A REPORT ON NONDESTRUCTIVE TESTING AND STRUCTURAL ANALYSIS ON ELEVEN IRON CASEMATE CARRIAGES AND CHASSIS

FORT SUMTER NATIONAL MONUMENT

Charleston, South Carolina

April 2, 1979

LEE WAN and ASSOCIATES, INC.
engineers / architects / surveyors

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AT

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CHARLESTON, S.C.

PREPARED BY

LEE WAN AND ASSOCIATES, INC.

4321 Memorial Drive, Suite P
Decatur, GA 30032

April 2, 1979

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PART I

SUMMARY OF FINDINGS

and

RECOMMENDATIONS

There were three teams that undertook the tasks of this study. They are as follows:

1) Lee Wan and Associates, Inc., the principal researcher, undertook the task of project management and structural analysis.

2) Dr. S. Spooner, Dr. S.B. Chakraportty and Dr. James Lai, undertook the task of material/metallurgical testing and analysis.

3) McPherson NDT and Atlanta Testing Company are jointly responsible for the task of radiographic testing.

Each group's findings are narrated in the following chapters.

In summary, radiographic testing has found that the material though heavily rusted, pitted, flaked, or even rotted through in areas, the remaining base metals are still in sound quality. Little or no flaws, cracks, or fractures were detected.

Metallurgical/material test and analysis has concluded that the iron casemate carriage and chassis were made of wrought iron with "good old" 19 century workmanship. It is uniform in quality and possess good hardness and tensile strength that are even superior to the modern carbon steel.

The structural analysis, based on the findings of the radiographic and metallurgical report, and taking into proper account of rust-aways, has found that the chassis plates and carriage rail beams are adequate in supporting the weight of the cannon, without the problem of buckling or overstress. The safety factor against buckling and flexural yield is in the order of 2.5.

Since the iron casemate carriages and chassis are continually exposed to the corrosive salty atmosphere, its deterioration can be accelerating if without preservation.

It is felt that conventional sandblasting and multi-coat protective painting will be sufficently effective and economical to protect the base metal from being further deteriorated. It is therefore, so recommended.

PART II

METALLURGICAL/MATERIAL

REPORT

Metallographic Investigation of Selected Metal Samples from the Cannon Casemate and Rail at Fort Sumpter, S.C.

by
S. Spooner & S. B. Chakrabortty

Summary

Optical metallography, x-ray energy spectrometry, and hardness tests were performed on several samples of material from the casemate and rail portions of a cannon implacement for the purposes of identifying the material, type of manufacture, and the mechanical properties of the selected specimens. All specimens were found to be wrought iron whose structure consists of a fine and anisotropic dispersion of slag in very pure iron of equiaxed crystal grain structure. Metallic impurities (principally Mn, Si, S, P) were found to be low and the slag volume fraction was typical of modern wrought iron manufacture. The mechanical properties indicated by both Rockwell B-scale hardness and Vicker's hardness numbers suggested a tensile strength of 60 ksi ($\pm$ 7 ksi). The material is typical of iron alloy applied to a wide variety of uses in the mid-nineteenth century. The corrosion resistance of wrought iron is known to be superior to cast iron and steels produced in mid- to late-nineteenth century. The direction of corrosion attack is along the fibrous structure of the slag.

Contents

References

Wrought Iron, J. Aston and E. B. Stony, A. M. Byers Co., Pittsburgh, PA, (1957).

A History of Metallurgy, R. F. Tylecote, The Metals Society, (1976).

Table 1: XES Microanalysis (See Figure 4)

Piece A: (A portion of the casemate plate)

Elemement	Metal Matrix Composition (wt %)	Slag Composition (wt %)
Al	.04	-
Si	.09	1.3
P	.03	.54
S	.005	-
Mn	.01	1.45
	Slag - Light Areas	- Dark Areas
Si	.34	1.10
P	.25	.48
Ca	.16	.23
Ti	.26	.07
V	.38	.10
Cr	.68	.45
Mn	1.20	1.50

Piece B: (A portion of the rail)

Element	Metal Matrix
Si	.06
Cr	.09
Mn	.015
Al	.04
	Slag
Si	1.20
P	.8
S	.25
Mn	2.2

Table 2

Sample	Vicker's Hardness Number	Rockwell B-scale	Estimated Ultimate Tensile Strength (ksi)
A. Right Face Plate	160	82	64
B. Rail	132	71	53
C. Rail	144	74	58
D. Left Face Plate	150	79	60
E. Right Face (Rusty)	150	79	60
F. Rail (Rusty)	150	79	60
G. Left Face (Rusty)	167	84	67
H. "Modern" Wrought Iron	125	69	50

Figure 1a. Optical Micrograph of Right Face Plate (Piece A)

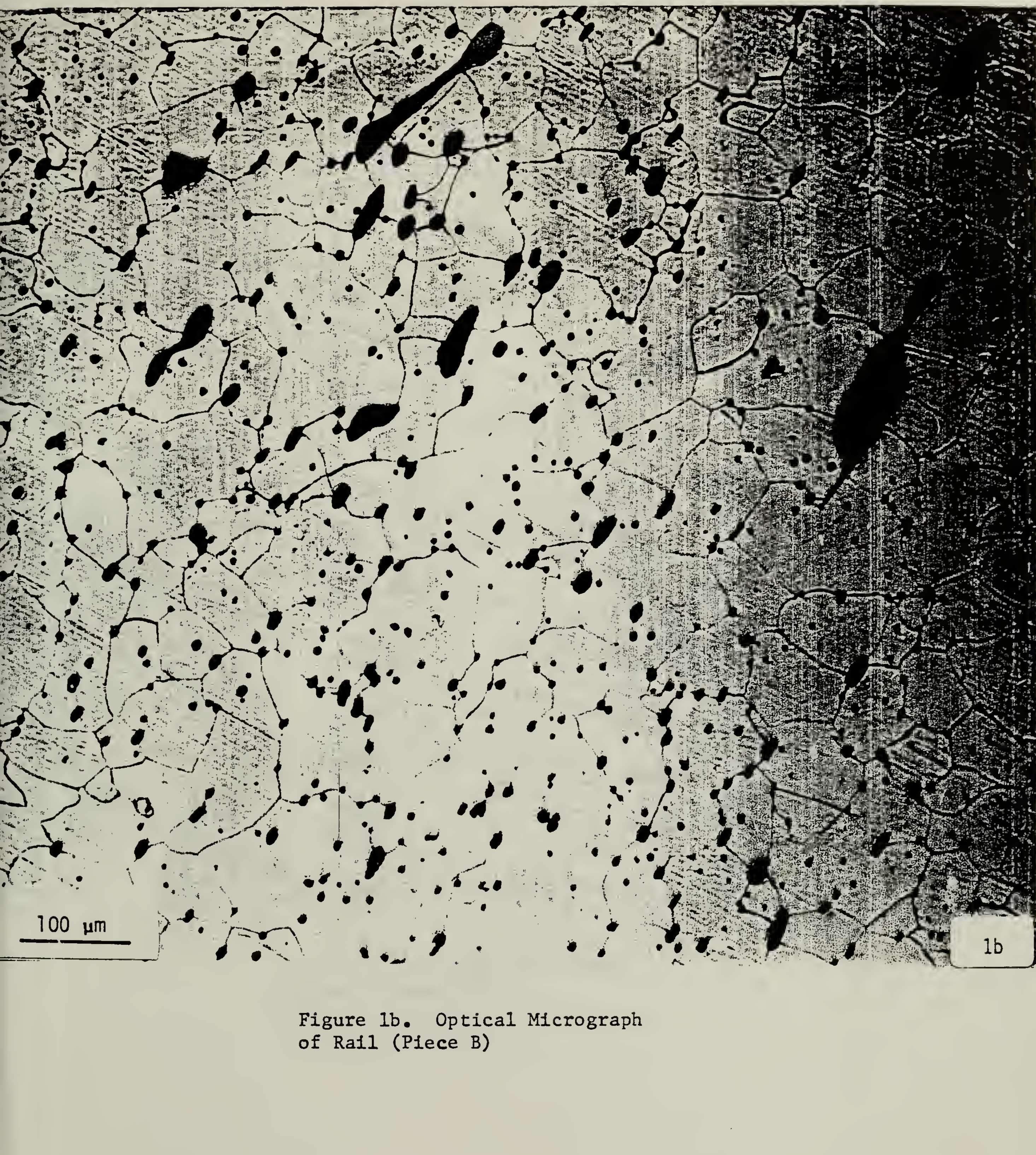


Figure 1b. Optical Micrograph of Rail (Piece B)

Figure 1c. Optical Micrograph
of Rail (Piece C)

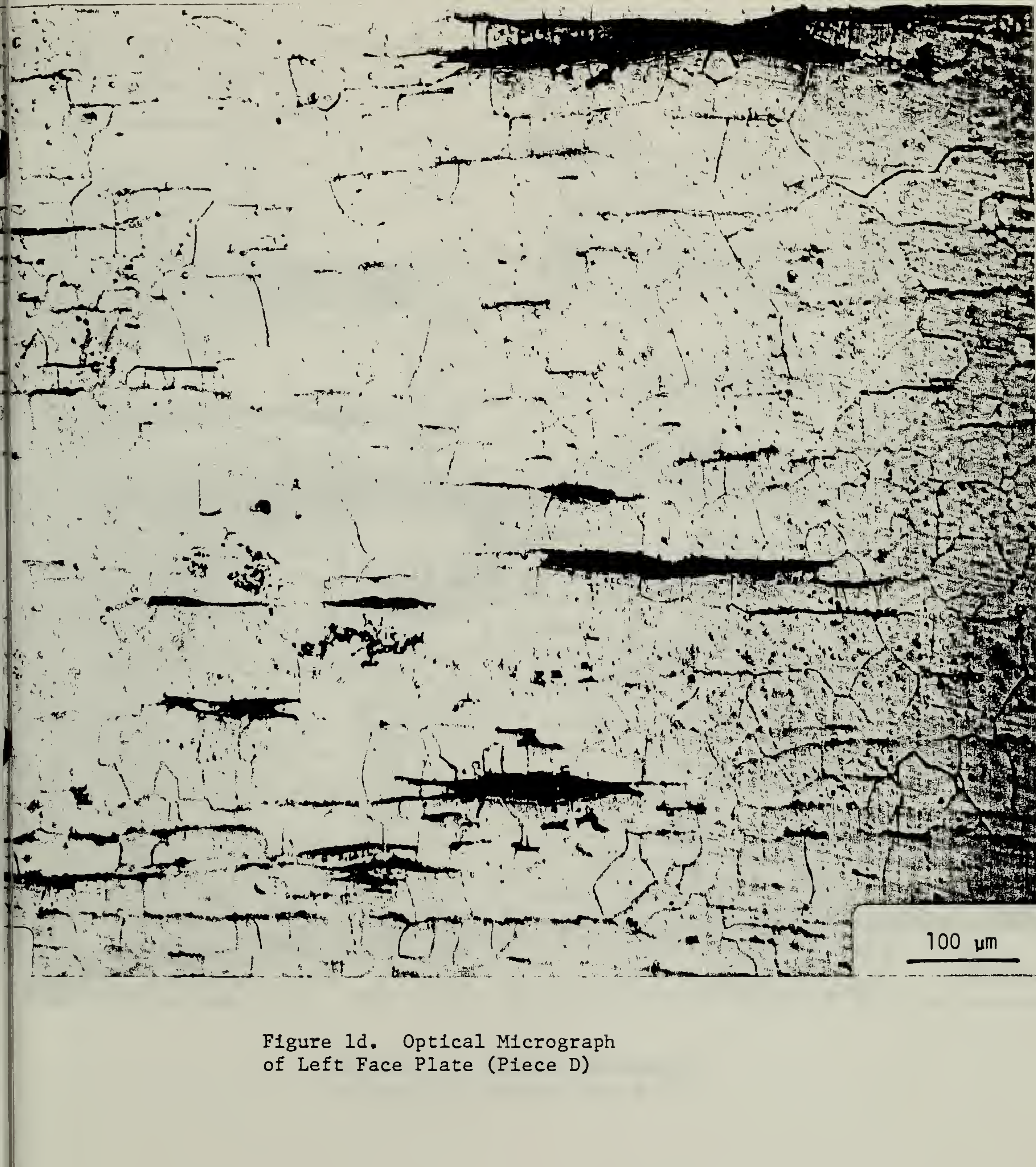


Figure 1d. Optical Micrograph
of Left Face Plate (Piece D)

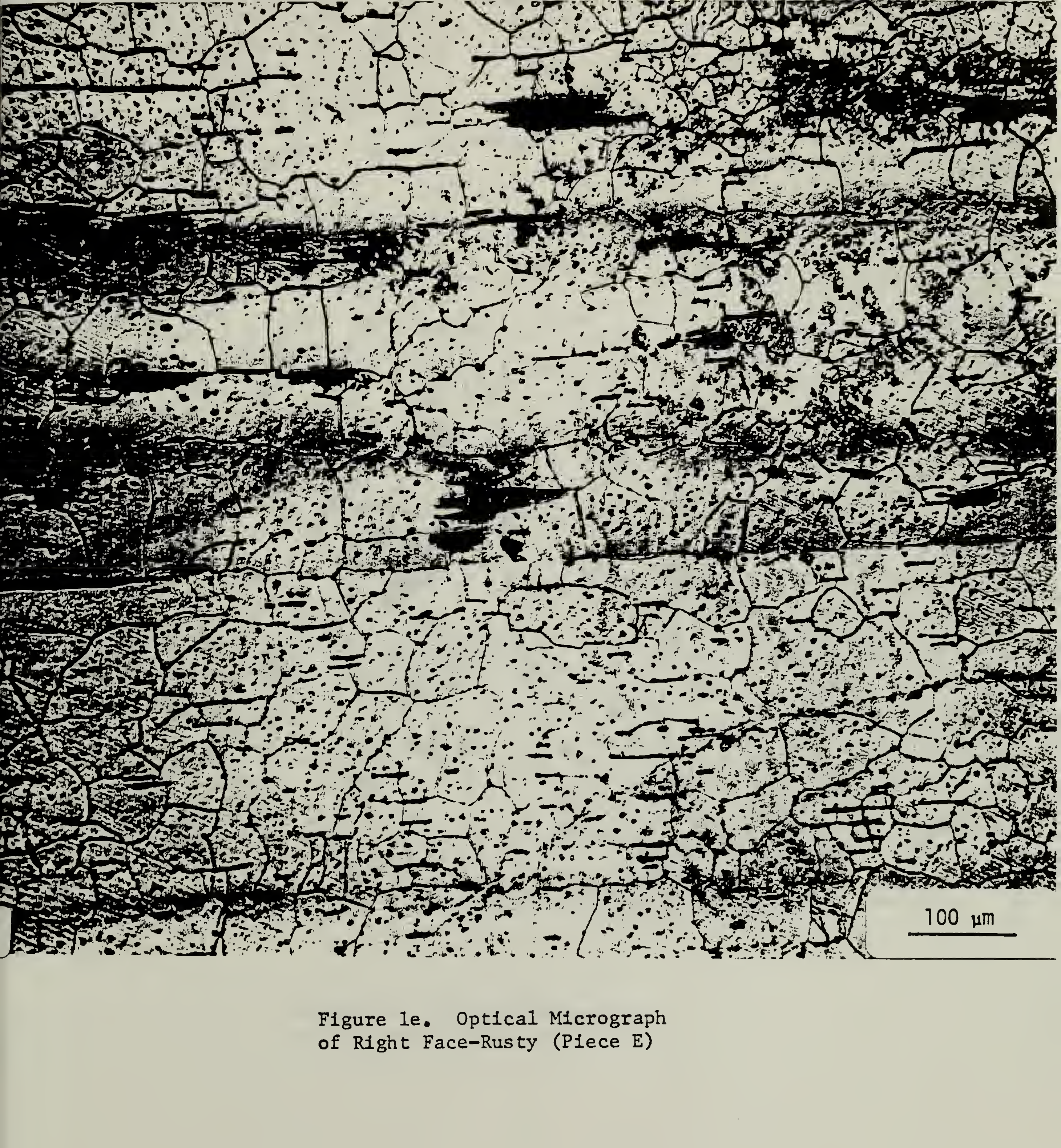


Figure 1e. Optical Micrograph of Right Face-Rusty (Piece E)

