Pars 1 & 2 of test.
(See paragraph 9 of Report body)

Pipe End	Reaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
O_{a_1}	Rx'	-3.25				0	+0.11
	Ry'	-17.99				-14.53	-14.54
	Rz'	+2.05				+ 1.57	+1.08
	Rx'y'	+16.95				+13.5	+13.9
	Ry'z'	+ 9.20				+ 8.14	+ 8.4
	Rz'x'	+ 8.40				+ 6.52	+ 7.22
O_{a_2}	Rx'	-24.35	-34.15		-28.85	-28.9	-28.85
	Rx'y'	+9.63	+10.0		+7.16	+8 .52	+9.4
	Rz'x'	-10.37	-10.13		-10.80	- 9.33	-9.35
O_{b_1}	Rx'		- 6.72	-7.42	-6.1		
	Ry'		+ 2.1	+1.12	+0.8		
	Rz'		+3.5	+3.08	-3.64		
	Rx'y'		+2.6	+4.04	+2.4		
	Ry'z'		+1.73	+0.05	+1.61		
	Rz'x'		-1.88	-1.19	-0.70		
O_{b_2}	Rx'	-25.35	-27.6	-26.0	-27.7		
	Rx'y'	+1.27	+ 1.08	+ 0.43	+ 1.74		
	Ry'z'	-8.06	-8.6	-8.26	-9.43		
O_c	Rx'					-2.11	-2.2
	Ry'	+12.6				+12.5	+11.67
	Ry'z'	- 2.4				-2.0	-2.0
	Rz'x'					+ 0.26	+0.27
O_d	Rx'	- 1.62	-6.3	-6.16	-6.52		
	Ry'	-15.25	-16.2	-18.75	-21.3		
	Rx'y'	-6.52	-10.0	-8.81	-8.48		
	Ry'z'	+0.19	+0.97	+2.94	+4.06		
	Rz'x'	-5.6	-7.7	-9.52	-9.24		
O_s	Rx'		-11.05	-13.15	-12.66		
	Ry'		+5.46	+5.8	+6.2		
	Rz'		-8.68	-10.07	- 9.56		
	Rx'y'		+0.11	0.0	+0.21		
	Ry'z'		-3.36	-3.64	-4.35		
	Rz'x'		-8.91	-9.96	-9.0		

The forces and moments in the measuring head coordinate systems are given in Table 2. These are obtained from Table 1 by the equations:

$$Fx' = Rx' + Rx'y' - Rz'x'$$
$$Fy' = Ry' + Ry'z'$$
$$Fz' = Rz'$$
$$Mx' = 5\ Ry'z'$$
$$My' = 5\ Rz'x'$$
$$Mz' = 5\ Rx'y'$$

TABLE 2

Reactions obtained from Values Given in Table 1. Forces are in Pounds. Moments are in Inch-Pounds.

Pipe End	Reaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Average
O_a	Fx'	+5.0				7.0	+6.79	+6.26
	Fy'	-8.73				-6.39	-6.14	-7.086
	Fz'	+2.05				+1.57	+1.08	+1.57
	Mx'	+46.3				+40.70	+42.0	+43.0
	My'	+42.0				+32.66	+36.10	+36.9
	Mz'	+83.25				+67.5	+69.5	+73.42
	Resulant force Fr	10.26				9.6	9.23	9.65
	Resultant Mom. Mr	104.2				85.3	88.9	92.8
O_{a_2}	Fx'	-4.35*	-14.02		-10.9	-11.05	-10.10	-11.56
	My'	-51.85	-50.65		-54.0	-46.65	-46.75	-49.98
	Mz'	+48.15	+50.0		+35.80	+42.60	+47.0	+44.71
	Resultant force Fr	4.35*	14.02		10.9	11.05	10.1	11.56
	Resultant Mom. Mr	70.75	71.15	•	64.8	63.2	66.3	67.02
O_{b_1}	Fx'		-2.24	-2.2	-3.0			-2.48
	Fy'		+3.83	+1.17	+2.41			+2.47
	Fz'		+3.5	+3.08	+3.64			+3.41
	Mx'		+8.65	-0.1	+8.05			45.53
	My'		-9.40	-5.95	-3.5			6.28
	Mz'		+13.00	+20.20	+12.0			+15.17
	Resultant force Fr		5.65	3.96	5.2			4.89
	Resultant Mom. Mr		18.23	21.23	14.87			17.3

*Not included in average because of large deviation from other values.

TABLE 2 (Cont'd)

