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TESTING HOT METAL LADLES

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SUMMARY

Presented herein are test techniques applied in structural tests of hot-metal ladle models for the Association of Iron and Steel Engineers. Strains were measured with SR-4 Electric Strain Gages, and deflections, by means of deflection dials reading to 1/1000 inch. The loading of the ladle models involved special problems.

INTRODUCTION

Hot-metal ladles are vessels, lined with refractory material, and used for conveying molten metal in the steel mill from the furnace to the ingot mold. The ultimate goal of the investigation of these ladles was the development of rational design procedures. To this end, three typical models in linear scale ratio of 1:5 of 150 ton net capacity prototypes were tested in the Fritz Engineering Laboratory of the Lehigh University Civil Engineering Department. One of these models is shown in Fig. 1. The ladle consists basically of a comparatively thin side shell of the shape of a frustum of a cone, closed with a flat or dished bottom of about the same thickness as the side shell. The side shell is reinforced with stiffener rings at various levels. Two trunnion assemblies distribute the concentrated reactions of the supports acting on the trunnion pins.

Structural variables in the program were as follows:

1. Comparison of riveted and welded construction.
2. Comparison of circular and oval ladle cross section.
3. Comparison of flat and dished bottom shapes.
4. Effect of number and size of reinforcing rings.
5. Effect of size of trunnion assemblies.
6. Structural effect of refractory lining.

Other test variables were:

7. Amount of load.
8. Effect of distance between the two points of support.
9. Effect of angle of tilt about the trunnion pin axis.

The effect of temperature differentials caused by the molten metal was not considered in this investigation.

Radial deflection of the side shell and rein-

Fig. 1. Ladle Model. Height: 30 in. Top Diameter: 30 in. Surfacing for Outside Gages and Drilled Holes for Leads from inside Gages Shown.

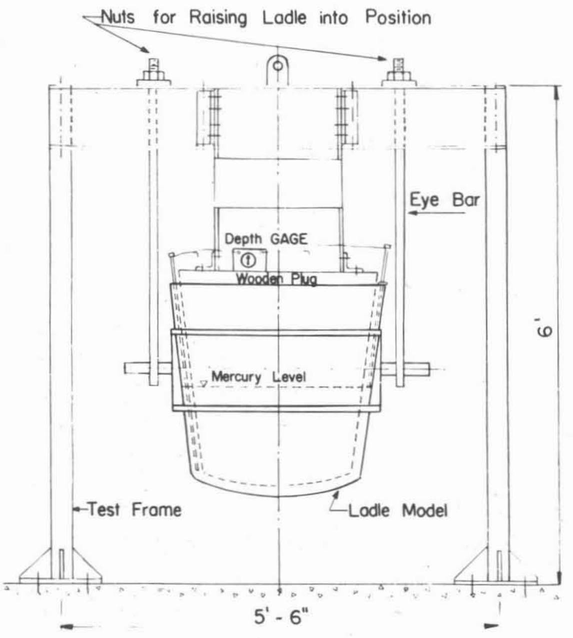

Fig. 2.

LOADING DEVICE

forcing rings, and vertical deflections of the bottom were measured in order to obtain a physical picture of the ladle behavior as a guide towards a design procedure. Strain readings were taken at the outer and inner surface of side shell, bottom, reinforcing rings, and on the trunnion assemblies, for evaluation of stresses and bending moment to be compared with values obtained by analytic stress analyses.

The extensive program of test variables and the large number of measurements in each test called for rapid and dependable test techniques. The total number of single readings during the whole testing program is estimated to be five thousand deflection readings and fourteen thousand strain gage readings.

Some features of the procedures used will be described.

TEST PROCEDURES

Loading Agent

The actual ladles are loaded with molten metal weighing approximately 420 lbs per cubic foot. Since, for the purpose of experimental stress analysis, it is undesirable to load the models in the laboratory with hot liquid metal, some substitute had to be found. Amount of load was one of the test variables. This could be obtained in two ways:

1. By completely filling the ladles with several liquids of different specific gravities.
2. By using different amounts of one particular liquid, in which case the change in load would alter the stress distribution.

