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PROGRESS REPORT

RISERING OF DUCTILE CAST IRON

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PROGRESS REPORT

RISERING OF DUCTILE CAST IRON

I. SUMMARY

The objective of this research is to determine formulae for the most economical risering system to eliminate shrinkage cavities in ductile iron castings in the range 3.4 - 3.9% TC, 1.8 - 2.8% Si.

Three types of shrinkage defects are encountered:

1) Continuous centerline shrinkage from the riser into the casting;

2) Isolated centerline shrinkage in the casting, usually near the center in the plan view; and

3) Surface shrinkage as shown by a depression in the casting skin either near the riser or near the center of the cope surface.

To feed any of these types of shrinkage it is axiomatic that: (1) The riser must freeze more slowly than the casting and (2) an open feeding channel must exist between the riser and the casting.

To fulfill condition (1) the following calculations are made. First, the surface area/volume ratio of the casting is determined. Since this ratio governs the cooling rate, the riser dimensions must be selected to provide a smaller A/V value (slower cooling rate). In practice the ratio of A/V for the casting to A/V for the riser should be greater than 1.3; the exact values are shown in the graph, Fig. 1.

The most efficient, practical side blind riser is cylindrical with height equal to diameter. A satisfactory riser of this geometry may be calculated from the simple formula:

$$\text{Diameter of riser} = 7.8 \frac{\text{Volume of casting}}{\text{Surface area of casting}}$$

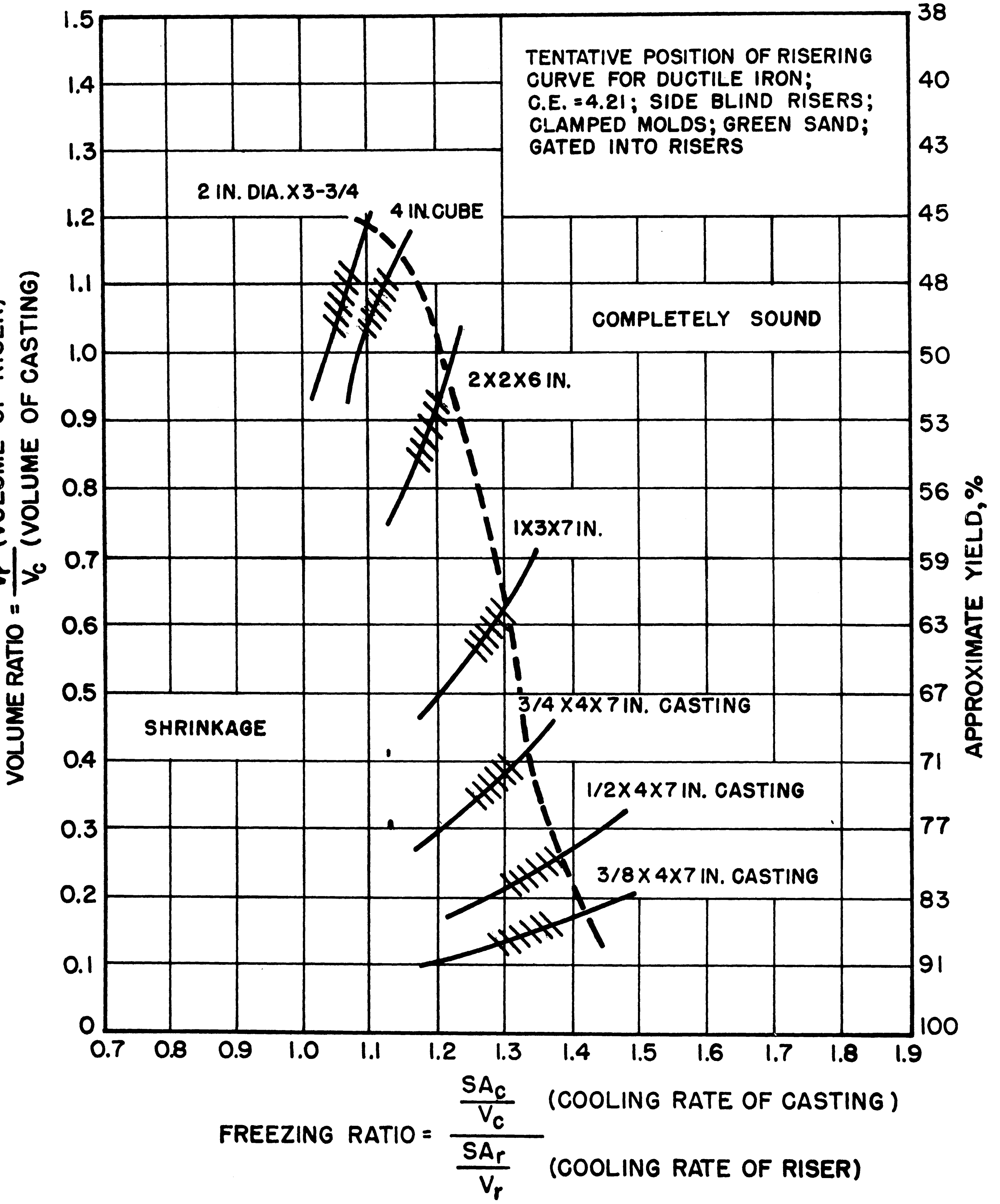

TENTATIVE POSITION OF RISERING CURVE FOR DUCTILE IRON; C.E. =4.21; SIDE BLIND RISERS; CLAMPED MOLDS; GREEN SAND; GATED INTO RISERS
2 IN. DIA. X 3-3/4
4 IN. CUBE
COMPLETELY SOUND
2X2X6 IN.
1X3X7 IN.
3/4 X 4 X 7 IN. CASTING
1/2 X 4 X 7 IN. CASTING
3/8 X 4 X 7 IN. CASTING
SHRINKAGE
VOLUME RATIO = Vr (VOLUME OF RISER) / Vc (VOLUME OF CASTING)
APPROXIMATE YIELD, %
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
38
40
43
45
48
50
53
56
59
63
67
71
77
83
91
100
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
FREEZING RATIO = (SAc / Vc) (COOLING RATE OF CASTING) / (SAr / Vr) (COOLING RATE OF RISER)

FIG. 1

A more precise value, or a riser of different proportions, may be selected from Fig. 1.

To fulfill condition (2) the effective feeding distance of a given riser must not be exceeded. For example, it is not possible to feed a sand cast 21-in. bar, 1 in. in diameter, with a single riser at one end. The effective feeding distance of ductile iron appears to be similar to that of steel, but this requires further study. Additional work is also needed regarding the effects of top open and blind risers, exothermic compounds, carbon equivalent, knockoff and neck design, larger castings, use of a common riser for several castings, and cupola melted metal.

II. Procedure

Since the earliest experiments with magnesium-treated iron, it has been evident that castings of this material are prone to greater shrinkage than soft gray iron castings with flake graphite. This shrinkage problem has assumed particular importance for ductile iron because the major use has been in highly stressed parts in which shrinkage defects can result in serious failure in service.

Castings Investigated

It seemed important, therefore, to develop general risering formulae which would insure sound castings without expensive experimentation by the producer with each new casting design. A series of standard castings of various sections and shapes within the scope of the melting equipment was therefore selected to determine if such formulae could be developed. These experimental shapes are listed in Table I below and illustrated in Fig. 2.

