Specifications for design of hot metal ladles, AISE Standard No. 9 (Tentative), September 30, 1951

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LADLES

HOT METAL
HOT METAL WELDED and RIVETED
TRANSFER
BESSEMER
OPEN HEARTH
ELECTRIC FURNACE
FOUNDRY

TREADWELL CONSTRUCTION Co.
MIDLAND, PENNSYLVANIA

SALES OFFICES

208 S. LaSalle Street
CHICAGO 4, ILL.
CEntral 6-9784

140 Cedar Street
NEW YORK 6, N. Y.
WOrth 4-3344

1217 Farmers Bank Building
PITTSBURGH 22, PA.
ATlantic 1-2883
LADLES

WELDED OR RIVETED
5 TO 300 TON CAPACITY
FOR
BLAST FURNACE
OPEN HEARTH
ELECTRIC FURNACE
BESSMER CONVERTER
FOUNDRY

LADLE TRANSFER CARS
LADLE STANDS
LADLE BAILS
LADLE HOOKS

ALL WELDED LADLES
STRESS RELIEVED
Over 600 POLLOCK welded Open Hearth ladles in capacities ranging from 15 to 300 tons are being used by major steel companies in the United States and Canada.

The welded ladle was introduced by POLLOCK in 1932 and the advantages over heavier, riveted types were recognized immediately.

Lighter weight and smoother inside and outside surfaces add to their importance.

POLLOCK welded ladles are custom designed to suit existing plant conditions. Construction details of spouts, stopper holes, stopper riggings, etc., are detailed to meet specific requirements.

THE WILLIAM B. POLLOCK COMPANY
YOUNGSTOWN, OHIO
STEEL PLATE CONSTRUCTION - ENGINEERS
FABRICATORS - ERECTORS
22. Location of teeming spout will be as follows:

23. Diameter of tap hole will be as follows:

24. Location and number of pouring lips will be as follows:

25. Painting required is as follows:

26. Protection of finished parts for shipment will be as follows:

27. Ladle will be unloaded by

28. (See 3 A, a) material for bottom plate will be

29. (See 3 A, b) material for shell plate stiffener rings, etc., will be

30. (See 3 A, f) the lining shall be composed of the following:

31. Lining will be furnished by

32. (See 4 B) Bottom plate will be dished or flat as checked.

33. Ladle will be welded or riveted as checked.

34. (See 4 F) Are steel bushings required for trunnions?

35. (See 4 F) Are oilless bronze bushings required on the trunnion pin?

36. (See 4 I) Are heat protection plates required around pouring nozzle?

37. (See 4 K) Are weep holes required on side of ladles?

SPECIAL FEATURES

ASSOCIATION OF IRON AND STEEL ENGINEERS
STANDARDS

AISE Standard No. 1 — D-C MILL MOTOR STANDARDS ........................................... $0.25 ea
AISE Standard No. 2 — STANDARD DIMENSIONS FOR ENCLOSED SWITCHES ............... 0.25 ea
AISE Standard No. 3 — STANDARDS FOR MACHINED SURFACE FINISHES ................. 0.25 ea
AISE Standard No. 4 — SLING AND CRANE CHAIN STANDARDS ............................. 0.25 ea
AISE Standard No. 5 — STANDARDS FOR WIRING DIAGRAMS .............................. 0.25 ea
AISE Standard No. 6 — SPECIFICATIONS FOR ELECTRIC OVERHEAD TRAVELING CRANES FOR STEEL MILL SERVICE .................................................. 1.00 ea
AISE Standard No. 7 — SPECIFICATIONS FOR DESIGN OF LADLE HOOKS ............... 0.25 ea
AISE Standard No. 8 — CRANE WIRING STANDARDS ........................................... 0.25 ea
AISE Standard No. 9 — STANDARDS FOR DESIGN OF HOT METAL LADLES (Tentative) ... 0.25 ea
AISE Standard No. 10 — CARBON BRUSH SIZE AND SHUNT STANDARDS (Tentative) .... 0.25 ea
AISE Standard No. 11 — D-C MILL MOTOR BRAKE STANDARDS (Tentative — In Process) ... 0.25 ea

RECOMMENDED PRACTICES

AISE Recommended Practice No. 1—PLAIN BEARING RECOMMENDED PRACTICE (Tentative) ... 1.00 ea

Quantity prices may be obtained on request.
Minimum price for any order $1.00.

IRON AND STEEL ENGINEER, MARCH, 1952
lip ring, which may in practice be weakened by spouts or hot metal spills.

9. DESIGN OF SIDEWALL PLATES

Minimum sidewall thicknesses are in accordance with usage requirements, and in addition it is specified that the sidewall thicknesses shall not be less than 0.75 times the bottom plate thickness. This last requirement is set up to provide adequate restraint or fixity to the edge of the bottom plate.

CONCLUSION

Simplified design and analysis procedures for open top hot metal ladles have been presented and the results compared with laboratory tests and actual design practice. Reasonably good agreement has been found in each case. Generally accepted rules of good practice have been incorporated into the specification, as a result of suggestions by the Hot Metal Ladle Committee of the Association of Iron and Steel Engineers. Preliminary drafts of the specification, later revised by the committee, were prepared by Dr. Bruce G. Johnston, Professor of Structural Engineering, at the University of Michigan. The formulas for dished bottom shell thickness in Section 7 were prepared by Dr. Bruno Thurlimann, former research worker in the field of thin shell structures at Fritz Engineering Laboratory of Lehigh University.