Pipe End	Reaction	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Average
O_{b_z}	Fx'	-16.0	-17.92	-17.31	-16.63			-16.96
	My'	-40.3	-43.0	-41.3	-47.15			-42.94
	Mz'	+ 6.35	+5.4	+2.15	+8.70			+ 7.53
	Resultant Force Fr	16.0	17.92	17.31	16.63			16.96
	Resultant Mom. Mr	40.8	43.3	41.35	47.9			43.5
O_c	Fx'					-2.37	-2.47	-2.42
	Fy'	+10.2				+10.5	+9.67	+10.12
	Mx'	-12.0				-10.0	-10.0	-10.67
	My'					+1.30	+1.35	+1.33
	Resultant Force Fr.	10.2				11.22	9.98	10.4
	Resultant Mom. Mr	12.0				10.1	10.1	10.8
O_d	Fx'	-2.54	-8.6	-5.45	-5.76			-5.59
	Fy'	-15.07	-15.23	-15.81	-17.24			-15.84
	Mx'	+0.95	+4.85	+14.20	+20.30			+10.18
	My'	-28.0	-38.5	-47.60	-46.20			-40.08
	Mz'	-32.7	-50.0	-44.05	-42.4			-42.29
	Resultant Force Fr	15.3	17.48	16.72	18.18			16.8
	Resultant Mom Mr	43.05	63.2	66.4	65.9			59.6
O_e	Fx'		-2.03	-3.19	-3.45			-2.89
	Fy'		+2.10	+3.10	+1.95			+2.42
	Fz'		-8.68	-10.07	-9.56			-9.2
	Mx'		-16.80	-18.20	-21.75			-18.92
	My'		-44.55	-49.80	-45.0			-46.45
	Mz'		+0.55	0.0	+1.05			+0.53
	Resultant Force Fr		9.16	11.6	10.35			10.16
	Resultant Mom. Mr		47.65	52.95	49.9			50.12

A third test (see paragraph 9 of report body) was run independently of the first two. In the third test the reactions caused by pipes f and g were determined. Reactions at O_f, O_g, O_{a2} and O_{b2} were obtained. These are shown in Table 3. Table 4 gives the forces and moments at these heads in the respective measuring head coordinate systems.

TABLE 3

Forces in Pounds Obtained from Measuring Heads for Part 3 of Test. (See paragraph 9 of Report body)

Head Reading	Measuring Head Forces at Pipe End Oa_2	Pipe End Ob_2	Pipe End Of	Pipe End Og
Rx'	-2.69	+1.48	-0.43	+3.5
Ry'	+0.59	0.0	+2.14	-6.8
Rz'	-0.4	0.0	-1.67	+1.94
Rx'y'	-3.23	+1.53	+1.99	-1.96
Ry'z'	+0.38	+0.21	+0.404	+3.72
Rz'x'	-2.02	+1.0	+1.02	+0.05

TABLE 4.

Reactions obtained from Values Given in Table 3. Forces are in Pounds. Moments are in Inch-Pounds.

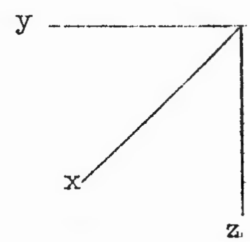
Reaction	Measuring Head Reactions at Pipe End Oa_2	Pipe End Ob_2	Pipe End Of	Pipe End Og
Fx'	-3.9	+1.48	+0.54	+1.5
Fy'	+0.97	0.0	+2.54	-3.1
Fz'	-0.4	0.0	-1.67	+1.94
Mx'	+1.90	+1.05	+2.22	+18.60
My'	-10.0	+5.0	+5.10	+ 0.25
Mz'	-16.1	+7.65	+9.95	+9.80
Resultant Force Fr	4.04	2.02	2.92	3.95
Resultant Mom. Mr	19.15	9.20	11.4	20.8

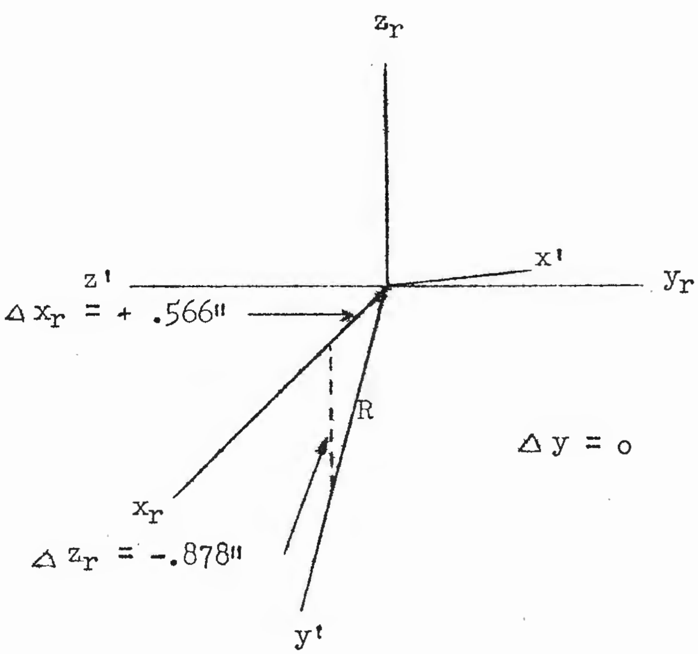
The following diagrams give the displacements Δx, Δy, and Δz, of the ends of the pipes. The actual displacements of the ends of the model pipes were $\frac{5}{18.08}$ of the values given in the diagrams.

The diagrams also give the relations between the measuring head coordinates, (primed) reference coordinates (subscript r), and the pipe system coordinates. The use and significance of the coordinates are given in reference 3 paragraphs 16 through 22. The distance of a pipe end from a corresponding measuring head is given by the distance necessary for the moment transfer from a measuring head to its corresponding pipe end.

I.