TABLE I

EXPERIMENTAL CASTINGS USED IN THE INVESTIGATION

Casting dimensions, in.	Area of Surface, $in.^2$	Volume $in.^3$	A/V, $in.^{-1}$	Weight, lbs
1/4 x 4 x 7	61.5	7.0	8.78	1.9
3/8 x 4 x 7	64.3	10.5	6.12	2.8
1/2 x 4 x 7	67.0	14.0	4.78	3.8
3/4 x 4 x 7	72.5	21.0	3.45	5.7
1 x 3 x 7	62.0	21.0	2.95	5.7
2 (Dia.) x 3-3/4	29.9	11.8	2.54	3.2
2 x 2 x 6	56.0	24.0	2.33	6.5
1-3/4 x 4 x 9	117.5	63.0	1.87	17.0
4 x 4 x 4	96.0	64.0	1.50	17.3

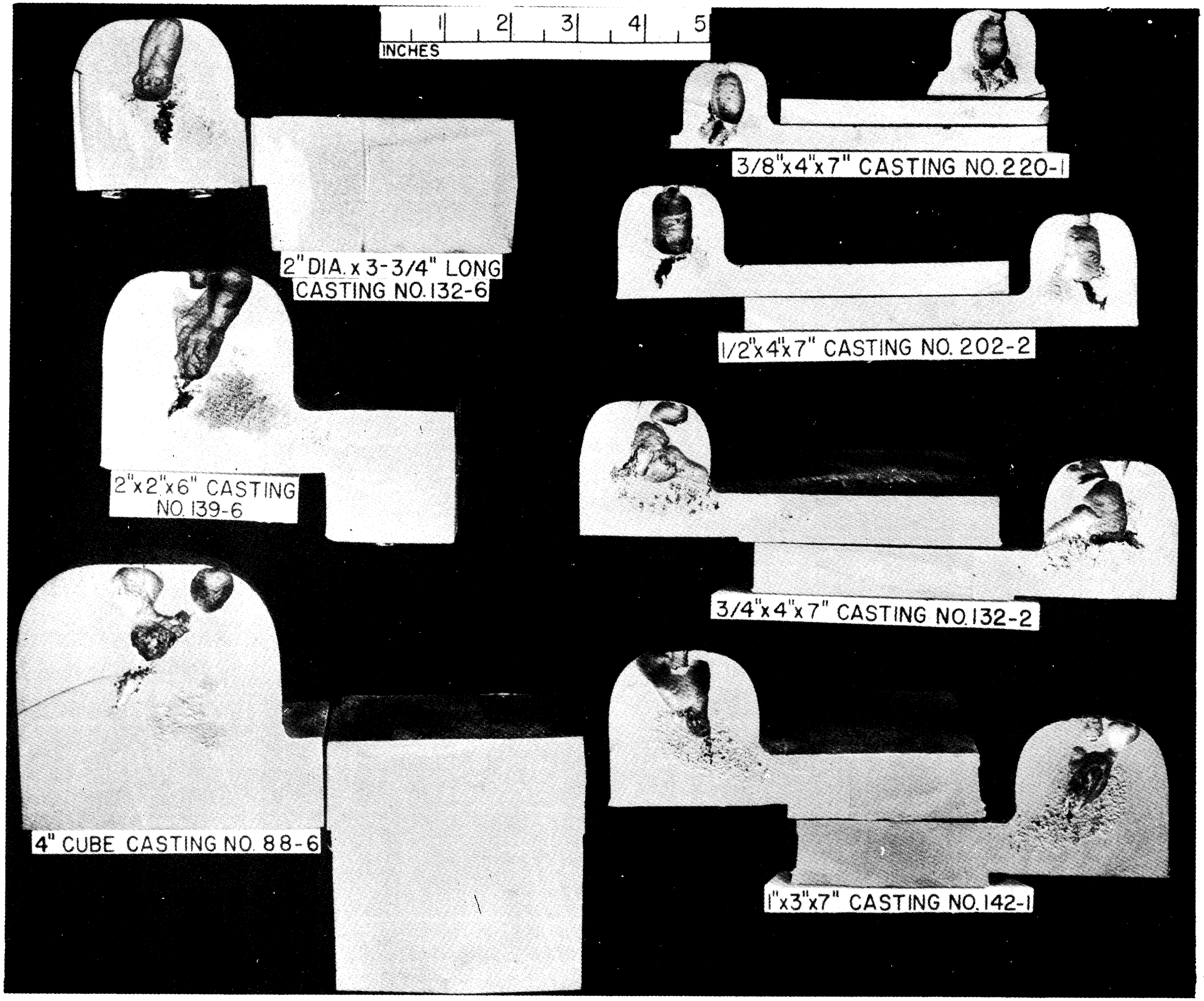


Fig. 2. Seven Castings Used in This Investigation, Shown Sectioned through Risers.

Riser Design

Since the cooling rate of a casting increases as the ratio of surface area to volume grows larger, it is obvious that a riser with a smaller A/V ratio than the casting is needed if the riser is to feed the casting. This elementary principle arises from the fact that the amount of heat in either the riser or the casting is a function of the volume, while the rate of heat dissipation is a function of surface area. The cooling rate decreases with large volume and increases with large surface area. A few simple calculations will show that a given weight of metal will exhibit the slowest cooling rate in a sphere and increasing rates in a bar and a plate respectively.

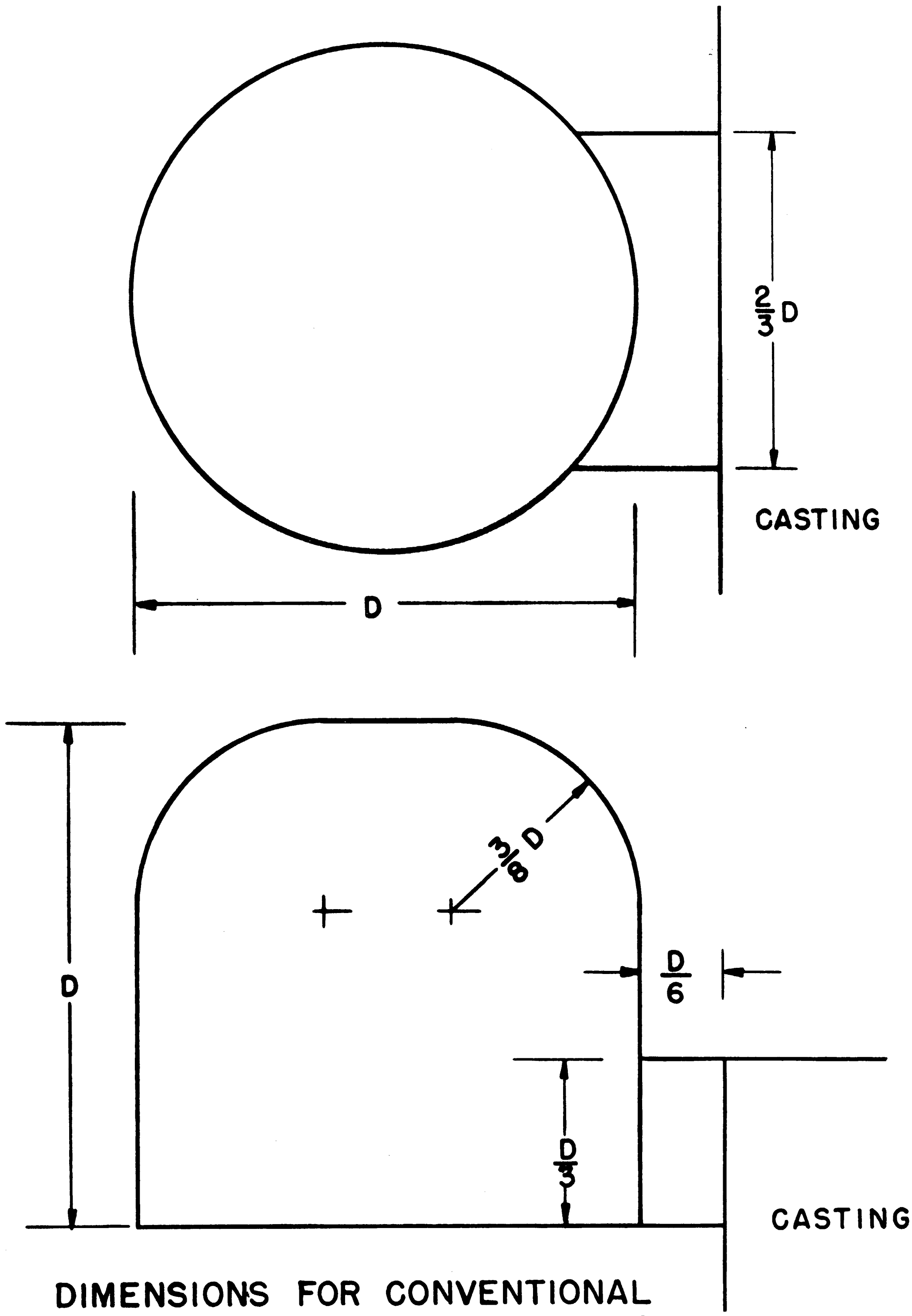
The most efficient riser is therefore spherical, but because of practical molding consideration, cylinders with heights equal to the diameters were employed. In the later stages of the work the upper portion of the cylinder was rounded to practically hemispherical shape as illustrated in the photograph, Fig. 2.