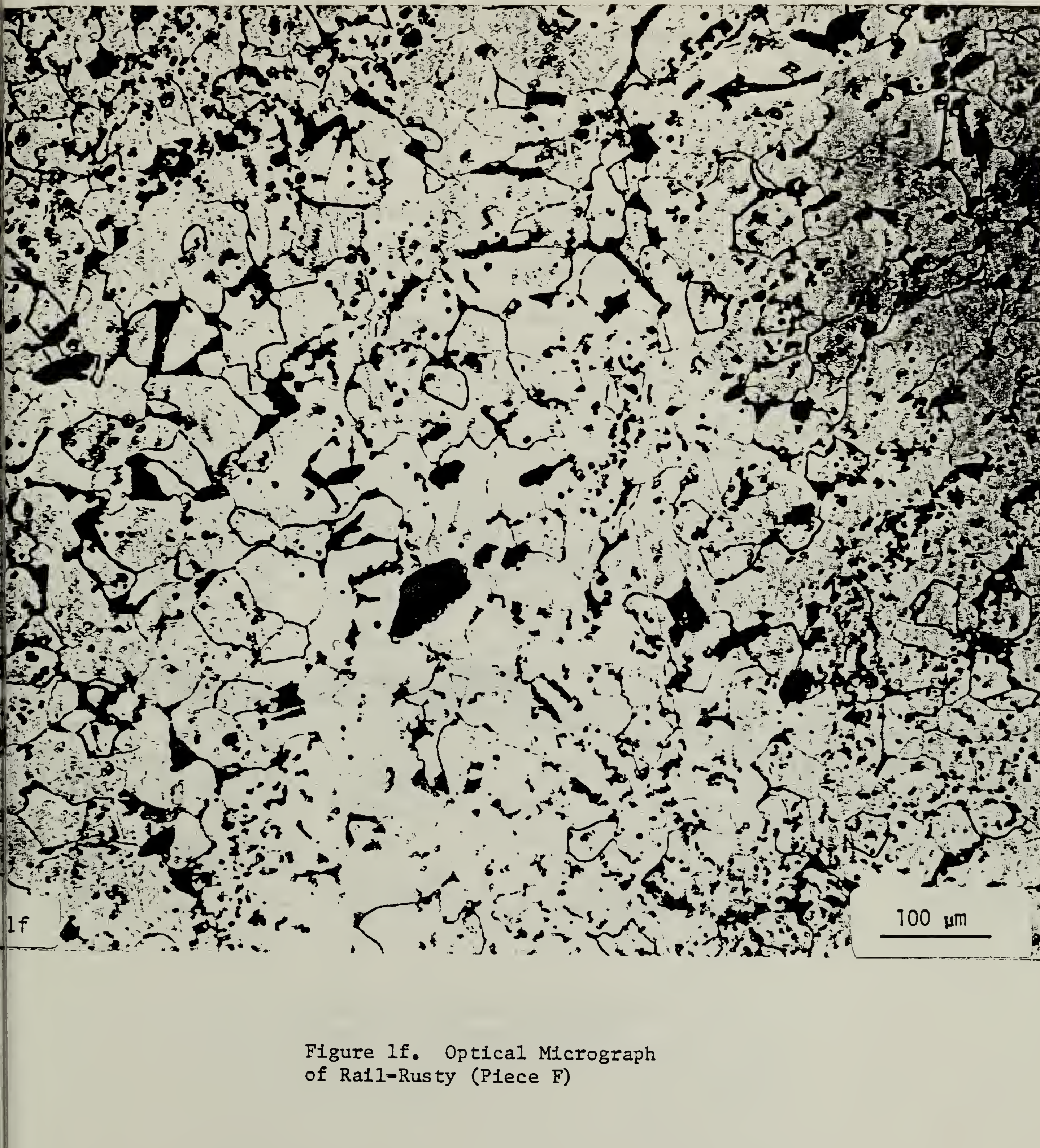


Figure 1f. Optical Micrograph
of Rail-Rusty (Piece F)

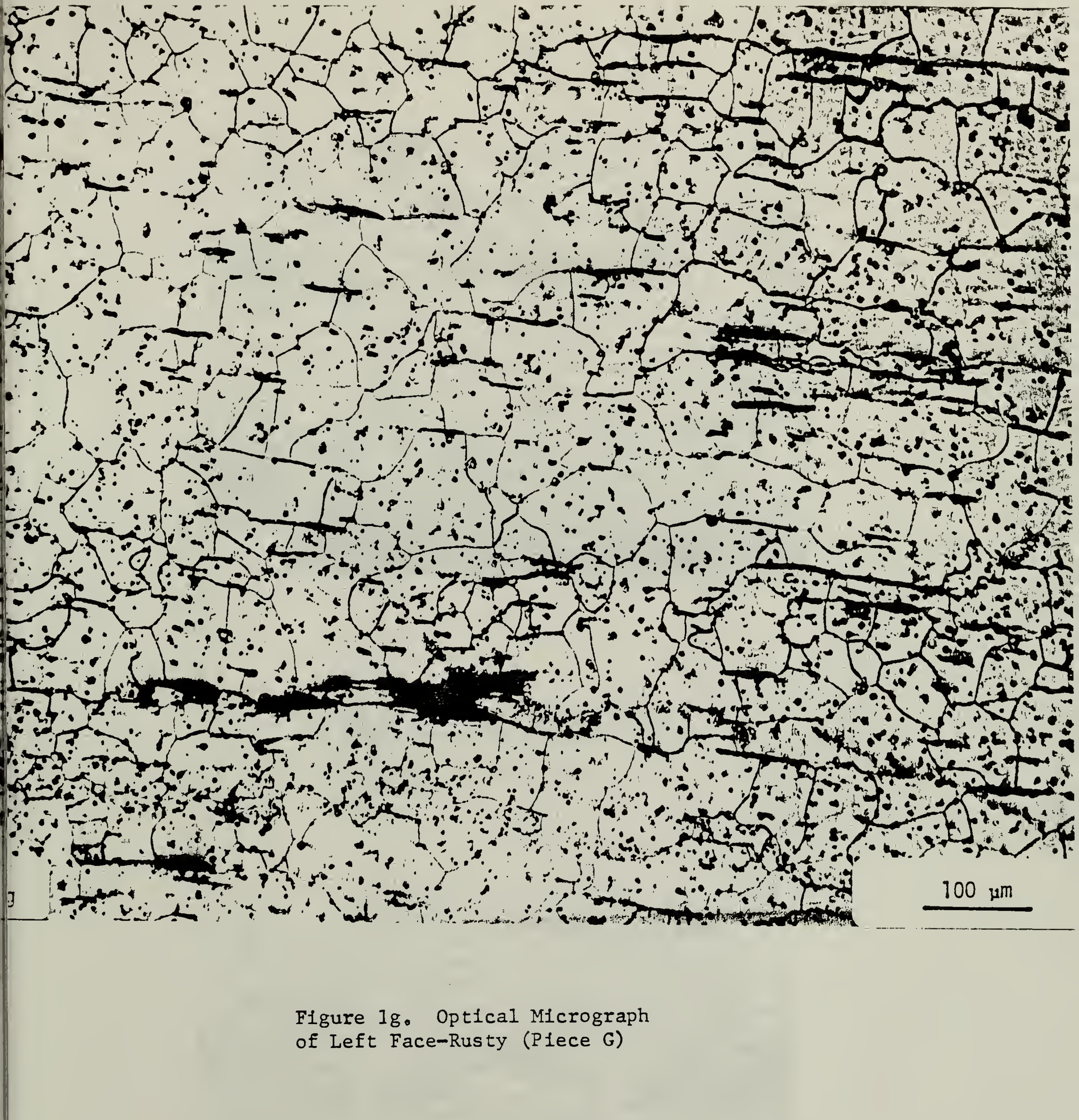


Figure 1g. Optical Micrograph of Left Face-Rusty (Piece G)

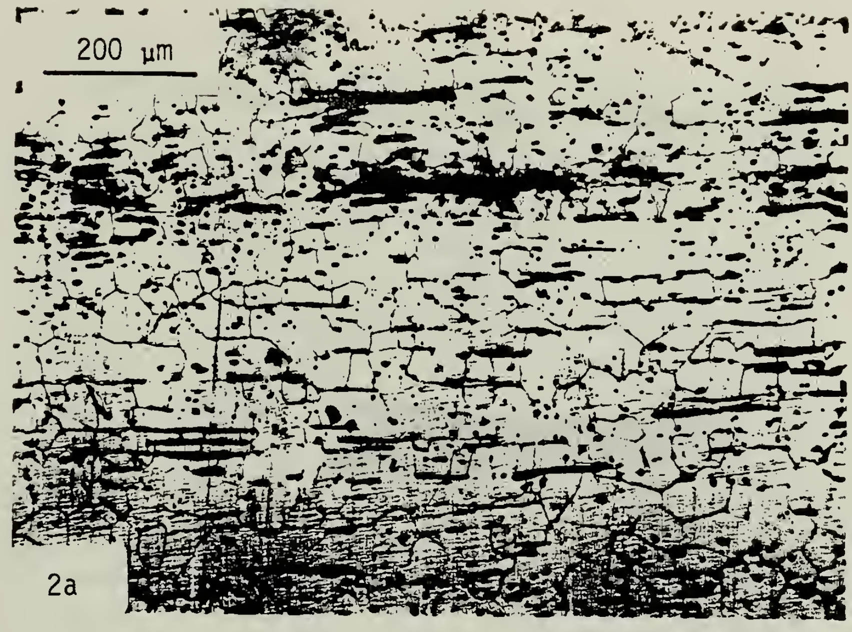
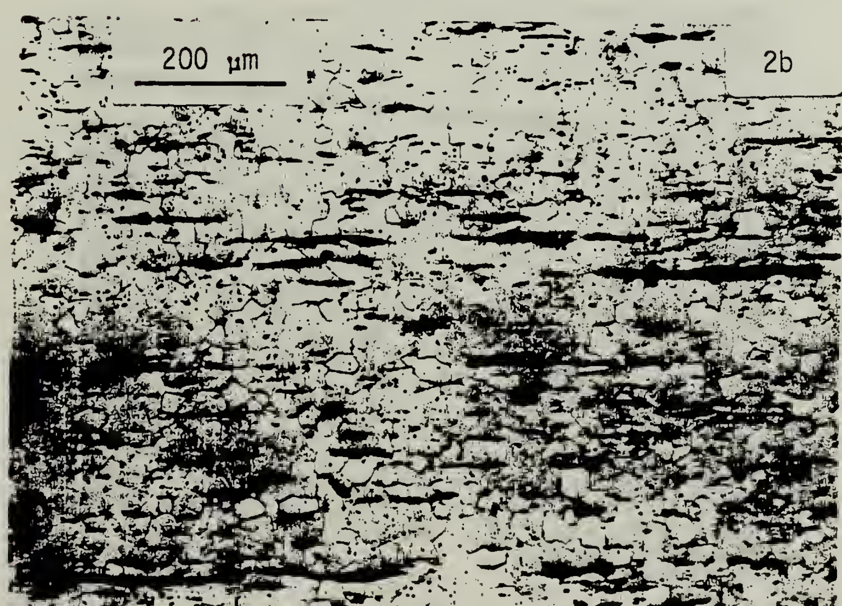


Figure 2. Optical Micrograph of
(a) Right Face Plate (Piece A)
(b) "Modern" Wrought Iron
(Piece H)



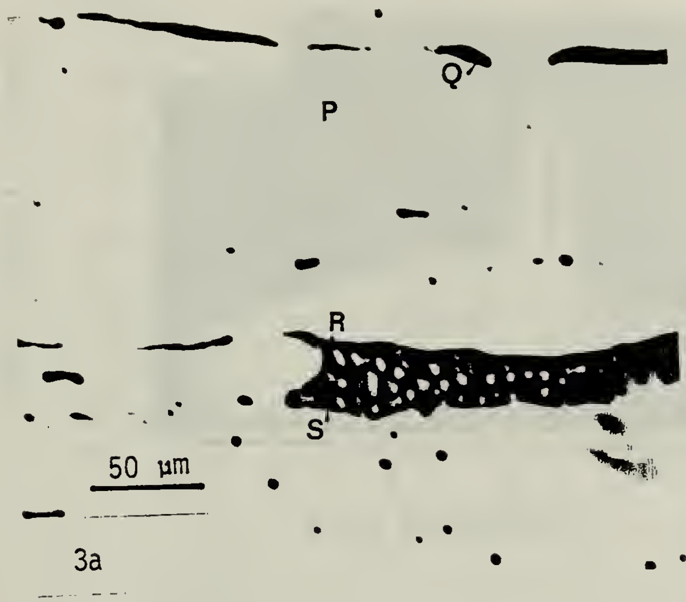
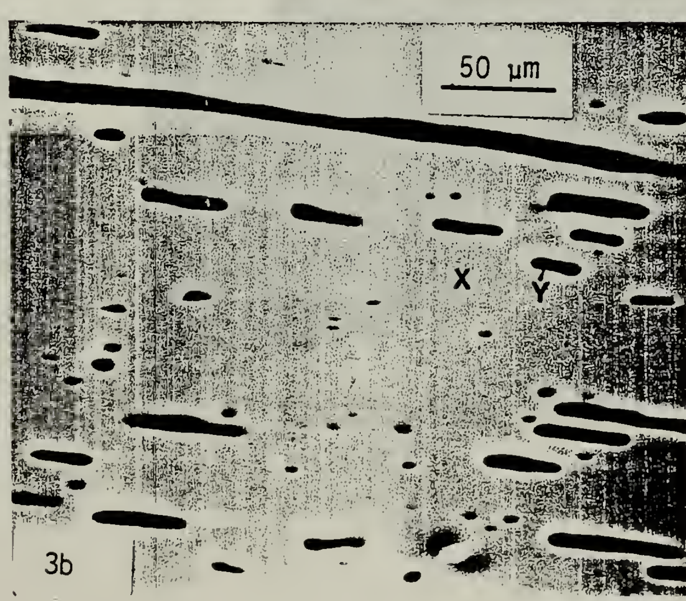


Figure 3. Compositional Back-scattered Electron Image
(a) Piece A

(b) Piece B



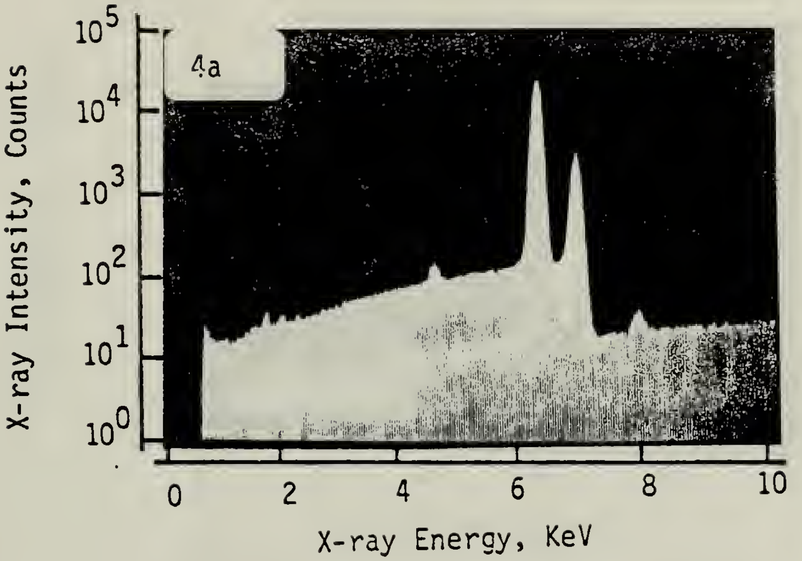
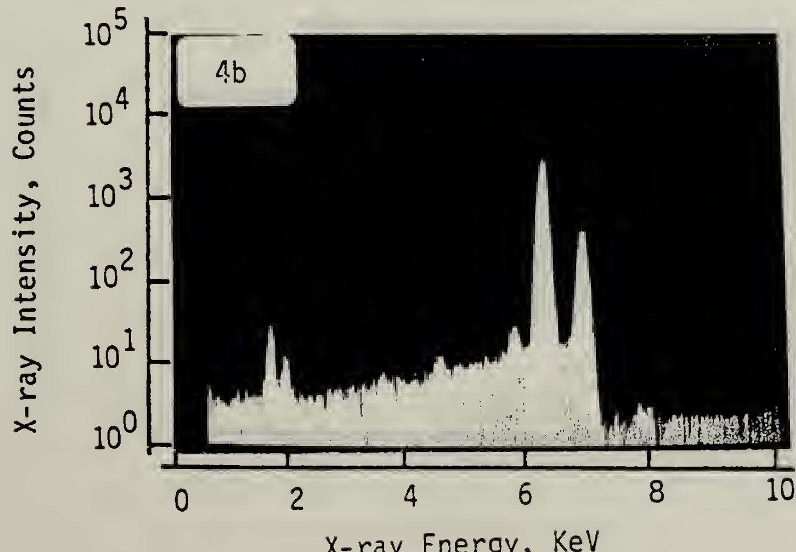


Figure 4a&b. XES Microanalysis Spectra from Piece A (Please see Figure 3a)
(a) Matrix (At point P)
(b) Slag (At point Q)



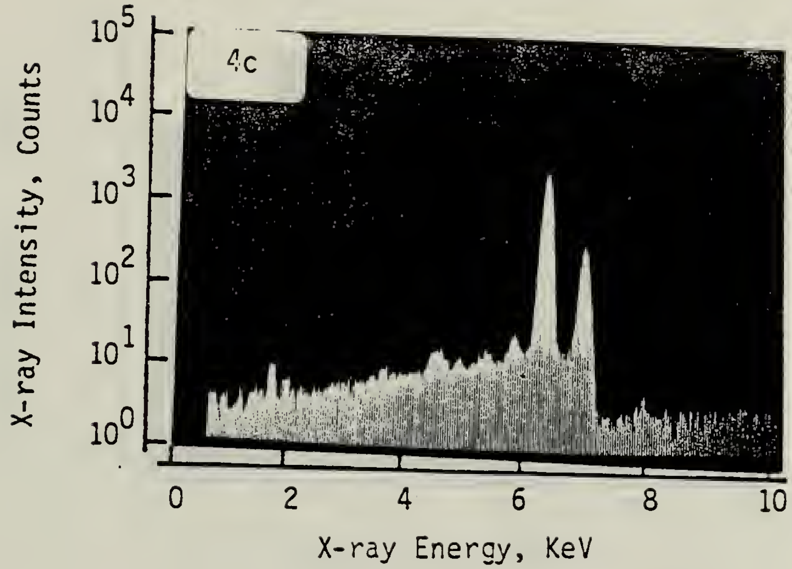
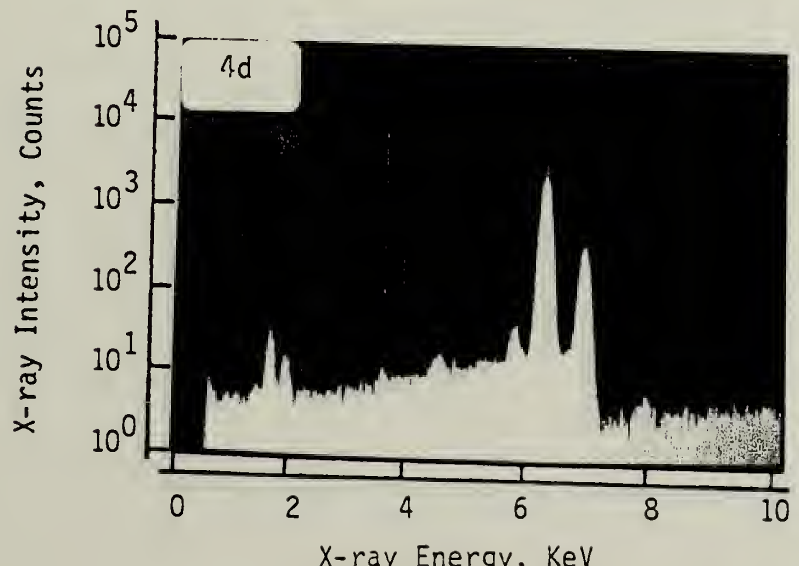