1 - Head A_1

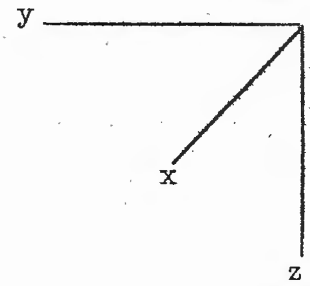


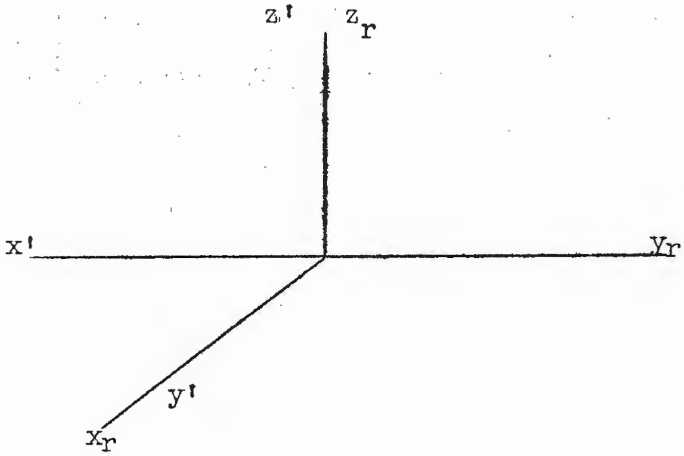


To transfer moments to the pipe end use $x_r = o$, $y_r = -3.4''$ $z_r = -1.062''$

2 - Head A_2

Pipe coordinates





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

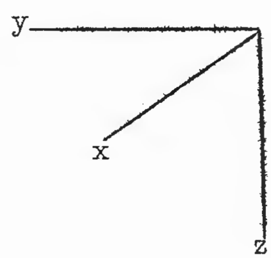
To transfer moments to the pipe end use

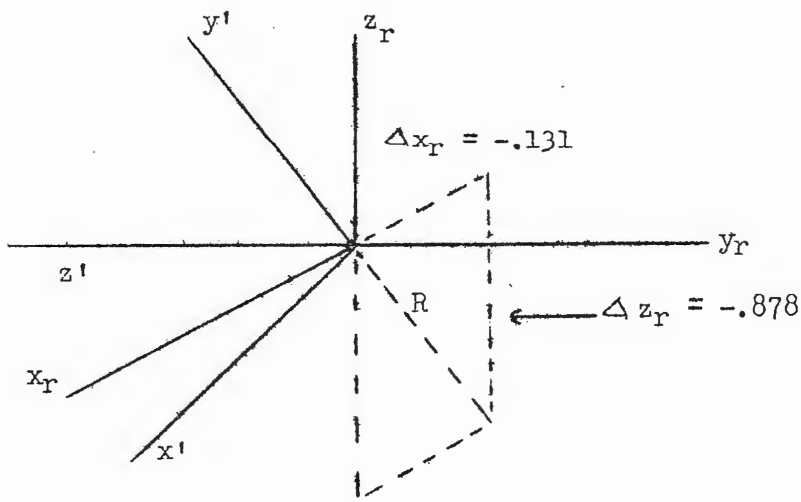
$x_r = 0 \qquad y_r = 0 \qquad z_r = 2.825''$

---

3 - Head B

Pipe coordinates





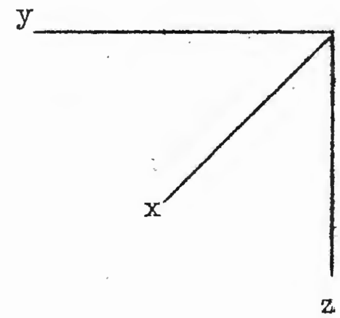
$\Delta x_r = -.131'' \qquad \Delta y_r = 0 \qquad \Delta z_r = -.878''$

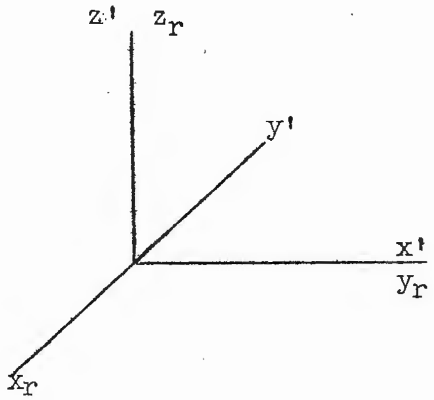
To transfer moments to the pipe end use $x_r = 0 \quad y_r = -3.437''$