<table>
<thead>
<tr>
<th>AISE HOT METAL LADLE SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>PURCHASER'S INFORMATION SHEETS</td>
</tr>
<tr>
<td>Company ---------------------------</td>
</tr>
<tr>
<td>Works ------------------------------</td>
</tr>
<tr>
<td>Located at. _______________________</td>
</tr>
<tr>
<td>Specification No. -----------------</td>
</tr>
<tr>
<td>Dated ____________________________</td>
</tr>
<tr>
<td>TON HOT METAL LADLE</td>
</tr>
<tr>
<td>(This information to be furnished bidder by purchaser)</td>
</tr>
</tbody>
</table>

1. The following specific information, together with the AISE Standard No. 9, Specifications for Design of Hot Metal Ladles, dated ________________, shall form the complete specifications of number as noted above.

2. Contractor shall furnish ________________

as covered by these specifications.

3. Ladle to be delivered F.O.B.  ____________________________

4. Number of sets of prints, etc., to be furnished:

   Specifications ______

   Are prints or tracings required? ______

5. Required delivery date is ____________________________

   GENERAL DETAILS

6. Capacity of ladles is ____________________________ tons.

7. Material which ladle will handle is ____________________________ lb per cu ft.

8. Weight of molten metal to be handled is ____________________________ lb.

9. Maximum allowable weight of ladle will be ____________________________ lb.

10. Limiting height of ladle is ____________________________ ft.  ________ in.

11. Limiting diameter of ladle is ____________________________ ft.  ________ in.

12. Centerline of trunnion to top of lining flange shall not exceed ____________________________ ft.  ________ in.

13. Centerline of trunnion to underside of bottom shall not exceed ____________________________ ft.  ________ in.

14. Inside diameter of ladle at top shall not exceed ____________________________ ft.  ________ in.

15. Thickness of ladle hooks is ____________________________ in.

16. Diameter of trunnions will be as follows:

17. Distance between centerlines of trunnions and ladle hooks is ____________________________ ft.  ________ in.

18. Side hook loops are required as follows:

19. Ladle stand seat is required as follows:

20. Is a heat shield required on bottom? ____________________________

21. Stopper rod rigging will be as follows:

<table>
<thead>
<tr>
<th>LS-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRON AND STEEL ENGINEER, MARCH, 1952</td>
</tr>
</tbody>
</table>

Tables I, II, and III show a comparison of the maximum stresses actually measured in model ladles, as reported in Reference (1), with the stresses obtained by the procedure given in Section 8. A study of these tables will show that reasonably good agreement exists between stresses by analysis and test, especially in the case of the most critical maximum stresses.

The proposed analysis procedure was also tried out on five actual designs selected to cover a wide range of ladle capacity, from 70 to 270 tons. Most of the stresses so calculated, as shown in Table IV, were below the proposed allowable value of 16,000 psi. However, two of the ladles, designated in the table as made by "C", had top rib sections markedly reduced for hook clearance at the critical section, with stresses in this location in the neighborhood of the yield strength of structural grade steel. It is also of interest that this manufacturer has reported actual yielding of ladles in service at this location.

In Section 8G, no computation is required for the bottom rib at the trunnion, since the ladle research program showed these stresses to be less than at the other locations. In addition, the bottom rib is sometimes strengthened here to enable the ladle to be set in a ladle stand seat. However, good practice usually dictates that the lower ring be as large if not larger than the top ring, and that it be fully as large if not larger at the trunnion than at 90 degrees from the trunnion. The lip ring is not considered in the specification, since it is felt that the ladle should be strong enough without the

### TABLE III

**STRESSES IN TEST LADLE C**
(Round, Welded, Sidewall Thickened Between Ribs)

<table>
<thead>
<tr>
<th>Location</th>
<th>21/2-in. Hook distance</th>
<th>71/2-in. Hook distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test</td>
<td>Formula</td>
</tr>
<tr>
<td>Lip ring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>-9,150</td>
<td>-9,350</td>
</tr>
<tr>
<td>Inside</td>
<td>+12,460</td>
<td></td>
</tr>
<tr>
<td>90°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>3,540</td>
<td>5,420</td>
</tr>
<tr>
<td>Inside</td>
<td>-5,930</td>
<td>-7,230</td>
</tr>
<tr>
<td>Top rib</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>-3,100</td>
<td>-4,220</td>
</tr>
<tr>
<td>Inside</td>
<td>3,700</td>
<td>3,600</td>
</tr>
<tr>
<td>90°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>5,250</td>
<td>7,290</td>
</tr>
<tr>
<td>Inside</td>
<td>3,440</td>
<td>3,610</td>
</tr>
<tr>
<td>Bottom rib</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>-3,100</td>
<td>-2,070</td>
</tr>
<tr>
<td>Inside</td>
<td>4,180</td>
<td>4,140</td>
</tr>
<tr>
<td>90°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>2,340</td>
<td>2,070</td>
</tr>
<tr>
<td>Inside</td>
<td>3,100</td>
<td>3,600</td>
</tr>
</tbody>
</table>

*Section was reduced for hook clearance.