Figure 4c&d. XES Microanalysis Spectra from Piece A (Please see Figure 3a)
(c) Light Areas of Slag (At Point R)

(d) Dark Areas of Slag (At Point S)



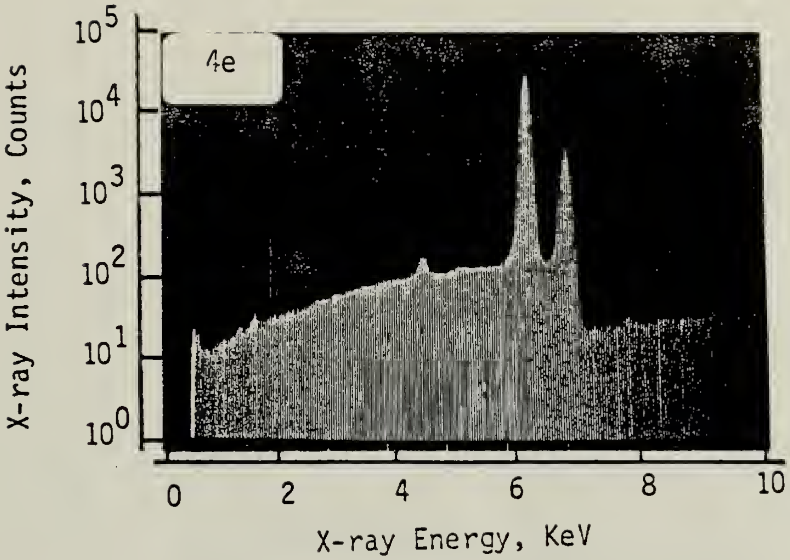
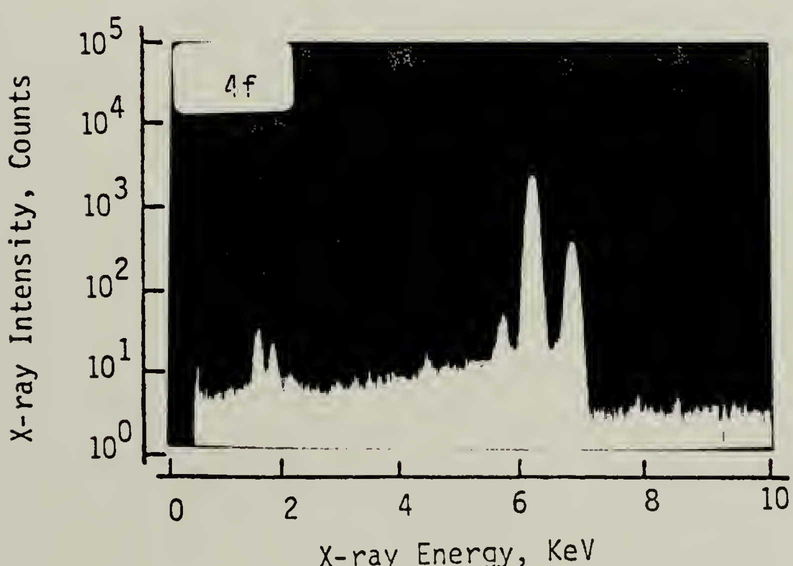


Figure 4 e&f. XES Microanalysis Spectra from Piece B (Please see Figure 3b)
(e) Matrix (At Point X)
(f) Slag (At Point Y)



PART III

RADIOGRAPHIC REPORT

Summary of Questionable Conditions

Radiographic Inspection

Iron Casemate, Carriage & Chassie Mounting 100#

Parrott Cannons

Fort Sumpter, South Carolina

Cannon Number	Remarks
#1 (For film location refer to enclosed sketches)	1) View 1 revealed crack indication as marked on radiograph.
	2) View 7 & 8 revealed several areas of excessive corrosion (as marked) that appear to be thru the metal.
#2 (For film locations refer to enclosed sketches)	1) General condition reveals corrosion & rust throughout entire inspection area.
	2) View 3 reveals 2 areas of heavy corrosion as marked on radiographs.
#3 (For film locations refer to enclosed sketches)	1) View 1 indicates possible minor cracking as marked on radiographs.
	2) View 8 reveals cracking beginning in parent metal around bolted connection as marked on radiographs. No other apparent effects noted.

Cannon Number	Remarks
#4 (For film locations refer to enclosed sketches)	1) View 1 reveals one area corroded completely thru parent metal
	2) View 2 reveals 3 areas completely thru parent metal.
	3) View 3 reveals three small holes completely thru parent metal.
	4) View 4 reveals 2 areas almost thru parent metal.
	5) View 5 reveals one area almost thru parent metal.
	6) View 6 reveals several areas rusted thru parent metal as marked on radiograph.
	7) Views 8 & 9 reveal areas of in-line Inclusions that appear to· be separations of metal.
#5 (For film locations refer to enclosed sketches)	1) View 1 reveals heavy corrosion with several areas rusted completely thru.
	2) Views 2 & 3 also reveal heavy corrosion and rust with several areas completely thru parent metal.
	3) View 4 indicates an in-line indication that appears to be seperation of parent metal.
	4) View 5 reveals heavy corrosion and rusting with one area rusted completely thru.
	5) View 7 indicates in-line indications that appear to be seperation of parent metal.
	6) View 8 reveals heavy corrosion and rusting with one area completely thru.
	7) View 9 reveals gross corrosion and rust with crack indications.
	8) View 10 reveals heavy corrosion with cracks.
	9) View 11 indicates heavy corrosion and rust with several areas rusted thru.

Cannon Number	Remarks
#6 (For film locations refer to enclosed sketches)	1) Entire inspection area revealed heavy corrosion and rusting with numberous areas rusted thru parent metal.
	2) Views 4 & 5 reveal in-line indications that appear to be seperation of parent metal.
	3) View 8 reveals cracking indications as marked on radiographs.
#7 (For film locations refer to enclosed sketches)	1) Views 3 & 5 reveal in-line indications with possible cracking.
	2) Views 8 & 9 reveal heavy corrosion and rusting.
#8 (For film locations refer to enclosed sketches)	1) Entire inspection area reveals heavy corrosion, rust and pitting.
#9 (For film locations refer to enclosed sketches)	1) View 5 reveals in-line indications that appear to be seperation or parent metal with possible cracking.
#10 (For film locations refer to enclosed sketches)	1) View 3 reveals in-line indications that appear to be seperation and cracking.
	2) Views 7 & 8 indicate heavy corrosion and rusting with several areas rusted almost completely thru parent metal.
	3) View 8 reveals excessive wear but appears to be from normal use.
#11 (For film locations refer to enclosed sketches)	1) View 4 reveals excessive wear but appears be from normal use.
	2) View 5 indicates in-line indications and possible cracking.
	3) View 9 reveals several areas rusted completely thru.

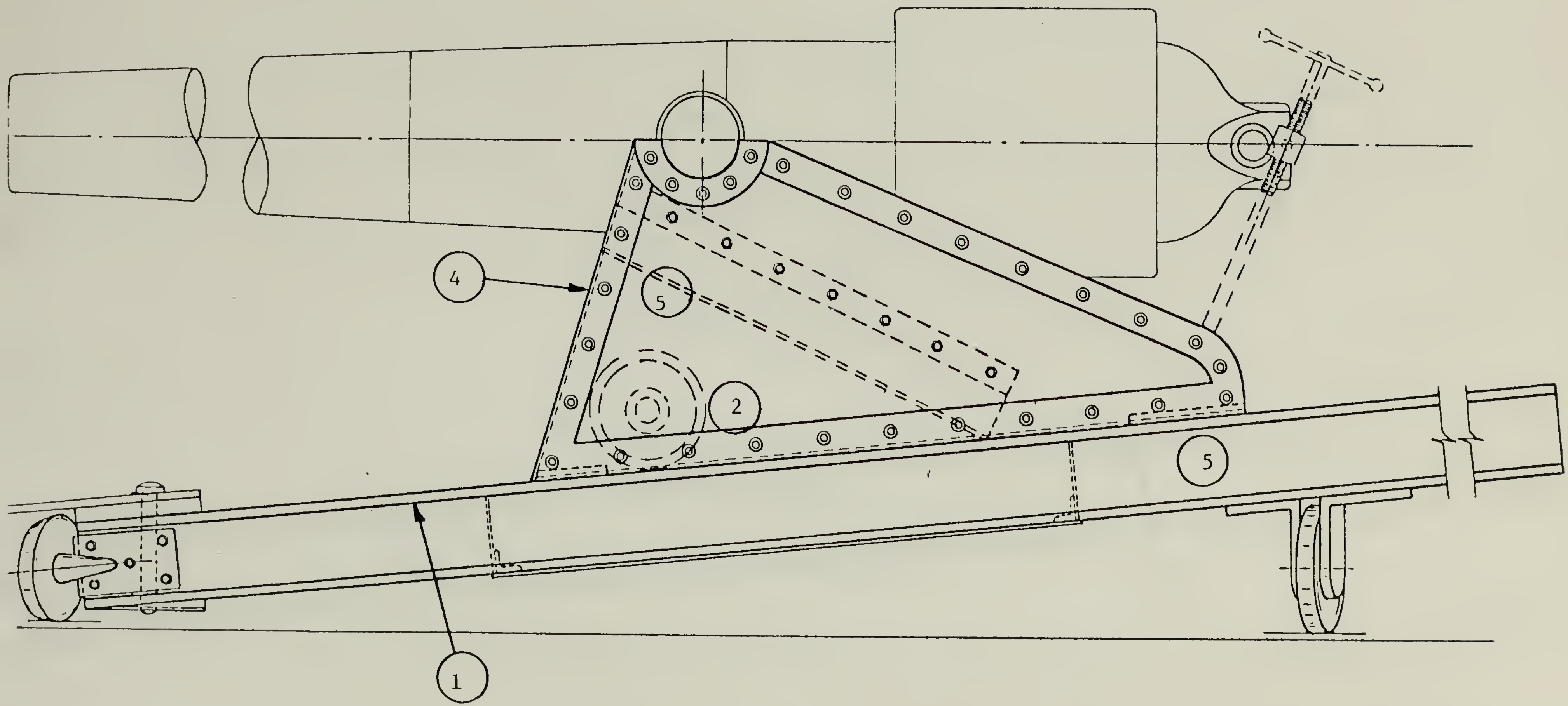
All indications noted above are clearly marked on the enclosed ratio-graphs for inspection.

Generally, all 11 cannons inspected showed excessive corrosion and rusting due to age and location with the most questionable areas noted above for further evaluation.

Ultrasonic thickness measurements were attempted to determine wall thickness of the metal but due to rust, pitting and surface conditions this inspection was unsuccessful.