Most of the work has been concentrated on side blind risers. Analgous work in steel by Caine has shown only minor differences between side blind risers and open side and top risers treated with exothermic insulating compounds. The data of this investigation can probably be applied generally, although spot checks will be made in the near future.

Neck Design

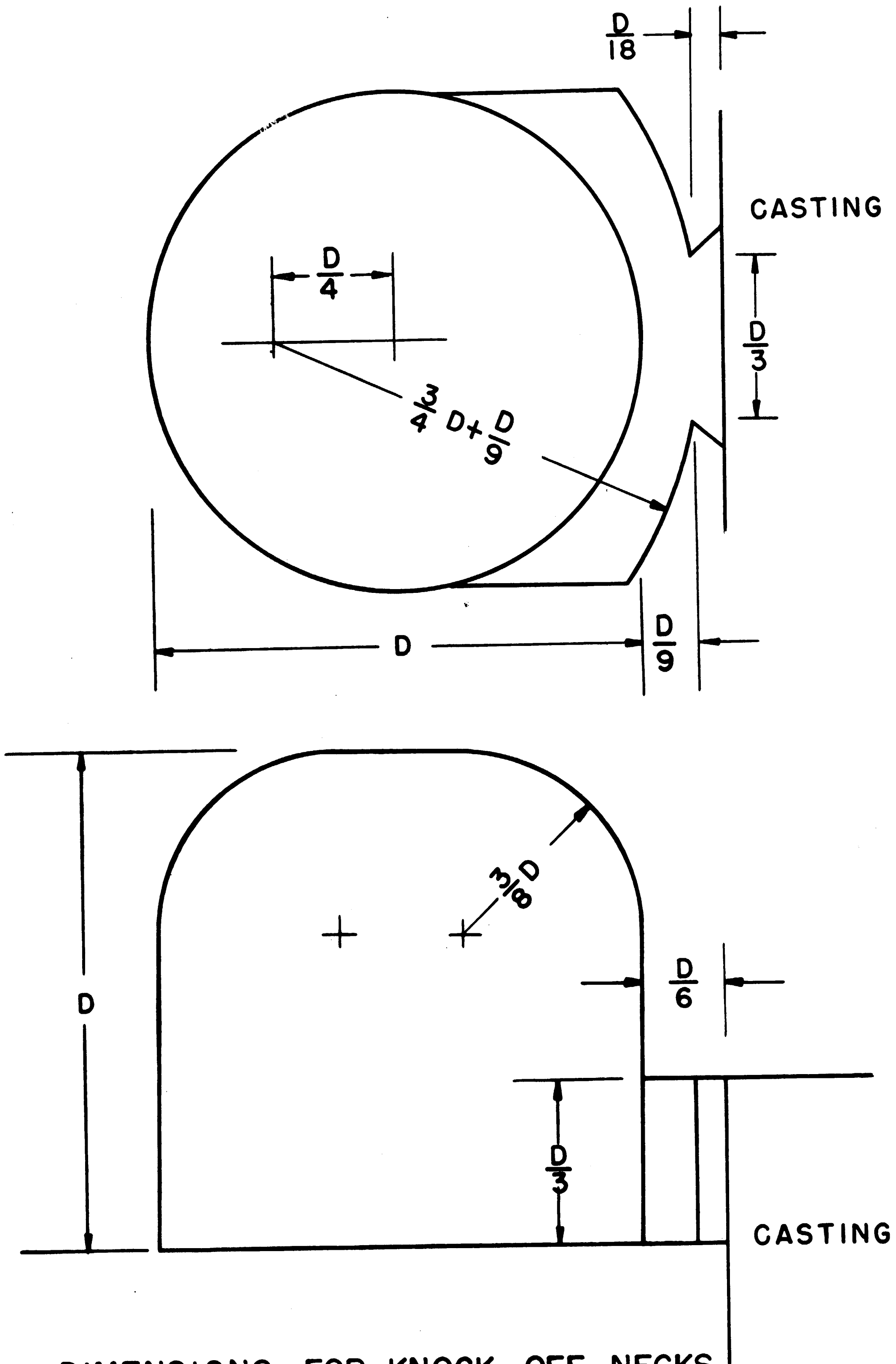
This problem has received much less general attention in the past than it has deserved. A well designed neck has two very important functions: (1) to provide the proper thermal gradient between the riser and the casting and (2) to allow easy knockoff without breaking into the casting but with a minimum of grinding. Considerable experimentation was required to arrive at the neck design shown in Fig. 3A. The risering formulae which have been developed apply only if this design is used. The design of 3B provides for easier knockoff. As an example of improper neck construction, the earlier phases of the work were conducted with the neck height equal to the casting section thickness. Although it was believed that this procedure would provide a maximum channel for feed metal, it had the unforeseen effect of including the neck-to-casting junction in the zone of metal which froze last. This resulted, of course, in a spongy zone at the breakoff point of the neck. The best design used to date employs a neck height equal to 1/3 the riser diameter.

Atmospheric riser cores were used consistently to develop the risering curve, Fig. 1. Although they are not essential in every case, it was decided to maintain this standard practice. In general, in the lighter sections the metal seems to freeze around the riser core and render it ineffective.



DIMENSIONS FOR CONVENTIONAL NECKS FOR SIDE BLIND RISERS ON DUCTILE IRON CASTINGS

FIG. 3A



DIMENSIONS FOR KNOCK-OFF NECKS FOR SIDE BLIND RISERS ON DUCTILE IRON CASTINGS.

FIG. 3B

Gating

A standard gating arrangement delivering hot metal to the riser was used as shown in Fig. 4. The same tapered sprue and runner areas, 0.31 in.^{2} and 0.375 in.^{2}, respectively, were used throughout the work.

Mold Conditions

Since the most common sand mixture is of the greensand-seacoal type, the following standard mix has been used throughout the investigation. New sand was used each time, so that the reconditioning variable was not encountered.

Mix (lbs)		Properties	
200	Michigan City Sand A.F.S. 55	Moisture	2.9 - 3.3 %
9	Western Bentonite	Permeability	130 - 150
10	Seacoal	Green Comp. Str.	7 - 10 psi
6	Water	Green Deformation	.017 - .021 psi
		Dietert Flowability	75 - 80

Hand ramming to a mold hardness of approximately 77-85 has been followed. Patterns have been mounted for accurate control of neck dimensions.

Clamping vs. Weighting of Molds

In the early stages, two 40-lb weights were used with 9 x 9-in. flasks, but castings were consistently oversize with a crown in the center (Fig. 5). It is believed that this effect was caused by the graphitization reaction (expansion). Clamping has minimized the growth of castings, restricting the graphitization expansion to the original mold volume, and has provided sound castings with minimum riser size. The risering curve is therefore based on clamped molds.

Melting Conditions, Compositions Explored

Thirty heats were made in the 150-lb high-frequency induction furnace with a basic magnesite lining. The charge was composed of Lyle pig, steel punchings, and standard ferroalloys. The melt was heated to 2770°F and tapped into a preheated ladle with the addition of 2% of NMA No. 1 alloy. Instead of using another ladle, the metal was poured back in the hot furnace while adding .55% Si as 85% ferrosilicon and then immediately returned to the ladle. No power was applied after the initial tap.

After the initial survey of pouring-temperature effect, the pouring temperature was maintained in the range 2540 - 2620°F.