As the first of these solutions seemed most satisfactory from a theoretical point of view, the use of several liquids with different specific gravities was proposed: water, carbon tetrachloride, sodium silicate, mercury, etc. Also, granular materials were considered, among which were sand, iron shot, and lead shot.

Serious inconveniences result in the case of some of these loading agents. The granular

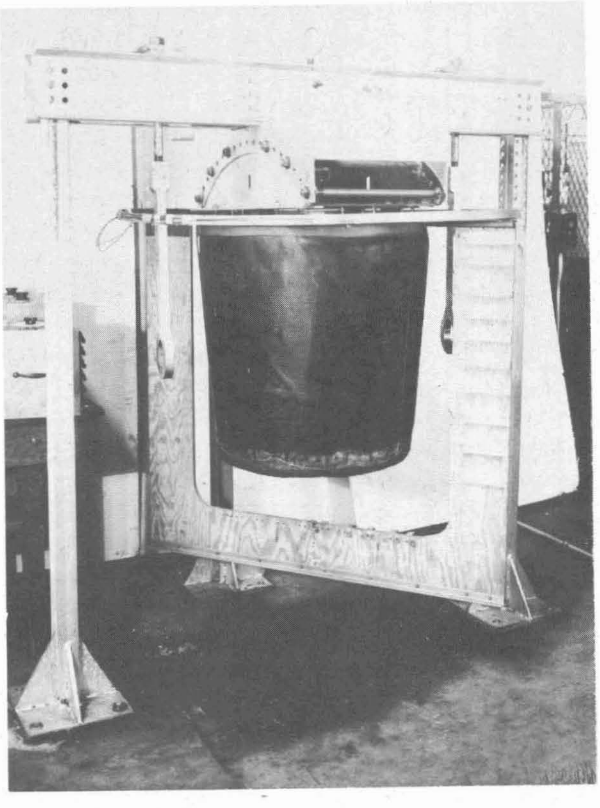

Fig. 3. Test Frame with Wooden Plug and Inflection Bracket.