Cannon Number One

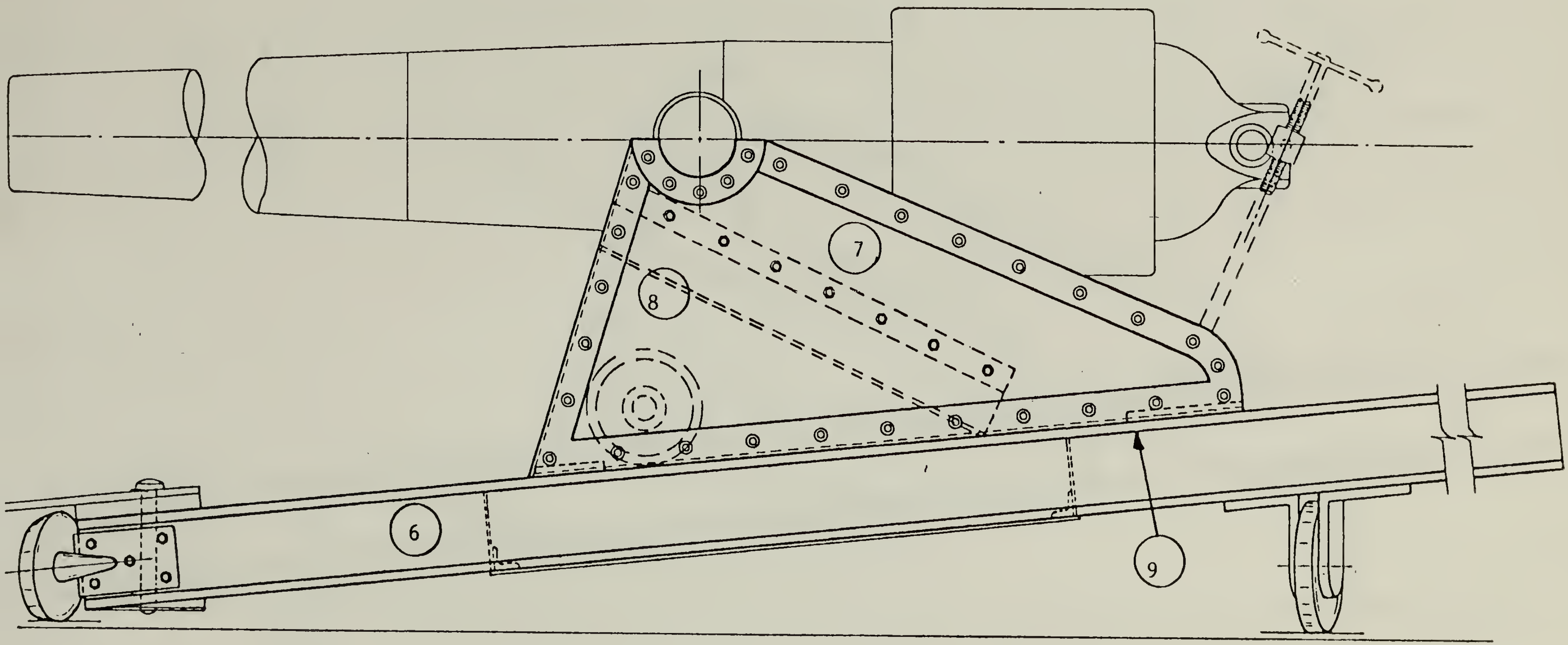
Left Half



(6) - Exposure Locations

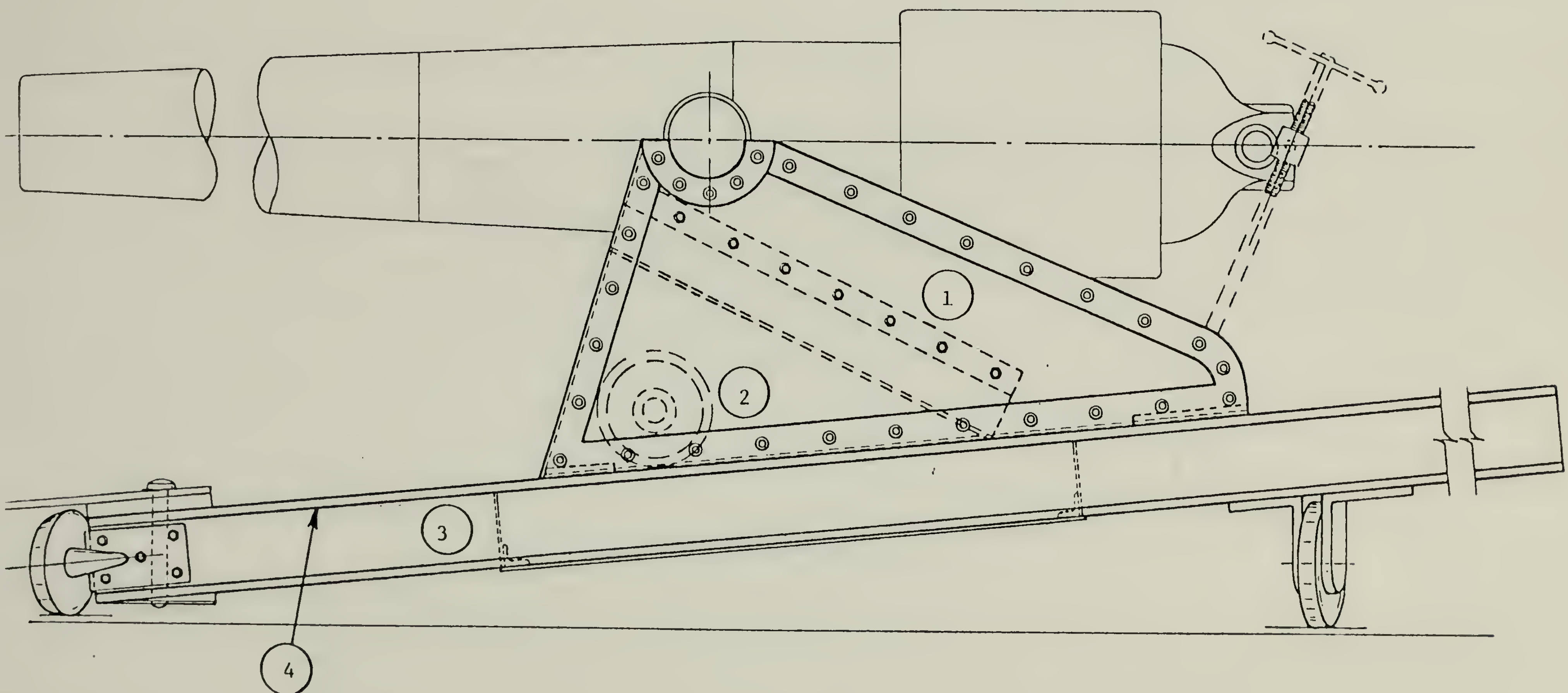
Cannon Number One

Right Half



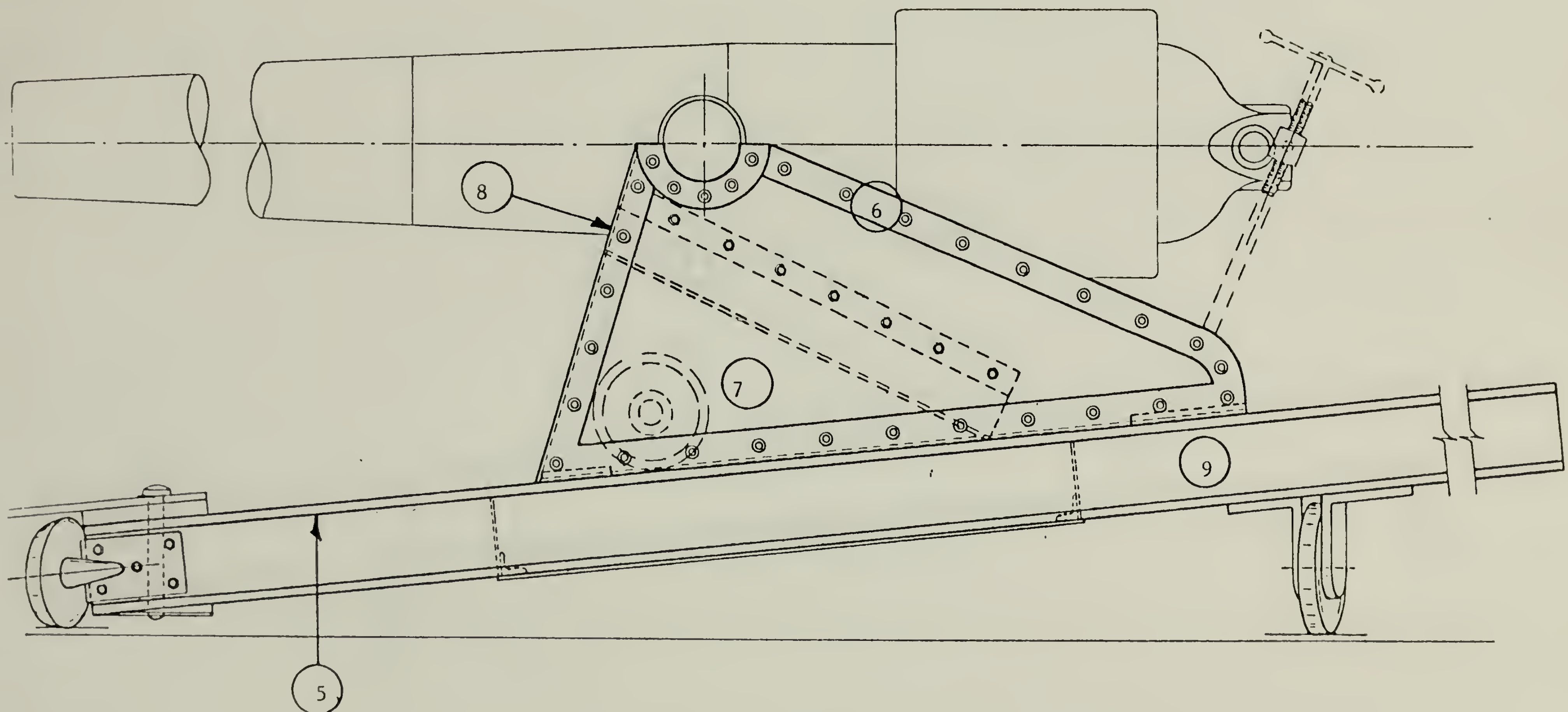
Cannon Number Two

Left Half



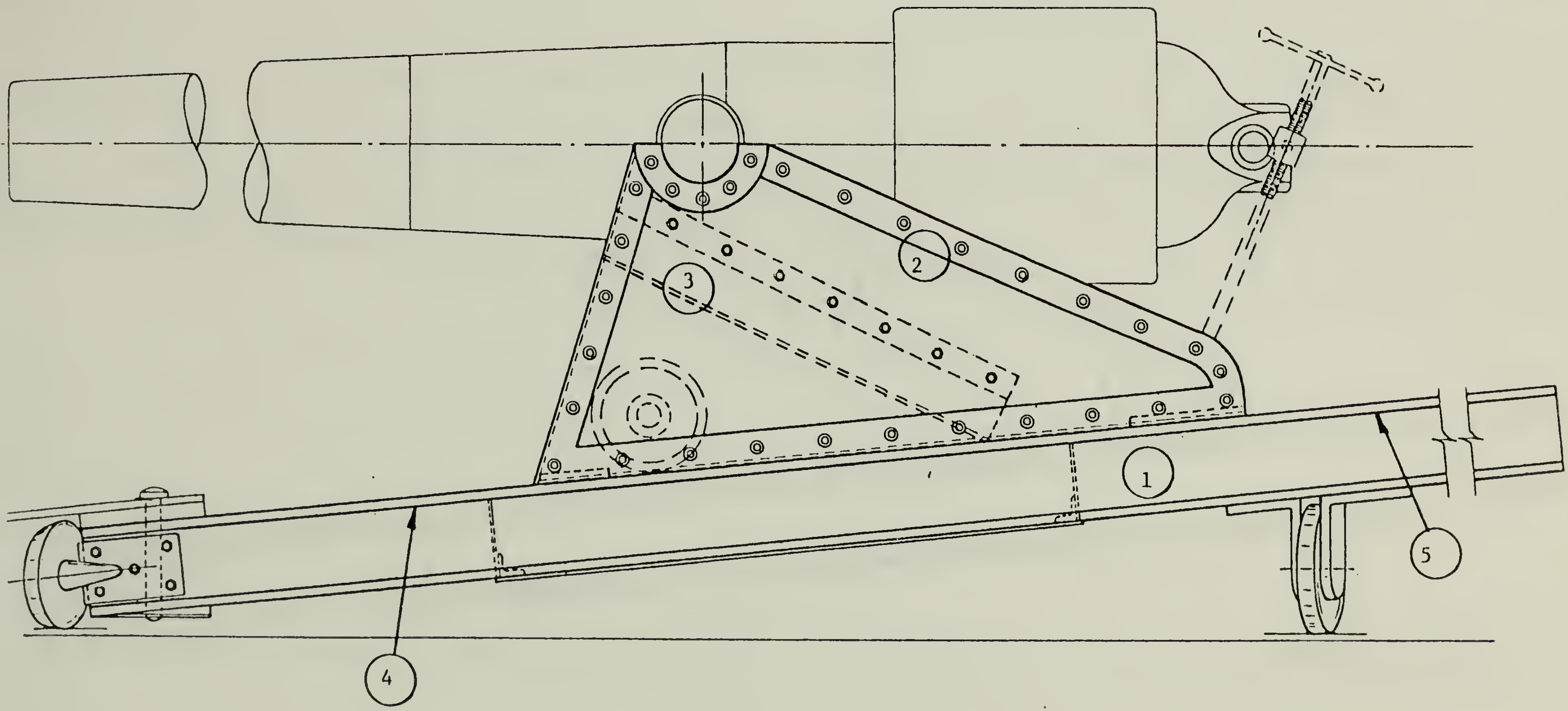
Cannon Number Two

Right Half



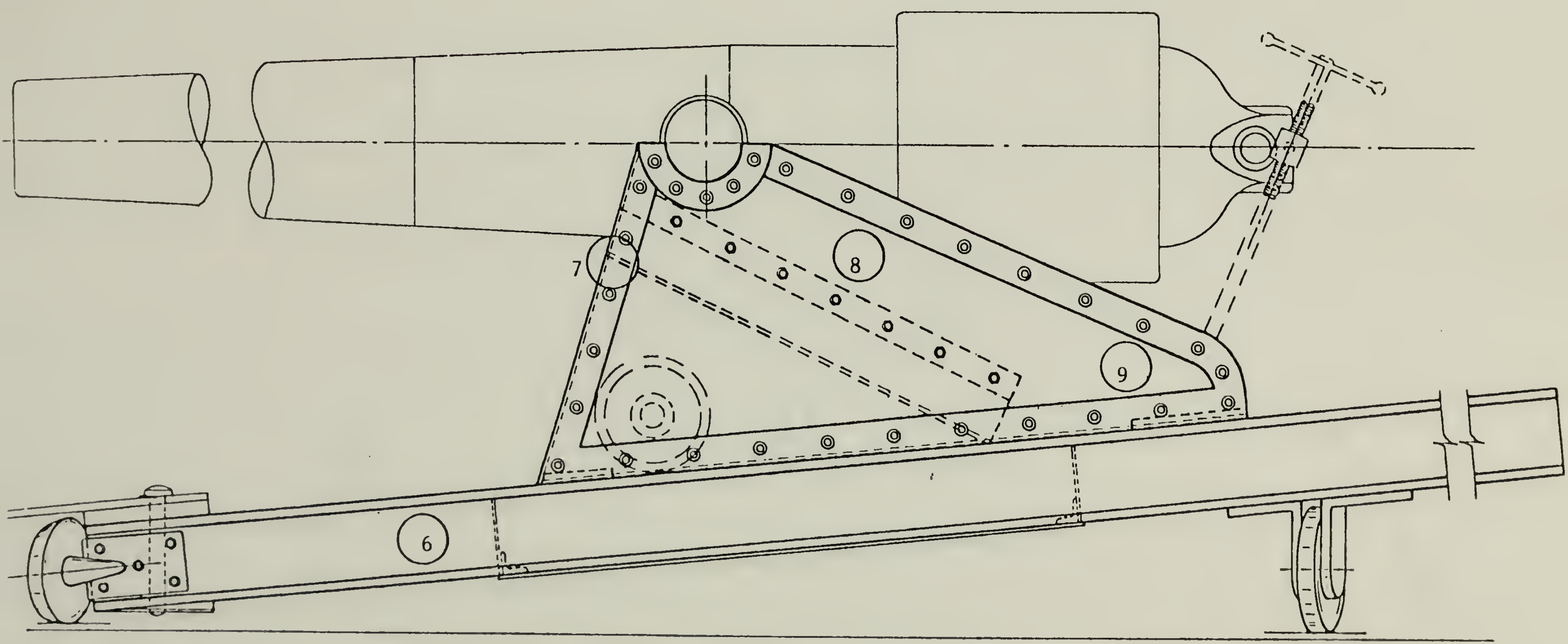
Cannon Number Three

Left Half



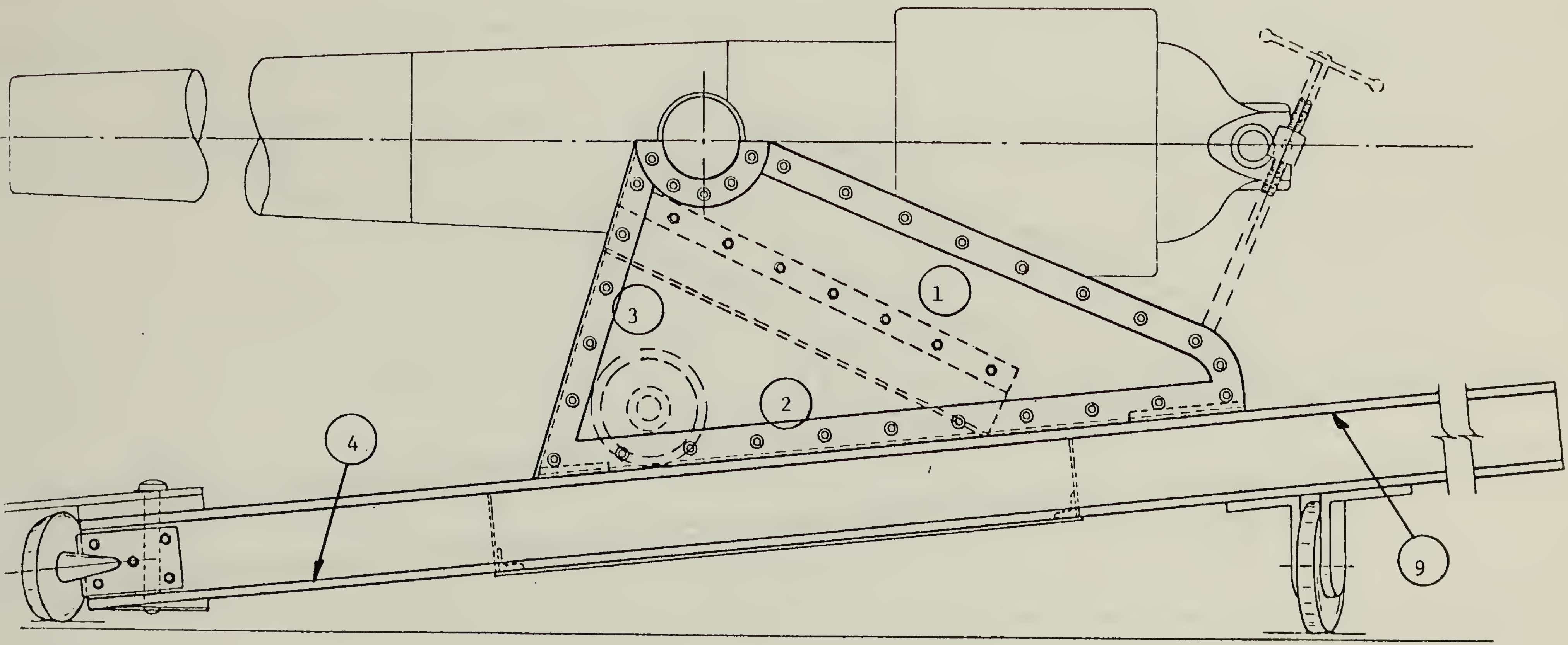
Cannon Number Three

Right Half



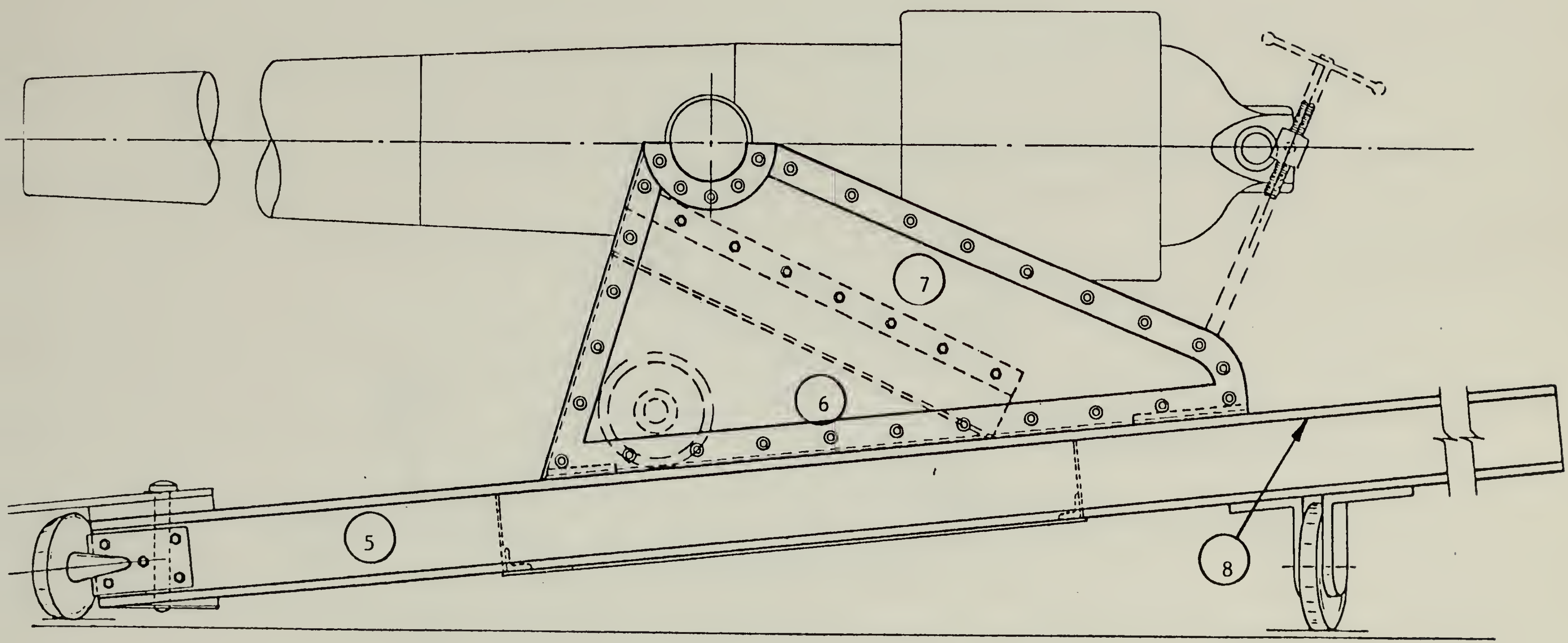
Cannon Number Four

Left Half



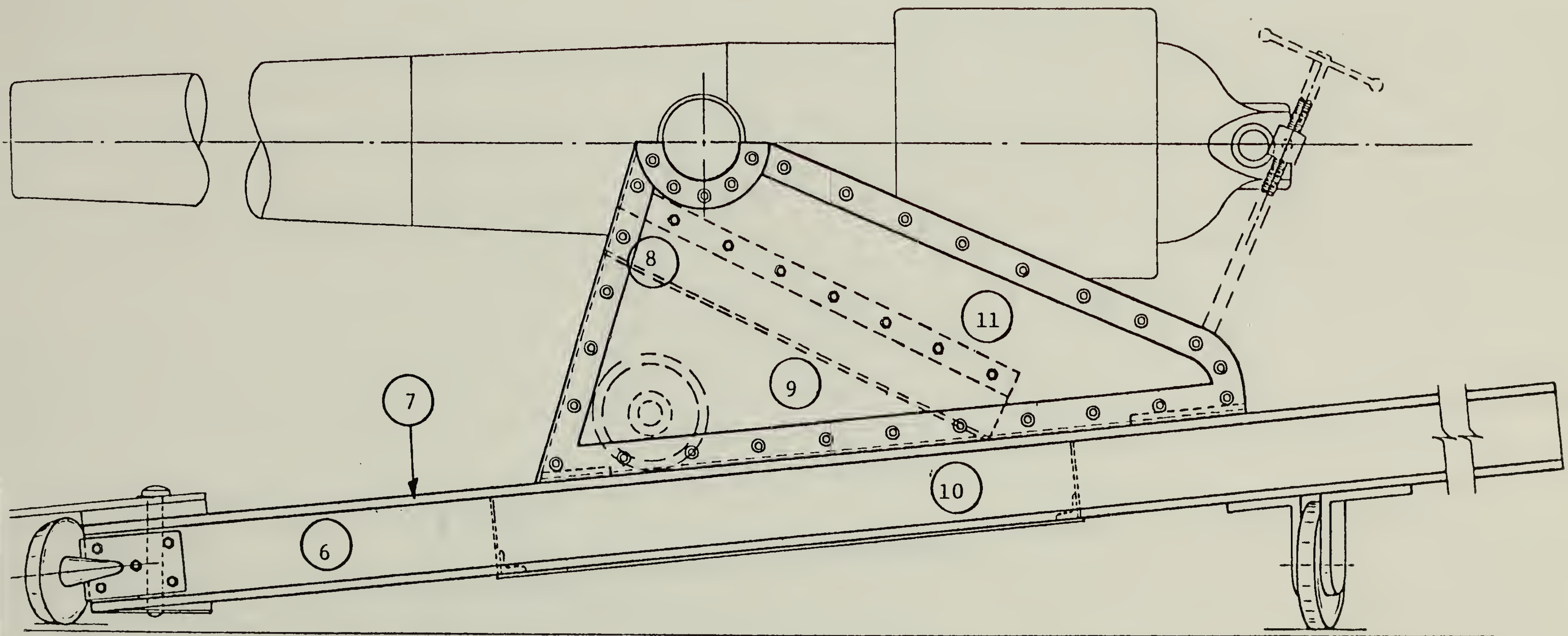
Cannon Number Four

Right Half



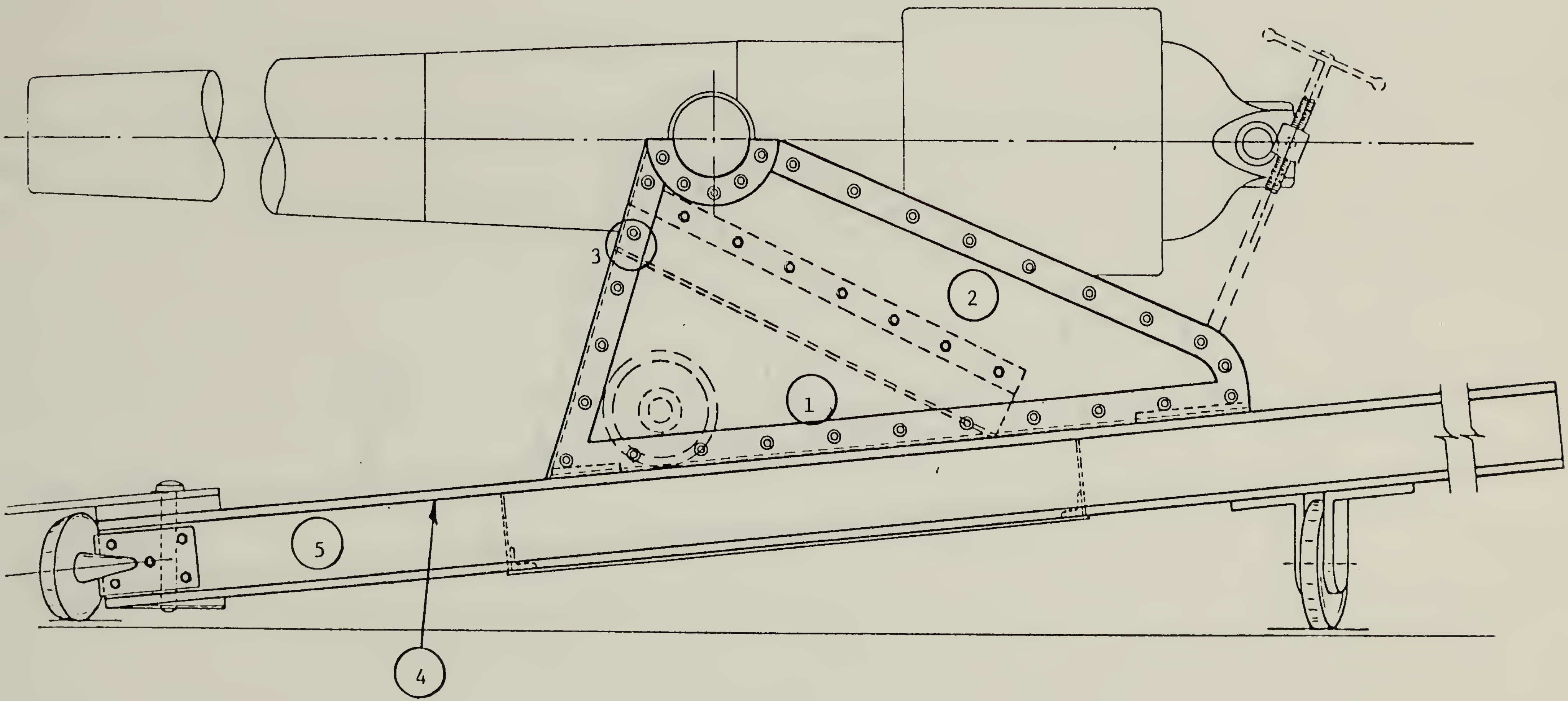
Cannon Number Five

Right Half



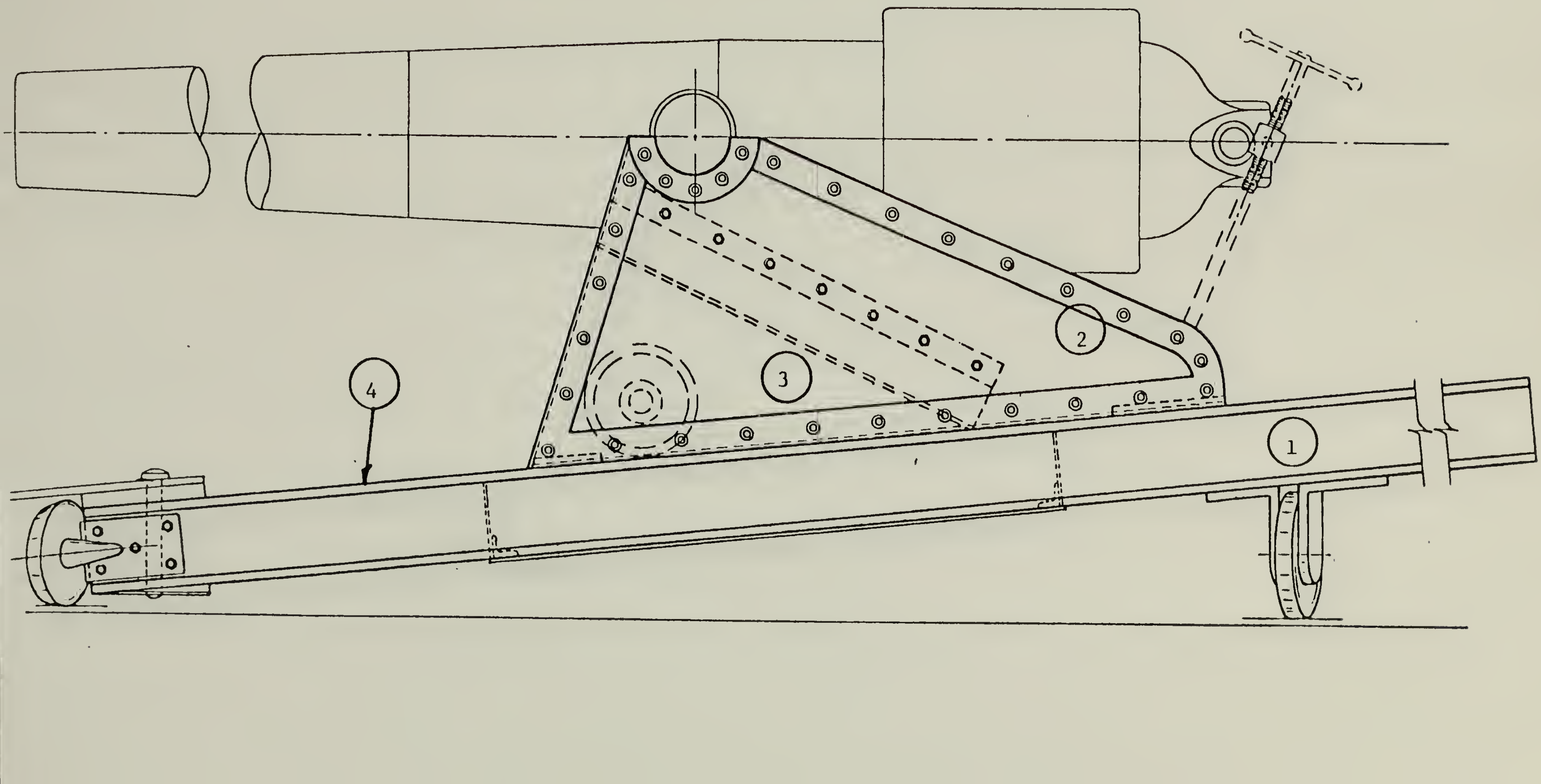
Cannon Number Five

Left Half



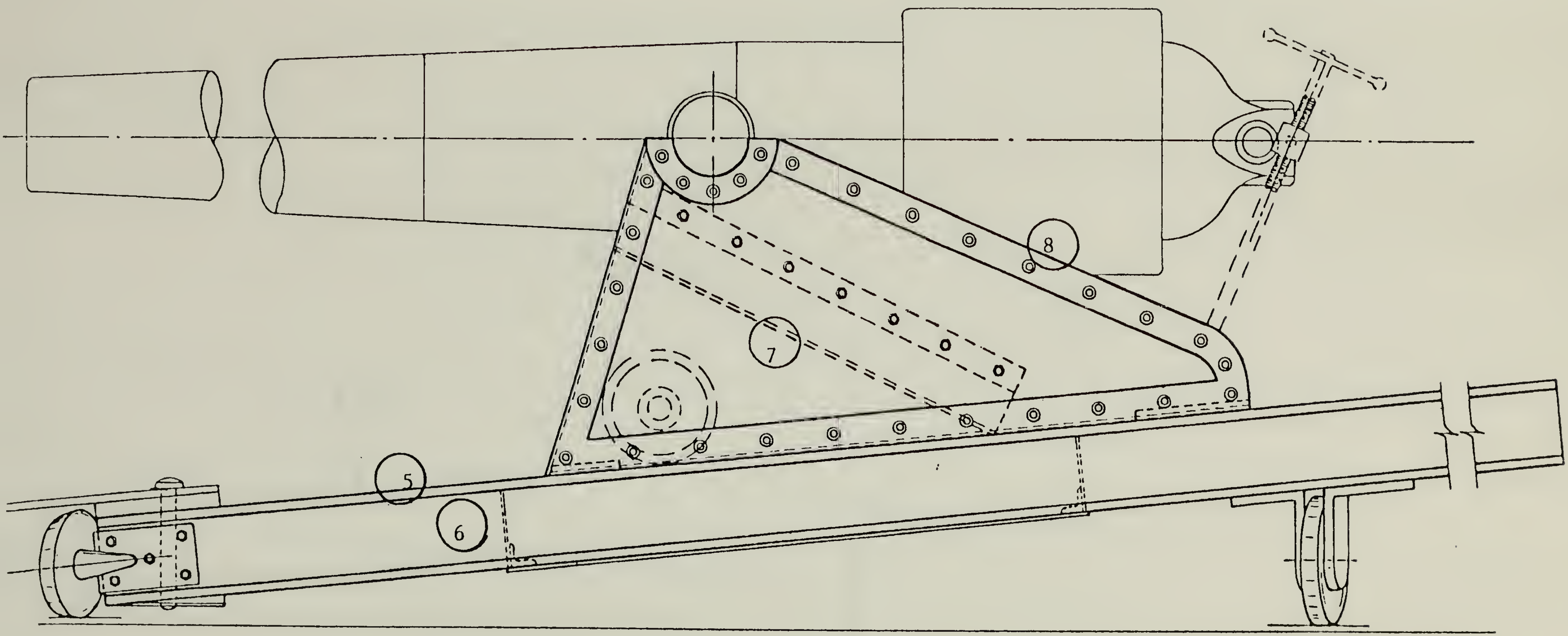
Cannon Number Six

Left Half



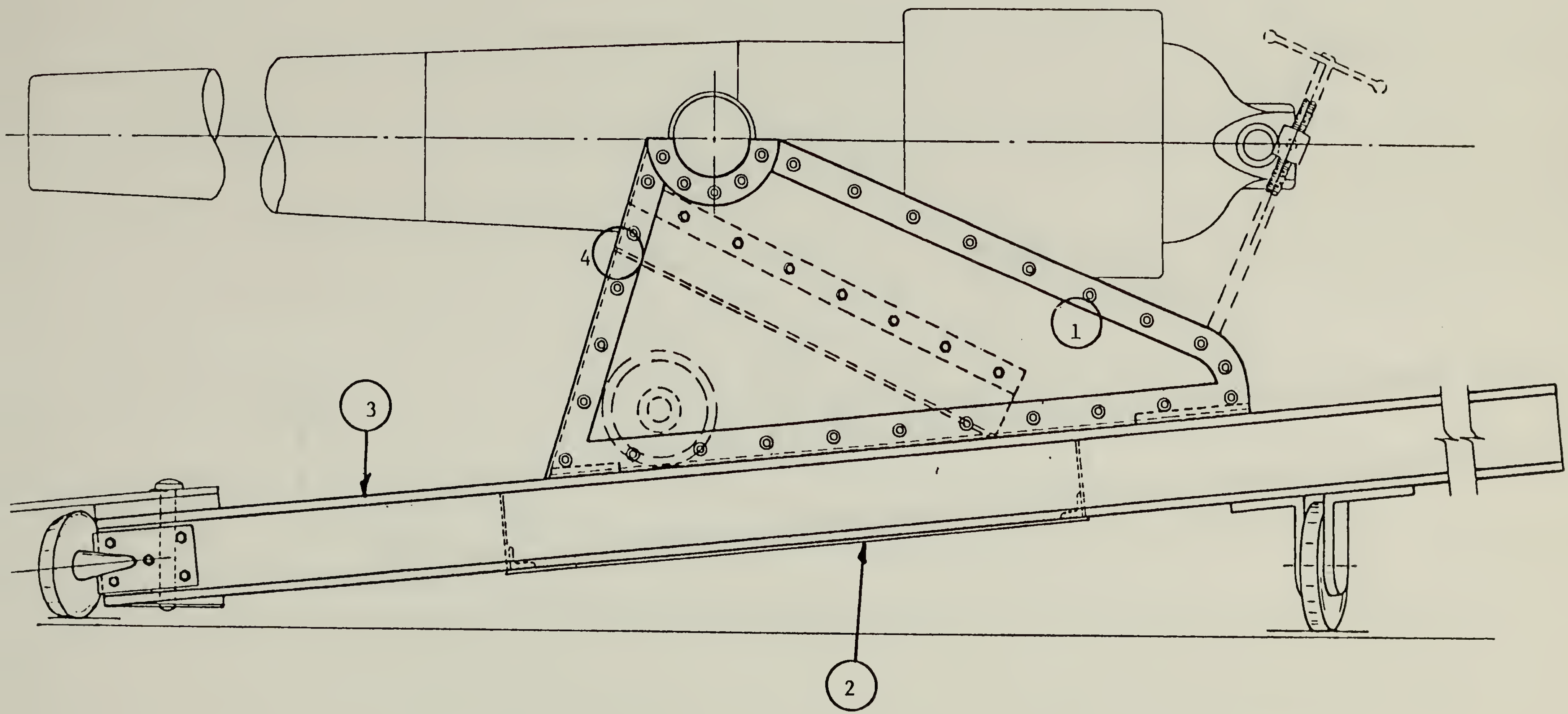
Cannon Number Six

Right Half



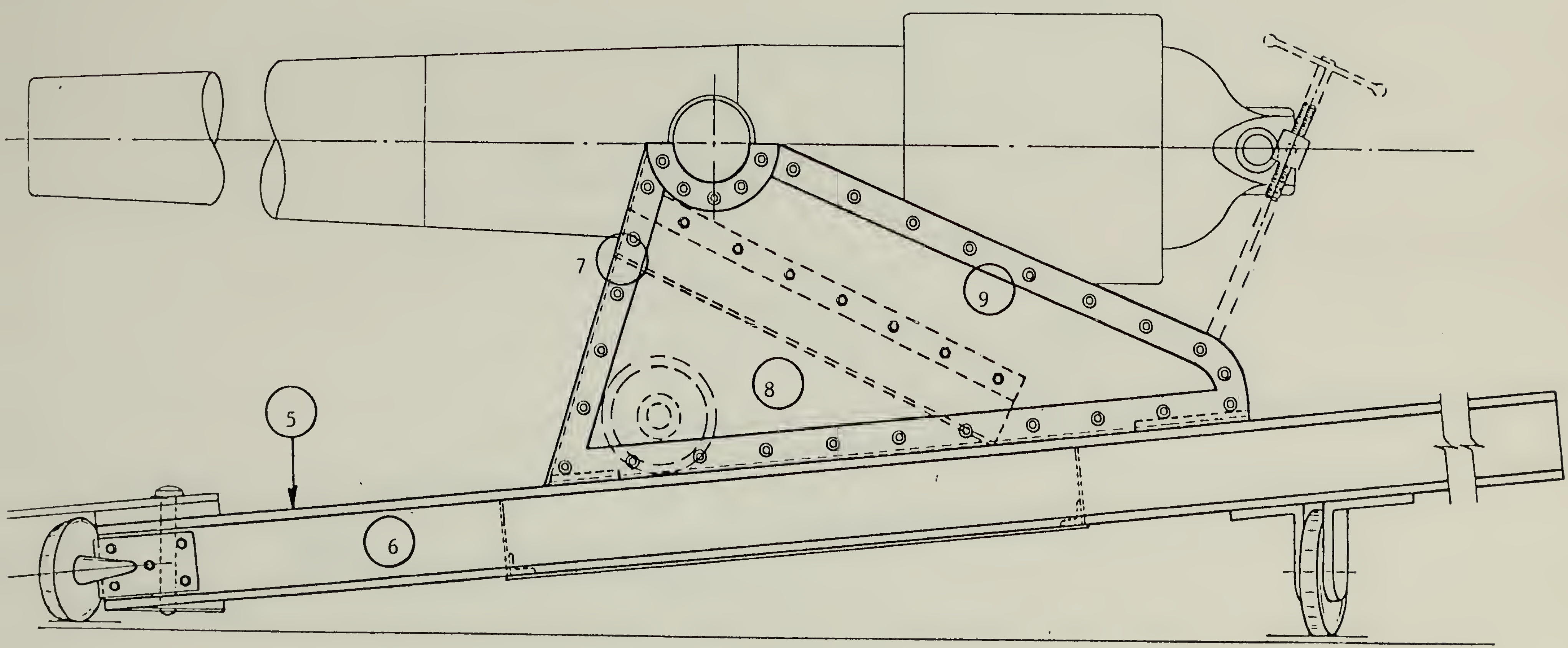
Cannon Number Seven

Left Half



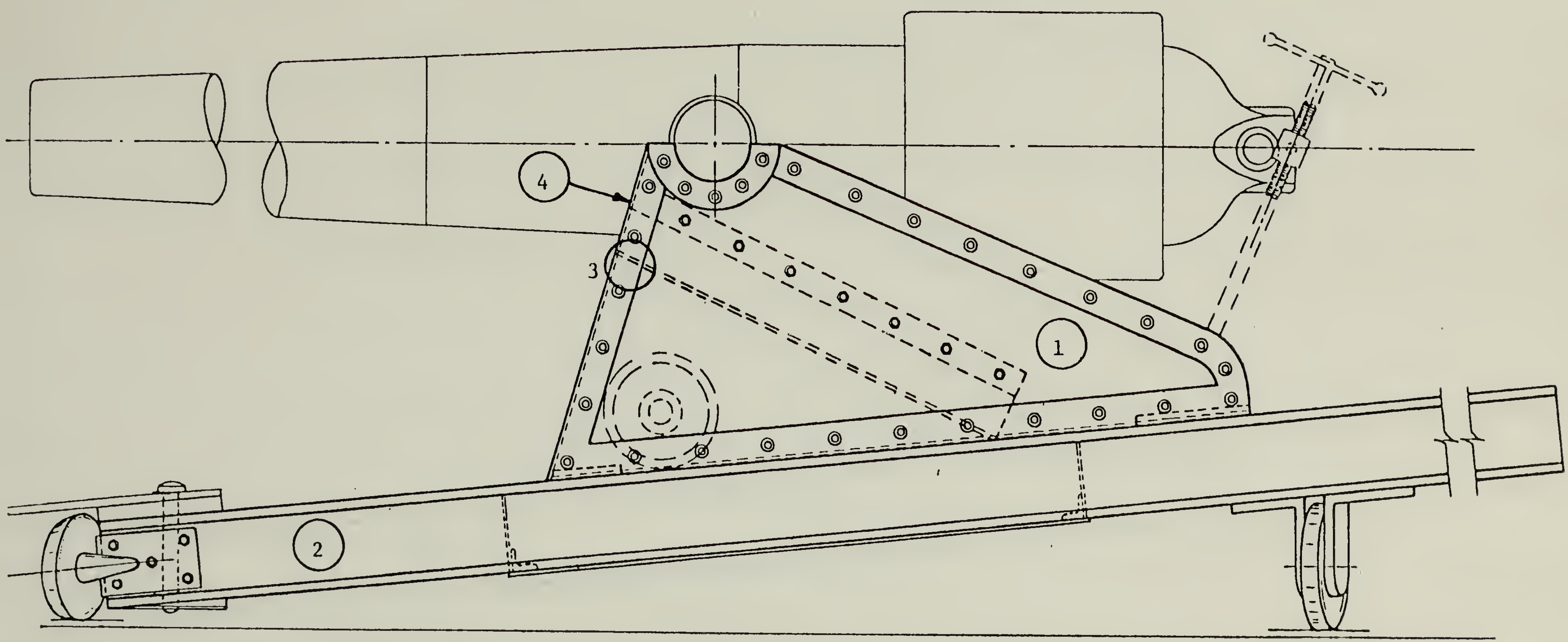
Cannon Number Seven

Right Half



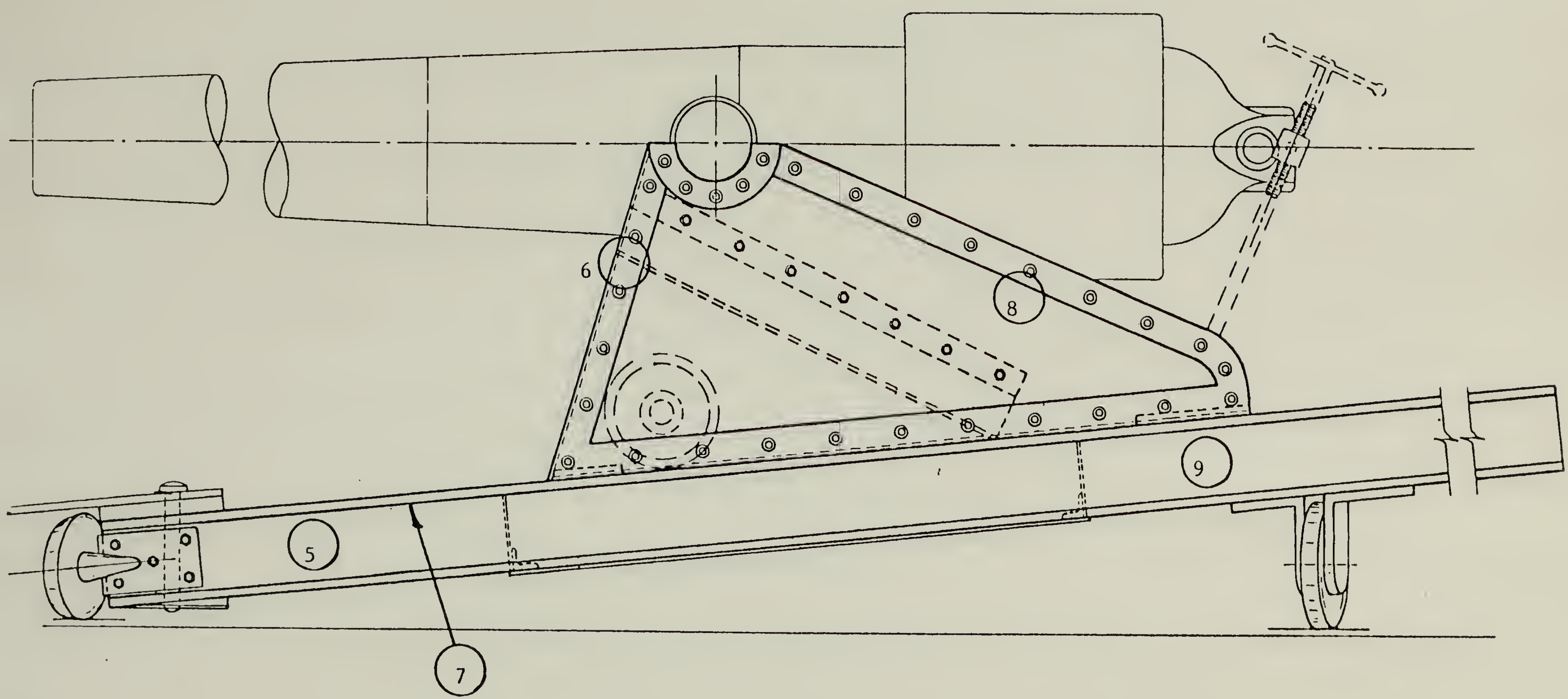
Cannon Number Eight

Left Half



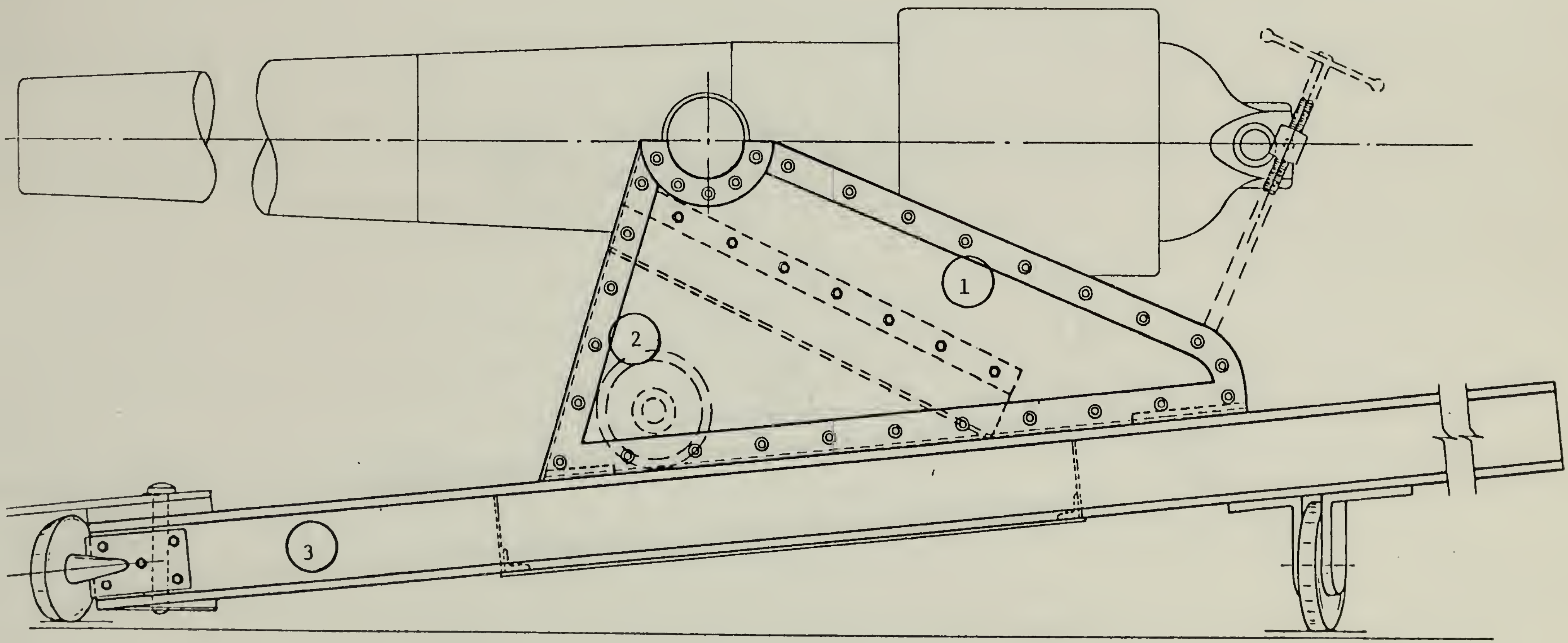
Cannon Number Eight

Right Half



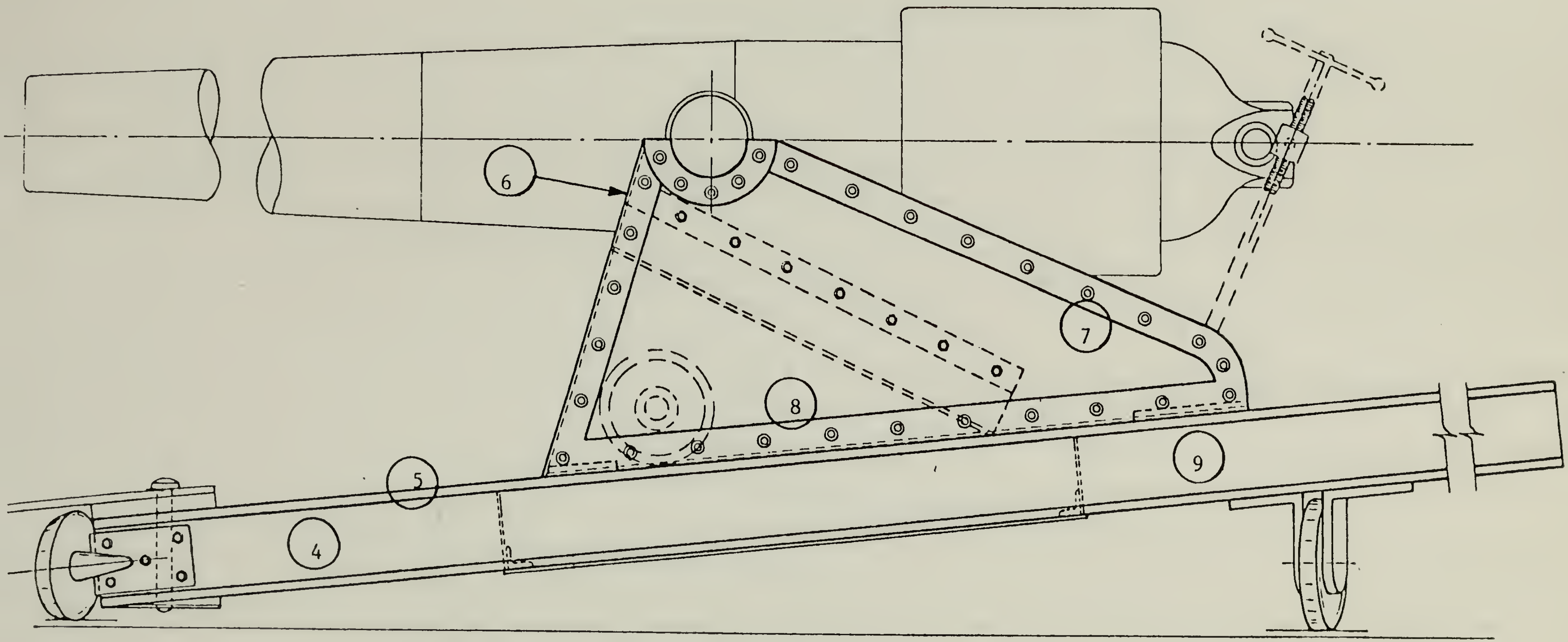
Cannon Number Nine

Left Half



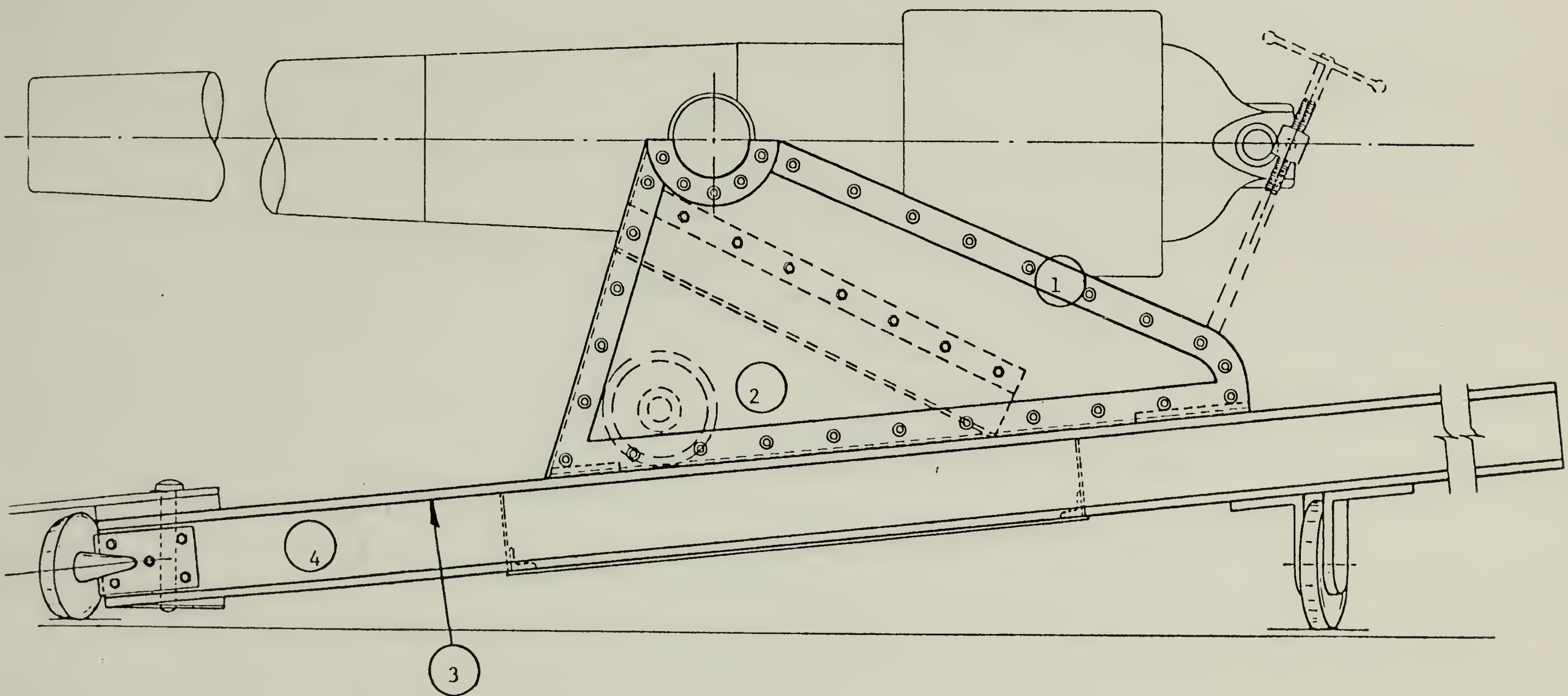
Cannon Number Nine

Right Half



Cannon Number Ten

Left Half



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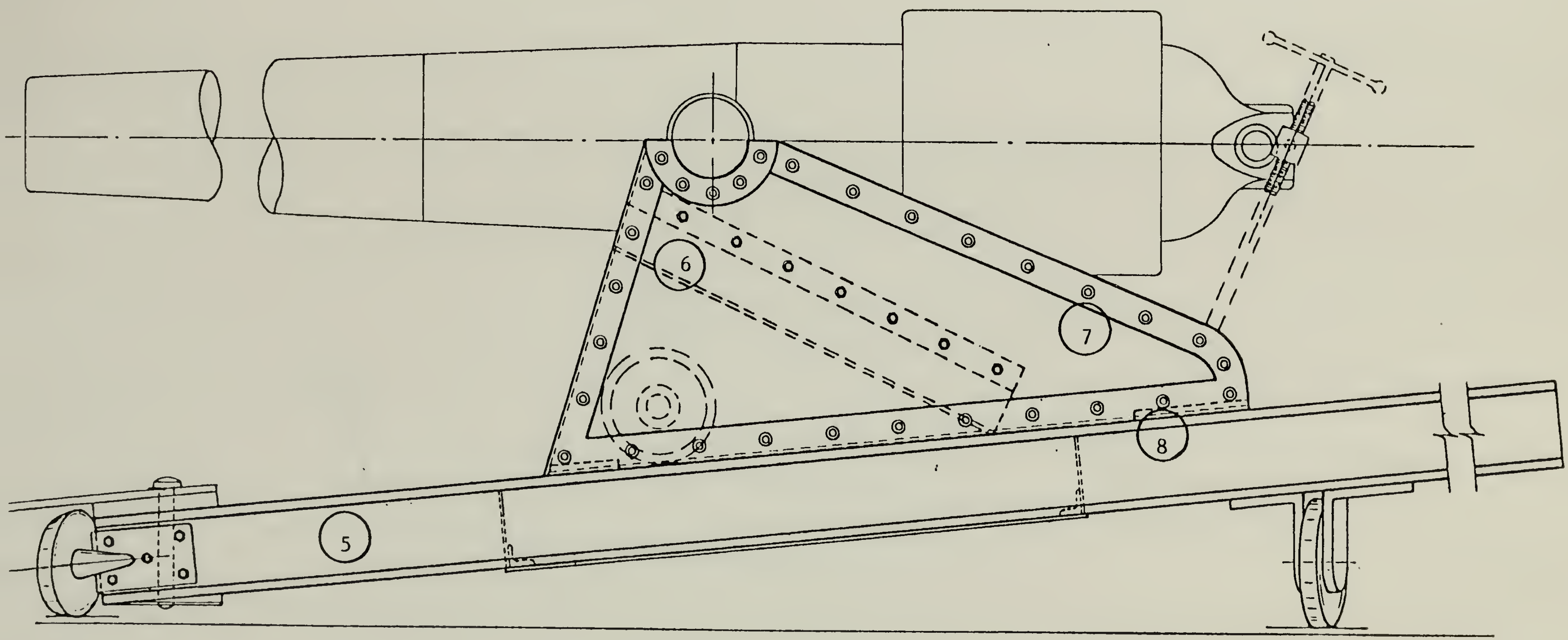
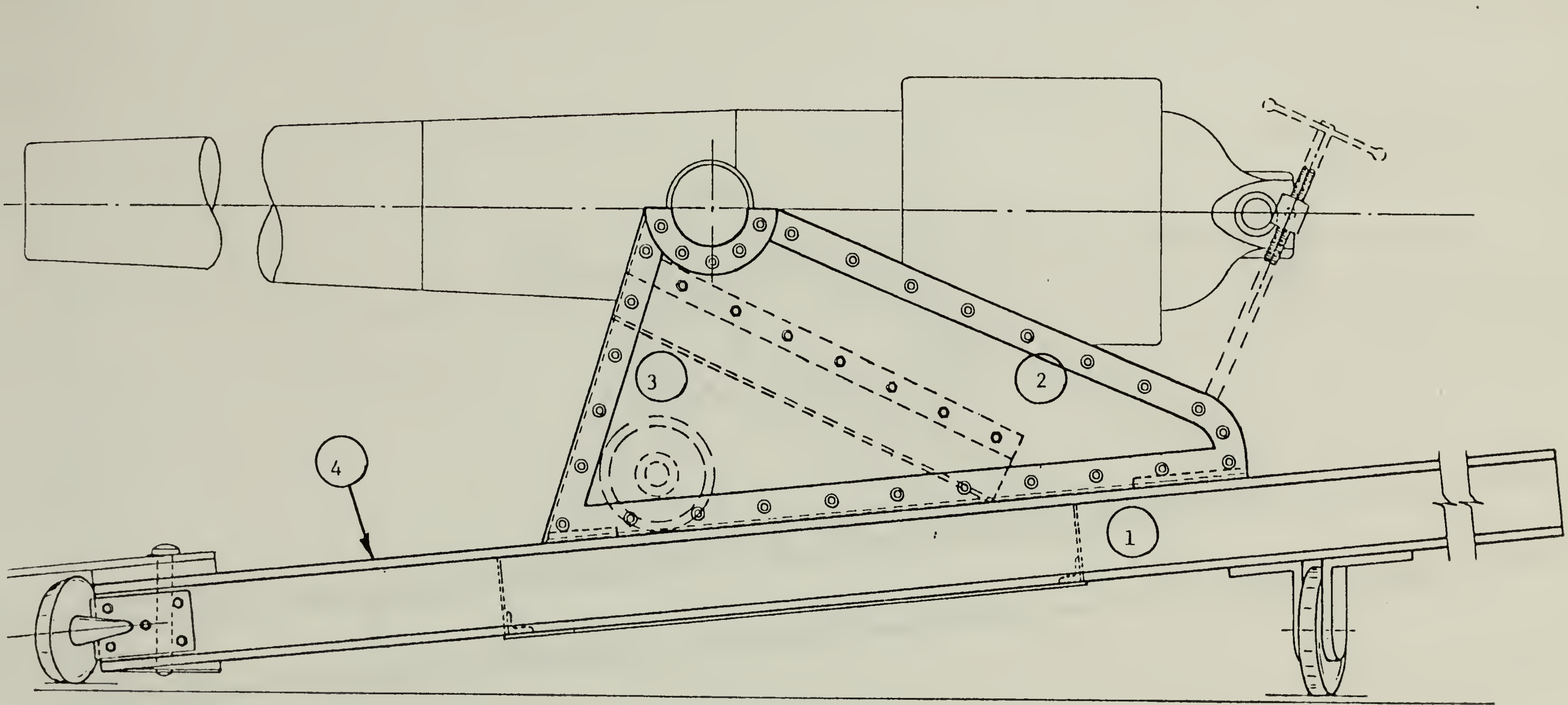
Right Half



