



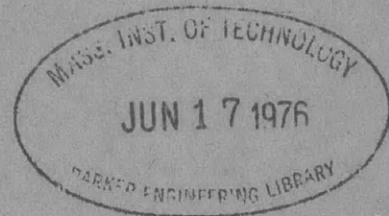
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NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D. C.

THE REDUCTION IN BUOYANCY OF VARIOUS MATERIALS
WHEN SUBMERGED DEEPLY IN WATER

by



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THE REDUCTION IN BUOYANCY OF VARIOUS MATERIALS WHEN SUBMERGED DEEPLY IN WATER

ABSTRACT

Experiments were conducted in a pressure chamber on specimens of balsa, white pine, cork, and "Foamglas," to determine the amount of buoyancy lost by these materials at various depths up to 150 feet under water.

It was found that balsa wood sheathed in brass and Foamglas were the best buoyant materials for operation at great depths under water.

INTRODUCTION

In connection with the development of a towed underwater device at the David Taylor Model Basin, it was necessary to obtain information on the behavior of various types of buoyant materials when submerged in sea water at depths up to and including 150 feet. Tests of this kind had been made in the past but the data could not be found. It was believed that no previous tests had been carried to such great depths.

It should be kept in mind that these experiments were conducted to obtain information for a specific production development. In any thorough systematic investigation of this problem, several specimens of each type of material, as well as different shapes and sizes of specimens, should be tested to obtain average values.

It was desired to obtain the following specific information for certain selected materials:

1. The decrease in volume and the resultant decrease in buoyancy due to pressures ranging from atmospheric to a pressure equivalent to 150 feet of sea water.
2. Structural failures, if any, of the materials when subjected to these pressures.

MATERIALS TESTED

Six blocks of buoyant materials, each 1/2 cubic foot in volume, were tested. They are described and identified in Table 1 and in Figure 1.

TEST APPARATUS

The pressure chamber at the Experimental Diving Unit, Navy Yard, Washington, D.C., in which the specimens were tested, is cylindrical in shape, with a length of approximately 7 feet and an inside diameter of approximately 6 feet. The pressure is increased as required by pumping in compressed air.

A tub of fresh water 36 inches high by 23 inches in diameter was placed inside the pressure chamber. Each specimen was ballasted in this tub of water with enough weight to make it sink. This weight was attached to the bottom of the block by a line. Another line, attached to the top of the test specimen, was led over a

TABLE 1

Structure and Composition of Specimens

Specimen	Dimensions inches	Construction	Material
1	6 x 6 x 24	Laminated; built up of four 1 1/2-inch pieces glued together	White pine, with two coats of linseed oil brushed on
2	6 x 6 x 24	Laminated; built up of three 1 3/4-inch pieces and one 3/4-inch piece glued together	Balsa wood, with two coats of linseed oil brushed on
3	6 x 6 x 24	Laminated; built up of three 1 3/4-inch pieces and one 3/4-inch piece glued together	Balsa wood, with two coats of paraffin, applied by dipping
4	4 x 12 x 18	Two slabs, each 2 x 12 x 18, tied closely together with string	"Foamglas." This is a patented product manufactured by the Pittsburgh Corning Corporation. It is a true glass which has been cellulated by the evolution of internal gas at a high temperature. Its outstanding characteristics are light weight, 10 to 11 pounds per cubic foot, and low water absorption.
5	6 x 6 x 24	Laminated; built up of 1/2-inch slabs glued together	Compressed cork sheathed with 0.017-inch-thick sheet brass, soldered watertight.
6	6 x 6 x 24	Laminated; built up of three 1 3/4-inch pieces and one 3/4-inch piece glued together	Balsa wood sheathed with 0.017-inch-thick sheet brass, soldered watertight.

frictionless pulley to a scale pan carrying balancing weights, in the case of Specimen 1, and directly to a calibrated 20-pound spring scale, in the case of Specimens 2 to 6 inclusive; see Figure 2.