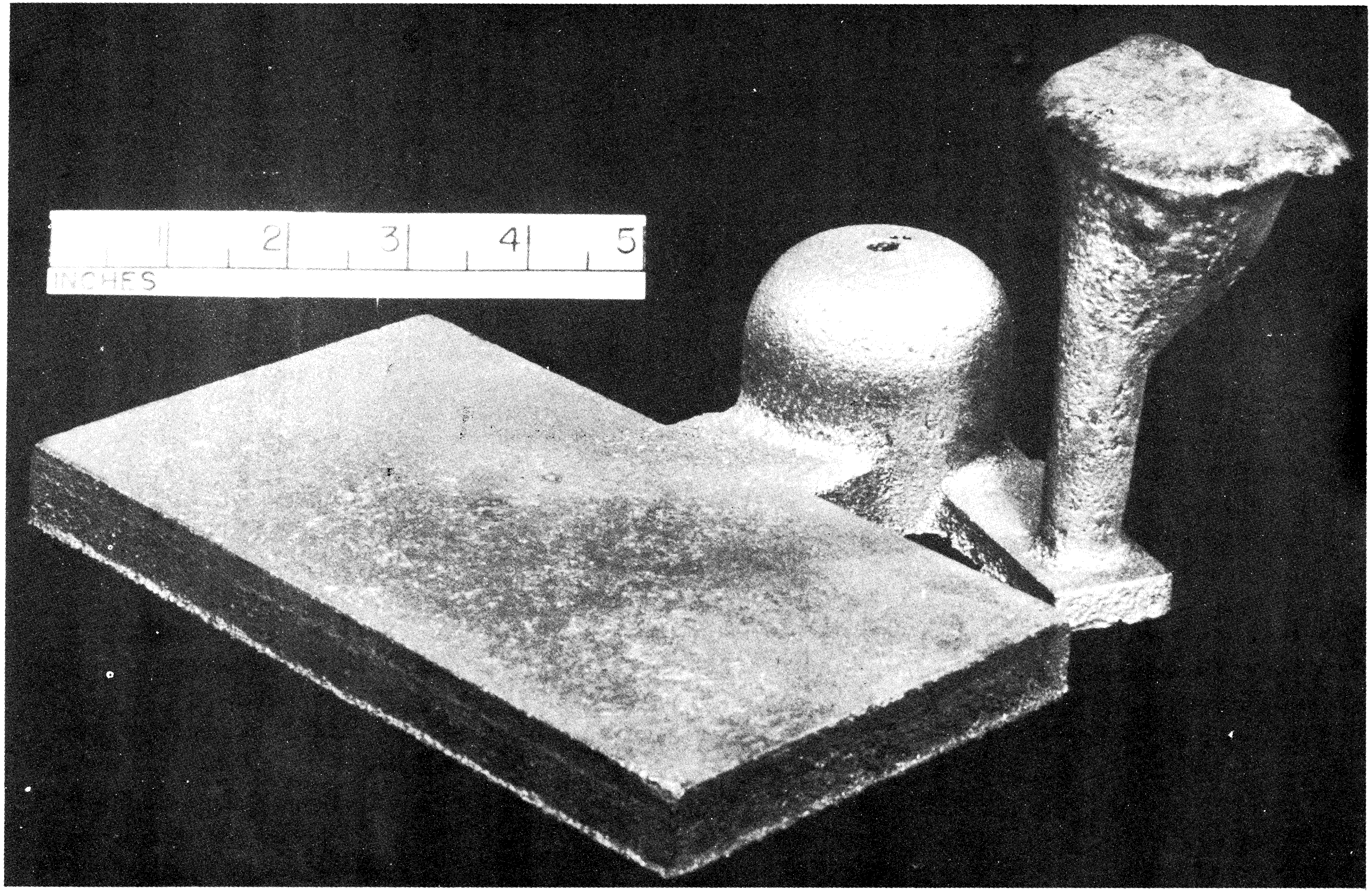


Fig. 4. Gate Design Used in This Investigation.

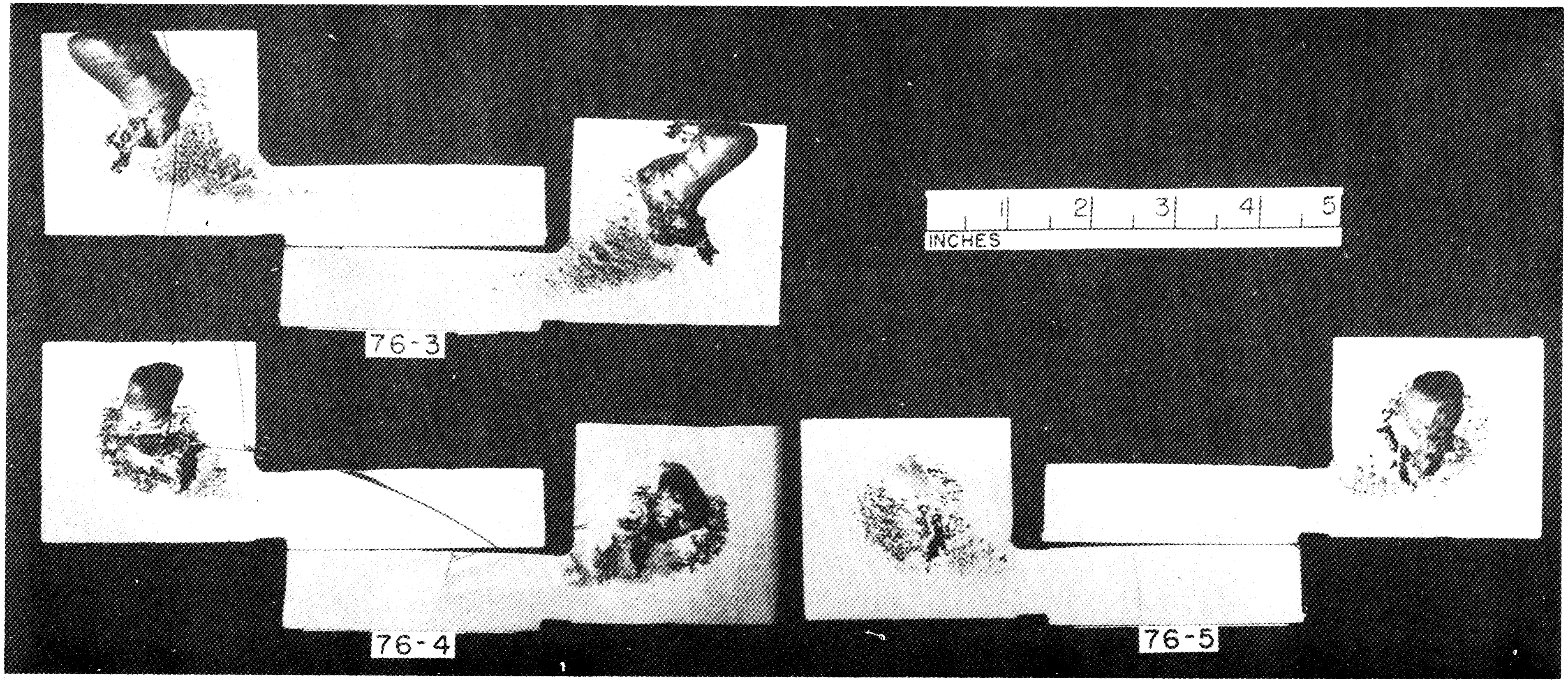


Fig. 5. Effect of Mold Restraint. 1 x 3 x 7-in. Castings Sectioned through Risers. Casting No. 76-3 Made in 13 x 13-in. Flask and Weighted; No. 76-4 in 13 x 13-in. Flask and Clamped; No. 76-5 in 9 x 9-in. Flask and Clamped.

Three analysis ranges were surveyed, but the principal attention was given to the 3.6% C and 1.8% Si type.

	TC	Mn	P	Si
1	3.6	.2	.02	1.8
2	3.56	.2	.02	2.5
3	3.9	.2	.02	2.5

A summary of the analysis is given in Table II.

Inspection

In a research problem of this type, it is difficult to select an inspection tool for shrinkage that will be universally acceptable. As a compromise between the overexacting microscopic inspection for microshrinkage and the crude fracture test, a sectioning and sandblasting technique was developed. A cut was made through the center of the riser and the centerline of the casting with a soft abrasive cut-off wheel, using a voluminous supply of coolant. The cut surfaces were then carefully sandblasted to remove any flowed metal and to expose shrinkage. This technique was more delicate than hot acid etching, which was also tried. Photographs of typical castings are shown in Fig. 6.

In addition to the chemical analysis, a metallographic inspection was made of each heat. Completely spheroidal graphite was obtained consistently. Some carbides were obtained in the lighter sections and further work is needed on the effects of these free carbides.

III. DISCUSSION OF DATA

The most useful summary of data is contained in risering curve, Fig. 1, and this will be discussed first (Section A, below). It is important to understand that this curve holds true only for clamped molds; with side blind risers and of the neck design of Fig. 3A. The curve is probably a good first approximation, i.e., to 1/4-in. riser diameter, for open insulated risers or top risers, but these points require further study. The observations on which Fig. 1 are based are contained in Appendix I.

Following the discussion of the risering curve the effects of the following variables will be considered in Section B: (1) neck design, (2) mold restraint, (3) pouring temperature, and (4) metal composition.