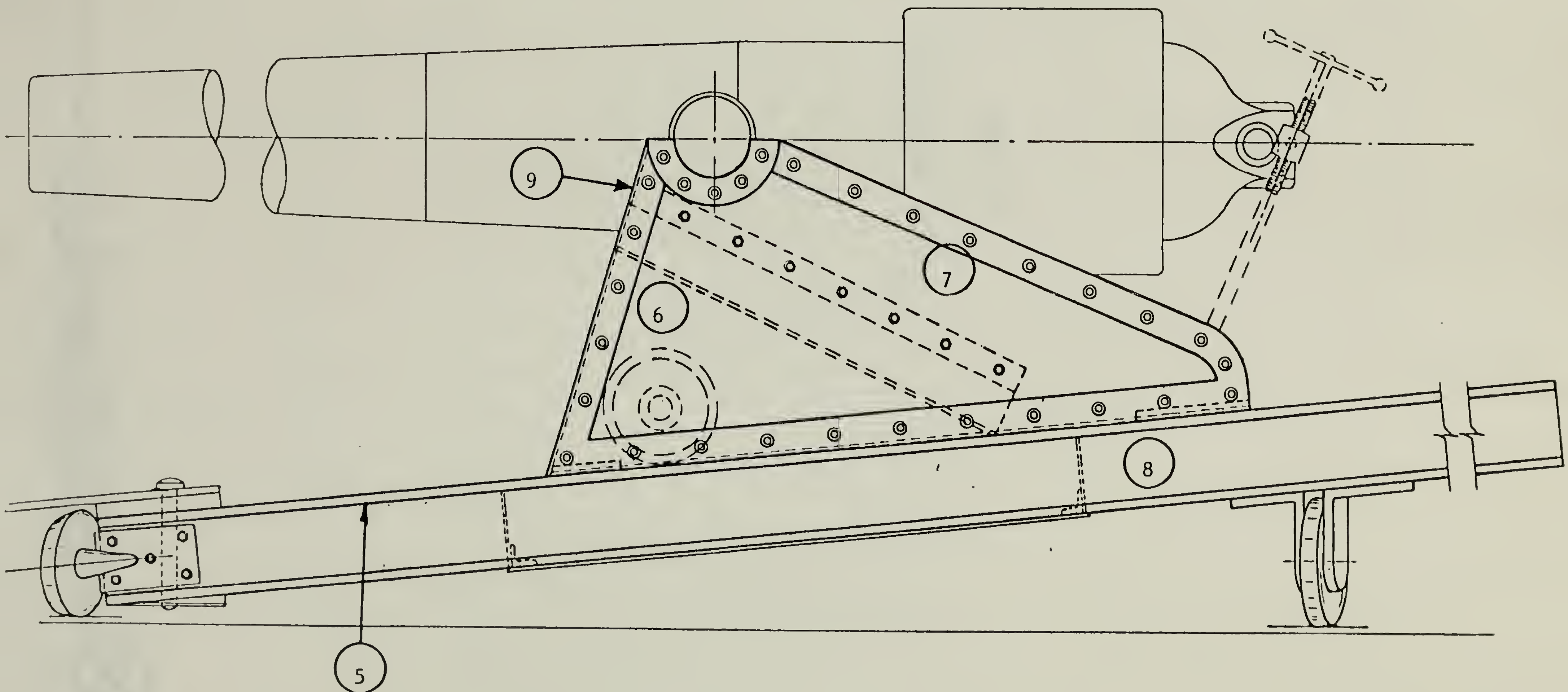
Cannon Number Eleven

Left Half



Cannon Number Eleven

Right Half



PART IV

STRUCTURAL REPORT

A. Principal Structural Elements

The principal structural elements are identified in figure 1. The weight of the 9700 lb cannon is supported by 8" diameter pins which in turn are supported by two 1/2" thick face plates. The face plates are edge-stiffened by plates or angles and are also mutually connected and braced by a 1/2" curved diaphragm plate. Each face plate is mounted on a 9" carriage beam. The cannon-pin-face plate assembly were movable in relation to the carriage beam. The carriage beams are supported by wheels that are travelable on concentric rails.

B. General Conditions Observed

There are eleven cannons covered in this study. They had been buried in the sea sand for quite sometime before they were unearthed and displayed. Most of the cannons are heavily rusted, pitted, and flaked. Thinner elements such as curved diaphragm and diaphragm pan have rusted to a degree that large holes have been observed. The carriage wheels have mostly rusted to flakes that crumble. Fortunately, main load carring elements, such as side plates and carriage beams were all made of thicker plates. After deterioration, there are still substantial portions of metal left to offer support to the 9700 lb cannon.

The observed condition has been documented and tabulated in Table I and Table II.

C. The Material Strength

According to the metallographic investigation made in this study, it has been found that the two principal