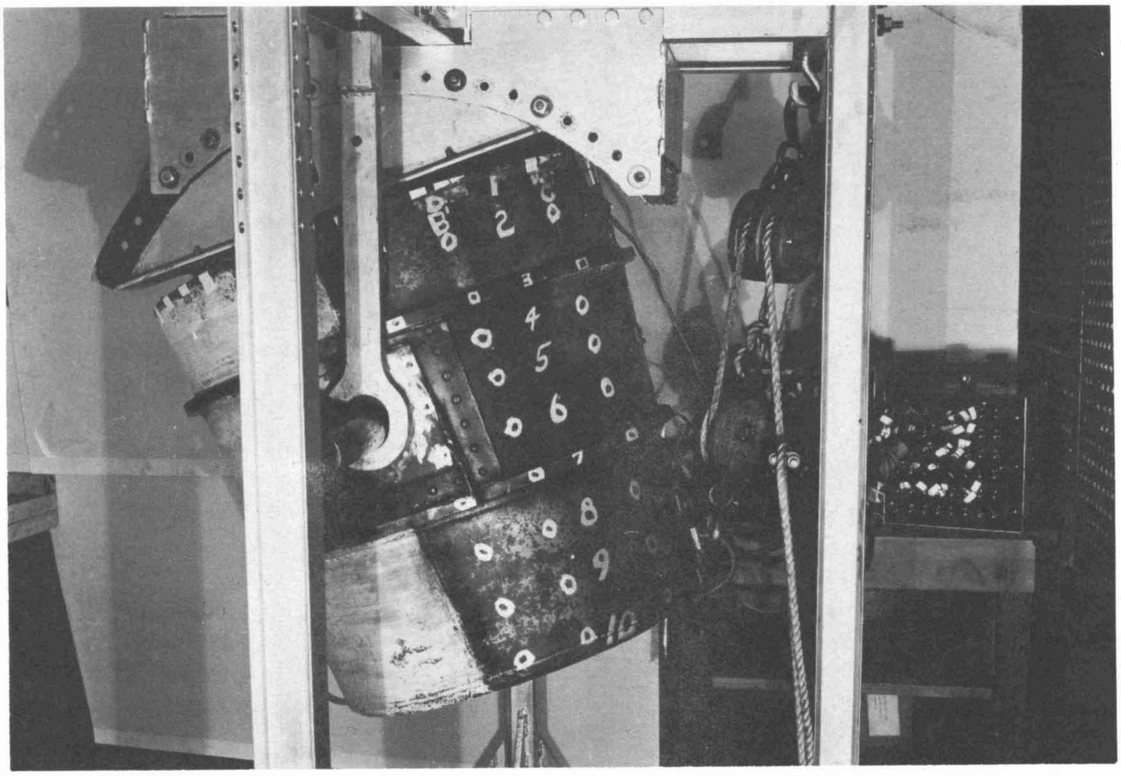

Fig. 4. Arrangement of Tests in Tilted Position.

materials will not truly simulate a fluid. Some of the liquids mentioned are difficult to handle, others are expensive. Mercury was finally chosen as loading agent for all tests, the conditions obtained being according to Case II above. Since some parts of the ladle might reach their maximum stress at less than full load of liquid mercury, steps of approximately 25%, 50%, 75% and 100% of the weight of full load were applied, "full load" referring to an amount of mercury reaching three inches below the lip of the ladle model.

General Test Arrangement

The general test arrangement is shown in Figs. 2 and 3. A supporting frame is erected to carry the specimen during test operation. The usual hooks have been replaced by eye-bars which were movable along the top beam of the frame, providing a means of varying the distance between the supports of the ladle.

The frame also supported a wooden plug covered by a tight fitting rubber casing to prevent leakage of mercury, (Fig. 3). The plug then displaced 93% of the mercury volume otherwise required for full mercury load, yet provided a completely equivalent full load condition at a considerable saving of investment in mercury. Intermediate loads were obtained by lowering the ladle by means of the nuts on top of the eye-bars, or by using a fraction of the mercury volume required for full load. The upward flotation force imposed upon the wooden plug was resisted by the top beam of the test frame.

The volume of the ladle models at all levels was calibrated with water before testing. After multiplying these volumes by the specific gravity of mercury, a graph was plotted of the load as a function of distance between the mercury level and the lip of the ladle. This distance was measured by means of a simple electric depth gage as indicated on the drawing, Fig. 2.

Tests in the tilted position were included in the test program. To this end, the support of the wooden plug was arranged as shown in Fig. 4. A series of bolts designed for the full force

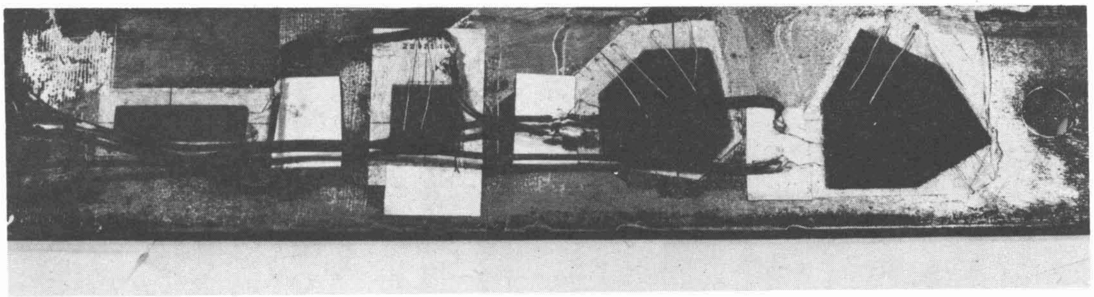

Fig. 5. Compensating Gages, Showing Types of SR-4 Gages Used, Except for Type A-12.

of flotation was placed along the arc of a circle with the radius point on the center line through the trunnion pins. The ladle models were tilted in a manner similar to that normally used in the mills.