$z_r = -1.062''$

Appendix I

4 - Head B_2





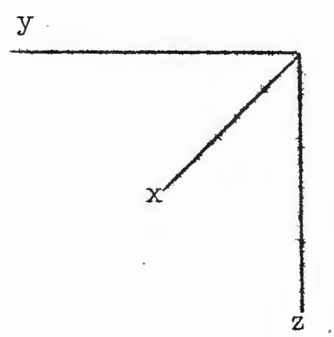
$\Delta x = \Delta y = \Delta z = 0$

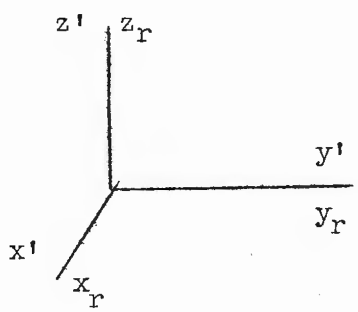
To transfer moments to the pipe end use

$x_r = 0 \quad y_r = 0 \quad z_r = +3.125''$

---

5 Head C



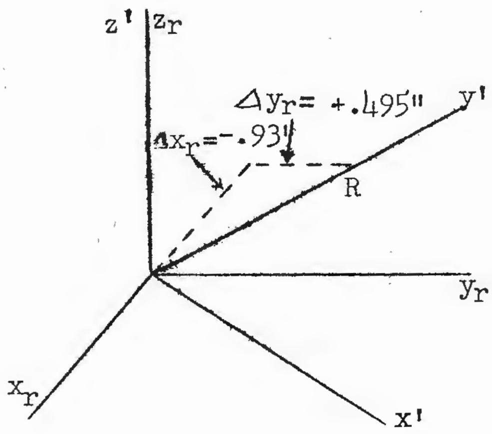


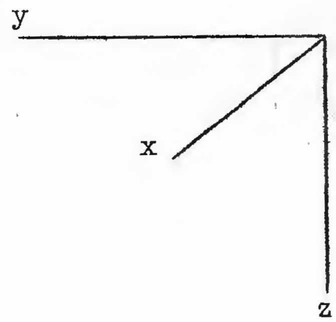
$\Delta x = 0$, $\Delta y = -1.808''$ $\quad \Delta z = 0$

To transfer moments to the pipe end use

$x_r = 0 \quad y_r = 0 \quad z_r = 2.62''$

6 - Head D





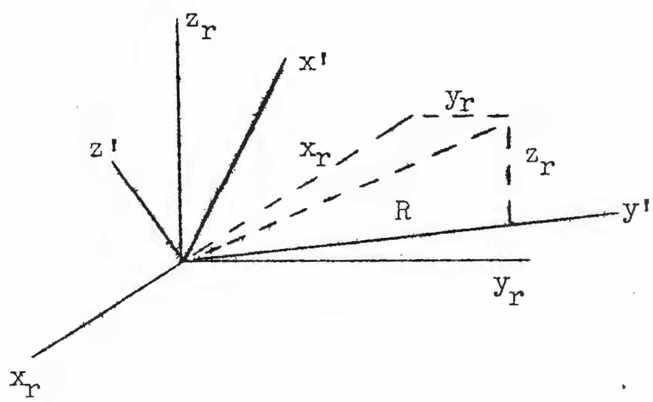
$\Delta x_r = -.93"$ $\Delta y_r = + .495"$ $\Delta z_r = 0$

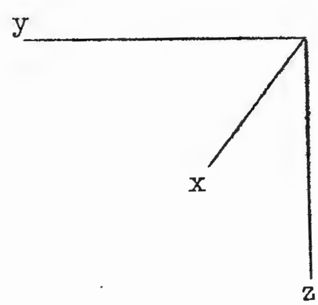
To transfer moments to the pipe end use

$x_r = -1.287"$ $y_r = + 1.78"$ $z_r = 2.81"$

---

7 Head E



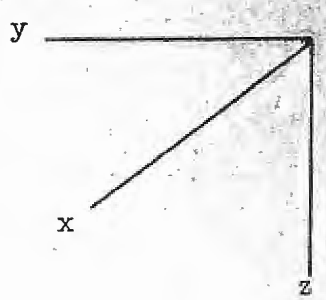


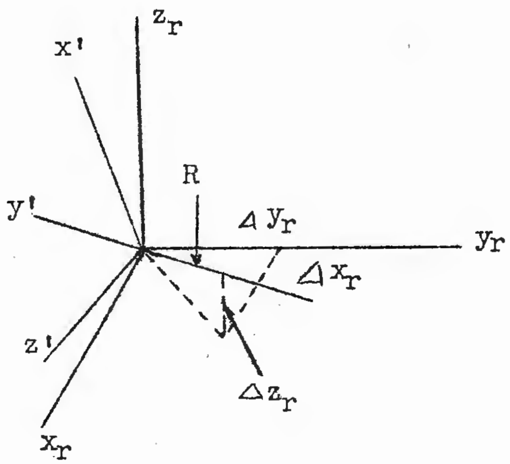
$\Delta x_r = -.95"$ $\Delta y_r = +.465"$ $\Delta z_r = -.417"$

To transfer moments to the pipe end use

$x' = 0$ $y' = 0$ $z' = 4.25"$

Appendix I



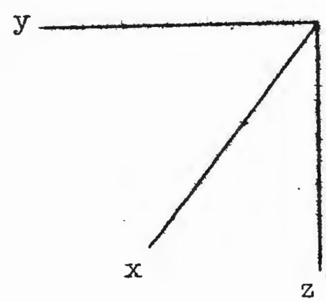


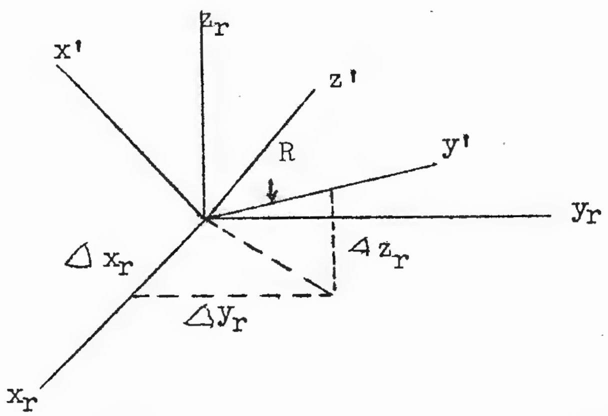
$\Delta x_r = +1.094"$ $\Delta y_r = +1.087"$ $\Delta z_r = +0.460"$