FIGURE 1. STRUCTURAL ELEMENTS

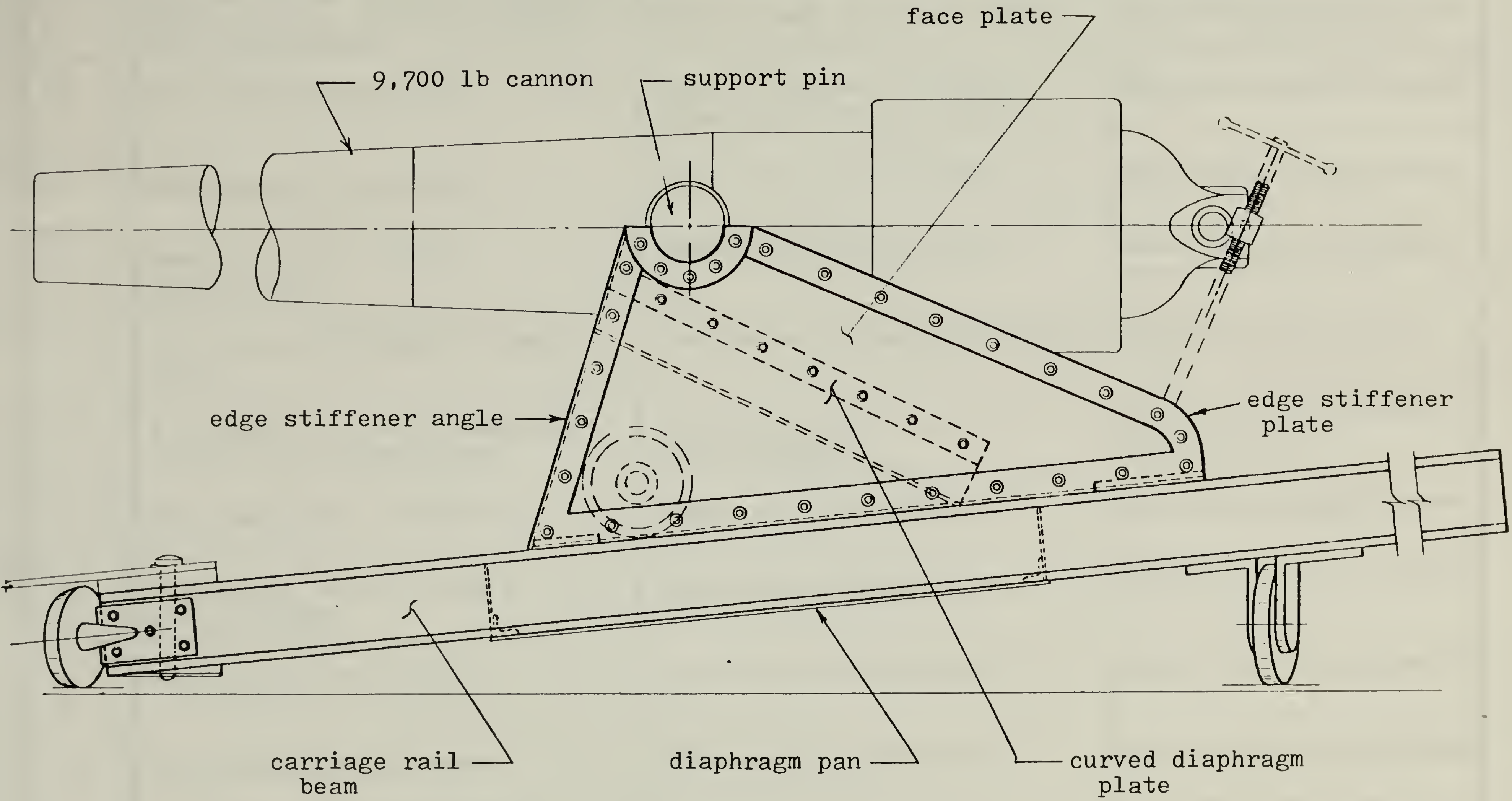


PLATE I

GENERAL CONDITION OF CANNON UPPER STRUCTURE

CANNON NUMBER	SIDE PLATES	CURVED DIAPHRAGM	EDGE STIFFENERS
1	Moderately to Severely Deteriorated, Rusted, Pitted, Flaked, with Small Holes	Rot Through with a 2' Hole	Moderately Deteriorated
2	Moderately Deteriorated	Two 1"Ø Holes. Otherwise Moderately Deteriorated	Moderately Deteriorated
3	Moderately Deteriorated	Moderately Deteriorated	Moderately Deteriorated
4	Moderately to Severely Deteriorated	Moderately Deteriorated	Moderately to Severely Deteriorated
5	Severely Rusted. Full of Small Holes	Bottom Part Completely Rotted	Very Severely Deteriorated
6	1"Ø Holes in Plates, Moderately to Severely Deteriorated	1/3 Rotted Away Severely Deteriorated	Moderately to Severely Deteriorated
7	Moderately Deteriorated	Moderately Deteriorated	Moderately Deteriorated
8	Moderately Deteriorated Bent a Little	Moderately Deteriorated	Moderately Deteriorated
9	Moderately Deteriorated	Moderately Deteriorated	Moderately Deteriorated
10	Moderately Deteriorated	Moderately Deteriorated	Moderately Deteriorated
11	Moderately Deteriorated	Moderately Deteriorated	Moderately to Severely Deteriorated

PLATE II

GENERAL CONDITION OF CANNON LOWER STRUCTURE

CANNON NUMBER	RAIL FLANGE	RAIL WEB	DIAPHRAGM PAN	COMMENTS
1	Moderately Deteriorated	Moderately Deteriorated	Flaked but with no Holes	Side Plates 2" out of Plumb 50% Rust on Side Plate 30% Rust on Rail Beam
2	Moderately Deteriorated Bottom Flange Worse	Moderately Deteriorated	Severely Flaked, up to 3"Ø Holes	40% Rust on Side Plate 30% Rust on Rail Beam