TEST PROCEDURE

The spring-scale method was adopted after Specimen 1 had been tested, because it was found that the readings could be taken by this means with greater convenience and in much less time. In the weight-balance method, it was necessary for a man to be inside the chamber under pressure for an extended period, because each time a reading was taken, it was necessary to bring the system into balance by adding or removing weights. Due to the long time the man performing this operation was under pressure, the decompression time was correspondingly long, and the overall time for the test on Specimen 1 was well over an hour.

By substituting the spring scale, the man had only to take an instantaneous scale reading at any specific time. With this method, each test was run off in about 15 minutes, and the results were more accurate.

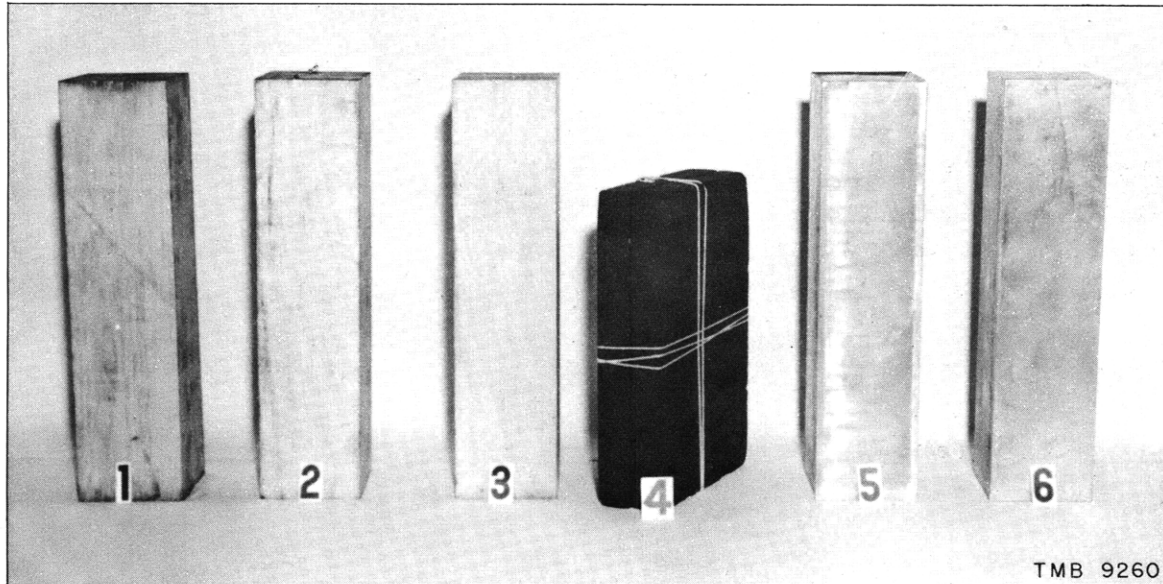


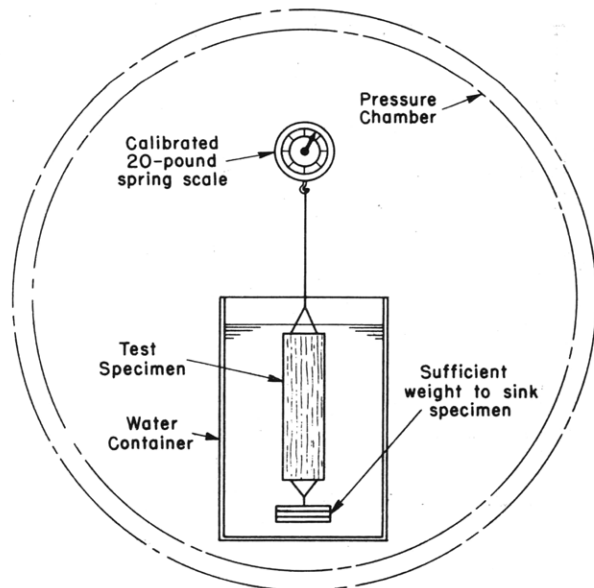
Figure 1 - Buoyant Materials after Test

This photograph shows the 6 buoyant specimens after they had been submerged under water and subjected to a pressure of 150 feet of sea water. From left to right, they are:

1. White pine, coated with linseed oil.
2. Balsa wood, coated with linseed oil.
3. Balsa wood, coated with paraffin.
4. Foamglas.
5. Compressed cork, sheathed with thin sheet brass.
6. Balsa wood, sheathed with thin sheet brass.