To transfer moments to the pipe end use

$x' = o$ $y' = o$ $z' = 2.62"$

9-Head G





$\Delta x_r = +.667"$ $\Delta y_r = +1.087"$ $\Delta z_r = +.458"$

To transfer moments to the pipe end use

$x' = o$ $y' = o$ $z' = +2.62"$

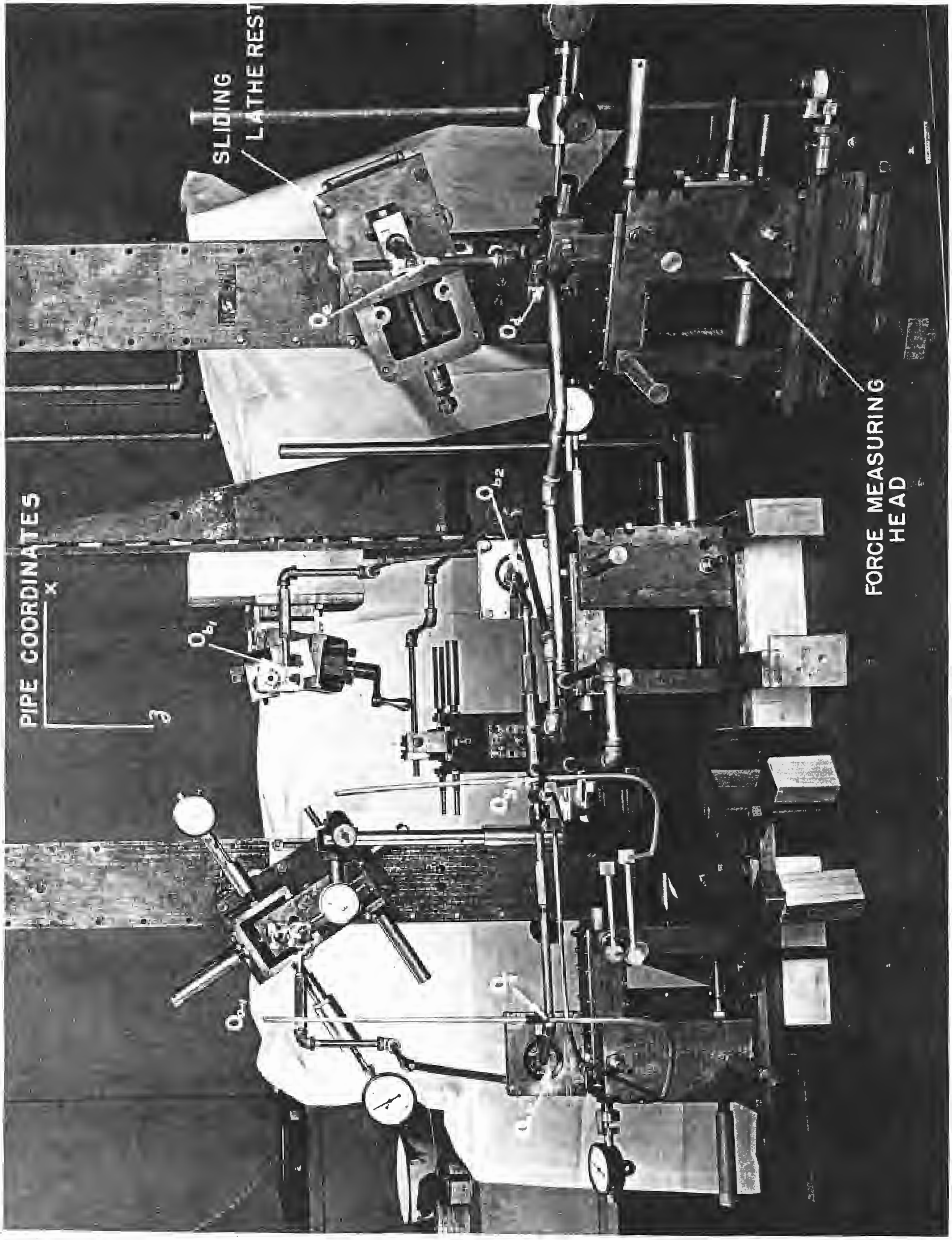


PLATE I

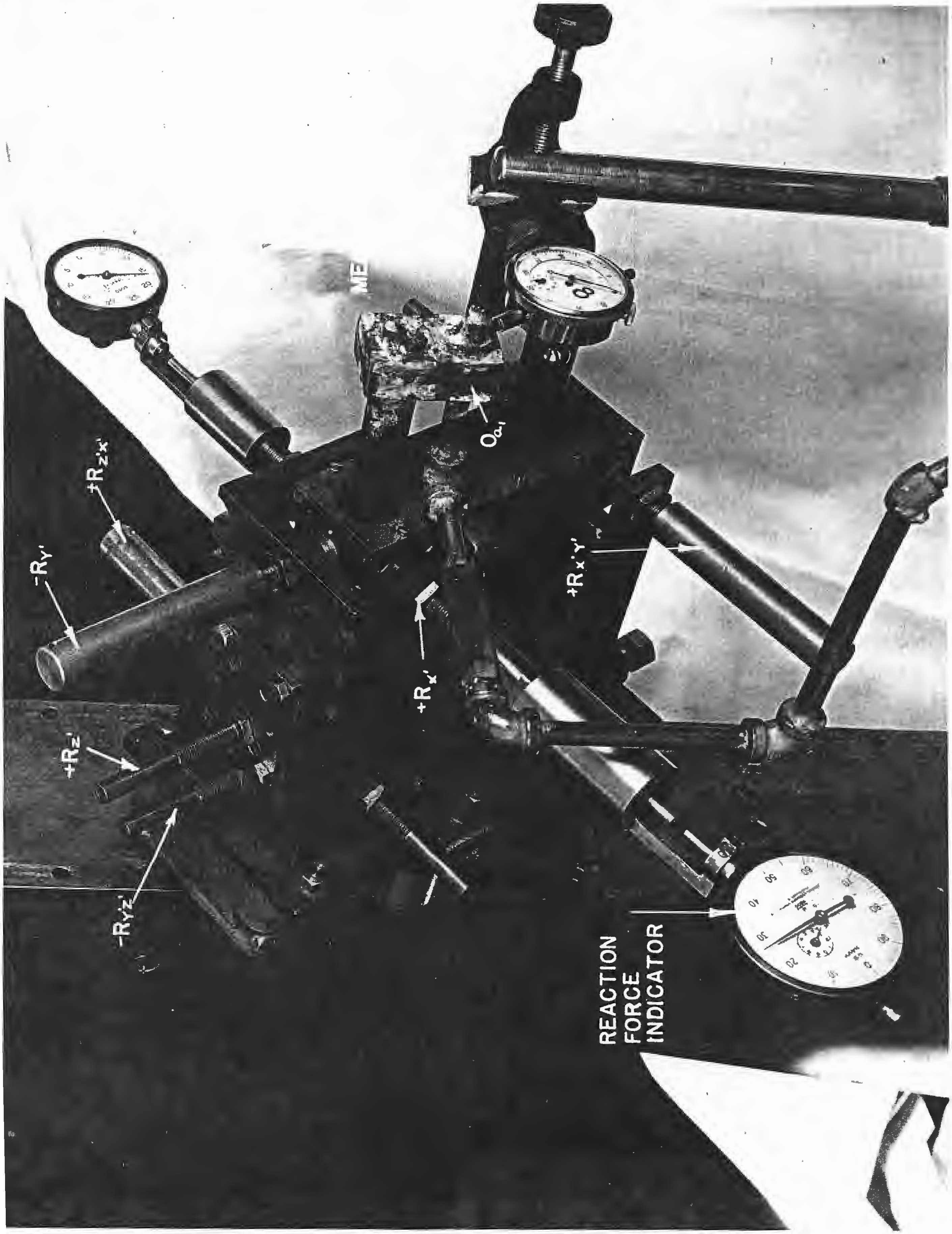