3	Moderately Deteriorated	Moderately Deteriorated	Moderately Deteriorated 1"Ø Holes	40% Rust on Side Plate 30% Rust on Rail Beam
4	Moderately to Severely Deteriorated	Moderately to Severely Deteriorated	Severely Rusted	40% Rust on Side Plate 40% Rust on Rail Beam
5	Very Severely Rusted and Flaked. Especially Bottom Flange	Very Severely Rusted	Practically Rusted Away	60% Rust on Side Plate 50% Rust on Rail Beam
6	Moderately to Severely Deteriorated	Moderately to Severely Deteriorated	1/5 Rusted Away, Severe	Side Plates out of Plumb 2"± 50% Rust on Side Plate 40% Rust on Rail Beam
7	Moderately Deteriorated	Moderately Deteriorated	Moderately to Severely Deteriorated	50% Rust on Side Plate 40% Rust on Rail Beam
8	Moderately Deteriorated	Moderately to Severely Deteriorated	Big Holes.40% of the Area Gone	Side Plates Bent Somewhat 40% Rust on Side Plate 35% Rust on Rail Beam
9	Moderately Deteriorated	Moderately Deteriorated	Severe 2"Ø Holes	40% Rust on Side Plate 30% Rust on Rail Beam
10	Moderately Deteriorated	Moderately Deteriorated	Severely Flaked, no Holes	40% Rust on Side Plate 30% Rust on Rail Beam
11	Moderately Deteriorated	Moderately Deteriorated	Pitted, Flaked, but no Holes	40% Rust on Side Plate 30% Rust on Rail Beam

load-carring elements, namely the face plates and carriage beams are all made of wrought iron with a high degree of uniformity, purity, and workmanship. The minimum tensile strength for the face plates and rail beams are 60 ksi and 53 ksi respectively.