Figure 2 - Set-up for Buoyancy Tests
in the Pressure Chamber at the
Washington Navy Yard

Sufficient weight was suspended under the buoyant specimen to sink it under water. As the pressure was increased, the specimen was compressed, with a resultant loss of buoyancy. The amount of this lost buoyancy was measured on the spring scale.



The following procedure was used in making the tests. The amount of weight tied to the bottom of the specimen to sink it was recorded, as well as the reading on the spring scale for atmospheric pressure. With a diver inside, the chamber was closed, the pressure head was increased to the equivalent of 20 feet of sea water, and the reading on the spring-scale was recorded. From then on the pressure was increased to 150 feet of sea water, and readings were taken at every 20 feet. Each specimen was tested separately.

Immediately after the tests, the specimens were reweighed in air to obtain the weight of water absorbed during the experiments.

The test at atmospheric pressure was repeated 24 hours later to determine the permanent decrease in volume, if any.

TEST RESULTS

The schematic diagram, Figure 3, shows the relations used in computing the loss of lifting force of each of the specimens.

The curves in Figure 4 show the percentage loss of lifting force of the materials tested, at pressures ranging from atmospheric to 150 feet of sea water.

The results of the tests are summarized in Table 2.

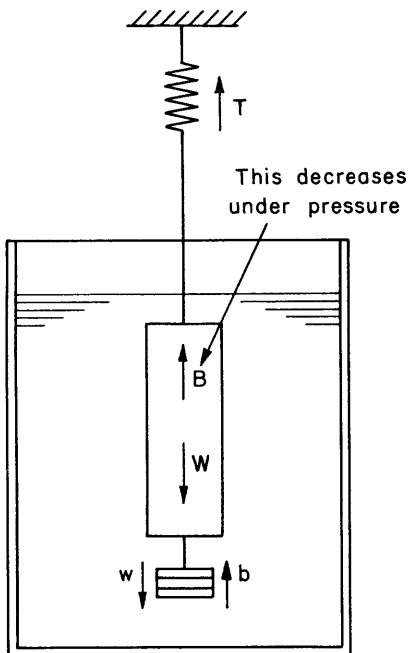


Figure 3 - Schematic Diagram to Show Method Used in Computing Loss of Lifting Force

T is the spring-scale tension
 B is the buoyancy of specimen
 W is the weight of specimen, in air
 w is the weight in air used to sink specimen
 b is the buoyancy of weights