PLATE 2

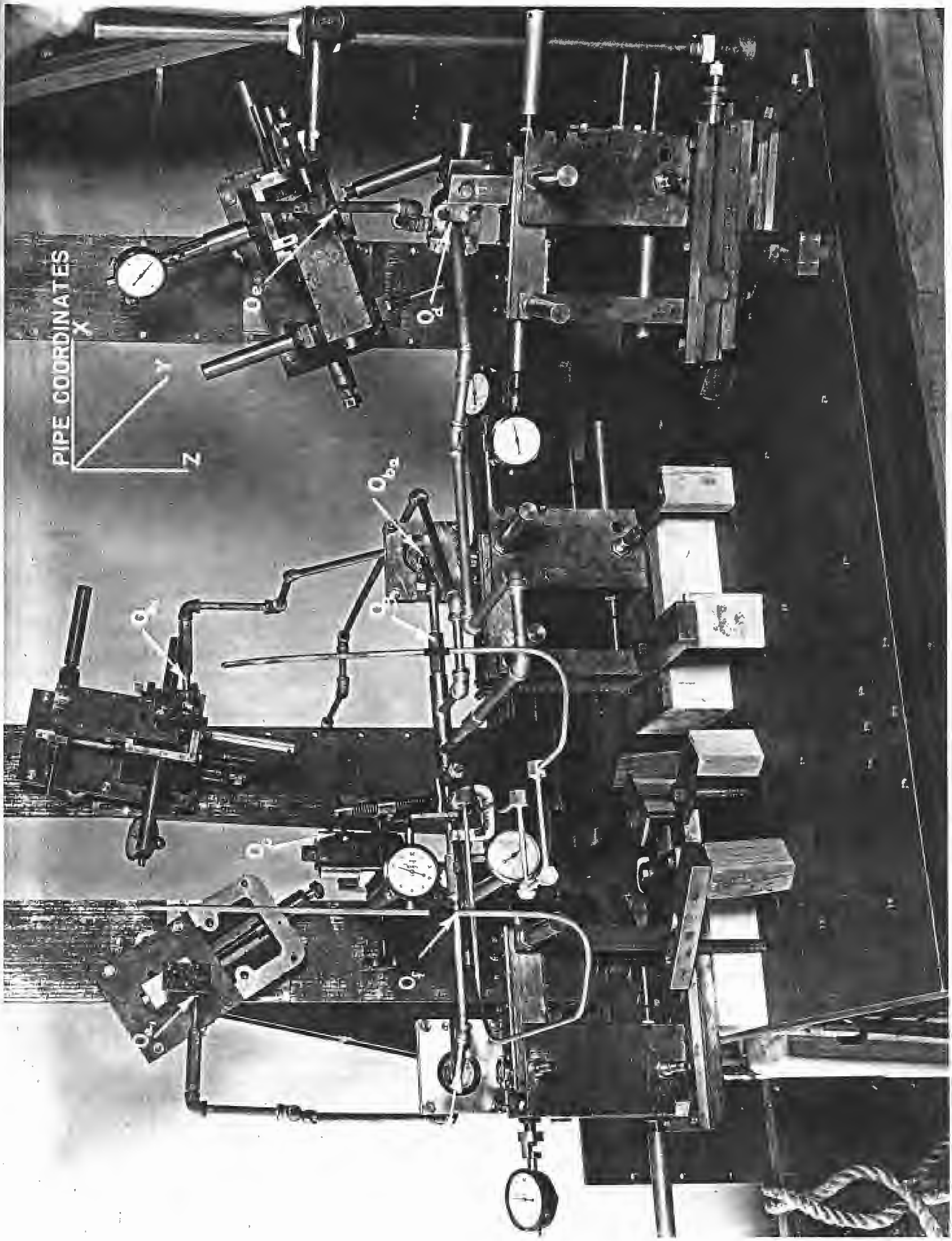
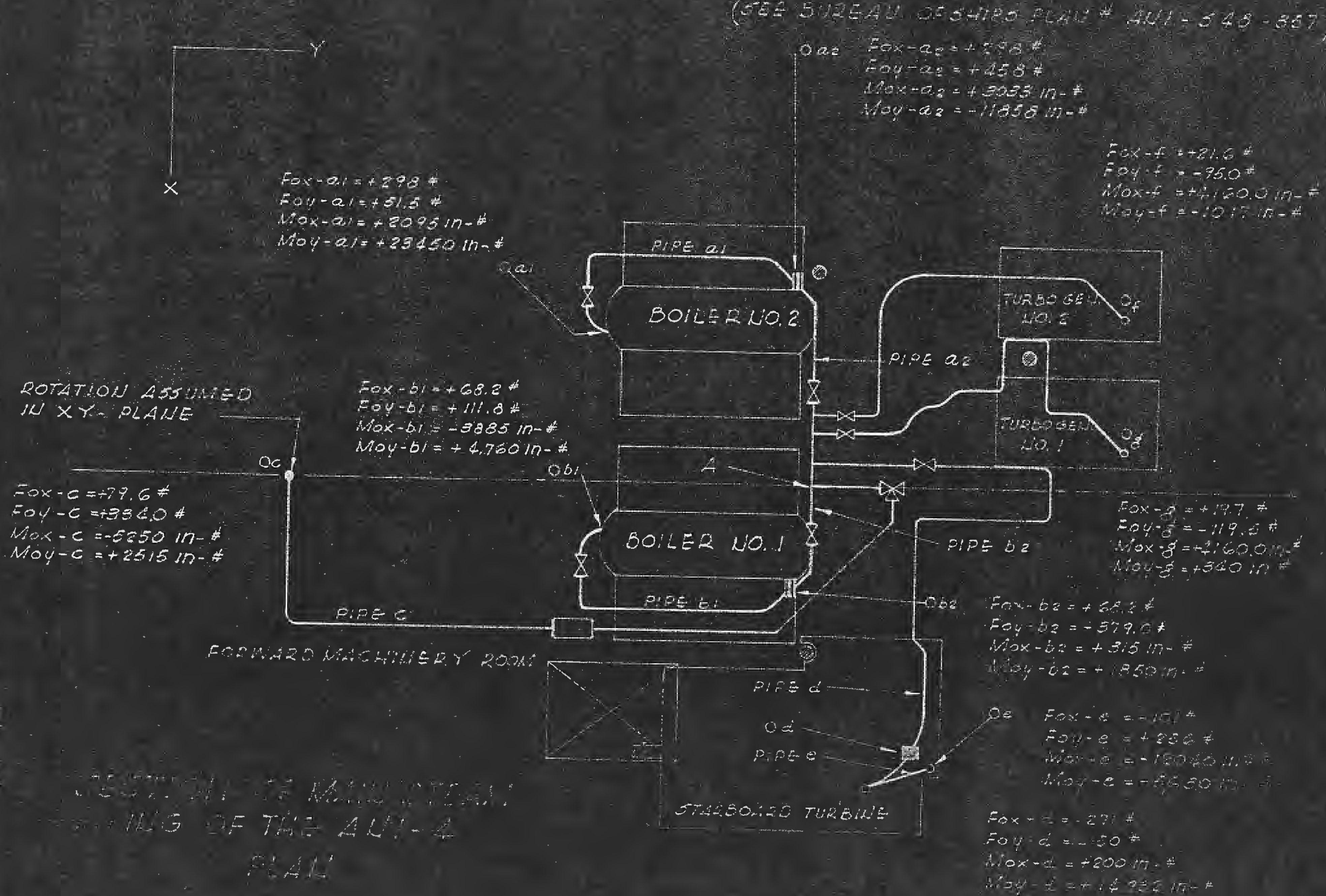
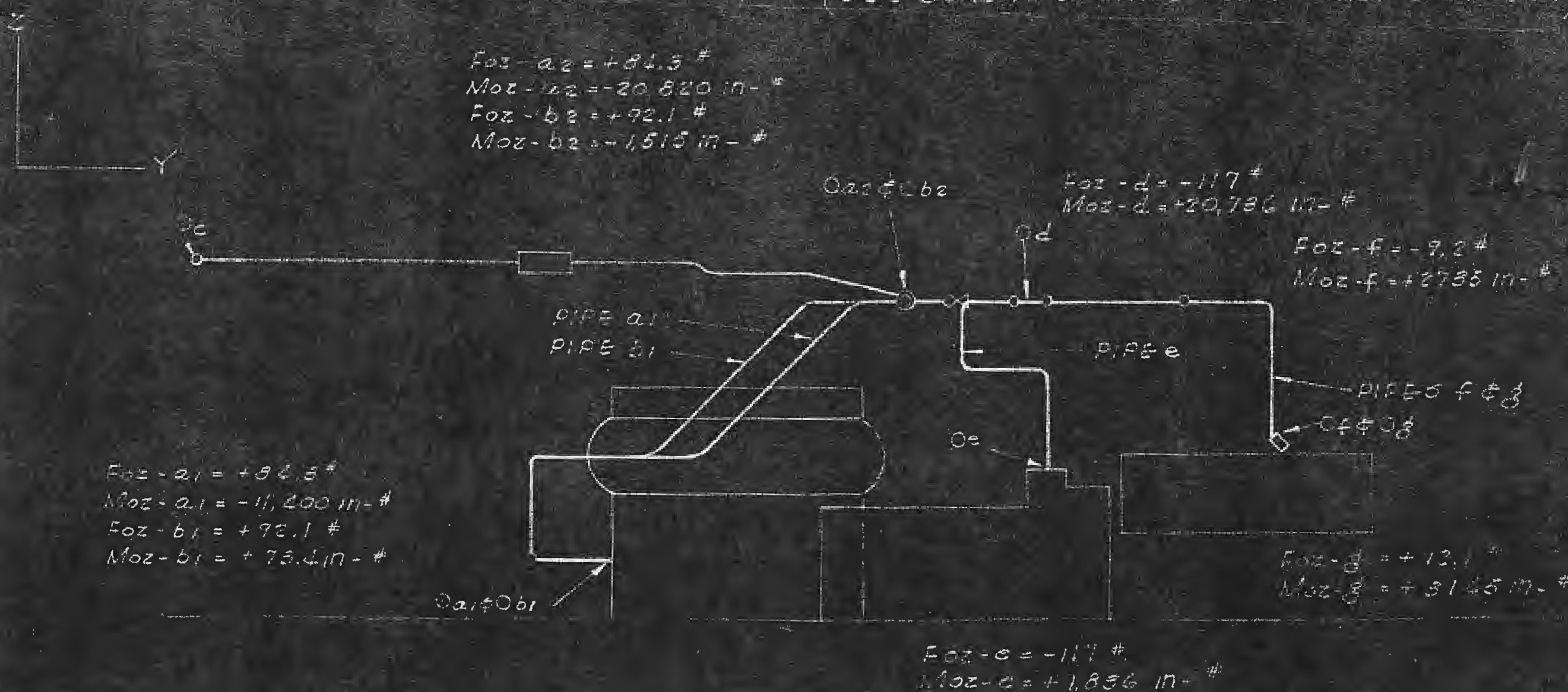