In generality, the yield stress for ferrous metal is approximately 60% of its tensile stress and allowable flexural stress is 60% of its yield stress. Therefore, the allowable flexural stress for face plates is at 22 ksi and that for rail beam is at 20 ksi respectively.

D. The Support Pin

The support pins are 8" in diameter. Allowing an 1/2" rust-away, the shear stress is computed to be as low as 115 psi as versus 13,000 psi allowable.

It is therefore concluded that the pins remain more than adequate for supporting the cannon.

E. The Face Plate

1) Make-up

The face plate was a 1/2" thick plate of wrought iron. All face plates of the eleven cannons are severely deteriorated. The worst condition existed in cannon No. 5, where the side plates are rusted through with small holes. About 60% of the thickness of the plates were rusted, pitted and flaked away.

2) Bracing

The side plates are mutually braced by a curved diaphragm plate. This bracing offers to reduce the slenderness of the side plate and render it stronger in resisting buckling.

3) Gravity Load Distribution

Since the triangular-shaped side plate is stiffened on edges and lateraly braced by diaphragms, it somewhat acts as a rigid plate in its own plane. The load distribution can be assumed to follow a 30° angle from the vertical axis and uniformly distributed therein.

4) Findings

It has been found that the side plates, with only 40% of its base metal remaining, can still sustain the weight of the cannon, with a safety margin of 2.5 against buckling.

F. The Carriage Beam

1) Make-up

The carriage beam is a 9" I beam of wrought iron. The flange averaged 1" thick and the web 5/8" thick when new. The severest rust occurs at cannon No. 5, where 50% of the base metal has been rusted away.

2) Support and Load

The carriage beam is supported by rollers 11' apart. The cannon and its supporting assembly can situate anywhere in between the supports.

It has been found that the most damaging position occurs when the pin is located right over the center of the 11' span. Analysis of beam stresses has been made accordingly.

3) Findings

It is found that the carriage beam with 50% of its base matal rusted away can still safely support the cannon with a safety factor of 2.5 against yield.

SIEGE AND GARRISON ARTILLERY

	Bore diameter (inches)	*Material*	*Length of tube (inches)*	*Weight of tube (pounds)*	*Weight of projectile (pounds)*	*Weight of charge (pounds)*	*Range at 5° elevation (yards)*
4½-inch rifle	4.50	iron	133.00	3,450	33.0	3.50	2,078
30-pdr Parrott rifle	4.50	"	136.00	4,200	29.0[1]	3.75	2,200
24-pdr gun	5.82	"	124.00	6,240	24.4	6.00	1,901
18-pdr gun	5.30	"	123.25	4,680	18.5	4.50	1,592
12-pdr gun	4.62	"	116.00	3,120	12.3	4.00	1,834
8-inch howitzer	8.00	"	61.50	2,614	50.5[1]	4.00	1,241
8-inch mortar	8.00	"	22.50	930	44.5[1]	3.75	1,200[2]
10-inch mortar	10.00	"	28.00	1,852	87.5[1]	4.00	2,100[2]
24-pdr coehorn mortar	5.82	bronze	16.32	164	17.0[1]	0.50	1,200[2,4]

SEACOAST ARTILLERY

	Bore diameter (inches)	*Material*	*Length of tube (inches)*	*Weight of tube (pounds)*	*Weight of projectile (pounds)*	*Weight of charge (pounds)*	*Range at 5° elevation (yards)*
32-pdr gun	6.40	iron	125.20	7,200	32.6	8.00	1,922
42-pdr gun	7.00	"	129.00	8,465	42.7	10.50	1,955
8-inch columbiad	8.00	"	124.00	9,210	65.0	10.00	1,813[5]
10-inch columbiad	10.00	"	126.00	15,400	128.0	18.00	1,814[6]
15-inch columbiad	15.00	"	182.00	50,000	302.0[1]	40.00	1,518[7]
100-pdr Parrott	6.40	"	151.00	9,700	100.0	10.00	2,247[8]
200-pdr Parrott	8.00	"	159.00	16,300	175.0	16.00	2,000
300-pdr Parrott	10.00	"	173.00	26,500	250.0	25.00	—
10-inch mortar	10.00	"	46.00	5,775	87.5[1]	10.00	4,250[2]
13-inch mortar	13.00	"	53.00	17,120	220.0[1]	20.00	4,325[2]
80-pdr Whitworth rifle	5.00	iron & steel	120.00	8,960	70.0	12.00	7,722
70-pdr Armstrong rifle breechloader	6.40	"	110.00	6,903	71.7	10.00	2,266[9]
8-inch Blakely rifle	8.00	"	156.00[3]	17,000	200.0	50.00	—
150-pdr Armstrong rifle	8.50	"	129.75	14,896	c.150.0	20.00	—
12¾-inch Blakely rifle	12.75	"	192.00	54,000	700.0[1]	—	—

[1] Weight of shell.
[2] Mortar ranges are given at an elevation of 45°.
[3] Bore length only.
[4] Designed to be moved and operated by two men.
[5] Obtained ranges of over 4,812 yards with shell and 27° elevation.
[6] Obtained ranges of over 5,600 yards with shell and 39° elevation.
[7] Obtained ranges of 4,680 yards with a 315-lb. shell and 50 lbs. powder at 25°.
[8] Extreme range 8,428 yards.
[9] Muzzle-loading Armstrongs had practically identical dimensions and ranges.

Characteristics of Principal Civil War Siege, Garrison, and Seacoast Artillery Weapons (reprinted from Harold L. Peterson, *Notes on Ordnance of The American Civil War* by courtesy of the American Ordnance Association)

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JOB: FORT SUMPTER, S.C.
SHEET NO: 1 OF
CALCULATED BY: A KOO DATE: 3-79
CHECKED BY: LW DATE:
SCALE:

ANAYSIS OF IRON CASEMATE CARRIAGES & CHASSIS

WT OF CANNON TUBE		=	9.70^{k}
2 FACE PLATES	$2\times(\frac{1}{2}\times 6.13'\times 3.0')\times\frac{1}{2}''\times .490$	=	.38
$\frac{1}{2}''$ CURVED DIAPHRAGM	$(\frac{1}{2}''\times 2.95'\times 4.0')\times .490$	=	.24
$2-\angle 2\frac{1}{2}\times 2\frac{1}{2}\times\frac{1}{8}$	$2\times 3.07^{plf}\times 3.0'$	=	.018
$2-\angle 3\frac{1}{2}\times 3\frac{1}{2}\times\frac{1}{2}$	$2\times 11.1\times 6.0'$	=	.133
			10.47^{k}

SAY 10.5^{k} UNRUSTED

ESTIMATED ULTIMATE TENSILE STRENGTH : (MIN) *

FACE PLATE : 60^{ksi} $F_y = 36^{ksi}$
RAIL : 53^{ksi} $F_y = 31.8$

* FROM METALLOGRAPHIC INVESTIGATION BY SPOONLIE & CHAKRABORTTY

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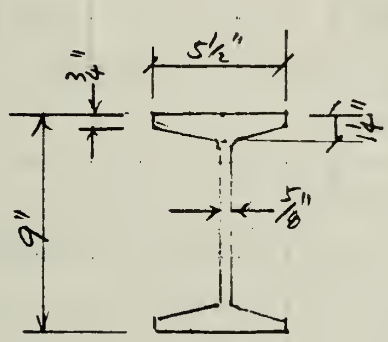
RAIL



ORIGINAL SHAPE

$w = (5.5 + 4.375) \times .490 = 34\ plf$

$I = 2 \times (1 \times 5.5) \times 4^2 = 176$

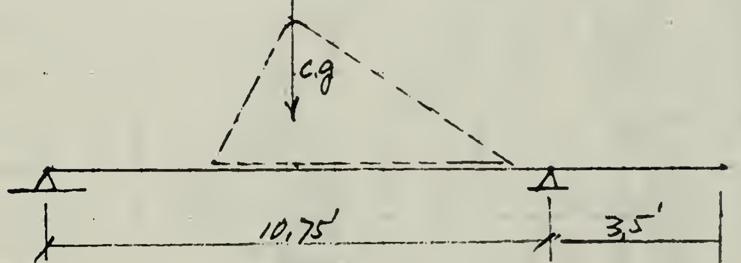
$\frac{1}{12}(\frac{5}{8} \times 7^3) = 18$

194 say 200

→ RUSTED TO 50% $I = 100\ in^4$

$S = \frac{100}{4} = 25\ in^3$

$W = 10.5/2 = 5.25^k$



+M_{max} WHEN W @ CENTER OF SPAN: $+M \le \frac{PL}{4} = \frac{1}{4} \times 5.25 \times 10.75' = 14.1^{k-'}$

$f_b = \frac{M}{S} = \frac{14.1 \times 12}{25} = 6.8^{ksi} < F_b$

$F_b = .6F_y = .6 \times 30 = 18^{ksi}$ ok.

MAX SHEAR WHEN W NEAR SUPPORT:

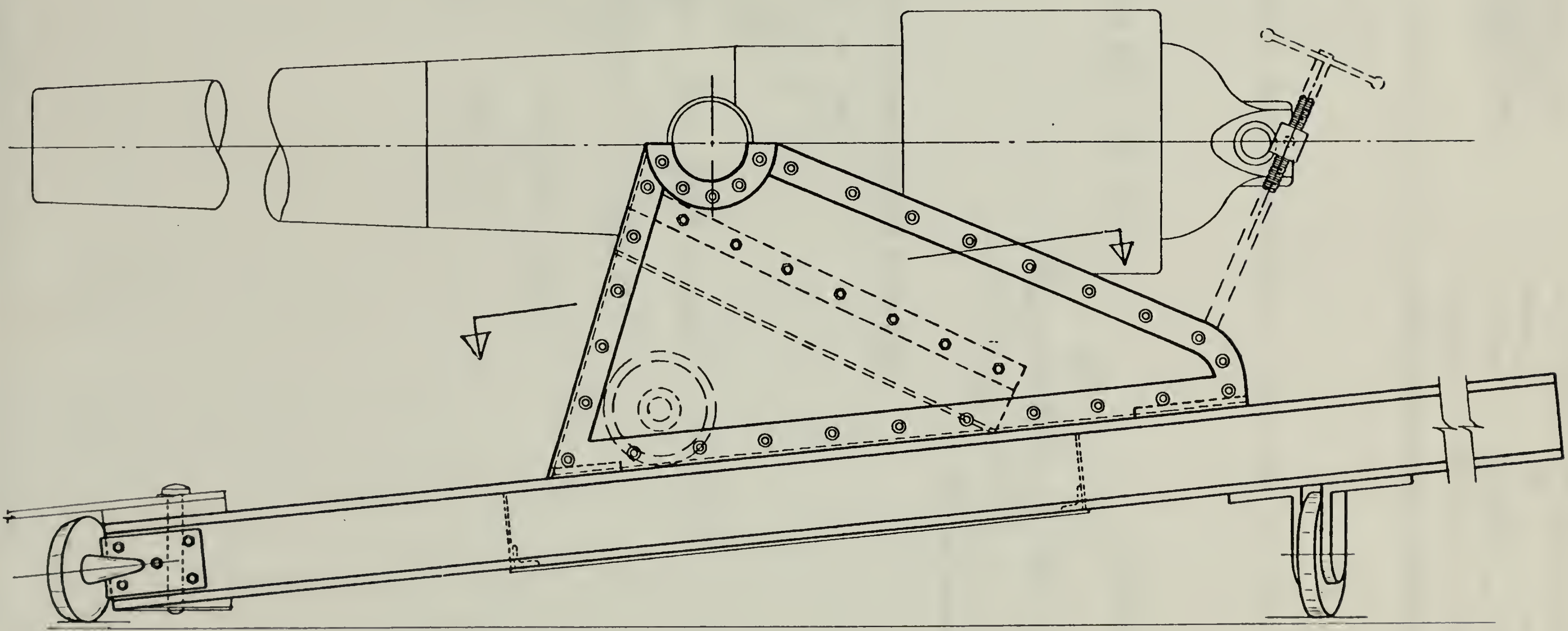
$V = 5.25^k + .034 \times \frac{10.75}{2} = 5.43^k$

$f_v = \frac{5.43}{(\frac{5}{8} \times 9) \times 50\%} = 1.93^{ksi} < F_v$

$F_v = .4F_y = .4 \times 30 = 12^{ksi}$

ok

RAIL IS OK



3/4" = 1'-0"

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FACE PLATE $F_y = 36^{KSI}$

RE: "DESIGN MANUAL FOR HIGH STRESS ~~STEEL~~ – U.S.S 1961 P: 40–63."

ALL MATERIAL RUSTED TO 40% ∠ $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{8}$

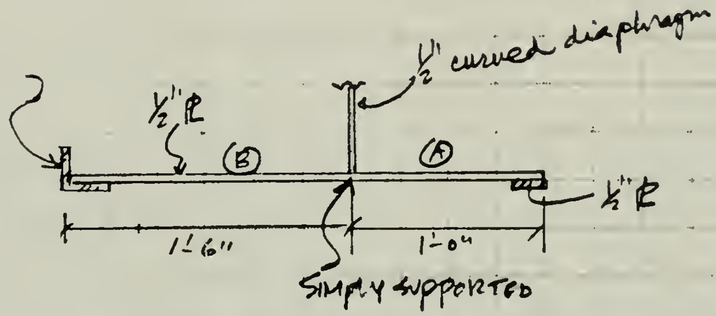

PLATE (A)

ONE EDGE SIMPLY SUPPORTED, ONE EDGE FREE.

$t = \frac{1}{2}'' \times 40\% = .20''$

$K = .425 \quad b = 12''$

$\frac{b}{t} = \frac{12}{.2} = 60$

$(b/t)/\sqrt{K} = \frac{60}{\sqrt{.425}} = 92 > \frac{5720}{\sqrt{F_y}} = 30.15$ EQ (8C)

$\therefore S_{cr} = \frac{13660000 K}{(b/t)^2} = 2321$ PSI

$P = 2321 \times (.20 \times 12) = 5.57^K$

$\omega_A = \frac{5.57}{12} = 464$ #/in

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PLATE (B)

BOTH EDGE SIMPLY SUPPORTED

$K = 4.0 \quad t = .20''$

FOR $S_{cr} = S_y = 36^{ksi}$

FROM FIG 11. $\left(\frac{b_e}{t}\right)^2 / K = 400$

$$\frac{b_e}{t} = \sqrt{400 \times 4} = 40$$

$$b_e = 40 \times .20 = 8''$$

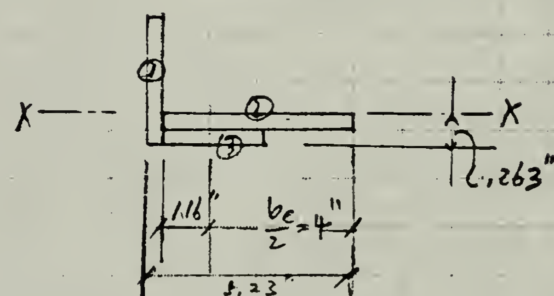
① $2.375 \times .0625 = .1484 \times \frac{1}{2}(2.375) = .176$

② $5.16 \times .2 = 1.032 \times .1625 = .168$

③ $2.313 \times .0625 = .145 \times \frac{1}{2}(.0625) = .005$

$A = 1.325\ in^2 \qquad .349$

$\bar{Y} = .263''$



$I_{xx} = \frac{1}{12} \times .0625 \times (2.375)^3 + (.1484)(.5 \times 2.375 - .263)^2 = .197$

$\frac{1}{12} \times 2.313 \times (.0625)^3 + (.145)(.5 \times .0625 - .263)^2 = .008$

$\frac{1}{12} \times 5.16 \times (.2)^3 + (1.032)(.1)^2 = .014$

$\Sigma I_{xx} = .22$

$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{.22}{1.325}} = \underline{.407}$

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PLATE (B) (CONT'D)

$L = 2.25' = 27''$

$\frac{KL}{r} = \frac{1.5 \times 27}{.407} = 99.5$

FROM Fig 4 "COLUMN FORMULAS" $F_y = 36.0^{KSI}$

$R = 112 > \frac{KL}{r}$

$B = 16000$

$C = .55$

$\frac{P}{A} = B - C\left(\frac{KL}{r}\right)^2 = 16000 - (.55)(99.5)^2 = 10555$ PSI.

$P = 10555 \times 1.325^{\square''} = 14^K$

$\omega_B = \frac{14000}{18''} = 778 \#/'' > \omega_A$

∴ PLATE (A) GOVERNS.

MAX LOAD $= 464 \times 30'' \doteq 14^K > 5.25^K$

∴ FACE PLATE WILL NOT BUCKLE