**Stress obviously greater at change of section.

### TABLE IV

**STRESSES BY PROPOSED DESIGN METHOD FOR VARIOUS FULL SIZE LADLES**

<table>
<thead>
<tr>
<th>Ladle mfg.</th>
<th>Actual ladle designs in service</th>
<th>Sample design example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladle capacity in tons</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>70</td>
<td>140</td>
<td>200</td>
</tr>
</tbody>
</table>

| Top rib | 0°   | Outside | -39,000 | -36,400* | ** | -16,750 | ** | -13,500 |
|         | Inside | +19,700 | +19,000 | ** | +10,300 | ** | +8,130  |
|         | At change of section | Outside | -15,600 | -12,100 | -16,700 | -15,500 |
|         | Inside | +10,000 | +6,500 | +10,600 | +8,400 |
| 90°     | Outside | 16,000 | 5,540 | 7,800 | 13,800 | 4,600 | 13,100 |
|         | Inside | -9,200 | -4,010 | -5,900 | -7,550 | -3,650 | -7,950 |
| Bottom rib | 90° | Outside | -10,500 | -4,250 | +6,100 | +8,900 | +4,600 | +9,600 |
|         | Inside | 6,800 | 3,230 | -4,700 | -5,500 | -3,450 | -6,700 |
7. DESIGN OF BOTTOM PLATES OF DISHED BOTTOM LADLES

The formulas for thickness of dished bottom ladles, as given in Section 7, were obtained by a theoretical analysis of the local bending stresses at the juncture between the ladle bottom and sidewall. Since these stresses are highly localized, and since the load is carried not by bending but by direct stress, an allowable stress of 24,000 psi, as explained in Section 5, was permitted.

The initial formulas resulting from this analysis were quite complex. Simplifications were introduced so that the resulting empirical formulas, as given in Sections 7A and 7C, for circular and oval ladles respectively, would give proportions on the safe side.

8. DESIGN OF STIFFENER RIBS

The notation used in the rib analysis and design has been given in Figures 1 to 4, and the design procedure illustrated in Appendix A for the ladle shown in Figure 5.

### Table I

**STRESSES IN TEST LADLE A**

(Round, Riveted, with Flat Stiffener Bands)

<table>
<thead>
<tr>
<th>Location</th>
<th>2 1/2-in. Hook distance, 8 x 8-in. trunnion pads</th>
<th>2 1/2-in. Hook distance, 8 x 16-in. trunnion pads</th>
<th>7 1/2-in. Hook distance, 8 x 16-in. trunnion pads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test</td>
<td>Formula</td>
<td>Test</td>
</tr>
<tr>
<td>Lip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ring</td>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>10,800</td>
<td>-10,900</td>
<td>6,850</td>
</tr>
<tr>
<td>Inside</td>
<td>+28,400</td>
<td>+25,900</td>
<td>+23,400</td>
</tr>
<tr>
<td>90°</td>
<td>+4,880</td>
<td>+5,400</td>
<td>+4,010</td>
</tr>
<tr>
<td>Inside</td>
<td>-15,500</td>
<td>-14,200</td>
<td>-17,990</td>
</tr>
<tr>
<td>Top</td>
<td>0°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rib</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>-6,540</td>
<td>-7,300</td>
<td>-2,180</td>
</tr>
<tr>
<td>Inside</td>
<td>+3,500</td>
<td>+5,600</td>
<td>+1,600</td>
</tr>
<tr>
<td>90°</td>
<td>+3,740</td>
<td>+3,800</td>
<td>+3,450</td>
</tr>
<tr>
<td>Inside</td>
<td>-1,820</td>
<td>-3,000</td>
<td>-2,010</td>
</tr>
<tr>
<td>Bottom</td>
<td>90°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rib</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>+4,600</td>
<td>+3,100</td>
<td>+4,220</td>
</tr>
<tr>
<td>Inside</td>
<td>-1,340</td>
<td>-2,700</td>
<td>-1,910</td>
</tr>
</tbody>
</table>

### Table II

**STRESSES IN TEST LADLE B**

(Oval, Welded, Uniform Sidewall Thickness)

<table>
<thead>
<tr>
<th>Location</th>
<th>2 1/2-in. Hook distance</th>
<th>7 1/2-in. Hook distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test</td>
<td>Formula</td>
</tr>
<tr>
<td>Lip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ring</td>
<td>0°</td>
<td>-10,260</td>
</tr>
<tr>
<td>Inside</td>
<td>+ 9,160</td>
<td>+13,200</td>
</tr>
<tr>
<td>90°</td>
<td>+ 2,750</td>
<td>+ 4,260</td>
</tr>
<tr>
<td>Inside</td>
<td>- 6,330</td>
<td>- 5,950</td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rib</td>
<td>0°</td>
<td>- 9,970</td>
</tr>
<tr>
<td>Inside</td>
<td>+ 3,620</td>
<td>+ 5,580</td>
</tr>
<tr>
<td>90°</td>
<td>+ 3,390</td>
<td>+ 4,560</td>
</tr>
<tr>
<td>Inside</td>
<td>- 1,880</td>
<td>- 2,600</td>
</tr>
<tr>
<td>Bottom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rib</td>
<td>90°</td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>+ 4,290</td>
<td>+ 4,600</td>
</tr>
<tr>
<td>Inside</td>
<td>- 3,310</td>
<td>- 3,700</td>
</tr>
</tbody>
</table>
5. DESIGN STRESSES AND DESIGN
ASSUMPTION

C. a. The lowest permissible stresses (8000 psi) are listed for cases where the stress is uniform or nearly so throughout the thickness of material, and in cases where initial yielding would be followed by large deformations.