PLATE 3



(SEE BUREAU OF SHIPS PLAN # AUX-548-887)
Y
X
Oa2
Fox-a2 = +298 #
Foy-a2 = +458 #
Mox-a2 = +3033 in-#
Moy-a2 = -11858 in-#
Fox-f = +21.6 #
Foy-f = -95.0 #
Mox-f = +4160.0 in-#
Moy-f = -1017 in-#
Fox-a1 = +298 #
Foy-a1 = +51.5 #
Mox-a1 = +2095 in-#
Moy-a1 = +23450 in-#
PIPE a1
Oa1
BOILER NO. 2
TURBO GEN. NO. 2
Of
PIPE a2
ROTATION ASSUMED
IN XY-PLANE
Fox-b1 = +68.2 #
Foy-b1 = +111.8 #
Mox-b1 = -3885 in-#
Moy-b1 = +4,760 in-#
TURBO GEN. NO. 1
Og
Oc
Ob1
A
Fox-c = +79.6 #
Foy-c = +334.0 #
Mox-c = -5250 in-#
Moy-c = +2515 in-#
BOILER NO. 1
PIPE b2
Fox-g = +19.7 #
Foy-g = -119.6 #
Mox-g = +2160.0 in-#
Moy-g = +340 in-#
PIPE b1
PIPE c
Ob2
Fox-b2 = +68.2 #
Foy-b2 = -579.0 #
Mox-b2 = +315 in-#
Moy-b2 = +1850 in-#
FORWARD MACHINERY ROOM
PIPE d
Od
PIPE e
Oe
STARBOARD TURBINE
Fox-d = -271 #
Foy-d = -50 #
Mox-d = +200 in-#
PLAN

(SEE BUREAU OF SHIPS PLAN # AM-5 48-351)



SECTION OF MAIN STEAM PIPING OF THE AM
ELEVATION