NAVY DEPARTMENT
THE DAVID W. TAYLOR MODEL BASIN
WASHINGTON 7, D.C.

PRESSURE TANK AND INSTRUMENTATION FACILITIES FOR
STUDYING THE STRENGTH OF VESSELS SUBJECTED
TO EXTERNAL HYDROSTATIC LOADING

by

E. E. Johnson

RESEARCH AND DEVELOPMENT REPORT

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Report 979
From: Commanding Officer and Director  
To: Chief, Bureau of Ships (Code 312)  

Subj: Facilities for studying structures under hydrostatic loading  

Encl: (1) TMB Report 979 entitled "Pressure Tank and Instrumentation Facilities for Studying the Strength of Vessels Subjected to External Hydrostatic Loading." 13 copies  

1. Enclosure (1) describes the large test tank installed at the Taylor Model Basin for studying pressure vessels under external hydrostatic loading. The tank, which is 8 ft in diameter and 15 ft long, has a special closure system which permits rapid installation and removal of the model as well as visual observation of, and access to the interior of models during a test. Also described in enclosure (1) is a deflection-measuring device by which initial departures from true circularity and radial deflections of the model with application of pressure can be measured.

E. WENK, JR.
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PRESSURE TANK AND INSTRUMENTATION FACILITIES FOR STUDYING THE STRENGTH OF VESSELS SUBJECTED TO EXTERNAL HYDROSTATIC LOADING

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ABSTRACT

In the investigation of the strength of submarine pressure hulls, models are tested to verify the structural performance of a specific new structure and to corroborate general equations used in design. In this paper there is described a new pressure tank at the Taylor Model Basin for studying pressure vessels under external hydrostatic loading. The tank is 8 ft in diameter and 15 ft long. The model is installed so that its interior is accessible at all times for installation of strain and deflection-measuring instruments and for inspection of damage. The closure system of the tank permits rapid installation and removal of the model.

Also described is a deflection-measuring device by which initial departures from true circularity and radial deflections of the model with application of pressure can be measured. This instrument consists of a linear potentiometer attached to a shaft seated in the model. Rotation of the shaft provides for measurements at any desired angular orientation. Radial motion of the probe of the potentiometer is recorded by a proportional linear pen motion which can be magnified up to 50 times the motion of the probe. Records are made on a large disk which rotates in synchronism with the shaft so that a continuous plot is obtained on polar coordinates of the initial departures from circularity and of the radial deflections under pressure.

INTRODUCTION

The Navy's interest in hydrostatic pressurized tanks naturally stems mainly from its interest in submarines. The submarine as a whole is a very complex structure, and an exact analysis of it is impossible. In the process of analyzing the strength of a submarine it is necessary to consider all possible modes of failure. Fig. 1 shows diagrammatically the different things that might happen: (1) snap thru buckling of the dished heads, (2) instability at the conical shell, (3) failure at the joint of the cylindrical and conical shells, (4) failure of the stiffened cylinder itself by any of three modes - yielding, shell buckling, or general instability of shell and frames between bulkheads, (5) actual rupture due to stress concentrations around openings or in way of other hard spots, and finally (6) dynamic effects resulting from enemy attack.

Fig. 2 shows a collapsed stiffened cylinder that has failed by shell buckling between frames. Although this mode of failure has probably been studied at greater length than any of the others, agreement between theory and experiment leaves much to be desired. Therefore becomes rather obvious that the design of the whole submarine, particular where radical departures from previous designs are involved, must rely heavily on hydrostatic tests of structural models until all possible modes of submarine structural failure have been adequately studied under extensive research programs.

Prior to 1951 the largest pressure tank at the Taylor Model Basin had an internal diameter of 37½ ft. and necessitated the testing of very small scale models of proposed sub
FIG. 1. POSSIBLE MODES OF SUBMARINE PRESSURE HULL FAILURE.