C. b. The stress in the ladle rib is primarily bending and the ribs are usually rectangular in shape. After initial yielding in bending for such a shape, there is still considerable reserve strength before yielding is completely general throughout. Therefore, an allowable stress of 16,000 psi is used. Furthermore, yielding in one place will be followed by a redistribution of stress and will not be indicative of early failure. This is the basis for permitting a higher allowable stress in the elastic range since the real factor of safety of the structure is greater than indicated by the nearness of the allowable stress to the yield point.

The same reasoning applies to bending in the flat bottom plates, and there is the additional factor that as a flat bottom yields, it becomes dished and starts to take still more load through direct membrane stresses that are developed. The recommended allowable stresses, nevertheless, are within the elastic range of the material.

C. c. In this class (24,000 psi) are the stresses, such as concentrations near a sharp fillet or hole, that in themselves do not effectively help carry the load. They are to be considered only on a secondary basis as a possible indication of danger to brittle failure from fatigue or other cause. In a dished bottom, the load is carried by the membrane stresses and the local bending stresses at the boundary are put in this class. Initial yielding due to these stresses in itself has practically no effect on the general structural behavior.
APPENDIX B

BASIS AND EXPLANATION OF THE SPECIFICATION

This specification on Design of Hot Metal Ladles is based on an extensive program of research sponsored and financed by the Association of Iron and Steel Engineers at the Fritz Engineering Laboratory of Lehigh University at Bethlehem, Pa. In this research program, model test ladles were loaded and the stresses measured at various points in the ladle. The ladles were then analyzed by mathematical methods. The ladle models were scale models of various types in actual service. Primary attention in the analysis was given to the stiffening rings and trunnion assembly.

Guiding this work was a committee composed of steel mill engineers, ladle manufacturers, representatives of Lehigh University and the Association of Iron and Steel Engineers. Credit is due this entire group for directing the research work into channels which have resulted in a relatively simple, practical specification which is of value to the steel industry.

The committee to whom this credit is due consists of the following men:

F. E. Kling (chairman), Tenafly, N. J.
Leo J. Gould, Chief Engineer of Construction, Bethlehem Steel Co., Bethlehem, Pa.
H. A. Leermakers, Building Engineer, Construction and Engineering Department, Bethlehem Steel Co., Bethlehem, Pa.

4. DETAILS OF CONSTRUCTION

The recommendations in this section are based on accepted good practice in ladle design and in large part these are drawn verbatim from a previously proposed specification. Reference (1) also reviews these and other related recommendations.


**Illustrative Design Example**

These computations cover only the general features of the design. It is assumed that careful attention will be given to all details with proper grooves and welds provided to join all parts into an integral whole.

**General Dimensions determined by 10-ton capacity as shown in Fig. 5.**

**Estimated Weight**

- Metal: 30,000 lb.
- Ladle: 7,000 lb.
- Lining: 4,000 lb.
- Total: 41,000 lb.

**Bottom Plate** (See Section 7.8 for details laid.

- H: 144 in.
- B: 39 in. (Arbitrarily selected standard value)
- D: 85 in. (Selected in previous computations at 5")
- Rib thickness plate (bottom): 7.8 in.

- Use 5" 1/4 Bottom Plate: 1.5° in.

**Alternate Flat Bottom Plate Design**

- See Section 8.8: D=72x124 in.
- Reshaped for single plate

- Use 1/4 Bottom Plate: 1.5° in.
- Use 5" 1/4 Bottom Plate: 1.5° in. Required.

**Sidewall** (Section 9.1): 1/4 Required for 10-ton ladle

- Minimum: 2.50 in. 1/4 (slab plate)
- Use 1/2 thick sidewall

**Transition Pin and Housing** (Section 5.6 and 5.7)

- Toy 1" pin diam.
- Area: 7.87 sq. in.
- Section Modulus = 176.7 in. x sq. in.

- Normal stress due to bending @ f: 7.20 x 7,000 = 49,400 psi
- Avg. bearing stress (Sec. 5.7) at B: 4,500,000 (1 + 4.50) = 1,860 psi

- Bottom Rib

- Initial moment of inertia of rib: 50 in. x sq. in.
- Effective width (Sec. 8.6): b = 10.1 in.
- Slotted B: 7.87 in.
- Effective width (Sec. 8.6): b = 7.87 in.
- Effective width (Sec. 8.6): b = 7.87 in.

**Stiffener Rib (Section 8)**

**Effective Rib Properties**

- Top Rib

- Effective shell (Sec. 8.6): b = 7.87 in.
- Effective shell (Sec. 8.6): b = 7.87 in.
- Effective shell (Sec. 8.6): b = 7.87 in.

**Summary of Effective Rib Properties**

- A1 = 120.5 in.²; I1 = 1,210 in.⁴; S1 = 143.5 in.³
- A2 = 120.5 in.²; I2 = 1,210 in.⁴; S2 = 143.5 in.³
- A3 = 120.5 in.²; I3 = 1,210 in.⁴; S3 = 143.5 in.³

**Rib Forces (Section 8.6)**

- From Fig. 5: A = 120 in.²; R = 120 in.²
- C = 8.0 x 10⁵ lb. in.²
- Top Rib F1 = 43,000 lb.; F2 = 22,500 lb.
- Bottom Rib F3 = 13,500 lb.