TABLE II

SUMMARY OF ANALYSES OF ALL HEATS

Heat No.	T.C.	Si	Mn	P	Date
33	3.68	1.88	.28	.02	June 25, 1952
34	3.53	2.07	.25	.02	July 3, 1952
36	3.60	1.62	.23	.02	July 8, 1952
39	3.68	1.75	.21	.02	July 15, 1952
41					July 16, 1952
51	3.63	1.86	.26	.03	August 4, 1952
53	3.48	2.70	.26	.03	August 7, 1952
54	3.59	2.55	.23	.03	August 8, 1952
61	3.45	2.34	.24	.02	August 13, 1952
62	3.61	2.55	.31	.02	August 13, 1952
64	3.56	2.48	.24	.02	August 14, 1952
65	3.54	2.51	.25	.02	August 14, 1952
66	3.61	2.50	.23	.02	August 19, 1952
67	3.59	2.65	.27	.03	August 29, 1952
68	3.58	2.45	.26	.03	
76	3.57	1.80	.26	.03	October 3, 1952
88	3.59	1.74	.26	.03	October 24, 1952
99	3.58	1.89	.25	.03	November 7, 1952
111	3.56	1.88	.26	.02	November 22, 1952
113	3.54	1.87	.25	.02	November 25, 1952
132	3.61	1.83	.28	.01	January 5, 1953
135	3.65	1.76	.26	.01	January 10, 1953
136	3.70	1.79	.24	.03	January 20, 1953
138	3.66	1.93	.28	.03	January 26, 1953
139	3.58	1.72	.23	.03	February 2, 1953
142	3.60	1.76	.28	.03	
149	3.98	2.38	.20	.03	February 23, 1953
190	3.76	2.49	.29	.03	March 31, 1953
198	3.80	1.93	.20	.03	April 15, 1953
220	3.75	1.92	.27	.02	May 2, 1953

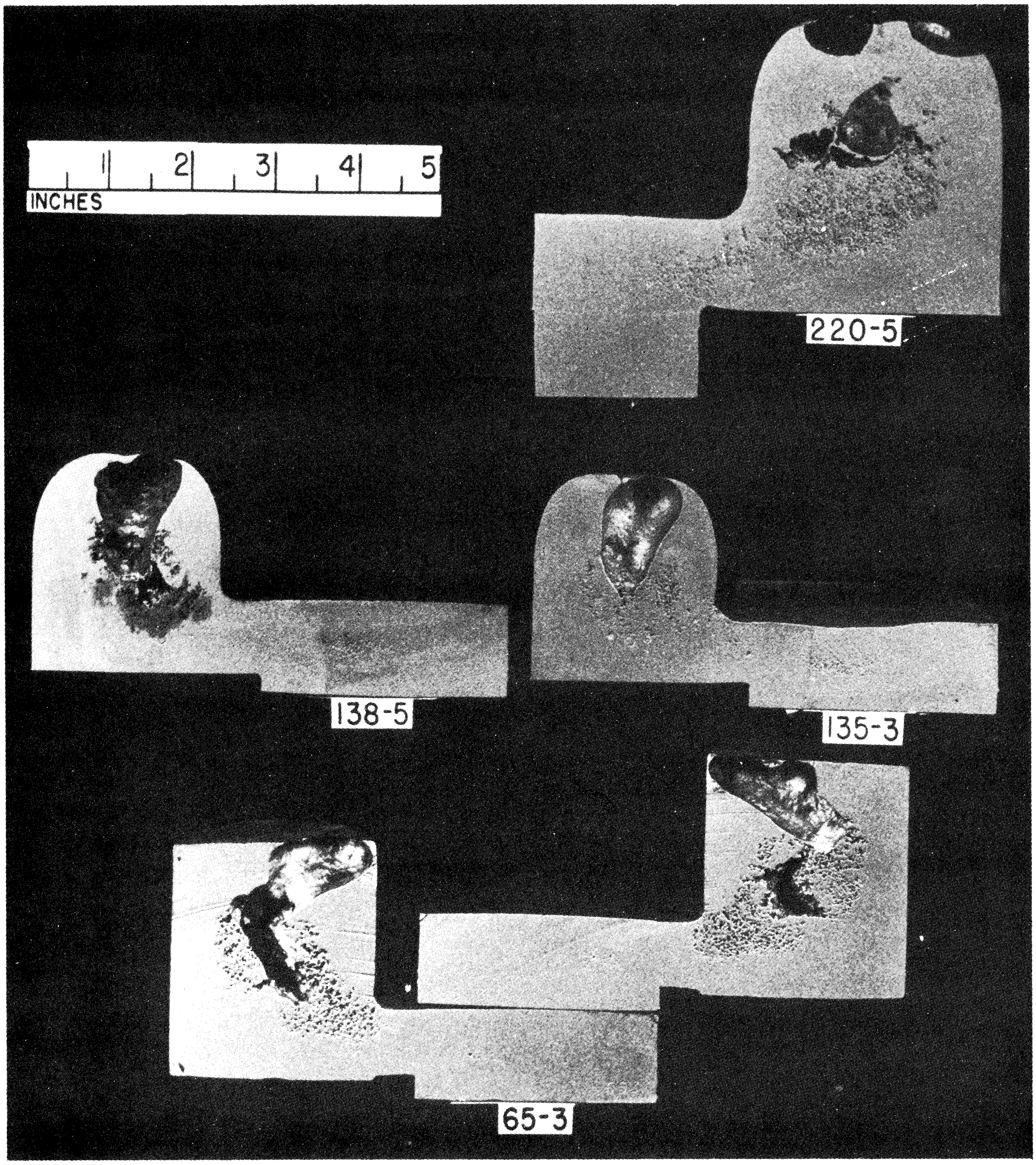


Fig. 6. Four Types of Defects Encountered in This Investigation. Casting No. 220-5 Has Riser Shrinkage; No. 138-5 Has Centerline Shrinkage; No. 135-3 Has Surface Shrinkage in Addition to Centerline; No. 65-3 Has Bulging (Thicker at Center than at Edges).

Section A. Risering Curve for Ductile Iron

The most familiar approach to riser dimensioning has been developed by Caine for steel and discussed in many issues of the A. F. S. Transactions. It will be shown that this is perhaps unnecessarily complicated for ductile iron because of the difference in solidification behavior compared with steel.

First, the axes of Fig. 1 should be explained. In the case of steel, shrinkage cavities can arise from two sources:

1. The riser freezes before the casting and therefore, instead of supplying liquid metal to compensate for liquid-to-solid shrinkage, may actually draw liquid from the casting and add to the casting shrinkage cavity.

2. The riser freezes after the casting but the quantity of liquid required by the casting cannot be provided completely by the riser.

These two important variables are represented by the x and y axes respectively as follows:

X-Axis: Ratio of Cooling Rates of Casting and Risering. As discussed earlier, the cooling rate is proportional to the surface area/volume ratio, since the area determines rate of heat dissipation and the volume determines quantity of heat. The higher the A/V ratio, the faster the cooling rate. Therefore, if the casting is to solidify before the riser, the A/V for the casting must be greater than the A/V for the riser. In other words the ratio of A/V for the casting to A/V for the riser must be greater than 1. A quick reference to Fig. 1 will show that this is true for all combinations in the sound region of the graph.

Y-Axis. Now the y axis may be considered briefly. The relative amount of feed metal in the riser is given simply by the ratio volume of riser/volume of casting. This is an important ratio in the case of steel castings of large surface and small volume such as thin plates. Here it is necessary but not sufficient for the riser to cool slower than the casting. It is easy to design a small chunky riser that would freeze slower than a large plate. The large plate also requires a large amount of liquid metal to compensate for the liquid-to-solid shrinkage of its relatively large volume. In this case the volume ratio rather than the A/V ratio become a dominating factor. In steel, the volume of the riser can never be less than 6 per cent of the volume of the casting and the curve is therefore asymptotic to this level.

In ductile iron there is an advantage in the expansion reaction which occurs on solidification: liquid → austenite + graphite. The demand for feed metal is therefore less than in the case of steel. To a first approximation then, the only consideration is to have a riser that will freeze more slowly than the casting by a factor of 1.3.

Very light plate sections show a slight tendency to follow the feed metal demand of steel and require more metal than is provided by the riser with the 1.3 ratio. This may be due to the lesser amount of graphite formed on solidification, as shown by the presence of primary carbides in these light sections. Under conditions more favorable to graphitization, such as very-low sulfur cupola metal treated with a minimum of magnesium, these sections may follow the behavior of the heavier castings.