FIG. 2. COLLAPSED MODEL WHICH HAS FAILED BY SHELL BUCKLING.
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Due to the limited size of the models, many important details of the prototype could not be faithfully reproduced. Particularly, it was impractical to reproduce welds to scale. Further, it was anticipated that with the many new uses which were being assigned to submarines, more unusual and complicated structural details would be required. The degree to which these structural details could be reproduced would, of course, depend on the size of the model which could be tested. In view of these considerations, it was believed highly desirable to construct a tank which could be used to test larger scale models. This paper describes an 8-foot diameter tank for testing structural models under hydrostatic pressure and a deflectometer for measuring and recording on polar coordinates the initial circularity of a model and the radial deflections caused by the application of hydrostatic pressure.

TANK DESIGN CONSIDERATIONS

The design of the 8 ft tank was influenced by the following considerations:
(a) Size of models to be accommodated,
(b) Operating pressure,
(c) Simplicity of operation,
(d) Cost of material and fabrication.

It was considered that the size of the new facility should permit the testing of approximately 1-scale models of sections of usual fleet-type submarines. It was also desirable.
that the new tank be sufficiently long to accommodate a length of model equivalent to a full section between bulkheads.

The operating pressure of the tank should be greater than the pressure equivalent to the collapse depth of the usual submarine in order that the tank could be used for basic research studies as well as for tests of proposed submarine designs.

In order to provide for maximum utility of the tank many unique features were incorporated in its design. It was desirable to provide a closure system of the tank which would permit rapid installation and removal of the models. Also it was deemed necessary that the interior of the model be accessible throughout the test. This would make possible the inspection of models for signs of incipient failure as well as facilitating the measurement of shell and frame deflections. In order to save floor space and simplify the installation of models with existing crane facilities it was decided to install the tank in a vertical position.

In order to fabricate the tank at a minimum cost available surplus material was used wherever possible.

**DESCRIPTION OF TANK**

The test tank finally developed is shown schematically in Fig. 3. It consists essentially of a cylinder 8 ft in diameter with ellipsoidal heads on each end. The top head, which is removable, has an opening to permit access to the interior of the model under test for visual inspection and for deflection measurements throughout the test. The removable head is attached to the main body of the tank by a clamping ring made in four circular segments, which are bolted together to seal up the tank. This clamping ring is provided with a machined groove whose top and bottom surfaces have a $2\frac{1}{2}$-degree taper which mates with circular projections on the main body of the tank and on the head. The dimensions of the groove and the circular projections are such that...
when the clamping ring is bolted together the head is brought to bear tightly against the tank body. The actual liquid seal is provided by an "O" ring.

The cylindrical portion of the tank was made from the salvaged conning tower of a submarine. This cylinder is 1 in. thick and 8 ft in outside diameter; it is made of high strength alloy steel equivalent to SAE 3325 steel. This material has a minimum specified ultimate strength of 115,000 psi and a minimum specified yield strength of 100,000 psi. The dished heads were also made of this material. However, the heavy circular members at the head-tank juncture and the clamping ring were made of high tensile steel having a minimum specified yield strength of 42,000 psi and an ultimate strength of 85,000 psi.

The main body of the tank is mounted vertically in the Laboratory Building. It rests on bitumastic compound which lines a hole in the rock bed of the basement floor. It extends through the first floor of the laboratory a distance of about a foot. This facilitates installation of the models in the tank and makes it possible to support the segments of the clamping ring on rollers so that they can be readily moved about when assembling or disassembling the tank.

The models are welded to an adapter which is brought to bear against the flat-bar reinforcement around the opening in the head by bolting. Bolts required here are relatively light as upon application of pressure the end thrust on the model holds the adapter firmly against the reinforcing ring. Fig. 4 shows a model welded to the adapter ready for lowering into the tank. An "O" ring provides the liquid seal.