**Rib Moments (Section 8.6)**

- Top Rib, adjacent to transition pad: M1 = 21,000 lb. in.
- Top Rib, 90° from transition axis: M2 = 15,000 lb. in.
- Bottom Rib, 90° from transition axis: M3 = 12,500 lb. in.

**Normal Stress in Rib due to Bending and Direct Force**

- At A: $f = 51,000$ psi
- At B: $f = 51,000$ psi
- At C: $f = 51,000$ psi
- At D: $f = 51,000$ psi

**Possible Solution**

- Increase Top Rib section, or
- Add additional side stringer

*In case of oval section, be sure to add "A" as per section 1.6.*

**In case of oval section, be sure to add "A" as per section 1.6.*

**In case of oval section, be sure to add "A" as per section 1.6.*
The rib bending moments are calculated by assuming that the inflection point of zero moment in each effective rib is located at a distance 0.3RT or 0.3Rn, measured inward from the rib neutral axis parallel with the cross axis of the ladle. See Figure 4A. By cross axis is meant the axis at right angles with the trunnion pin axis. Use plus and minus signs exactly as given in the following formulae which are based on the force diagram shown in Figure 4A. Plus rib bending moments indicate compression on the outside of the rib and tension on the inside of the rib. Minus rib bending moments indicate tension on the outside and compression on the inside of the rib. Minus signs for stresses indicate compression and plus signs for stresses indicate tension in accord with the usual practice.

Rib bending moments are to be calculated as follows:

1. Top rib above trunnion, at weakest section, that is, at trunnion axis in the case of open box framing (Figure 4B) or at edge of pad (Figure 4C) if trunnion housing is carried to upper rib and welded thereto. This moment may be calculated as follows:
   \[ M_{T1} = F_T \left( 0.7R_T + l - c \right) \]
   (l=0 in a circular ladle)

2. Top rib at cross axis, 90 degrees from trunnion axis:
   \[ M_{T2} = -(F_T)0.3R_T \]

3. Bottom rib at cross axis, 90 degrees from trunnion axis:
   \[ M_{T3} = -(F_B)0.3R_B \]

Normal stresses are not to exceed 16,000 psi and are to be calculated at each of the locations listed, as follows:

1. Top rib above trunnion:
   (outside) \[ f_o = \frac{-M_{T1}}{S_{TO}} \]
   (inside) \[ f_i = \frac{+M_{T1}}{S_{TI}} \]

2. Top rib at cross axis:
   (outside) \[ f_o = -\frac{F_T}{A_T} \frac{-M_{T2}}{S_{TO}} \]
   (inside) \[ f_i = -\frac{F_T}{A_T} + \frac{+M_{T2}}{S_{TI}} \]
   (Note: S_{TO} and S_{TI} may be different at locations 1 and 2 if rib varies in cross-section)

3. Bottom rib at cross axis:
   (outside) \[ f_o = -\frac{F_B}{A_B} \frac{-M_{T3}}{S_{BO}} \]

For intermediate capacities, sidewall thicknesses may be interpolated to nearest \( \frac{1}{6} \) in. Between the ladle bottom and the bottom rib, the sidewall thickness should preferably be the same as the bottom plate thickness. In the case of flanged bottom plates (Section 4B), sidewall thickness may be less than the bottom plate thickness, but in no case shall the side plate thickness be less than 0.75 times the bottom plate thickness.
C. Oval dished ladle bottoms (Figure 3) having a maximum diameter not more than 1.4 times the minimum diameter shall have a bottom plate thickness determined by the following formula:

\[ T = \left[ \frac{15.2 + (0.64 \frac{D_{\text{max}}}{D_{\text{min}}} - 0.04)H(0.1 + \frac{r}{R})}{10,000} \right] R \]

D. If the molten metal to be transported has a unit weight "q" per cu ft that is appreciably different from 430 lb per cu ft, the thickness is to be determined by the formulas in this section modified by multiplying the term "H" in the numerator by \( q \) of 480.

E. Reinforcing plates, if used, are not to be considered as effectively adding to the strength of dished bottoms.

8. DESIGN OF STIFFENER RIBS

A. The tendency of the ladle to collapse when suspended by the ladle hooks may be resisted by two stiffener ribs or rings, one above and one below the trunnion pad or framing, designated by the subscripts T and B, for top and bottom, respectively. The lip reinforcement of the ladle is not to be considered in calculating the stresses in the ladle ribs. The strength of each rib is to be determined on the basis of allowable stress, as calculated by the following procedure, which stress is not to exceed 16,000 psi.

B. Each "effective rib" shall consist of the stiffener ring together with a portion of the adjacent ladle sidewall of "effective width = be," provided however that the rib or band be welded or riveted to the ladle sides. Welding is recommended and should be continuous. If the ribs and trunnion band are not riveted or welded to the sides, no part of the sidewall shall be included in calculating the properties of the "effective rib."