Strain Measurements

The strains were obtained by means of SR-4 bonded electric strain gages of the types shown in Fig. 5. The gage locations and the types used are shown in Fig. 6 for one of the ladle models. All of the models were symmetrical about two mutually perpendicular vertical planes. For tests in the normal (not tilted) position, the load was also symmetrical about the same two planes. All four quadrants were assumed to behave identically, and the measurements were taken in only one quadrant. For testing in the tilted position, the loading was symmetrical about one plane only, and measurement in two quadrants were required. To avoid the mounting of gages on more than one quadrant, the stress distribution over one half of the ladle was obtained by tilting the ladle alternately in each of the two possible directions.

On the shell, three way rosette gages of type AR-1 or AR-4 were used. The data obtained from these gages allow the evaluation ofthe principal stresses and their directions. On the planes of symmetry the directions of the principal stresses are known. Type AX-5 two way gages were therefore used at such a location.

On the thin rings, the stress is essentially uni-directional and type A-1 or the narrower A-12 gage was used, depending on the space available.

Strain gages were mounted at identical locations on the outside and the inside of the ladle. The average direct stress (membrane stress) and the bending moment at a gage location could then be evaluated from the skin stresses obtained from a pair of outside and inside

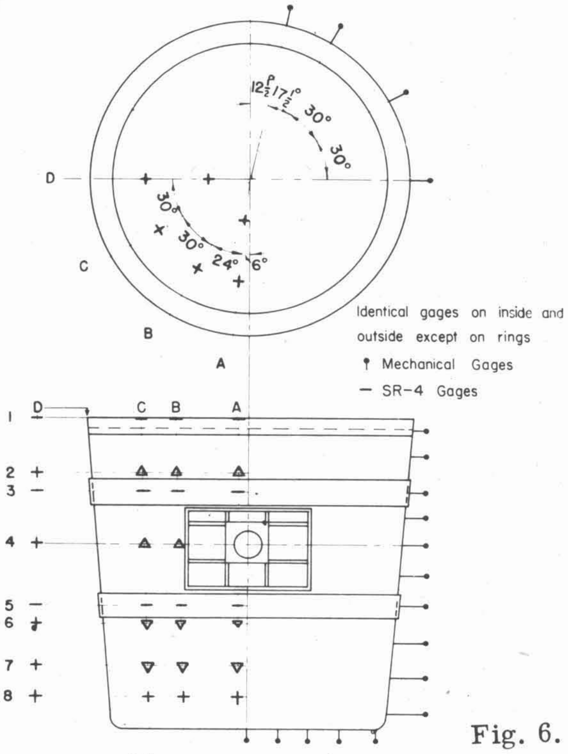

Fig. 6.