Oil pumped in from underground storage tanks serves as the pressure medium. Oil is used as the pressure medium to overcome the difficulty of waterproofing SR-4 strain gages. Pressure is applied by means of a motor-driven pump.

Fig. 5 shows the head being lowered onto
he main body of the tank. The disassembled segments of the clamping ring supported on their rollers can also be seen. Fig. 6 shows the tank sealed with the deflectometer in place and the recorder connected.

The tank was designed at the Model Basin and fabricated by the Portsmouth Naval Shipyard.

EXPERIMENTAL DETERMINATION OF TANK STRESSES

For economy reasons this tank was designed around available material as far as possible. This necessitated working with very small safety factors. It was therefore considered advisable upon initial pressurizing of the tank that the strains at various critical areas be observed. Fig. 7 shows stresses deduced from measured strains at critical regions in the head of the tank for a pressure of 900 psi. It can be noted that even at this pressure a stress of 57,000 psi was observed in the skirt of the head. This is one-half of the ultimate strength of the head material.

Because of the relatively large opening in the head it was feared that stresses around the opening might be large. In addition to the flat-bar reinforcement, a tapered insert was provided around the opening. It will be noted that stresses deduced from measured strains around the opening were moderate and the reinforcing was adequate.

The maximum stress in the heavy H.T.S. portion which engages in the clamping ring, deduced from strain measurements, was 34,000 psi.

CIRCULARITY-MEASURING DEFLECTOMETER

It is a well-known fact that the collapsing strength of stiffened circular cylinders under external pressure is adversely affected by departures from perfect circularity, or out-of-roundness. Any interpretation of model results therefore requires an accurate determination of the initial circularity of the model under test. Furthermore, measurements of inward deflection of frames and shell under pressure serve to give a measure of the average strains in these components as well as to
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Eight Foot Pressure Tank
Figures shown are the Computed Fiber Stresses in pounds per square inch at an Internal Hydrostatic Pressure at 900 ps.

\[ +42,500 (L) \]
\[ +20,700 (C) \]
\[ +57,600 (L) \]
\[ +34,600 (C) \]
\[ +34,200 (L) \]
\[ +29,300 (C) \]
\[ +33,300 (L) \]
\[ +27,700 (C) \]
\[ +40,300 (C) \]
\[ +3,600 (L) \]
\[ +7,500 (C) \]
\[ +9,800 (L) \]
\[ +18,650 (C) \]

**Fig. 7. Stresses measured at critical regions during first pressurizing of tank.**

indicate where the model is most apt to fail. It was therefore considered desirable to provide an instrument which would measure circularity of the model under no load and during the application of pressure.

Fig. 8 shows the major components of the deflectometer. They consist of:

(a) The tripod, which rests in a fixed position on the head of the pressure tank,
(b) A shaft which turns in a bushing at the center of the tripod and rests in a tapered roller bearing at the lower end of the shaft,
(c) A detachable probe,
(d) The recorder turntable which rotates in synchronism with the shaft, and
(e) The pen and its driving mechanism.

Fig. 9 shows the deflectometer mounted in the test tank. Set screws are provided at the tripod and at the bottom of the model for centering the shaft in the model. Centering of the shaft is accomplished by taking circularity measurements at a station near the bottom and one near the top of the model and making adjustments until the records for these two stations appear most nearly circular. The shaft is driven by a 230-V d-c variable speed reduction-gear motor through a worm and wheel gear. The shaft can be rotated at speeds from 0.5 to 1.5 rpm.

The probe carrier is keyed to the shaft and consequently turns with it. It can be moved vertically along the shaft to permit positioning of the probe at various elevations during the test. A graduated tape is used to measure these elevations. One end of the tape is secured to the carrier and the remaining portion of the tape is run over a wheel, the axis of which is fixed with respect to the shaft. Vertical probe positions may then be read from the metal tape. The free or loose end of the tape hangs in the tank and is weighted so as to remain taut.