In this case the only consideration is the relative freezing rate of casting and riser. The most efficient side blind riser has height equal to the diameter and if this ratio is maintained a very simple formula may be derived.

The surface area of the riser is

$$\pi dh + 2\frac{\pi d^2}{4} \quad \text{or if } h = d\text{:} \quad \pi d^2 + 2\frac{\pi d^2}{4} = 6\frac{\pi d^2}{4}$$

The volume is

$$\frac{\pi d^2}{4}h \quad \text{or if } h = d\text{:} \quad \frac{\pi d^3}{4}$$

$$\frac{A}{V} = \frac{\frac{6\pi d^2}{4}}{\frac{\pi d^3}{4}} = \frac{6}{d}$$

The expression

$$\frac{A/V\ (\text{casting})}{A/V\ (\text{riser})} = 1.3$$

becomes:

$$\frac{A/V\ (\text{casting})}{6/d} = 1.3$$

$$d\ \text{riser} = \frac{7.8}{A/V\ (\text{casting})}$$

$$= 7.8\ \frac{\text{Volume}}{\text{Area}}\ \text{of casting}$$

As an example, the riser for a 1 x 4 x 4-in. plate may be calculated:

$$\frac{A}{V} = \frac{4(1 \times 4) + 2(4 \times 4)}{4 \times 4 \times 1} = \frac{48}{16} = 3$$

$$d\ \text{riser} = \frac{7.8}{3} = 2.6 \text{ in.}$$

It should be re-emphasized that the effective feeding distance of the riser must not be exceeded. For the present the formulae developed by Pellini for steel may be used in the absence of any data for ductile iron. These are as follows:

Shape of Casting	Maximum Feeding Distance from Edge of Riser
Plates having width-to-thickness ratio of 1 to 3 or greater	4-1/2 times casting thickness
Bars having width equal to thickness (square cross sections)	$6\sqrt{T}$, where T is the casting thickness

Therefore it would be better to consider an 8 x 8 x 1-in. plate as composed of four 4 x 4 x 1-in. sections, each with a riser of the dimensions just calculated, than to attempt to use one side riser. Of course a single, centrally located riser might be used if satisfactory cleaning techniques were available.

Section B. Variables Affecting Riser Performance

As mentioned earlier, the risering curve is based on standard neck design, mold restraint, pouring temperature, and metal composition. The relative importance of these variables will now be discussed.

1. Neck Design. An offhand analysis of neck design indicates that a large area of neck contact would tend to keep a feeding channel open from the riser to the casting. It soon developed, however, that a large neck prevented a satisfactory thermal gradient from the casting to the center of the riser. The result was that the riser, the riser neck, and the zone of the casting adjoining the riser formed a "hot spot" and contained shrinkage.

When the riser neck was made smaller, the proper gradient was developed and the casting, neck, and riser froze in that order.

These effects are demonstrated in Fig. 7. Notice the shrinkage in the casting with the full neck compared with the sound castings with neck height = 1/3 D.

As a result of these experiments a standard neck dimensioning diagram has been developed (Fig. 3). Unless this diagram is followed the risering formulae just discussed do not apply.

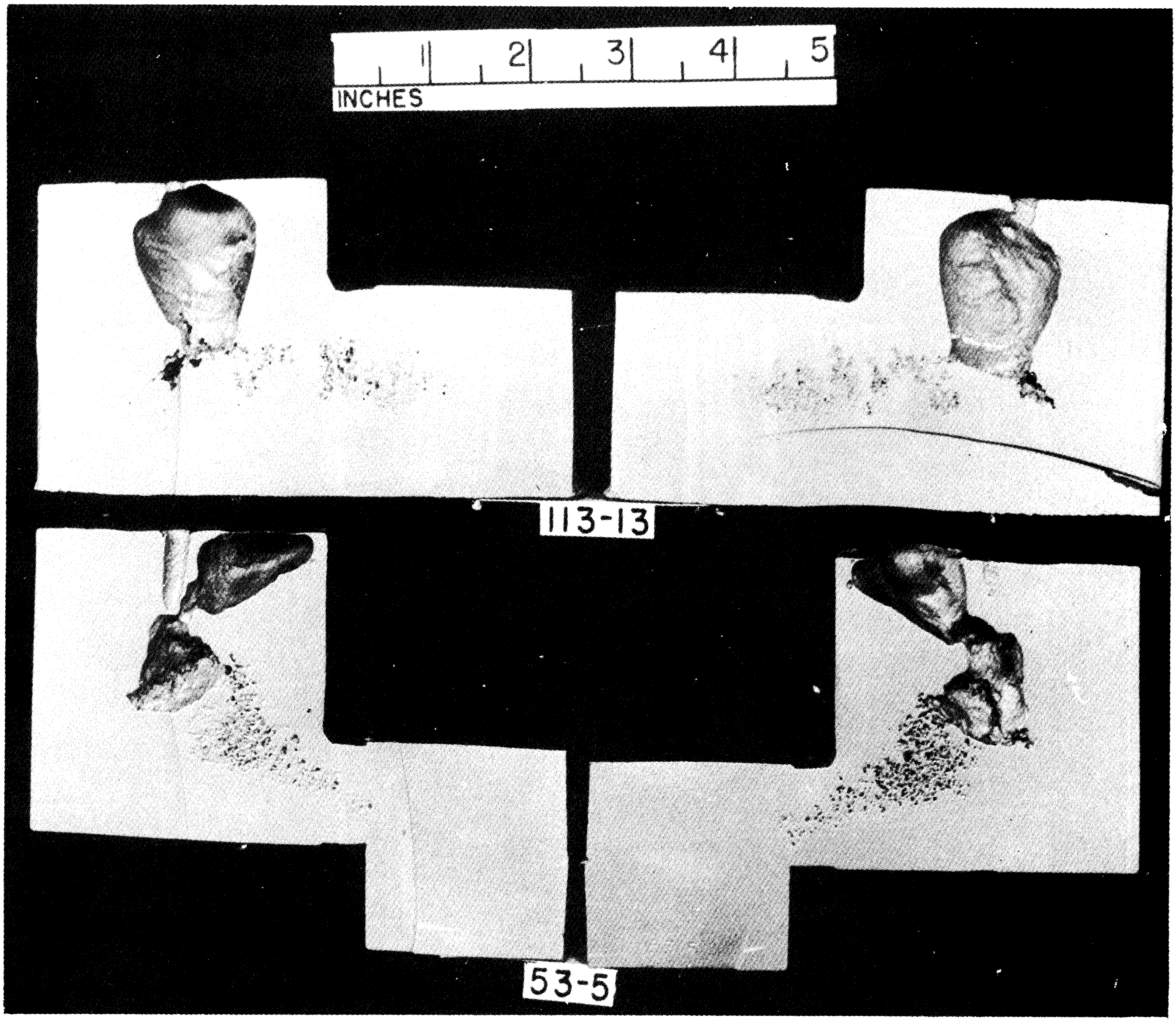


Fig. 7. Effect of Height of Neck. 2 x 2 x 6-in. Castings Sectioned through Riser. Casting No. 113-13 Has 2-in. Neck Height; No. 53-5 Has 1-in. Height.

2. Mold Restraint. At the beginning of the investigation the standard practice was to use two 40-lb weights on the 9 x 9-in. or 13 x 13 in. flasks. It soon developed that the castings were 1/32 to 1/16 in. oversize and crowned in the center. Clamping of the molds reduced this effect as shown by Table III below and Fig. 5.

Shrinkage was lessened at the same time. Apparently the graphitization reaction at solidification tends to bulge the castings and if restrained the remaining liquid is forced into zones of possible shrinkage.

TABLE III

EFFECT OF MOLD RESTRAINT ON SHRINKAGE AND CASTING DIMENSIONS

All Castings 1 x 3 x 7-in. with 2-1/2-in.-dia., 2-1/2-in.-high Riser
Heat No. 76: 3.57% C, .26% Mn, .03% P, 1.80% Si

Casting No.	Mold Restraint	Flask Size in.	Shrinkage Riser	Shrinkage Centerline	Casting Thickness
76-3	Weighted	13 x 13	13/16 in. into casting	1 in.	1-1/32 in.
76-4	Clamped	13 x 13	3/16 in. out of casting	3/16 in.	1-1/64 in.
76-5	Clamped	9 x 9	7/16 in. out of casting	none	1 in.