LADLE "A". GENERAL GAGE LOCATION

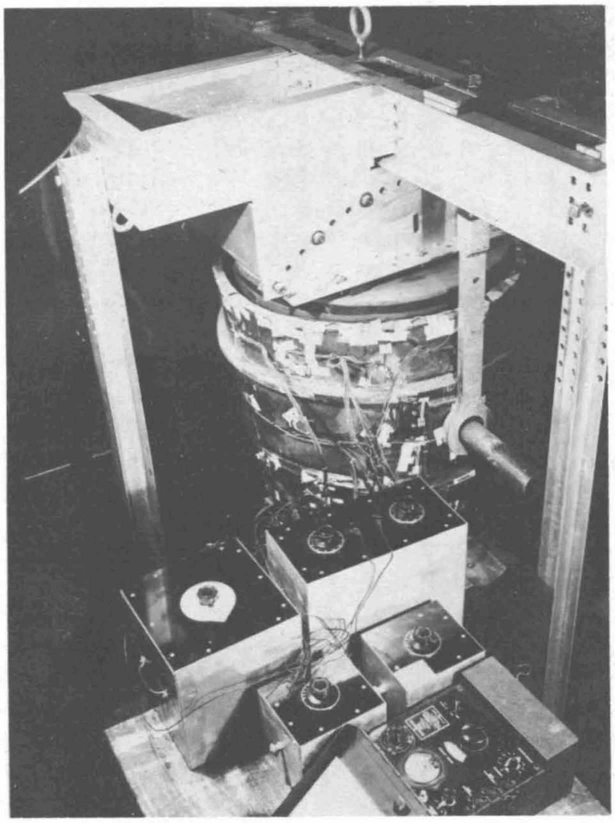

Fig. 7. Set-up for Strain Tests

gages.

The strain readings were measured by means of a Baldwin-Southwark Type K Indicator Box, Fig. 7. It was assumed that the temperature inside and outside the shell was the same. The gage readings before and after loading were taken within as short a time interval as practicable in order to reduce the effect of temperature gradients through the shell to the inside gages. The temperature of the loading agent was checked for each separate test to disclose the existence of such gradients. A brief study of the temperature effect and the reading dependability of the operator indicated an accuracy of ±5 micro-inches with corresponding maximum expected errors in evaluated stress of approximately ±150lbs per sq in.

A system of switch boxes manufactured at the laboratory, Fig. 7, provided rapid and dependable selection of measuring gages and the corresponding compensating gages. The leads from the inside gages were carried through small drilled holes in the ladle shell to the outside, as may be seen in Fig. 1. The inside strain gages were protected against attack from moisture in the clay lining and from possible leakage of mercury or water used for loading or calibration by means of a cover of wax. A detail of a cross section through the ladle and the wooden plug is shown in Fig. 8.

Mohr's Circle as well as numerical methods were used in the calculation of stresses on basis of the measured strains. The horizontal and vertical stress components, the principal stresses, and their directions were computed. It was found that untrained helpers obtained dependable stress values by means of graphical solutions.

Deflection Measurements

The deflection measurements were obtained by means of a series of 1/1000 inch dial gages. As in the case of strain measurements the symmetry of the ladles permitted the measurements to be taken in one quadrant only. The radial side deflections and the vertical bottom