The probe consists of a linear potentiometer attached to the probe carrier and a probe shaft which actuates the potentiometer. The probe shaft is spring-loaded to hold it against the shell and a small wheel on the end of the shaft provides minimum friction as the probe travels around the inside of the shell. Provision is made for checking the operation of and calibrating the electrical system at any time during a test. Through a pulley system oper-
From outside the tank, the probe can be pulled back against a stop fixed with respect to the probe housing, to check the absolute zero of the instrument. A second pulley system permits the insertion of a machined shim between the stop and probe to provide a calibration step of 0.04 inch.

Figure 10 is a diagrammatic sketch showing how the deflectometer recording system operates. As the probe traverses around the inside of the shell, any departures from true circularity cause relative motion between the probe and probe housing and actuate a commercial linear potentiometer inside the housing. The linear potentiometer forms part of the bridge circuit. The bridge is powered by a 50-V d-c power supply as shown. This is a null system and is actually a modified Leeds and Northrup recorder. Normally there is no difference of potential between points A and B. Upon displacement of the probe, an unbalance is set up between points A and B. This voltage is fed into a servo-amplifier which, in turn, operates a servo motor mechanically connected to both a balancing heliotor and the recording pen. The circuit is designed so as to rebalance the bridge automatically. Meanwhile this rebalancing moves the recording pen radially along the chart, an amount proportional to the motion of the probe.

The recording mechanism can be adjusted to indicate magnifications of 5, 10, 25, or 50 times the initial out-of-roundness of the cylindrical shell being tested. For example, if a magnification factor of 50 is used during a test and a 1.0-in. radial displacement is recorded on the circularity chart, then the radial displacement in the model at the corresponding point was 0.02 in. Probes with a maximum travel of 1 in. and 4 in. are provided. Since with full magnification 1 in. travel of the probe is equivalent to 50 inches on the chart, provision is made to introduce additional resistances in the bridge circuit to serve as zero balances. The probes have a resolution of one-half mil.

The chart on which circularity is recorded is carried on a turntable, which is locked electrically to the deflectometer shaft. A synchro transmitter is geared to the shaft, and a synchro repeater is geared to the turntable. The synchros are so connected that the turntable
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FIG. 9. DEFLECTOMETER INSTALLED IN TANK.

FIG. 10. SCHEMATIC DIAGRAM OF DEFLECTOMETER AND RECORDER CIRCUIT AND METHOD OF OPERATION.
turns opposite in direction to the shaft, thus the trace drawn as the probe traverses the inside of the shell is an actual plan view of the out-of-roundness of the shell.

**SAMPLE CIRCULARITY RECORDS**

Fig. 11 shows a sample circularity chart. From such a plot it is possible to obtain the initial out-of-roundness of the model and, by measuring the changes in radius with each pressure increment, to determine the deflection of the model under pressure. The model used to obtain the plot in Fig. 11 was reasonably circular. The high magnification used in recording deflections causes the large changes in curvature at zero pressure evident in this figure. Since a continuous record of the contour of the model is obtained, this makes it possible to make a careful study of the effects of out-of-roundness on the strength of stiffened cylindrical shells, and such studies are now underway at the Model Basin.

**CONCLUSION**

In conclusion it may be said that this tank has proven entirely successful. The time required to install a model and close up the tank is about two hours. While more extravagant designs could be evolved that would possibly permit more rapid opening and closing of the tank, emphasis was placed on cost when constructing this tank. The tank, exclusive of the deflectometer, was fabricated and installed at the Model Basin for a total cost of about $15,000.

**ACKNOWLEDGEMENTS**

The design of this facility was a joint effort of several personnel of the David Taylor Model Basin. Dr. E. Wenk, Jr. was particularly helpful in the design of both the tank and deflectometer as was Mr. P. Lofgren. Messrs. W.S. Campbell and R. Tuckerman contributed much to the design of the deflectometer.
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