3. Pouring Temperature. Pouring-temperature effects were explored over a wide range (2780-2400°F) in several heats. No pronounced effect was noted in the composition investigated, as shown by Table IV below and Fig. 8.

TABLE IV

EFFECT OF POURING TEMPERATURE ON SHRINKAGE

All Castings 1 x 3 x 7-in. with 2-1/2-in.-dia., 2-1/2-in.-high Riser
Heat No. 61: 3.45% C, .24% Mn, .02% P, 2.34% Si

Casting No.	Pouring Temperature, ° F.	Riser Shrinkage, in.
61-1	2780	1-1/8 into casting
61-2	2730	1-1/16 into casting
61-3	2600	1-1/16 into casting
61-4	2470	1 into casting
61-5	2400	1-1/16 into casting

4. Composition. Two heats (149 and 198) were made at higher carbon equivalents, 4.77 and 4.44 respectively. The higher-C.E. irons showed sometimes more and sometimes less shrinkage (Table V). It is believed that these effects are within ± 1/4-in. of the riser diameter in the casting range shown. They require further investigation, however, along with the metal history (cupola vs. induction melting).

Fig. 8. Effect of Pouring Temperature. 1 x 3 x 7-in. Castings Sectioned through Risers. Casting No. 61-1 Poured at 2780°F, No. 61-2 at 2730°F, No. 61-3 at 2600°F, No. 61-4 at 2470°F, No. 61-5 at 2400°F.

TABLE V

EFFECT OF METAL COMPOSITION ON RISERING

Casting	Riser, in.	Heat No.	C	Si	C.E.	Riser Shrinkage, in.
1 x 3 x 7	2-3/8 clamped	149	3.98	2.38	4.77	1-1/4 into casting
1 x 3 x 7	2-3/8 clamped	142	3.60	1.76	4.19	1-1/8 into casting
1 x 3 x 7	2-3/4 weighted	39	3.68	1.75	4.26	1-7/8 into casting
1 x 3 x 7	2-3/4 weighted	62	3.61	2.55	4.46	1-5/16 into casting
2 x 2 x 6	3 clamped	149	3.98	2.38	4.77	3/4 out of casting
2 x 2 x 6	3 clamped	139	3.58	1.72	4.15	1/2 into casting
3/4 x 4 x 7	2-1/8 clamped	198	3.80	1.93	4.44	1-3/16 into casting
3/4 x 4 x 7	2-1/8 clamped	111	3.56	1.88	4.19	5/8 out of casting
2(Dia.) x 3-3/4	2-1/2 clamped	198	3.80	1.93	4.44	1-1/2 into casting
2(Dia.) x 3-3/4	2-1/2 clamped	132	3.61	1.83	4.22	5/8 out of casting

IV. RECOMMENDATIONS FOR FURTHER WORK

This progress report has been compiled at this time to provide the Risering Committee with a resumé of the work at the University of Michigan. Throughout the report the need for further work has been indicated, particularly on the following topics:

- Risering of larger castings
- Effective feeding distance
- Risering curves for open risers with and without exothermic compounds
- Top blind risers versus side blind risers
- Effects of composition and previous history of metal, e. g., cupola metal
- Effect of common riser for several castings

In addition to these research items, it is highly important that the risering calculations be tested for commercial castings. It is hoped that the committee members will do this and criticize the utility of the risering curve freely. We shall be glad to cooperate in any calculations or analysis of data.

APPENDIX

APPENDIX

SUMMARY OF OBSERVATIONS OF CASTINGS USED FOR FIG. 1, THE RISERING CURVE

Riser Size, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
2-in.-Diameter x 3-3/4-in.-Long Casting					
2-1/2	1-15/16 half circle x 7/16	Clamped	132-6	Low	Completely sound
2-5/8	1-7/8 dia. x 7/16	Weighted	67-7	Int.*	Surface shrink
2-5/8	1-7/8 dia. x 7/16	Weighted	54-6	Int.	Riser froze over
2-3/4	1-7/8 dia. x 7/16	Weighted	53-6	Int.	Completely sound
2-7/8	1-7/8 dia. x 7/16	Weighted	51-7	Low	Completely sound
3	1-7/8 dia. x 7/16	Weighted	39-8	Low	Completely sound
2-1/2	1-7/8 dia. x 7/16	Weighted	62-5	Int.	Surface shrink
2-1/2	1-15/16 half circle x 1/2	Clamped	136-6	Low	Riser shrink 1-3/4 in.
	Large atmospheric pressure core				
2-3/8	13/16 x 2-3/8 to 13/16 x 3/8 x 1/8	Clamped	190-6	High	Riser shrink 1-5/8 in.
2-1/2	7/8 x 2-1/2 to 7/8 x 7/16 x 9/64	Clamped	198-6	High	Riser shrink 1-1/2 in.

Preliminary work has been done on top blind risers.

*Intermediate

Riser Size, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
4-in.-Cube Casting					
4-1/4	1-7/16 x 3 x 3/4	Clamped	88-6	Low	Riser shrink 5/8 in.
4-1/8	1-1/2 x 2-3/4 x 7/8	Clamped	99-6	Low	Riser shrink 3/4 in.
4	1-3/8 x 3 x 13/16	Clamped	111-6	Low	Riser shrink 1-5/16 in.
4-3/8	1-3/8 x 3-1/2 x 3/8	Weighted	76-6	Low	Riser shrink 1/16 in.
4-1/2	2 x 3-1/2 x 1/2	Weighted	64-5	Int.	Completely sound

Preliminary work has been done on top blind risers.

APPENDIX (cont.)

Riser Size in.	Neck Dimensions in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
2 x 2 x 6-in. Casting					
3	15/16 x 2-5/8 x 7/16	Weighted	53-5	Int.	Riser shrink 1/8 in.
3	1 x 2-1/4 x 9/16	Clamped	132-4	Low	Riser shrink 13/16 in.
3	1 x 2-1/4 x 9/16	Clamped	135-2	Low	Riser shrink 1 in.
3	1 x 2-1/4 x 9/16	Clamped	136-5	Low	Riser shrink 3/4 in.
	Large atmospheric pressure cored				
3	1 x 1 x 9/16	Clamped	138-6	Low	Centerline 3/8 in.
3	1 x 1-1/2 x 1/2	Clamped	139-5	Low	Riser shrink 15/16 in.
	On centerline of casting				
3	1 x 1-1/2 x 1/2	Clamped	139-6	Low	Riser shrink 1/2 in.
3	1 x 3 x 7/16	Clamped	142-5	Low	Riser shrink 11/16 in.
3	1 x 3 to 2-1/4 x 7/16	Clamped	142-6	Low	Riser shrink 5/16 in.
3	1 x 3 to 2-1/4 x 7/16	Clamped	149-5	High	Completely sound
3	1 x 3 to 1 x 7/16	Clamped	149-6	High	Completely sound
2-7/8	1 x 2-7/8 to 1 x 7/16	Clamped	190-5	High	Riser shrink 7/8 in.
2-3/4	1-15/16 x 1-3/4 x 3/8	Weighted	62-4	Int.	Riser shrink 3/16 in.
2-7/8	1-7/8 x 1-3/4 x 1/2	Weighted	54-5	Int.	Centerline 3/4 in.
3-1/4	1-15/16 x 1-3/4 x 1/2	Weighted	36-4	Low	Centerline 1 in.
3	2 x 2-1/4 x 9/16	Clamped	132-5	Low	Riser shrink 1/2 in.
3	2 x 2-5/8 x 7/16	Weighted	113-13	Low	Riser shrink 3/4 in.
3-1/4	2 x 1-1/2 x 7/16	Weighted	39-3	Low	Riser shrink 7/16 in.
3-1/4	2 x 2-1/4 x 3/4	Weighted	34-6	Low	Riser shrink 1/2 in.

Preliminary work has been done on top blind risers.