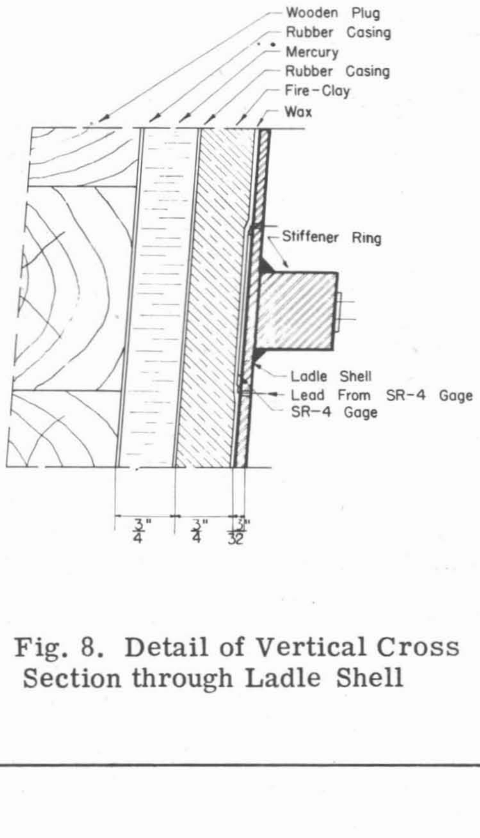

Fig. 8. Detail of Vertical Cross Section through Ladle Shell

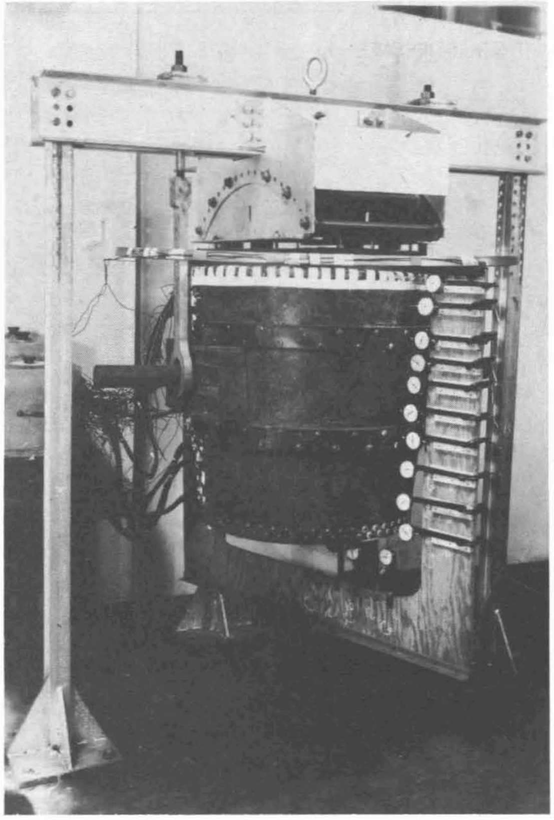

Fig. 9. Set-up for Deflection Tests.

deflections were obtained at locations as indicated in Fig. 6. The points shown fall in four radial planes located 12.5°, 30°, 60°, and 90° from the vertical section through the trunnions, respectively. The test set-up did not allow deflection measurements at 0° due to interference with the trunnion pins. Deflections were measured at ten levels along the side, including the points on the stiffener rings, and at five points along the bottom radii.

The test set-up for deflection tests is shown in Fig. 9. It would be desirable, but inconvenient, to refer the deflection readings directly to some immovable dial gage support. During the tests the dials were supported by a fairly rigid plywood bracket, which rested on radially orientated knife-edges fitting in slots on the lip of the ladle. The bracket was further secured against any horizontal motion at the center point of the ladle bottom, in a way allowing the measurement of the vertical deflection at that point. Thus, the bracket was supported at three points, restraining it to stay in a radial plane during the test. It is seen that the vertical bottom deflections obtained are relative to the lip ring on which the deflection bracket rests, and also that some freedom is left for the bracket to move and deform in its own plane. Some corrections to the readings were therefore required as described below.

The basic readings were taken on the dials shown in Fig. 9, while a few control dials on the opposite leg of the bracket unveiled possible shifting-over of the bracket in its own plane by sliding on the knife-edges. The lip of the ladle deflects horizontally during loading. The bracket, resting on the lip, will tend to deform in the direction of this deflection due to friction between the knife-edge supports and the slots on the lip of the ladle. This effect was minimized by attaching an aluminum ring to the two legs of the bracket, as shown in Fig. 9. On this ring were mounted two electric strain gages at points 90° apart. Any change in the distance between the two top points of the bracket would change the shape of the ring, thus causing measurable strains at the gage points.

The set-up as described furnished the data required for the four types of corrections which were applied to the basic deflection readings. The first compensates for the shifting of the bracket in its own plane during loading, as mentioned above. The readings on the control dials were made equal to the readings on the corresponding dials on the measuring side by readjusting the bracket, thus sharing the total horizontal changes of the top and bottom ladle diameters equally between the two sides.

The second correction eliminates errors due to change in shape of the plywood bracket and applies to the side deflections only. The readings from the two SR-4 gages on the aluminum ring attached to the top of the bracket yield, as mentioned, a means of evaluating the change in distance between the two top points of the bracket. As this change was only a few thousandths of one inch, the correction was linearly reduced from the value at the lip ring to zero at the bottom of the bracket, thus neglecting bending curvature of the vertical members of the bracket.