C. If the sidewall thickness is the same both above and below a rib, the total width of the ladle shell to be used in calculating the section properties of the effective rib shall be taken as:

\[ b_e = b_r + 1.4\sqrt{R_b} \]

where \( b_r = \) width of rib stiffener

\( R_b = \) sidewall radius

\( t = \) sidewall thickness at stiffener

If the sidewall thickness changes at a rib, the total width of the effective rib shall be taken as:

\[ b_e = b_r + b_1 + b_2 \]

where \( b_1 = \) the effective width of the thicker portion (thickness \( t_1 \)) of the sidewall and \( b_2 = \) the thinner portion (thickness \( t_2 \)) as follows:

\[ b_1 = 0.4\sqrt{R_b}(t_1 + 2t_2) \]

\[ b_2 = 0.7\sqrt{R_b}t_2 \]

D. After determining the effective width by Section 8C, the area, moment of inertia, section modulus, and effective radius of each rib are to be calculated. By effective radius is meant the radius of the neutral axis of the effective rib at the centerline of the stiffener. These properties and other necessary information will be designated as follows:

\( A_T = \) effective area of top rib

\( A_B = \) effective area of bottom rib

\( h_T = \) vertical height of top rib stiffener centerline above juncture of ladle bottom and sidewall

\( h_B = \) vertical height of bottom rib stiffener centerline above juncture of ladle bottom and sidewall

\( R_T = \) effective radius of top rib

\( R_B = \) effective radius of bottom rib

\( I_T = \) moment of inertia of effective top rib

\( I_B = \) Moment of inertia of effective bottom rib

\( S_{STO}, S_{STI}, S_{SOB}, S_{SBH} = \) section modulus for outer or inner surface of top or bottom effective rib, as designated by subscript 0 or 1, T or B, respectively.

\( W = \) total weight of ladle, lining, and molten metal when filled to maximum height

\( a = \) distance between lifting hook centerlines

\( c = \) distance from vertical section through trunnion pin to sections of top rib which are being checked for strength in region of trunnion. See Figure 4. This a variable distance.

\( l = \) in an oval ladle, one-half the width of the straight side

\( R_M = \) mid-height radius to middle plane of sidewall

E. The effective ribs develop compressive forces, with resultant parallel to the trunnion pin axis, that may be computed by the following formulas:

\[ C = \frac{I_T h_T R_T^2}{I_B h_B R_B^2} \]

"h" term in the numerator by \( 430 \).
7. DESIGN OF BOTTOM PLATES OF DISHED BOTTOM LADLES

A. The notation used in this section is shown in Figure 3. A ladle bottom may be considered as "dished" providing the dishing radius "R" is less than 10 times the minimum radius "r" of the bottom plate. The dishing must be to the shape of a spherical segment in circular ladles and in the end sections of oval ladles. The center section only of an oval ladle may be dished to a cylindrical shape.

B. The bottom plate thickness for dished circular bottoms shall be determined by the following formula:

\[ T = \frac{D\sqrt{H}}{625} \]

C. Reinforcing plates, if used, shall be placed on the inside of the ladle bottom, and shall be riveted to the bottom plate in a row or rows around the circumference, as well as throughout the entire reinforcing plate area, so as to make the two plates act as a unit. The diameter "d" of the reinforcing plate shall not be less than 0.88 times the diameter "D" of the bottom plate.

D. When a reinforcing plate is used, the combined thicknesses of the reinforcing plate (T_R) and bottom plate (T_B) shall not be less than:

\[ T_B + T_R = \frac{D\sqrt{H}}{510} \]

The thickness of the bottom plate (as distinguished from the reinforcing plate) shall be at least \( \frac{1}{2} \) in. more than one-half the combined thickness of the two plates.

E. When the molten metal to be handled has a unit weight "q" appreciably different from 430 lb per cu ft, the required minimum thicknesses shall be those given by the foregoing formulas, multiplied by \( \sqrt{\frac{q}{430}} \).

F. In the case of "oval" ladles, having a maximum bottom plate diameter not more than 1.4 times the minimum bottom plate diameter (see Figure 2), the foregoing formulas for bottom plate thickness as given in this section may be used by replacing circular bottom plate diameter "D" by an equivalent diameter for the oval ladle, "D_E", determined by the following formula:

\[ D_E = \frac{D_{\text{max}} + D_{\text{min}}}{2} \]

B. Circular flat bottoms with no reinforcing plate shall have a thickness not less than

\[ T = \frac{D\sqrt{H}}{625} \]

C. Reinforcing plates, if used, shall be placed on the inside of the ladle bottom, and shall be riveted to the bottom plate in a row or rows around the circumference, as well as throughout the entire reinforcing plate area, so as to make the two plates act as a unit. The diameter "d" of the reinforcing plate shall not be less than 0.88 times the diameter "D" of the bottom plate.

D. When a reinforcing plate is used, the combined thicknesses of the reinforcing plate (T_R) and bottom plate (T_B) shall not be less than:

\[ T_B + T_R = \frac{D\sqrt{H}}{510} \]

The thickness of the bottom plate (as distinguished from the reinforcing plate) shall be at least \( \frac{1}{2} \) in. more than one-half the combined thickness of the two plates.

E. When the molten metal to be handled has a unit weight "q" appreciably different from 430 lb per cu ft, the required minimum thicknesses shall be those given by the foregoing formulas, multiplied by \( \sqrt{\frac{q}{430}} \).