Riser Size, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
1-3/4 x 4 x 9-in. Casting					
3-3/4	1-1/4 x 3-3/4 to 1-7/8 x 9/16	Clamped	149-7	High	Riser shrink 1 in.
3-7/8	1-15/16 x 3-7/8 to 1-15/16 x 5/8 x 1/4	Clamped	190-7	High	Riser shrink 15/16 in. Improperly rammed, 1-7/8 in thick.
3-7/8	1-5/16 x 3-7/8 to 1-5/16 x 5/8 x 7/32	Clamped	198-7	High	Riser shrink 1-9/16 in.
1 x 3 x 7-in. Casting					
2-1/2 Flat	7/8 x 1-3/4 x 7/16	9 x 9-in. mold, Clamped	76-5	Low	Completely sound
2-1/2	7/8 x 1-3/4 x 7/16	13 x 13-in. mold, Clamped	76-4	Low	Centerline 3/16 in.
2-1/2	7/8 x 1-3/4 x 7/16	13 x 13-in. mold, Weighted	76-3	Low	Riser shrink 13/16 in.
2-1/2	7/8 x 1-3/4 x 9/16	9 x 9-in. mold, Clamped	111-4	Low	Riser shrink 1 in.
2-1/2	3/4 x 2-1/4 x 1/2	9 x 9-in. mold, Weighted	65-3	Int.	Centerline 9/16 in.
2-1/2	1 x 2-1/4 x 1/2	9 x 9-in. mold, Weighted	64-1	Int.	Riser shrink 1-3/8 in.
2-1/2	1 x 2-1/4 x 1/2	13 x 13-in. mold, Weighted	61-1 to 61-5	Int.	Riser shrink 1-1/16 in.
2-1/2	1 x 3 x 3/8	13 x 13-in. mold, Weighted	68-1	Int.	Riser shrink 7/16 in.
2-3/4	1 x 2-1/2 x 7/16	13 x 13-in. mold, Weighted	Many castings	Low	Riser shrink 3/4 in.
2-5/8	1 x 2-1/4 x 7/16	13 x 13-in. mold, Weighted	53-3	Int.	Centerline 1/8 in.
2-1/4	1 x 2 x 1/2	9 x 9-in. mold, Weighted	62-2	Int.	Surface shrink 3/32 in.
2-3/8	1 x 2 x 1/2	9 x 9-in. mold, Weighted	54-2	Int.	Riser shrink 1-1/2 in.
2-3/8	3/4 x 2-1/4 x 7/16	9 x 9-in. mold, Weighted	68-4	Int.	Riser shrink 1-1/4 in.
2-3/8	3/4 x 2-1/4 x 1/2	9 x 9-in. mold, Clamped	88-3	Low	Riser froze over Surface shrink
2-3/8	3/4 x 2-1/4 x 9/16	9 x 9-in. mold, Clamped	111-3	Low	Centerline 5/16 in.
2-1/4	3/4 x 1-11/16 x 7/16	9 x 9-in. mold, Clamped	132-3	Low	Riser shrink 2 in. Surface shrink

Riser Size, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
<u>1 x 3 x 7-in. Casting (cont.)</u>					
2-3/8	13/16 x 13/16 x 1/2	9 x 9-in. mold, Clamped	138-5	Low	Centerline 15/16 in.
2-3/8	13/16 x 2-3/8 x 11/32	9 x 9-in. mold, Clamped	142-2	Low	Riser shrink 1-1/4 in.
2-3/8	13/16 x 2-3/8 to 1-5/16 x 11/32	9 x 9-in. mold, Clamped	142-3	Low	Riser shrink 1 in.
2-3/8	13/16 x 2-3/8 to 1-7/8 x 11/32	9 x 9-in. mold, Clamped	142-4	Low	Riser shrink 1-1/8 in.
2-3/8	13/16 x 2-3/8 to 1-3/16 x 11/32	9 x 9-in. mold, Clamped	149-4	High	Riser shrink 1-1/4 in.
2-1/2	7/8 2-1/2 to 7/8 x 7/16 x 9/64	9 x 9-in. mold, Clamped	198-4	High	Riser shrink 1-3/16 in.

Some work has been done on gating not into riser
Some work has been done on end blind risers
Preliminary work has been done on top blind risers

Riser Size, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
<u>3/4 x 4 x 7-in. Casting</u>					
2-1/8	3/4 x 1-1/2 x 9/16	Clamped	111-1	Low	Centerline shrink 1/4 in.
2	11/16 x 1-9/16 x 7/16	Clamped	132-2	Low	Centerline shrink 1 in.
2-1/8	3/4 x 1-1/2 x 1/2	Clamped	88-1	Low	Riser froze over - surface shrink
2-1/8	3/4 x 1-1/2 x 1/2	Clamped	99-1	Low	Mold crushed in clamping
2	3/4 x 1-7/8 x 7/16	Weighted	62-1	Int.*	Riser shrink 1-5/8 in.

*Intermediate

Riser Size, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
<u>3/4 x 4 x 7-in. Casting (cont.)</u>					
2-1/8	3/4 x 2 x 7/16	Weighted	54-7	Int.	Riser shrink 1-1/8 in.
2-1/4	3/4 x 2 x 1/2	Weighted	54-3	Int.	Centerline 1-15/16 in.
2-3/8	3/4 x 2-1/8 x 7/16	Weighted	51-2	Low	Centerline 7/8 in.
2	11/16 x 11/16 x 7/16	Clamped	138-4	Low	Centerline 1-5/8 in.
2	11/16 x 2 to 11/16 x 5/16	Clamped	190-3	High	Riser shrink 2-5/16 in.
2-1/8	3/4 x 2-1/8 to 3/4 x 3/8 x 1/8	Clamped	198-3	High	Riser shrink 1-3/16 in.
Preliminary work has also been done on top blind riser					
<u>1/2 x 4 x 7-in. Casting</u>					
1-1/2	1/2 x 1-1/8 x 5/16	Clamped	135-1	Low	Riser shrink 1-7/16 in.
1-1/2	1/2 x 1-1/8 x 5/16	Clamped	132-1	Low	Riser froze over surface shrink 3/64 in.
1-1/2	1/2 x 1-3/8 x 3/8	Weighted	62-7	Int.*	Riser shrink 2-1/2 in.
1-5/8	1/2 x 1-1/2 x 3/8	Weighted	53-4	Int.	Centerline 15/16 in.
1-3/4	1/2 x 1-5/8 x 7/16	Weighted	51-1	Low	Centerline 5/8 in.
1-1/2	1/2 x 1/2 x 5/16	Clamped	138-3	Low	Centerline 1-1/8 in.
1-1/2	1/2 x 3/4 x 1/4	Clamped	139-2	Low	Riser shrink 3/16 in.
1-1/2	1/2 x 1-1/8 x 5/16	Clamped	149-1	High	Riser froze over
1-1/2	1/2 x 1-1/2 to 1/2 x 3/16	Clamped	149-2	High	Riser froze over
1-1/2	1/2 x 1-1/2 to 1/2 x 3/16	Clamped	190-2	High	Riser froze over
1-5/8	1/2 x 1-5/8 to 1/2 x 1/4 x 5/64 1/4 gate, atmospheric pressure core did not work	Clamped	198-2	High	Surface shrink 1/64 in.
2-1/4	1/2 x 1-7/8 x 1/2 Gated into casting	Weighted	33-5	Low	Riser shrink 2 in.

*Intermediate

APPENDIX (cont.)

Riser Size, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
1/2 x 4 x 7-in.Casting (cont.)					
no riser		Weighted	33-6	Low	Surface shrink 1/16 in. Centerline 1-11/16 in.
no riser		Clamped	136-2	Low	Surface shrink 1/16 in. Centerline 1-1/8 in.
Preliminary work has also been done on top blind risers					
3/8 x 4 x 7-in. Casting					
1-1/8	3/8 x 9/16 x 3/16 - 1/4 gate	Clamped	139-1	Low	Centerline 5/8 in.
1-1/8	3/8 x 3/8 x 5/16	Clamped	138-2	Low	Centerline 1 in.
1-1/4	3/8 x 1-1/4 x 3/8	Weighted	64-2	Int.*	Centerline 2-1/8 in.
no riser		Weighted	62-6	Int.	Surface shrink 1/32 in. Centerline 2-3/4 in.
no riser		Clamped	136-1	Low	Surface shrink 1/32 in. Centerline 2-1/4 in.
no riser		Clamped	190-1	High	Surface shrink 1/32 in. Centerline 2-1/2 in.
1-1/4	3/8 x 1-1/4 to 7/16 x 3/16 x 1/16 — 3/16 gate	Clamped	198-1	High	Wavy surface shrink
1/4 x 4 x 7-in. Casting					
no riser		Clamped	138-1	Low	Centerline 1-3/4 in.

*Intermediate