The third correction to the deflection readings applies to the bottom plate only. From the deflection diagram Fig. 11 it is seen that the side deflection is essentially a rotation around

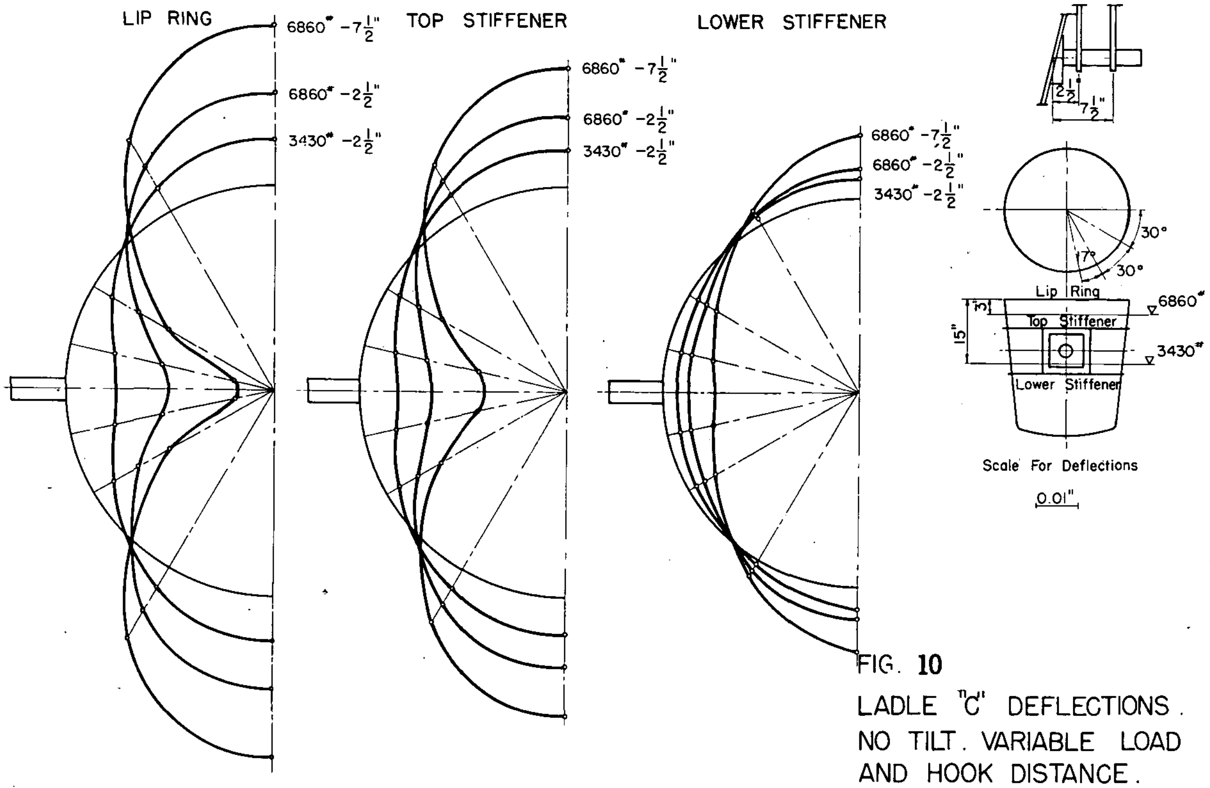

FIG. 10

LADLE "C" DEFLECTIONS. NO TILT. VARIABLE LOAD AND HOOK DISTANCE.