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\[ D_E = \frac{D_{\text{max}} + D_{\text{min}}}{2} \]

B. Circular flat bottoms with no reinforcing plate shall have a thickness not less than

\[ T = \frac{D\sqrt{H}}{625} \]

C. Reinforcing plates, if used, shall be placed on the inside of the ladle bottom, and shall be riveted to the bottom plate in a row or rows around the circumference, as well as throughout the entire reinforcing plate area, so as to make the two plates act as a unit. The diameter "d" of the reinforcing plate shall not be less than 0.88 times the diameter "D" of the bottom plate.

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\[ T_B + T_R = \frac{D\sqrt{H}}{510} \]

The thickness of the bottom plate (as distinguished from the reinforcing plate) shall be at least \( \frac{1}{2} \) in. more than one-half the combined thickness of the two plates.

E. When the molten metal to be handled has a unit weight "q" appreciably different from 430 lb per cu ft, the required minimum thicknesses shall be those given by the foregoing formulas, multiplied by \( \sqrt{\frac{q}{430}} \).

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\[ D_E = \frac{D_{\text{max}} + D_{\text{min}}}{2} \]

B. Circular flat bottoms with no reinforcing plate shall have a thickness not less than

\[ T = \frac{D\sqrt{H}}{625} \]

C. Reinforcing plates, if used, shall be placed on the inside of the ladle bottom, and shall be riveted to the bottom plate in a row or rows around the circumference, as well as throughout the entire reinforcing plate area, so as to make the two plates act as a unit. The diameter "d" of the reinforcing plate shall not be less than 0.88 times the diameter "D" of the bottom plate.

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\[ T_B + T_R = \frac{D\sqrt{H}}{510} \]

The thickness of the bottom plate (as distinguished from the reinforcing plate) shall be at least \( \frac{1}{2} \) in. more than one-half the combined thickness of the two plates.

E. When the molten metal to be handled has a unit weight "q" appreciably different from 430 lb per cu ft, the required minimum thicknesses shall be those given by the foregoing formulas, multiplied by \( \sqrt{\frac{q}{430}} \).

F. In the case of "oval" ladles, having a maximum bottom plate diameter not more than 1.4 times the minimum bottom plate diameter (see Figure 2), the foregoing formulas for bottom plate thickness as given in this section may be used by replacing circular bottom plate diameter "D" by an equivalent diameter for the oval ladle, "D_E", determined by the following formula:

\[ D_E = \frac{D_{\text{max}} + D_{\text{min}}}{2} \]

B. Circular flat bottoms with no reinforcing plate shall have a thickness not less than

\[ T = \frac{D\sqrt{H}}{625} \]

C. Reinforcing plates, if used, shall be placed on the inside of the ladle bottom, and shall be riveted to the bottom plate in a row or rows around the circumference, as well as throughout the entire reinforcing plate area, so as to make the two plates act as a unit. The diameter "d" of the reinforcing plate shall not be less than 0.88 times the diameter "D" of the bottom plate.

D. When a reinforcing plate is used, the combined thicknesses of the reinforcing plate (T_R) and bottom plate (T_B) shall not be less than:

\[ T_B + T_R = \frac{D\sqrt{H}}{510} \]

The thickness of the bottom plate (as distinguished from the reinforcing plate) shall be at least \( \frac{1}{2} \) in. more than one-half the combined thickness of the two plates.

E. When the molten metal to be handled has a unit weight "q" appreciably different from 430 lb per cu ft, the required minimum thicknesses shall be those given by the foregoing formulas, multiplied by \( \sqrt{\frac{q}{430}} \).

F. In the case of "oval" ladles, having a maximum bottom plate diameter not more than 1.4 times the minimum bottom plate diameter (see Figure 2), the foregoing formulas for bottom plate thickness as given in this section may be used by replacing circular bottom plate diameter "D" by an equivalent diameter for the oval ladle, "D_E", determined by the following formula:

\[ D_E = \frac{D_{\text{max}} + D_{\text{min}}}{2} \]
mended practice for these and other similar details shall conform with good practice as recommended by the 1950 ASME Code for Unfired Pressure Vessels, or later edition thereof. Details of welded ladles, or sub-assemblies, and welding symbols shown on drawings, and welding procedure shall conform with latest recommended practice of the American Welding Society.

D. The trunnion pin where it fits in the trunnion plate should not be reduced in diameter for this fit, but may be increased, in which case the fillet should be made to as large a radius as is possible.

E. Trunnion pins, which are press or shrink fitted into the block, shall preferably be installed after the ladle has been stress relieved.

F. If specified by the purchaser, trunnions for open hearth steel teeming ladles shall be provided with steel bushings to take the wear. Also, if specified by the purchaser, the trunnions for ladles which are tilted for pouring shall have oil-less type bronze bushings for 700 F temperature) fixed to the trunnion pin, and cast steel sleeve with collar revolving on the bushing.

G. Safety flanges shall preferably be provided on the end of the trunnion pin to guide the ladle hook into proper engagement.

H. Open hearth ladles shall be provided with a splash plate underneath the slag spouts, to prevent splashing slag from sticking to side plates of the ladle and building up on the stiffening ribs or bands. The plate shall be bolted and arranged to permit removal for inspection of ladle. This plate shall be a close fit around the spout and extend down below the lower rib. Allowance shall be made for expansion of the plate.

I. If so specified by the purchaser, teeming ladles shall be provided with heat protection plates around the pouring nozzle.