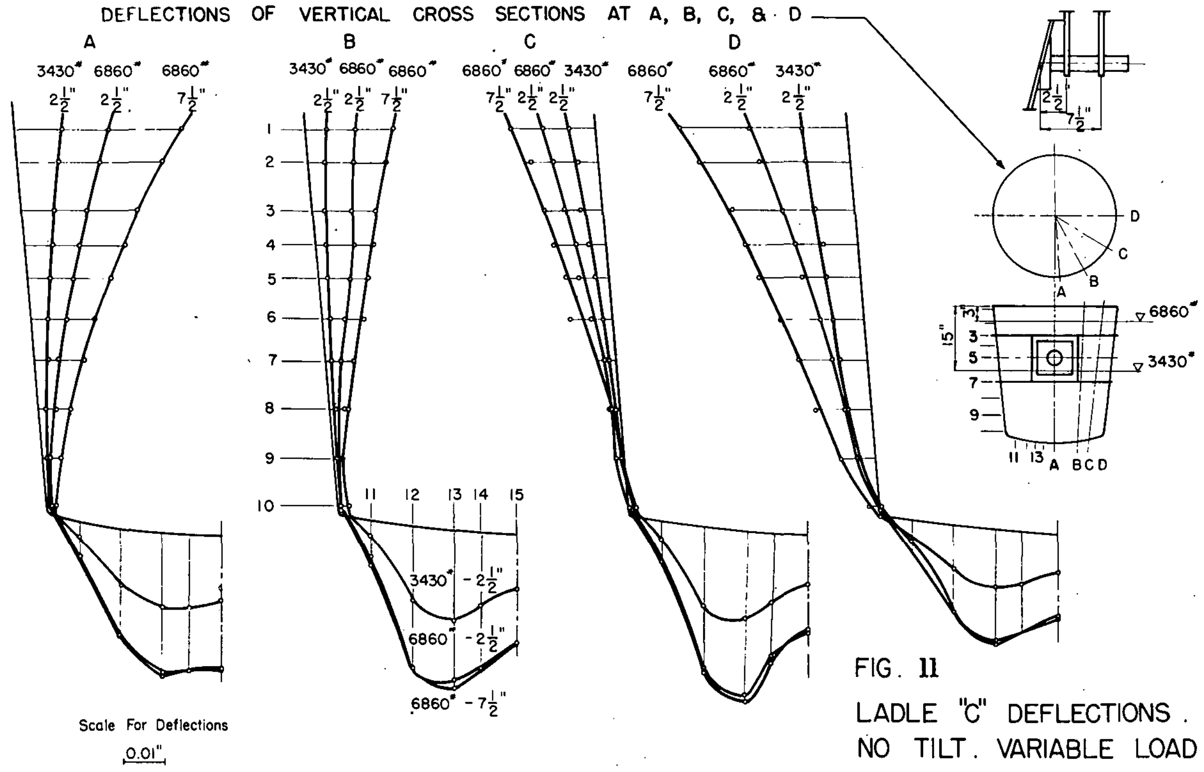

FIG. 11

LADLE "C" DEFLECTIONS. NO TILT. VARIABLE LOAD AND HOOK DISTANCE.

the joint of the ladle side and bottom. Due to the 1:12 slope of the side, a horizontal lip deflection will be accompanied by a vertical component equal to one twelfth of the horizontal deflection. The plywood bracket, resting on the lip ring, follows this vertical movement, which causes an error in the corresponding bottom deflection readings. The latter are therefore all corrected by 1/12 of the horizontal lip deflection, the sign of the correction depending on the direction of the lip deflection.

Finally, the air temperature was checked during all deflection tests, and corrections applied to the readings for over-all expansion or contraction of the ladle.

The lip ring also shows an additional vertical deflection as may be expected by regarding the ladle as a simple beam between the trunnion supports. This deflection will show up as a difference in recorded deflection of the bottom center point when recorded with the bracket resting on different points on the lip ring. The lip ring was chosen as reference line for the deflections, and therefore no corrections applied to the deflection data for this effect, which in most of the tests was small.

Whitewash

One quadrant of the ladle was painted with slaked lime whitewash before testing to give a warning as to appreciable yielding of any part of the ladle during loading. No such yielding was observed.

TEST RESULTS

A representative example of the result of the deflection test is shown in Figs. 10 and 11. The figures are believed to be self-explanatory. A report published by the Association of Iron and Steel Engineers* gives complete test results and compares these with semi-empirical procedures of analysis and design.

ACKNOWLEDGEMENT

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*"Stresses in Hot-Metal Ladles", by Knud-Edre Knudsen, William Munse, and Bruce G. Johnston, Iron and Steel Engineer, Vol. XXVI, No. XII, December, 1949, pp 49 - 70.