J. The ladle is to be stress relieved by uniformly heating in a furnace. The temperature of the furnace, when the ladle is put into it, shall not be over 500 F at start and increased to 1200 F at a rate not exceeding 200 F per hour, then held at that temperature for one hour per inch of thickness of ribs. It shall then be cooled in the furnace at a rate (not exceeding 200 F per hr) to 500 F, before being taken from the furnace.

K. Vent or weep holes will be provided in the bottom of the ladles. Examples of good practice in this regard are 1/2-in. holes on 9-in. centers or 3/4-in. holes on 8-in. centers. Weep holes may be provided on side of ladle, if specified on information sheet.

5. DESIGN STRESSES AND DESIGN ASSUMPTIONS

A. The combined center of gravity of the ladle and the molten metal when full shall be safely below the centerline of the trunnions, and trunnions shall be located at least 65 per cent of the overall vertical height above the lowest point of the shell. If trunnions must be located lower due to crane clearance, trunnions should be provided with lock bars or other means to prevent accidental tilting of the ladle.

B. Formula given in this specification are based on molten metal which has a unit weight of 480 lb per cu ft.

C. The following stresses will not be exceeded in the design of the ladle. These stresses are based on the use of the materials outlined in Section 3 A.

a. In members where the axial stress through the thickness is nearly constant, the stress shall not exceed 8000 psi. (Example: Direct stress in ladle wall or dished bottom).

b. Stresses in members which are subject to bending or combined bending and direct load shall not exceed 16,000 psi. (Example: Stress in stiffener ribs). An exception is the trunnion pin. See Section 5 E.

c. Stresses in members which do not help appreciably in carrying load, but which are secondary stresses or due to stress concentrations at discontinuities shall not exceed 24,000 psi. (Example: Normal stress due to bending at juncture of sidewall and bottom of dished bottom ladles).

D. The maximum allowable shear stress shall be 0.6 times the allowable tensile or compression stress.

E. The maximum normal stress in the trunnion pins due to bending, neglecting stress concentrations in fillets, shall not exceed 8000 psi. The average shear stress in the trunnion pins shall not exceed 2400 psi, computed by dividing the total shear by the area of the pin. (Maximum shear stress will be about double average shear stress in a circular section). In calculating the bending moment in the trunnion pins, the lifting force shall be assumed to act 1 in. in from edge of collar of trunnion pin.

F. The average bearing stress between the trunnion pin and trunnion block in the ladle shell shall be calculated by the following formula:

\[ f_B = \frac{W}{2DR_l} \left(1 + \frac{6e_p}{t_T}\right) \]

(See Figure 1 for notation)

but in no case shall this stress exceed 20,000 psi.

G. The trunnion blocks shall be rigidly connected to the ladle shell through ribs or other stiffening devices. Unit stresses in such connecting devices shall not exceed 16,000 psi.

6. DESIGN OF BOTTOM PLATES OF FLAT BOTTOM LADLES

A. Notation used in this section is shown in Figure 2. Slightly dished ladle bottoms shall be considered as "flat" if the dishing radius "R" (See Figure 3) is more than 10 times the minimum radius "r" of the bottom plate.
1. GENERAL
A. This specification shall be known as Specifications for Design of Hot Metal Ladles, AISE Standard No. 9, and shall cover such open top hot metal ladles of circular or oval cross-section as are used in steel mills for transporting molten metal. Insofar as applicable these specifications may be used in the design of other types of hot metal ladles.

B. These specifications are intended to cover only materials (by reference) and the more important structural design features, such as thickness of sidewalls and bottom, proportions of stiffener rings, etc. Supplementary specifications covering special features may be added by purchaser.

2. WORKMANSHIP, AND INSPECTION
A. Workmanship and material shall be first class in every respect, and subject to the inspection of purchaser’s representative at all times.

3. MATERIALS
A. Materials for the following parts of the ladle shall be in accordance with the latest revision of the following specifications:


(b). Shell plate, stiffener rings, splash plates, trunnion block — ASTM, Specification for Steel for Bridges and Buildings, A-7. If the A-7 steel used exceeds 1-in. and does not exceed 2 1/2-in. thickness, the steel must also meet the requirements of AWS Specification No.D2-0-47 Standard Specification for Welded Highway and Railway Bridges.

If specified on the information sheet, material shall meet the requirements of A-285, grade C firebox quality for thicknesses up to and including 2 in. For thicknesses over 2 in., if specified on the information sheet, the material must meet requirements of specification ASTM A-201, Grade A, flange quality.

(c). Trunnion pin, miscellaneous forged fittings — ASTM, Specification for Carbon Steel Forgings for General Industrial Use, A-235, Class C, normalized or annealed (unless integral part of cast steel trunnion band or pad).


(e). Rivets — ASTM A-31, boiler rivet steel, Grade A.
(f). Lining — As specified on information sheet.

4. DETAILS OF CONSTRUCTION
A. Details of construction not provided for in this specification shall be consistent with good practice in ladle design.

B. The bottom plate may be “flat” or “dished” and shall be flanged around the edge by hot forming with an inside radius not less than 3 and preferably 4 or more times the thickness. Connection to the sidewall shall be either by a full penetration double butt weld or by a lap riveted joint.

C. Openings in the ladle bottom for nozzles shall be fully reinforced by a welded stiffener plate. Recom-
SPECIFICATIONS FOR DESIGN OF HOT METAL LADLES

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