$$W + w = T + B + b$$

$$B - W = w - T - b$$

$B - W$ is the lifting force

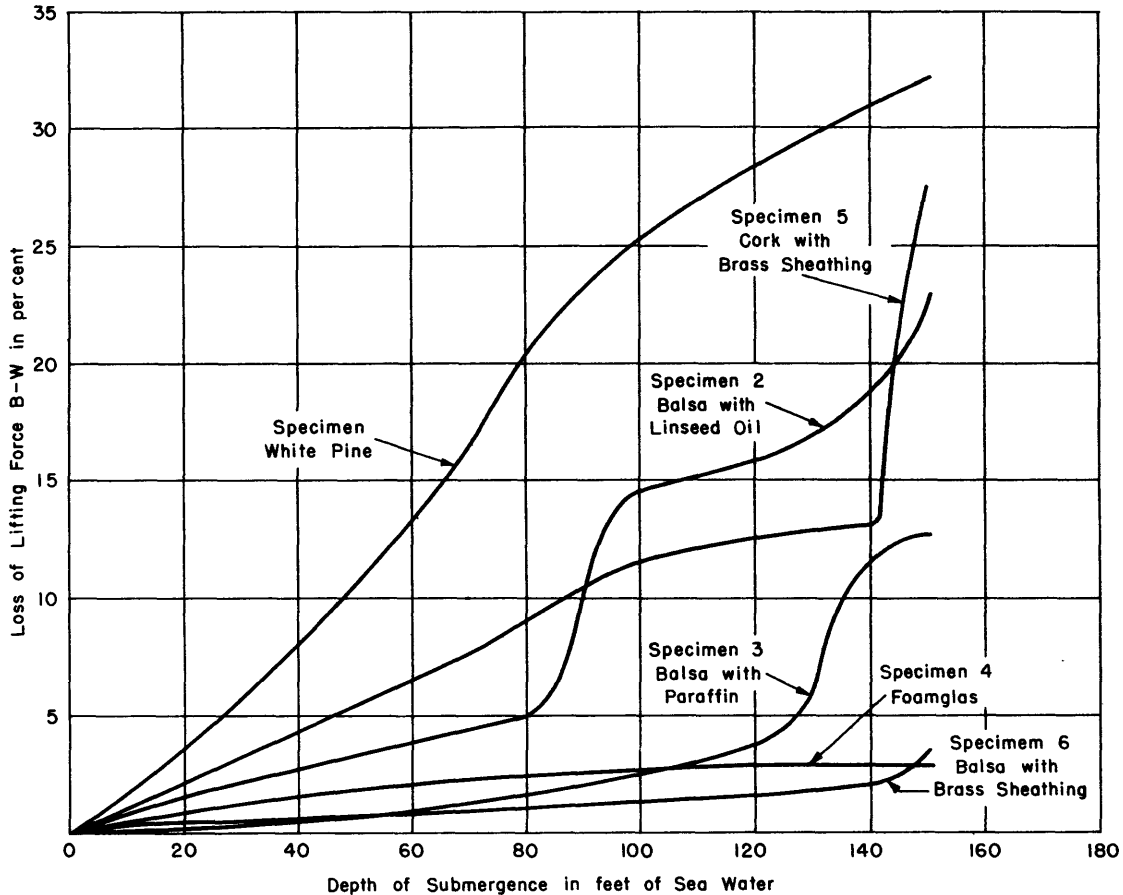


Figure 4 - Comparative Curves of Loss in Lifting Force Plotted on Depth of Submergence for All Specimens Tested

DISCUSSION OF TEST DATA

The results on Specimens 1, 2, and 3, which were non-watertight, mean relatively little insofar as determining the decrease in volume due to the increased pressure. Although these three specimens were well coated with either linseed oil or paraffin, the coating materials did not effectively keep out the water under pressure, and, as a result, the decrease in lifting force as shown on the curves in Figure 4 necessarily includes the increase in weight due to a considerable absorption of water.

In Table 2, the overall decrease in volume due to the pressure only was estimated by taking into account the weight of water absorbed. However, owing to the fact that water absorption is dependent, among other things, upon the time of immersion, it is felt that the results of the tests on Specimens 1, 2, and 3 should not be relied upon to the same degree as the tests on Specimens 3, 4, and 5, which were watertight. The loss of volume of Specimen 1 was not estimated, owing to the fact that the water absorbed could not be measured accurately.

TABLE 2
Summary and Reduction of Test Data

	Units	Specimen					
		1	2	3	4	5	6
		White Pine, Linseed Oil Coating	Balsa Wood, Linseed Oil Coating	Balsa Wood, Paraffin Coating	Foamglas	Cork, Brass Sheathing	Balsa Wood, Brass Sheathing
Weight in air before test, W	pounds	14.10	3.80	4.10	5.13	13.28	7.66
Scale reading at atmospheric pressure, T	pounds	0.10	0.625	0.81	1.31	3.50	0.375
Weight in air used to sink specimen, w	pounds	19.20	30.625	31.31	29.00	25.00	27.50
Computed buoyancy of brass weights used, b	pounds	2.26	3.61	3.80	3.52	3.03	3.34
Lifting force of specimen at atmospheric pressure, $B - W = w - T - b$	pounds	16.84	26.39	26.70	24.17	18.47	23.78
Weight in air after submergence in water under pressure, including weight of water absorbed, W_p	pounds	16.40	5.896	4.58	5.50	13.28	7.66
Scale reading at 150-foot pressure, T_p	pounds	5.50	6.50	4.25	2.00	8.56	1.156
Lifting force of specimen at 150-foot pressure, $B_p - W_p = w - T_p - b$	pounds	11.44	20.52	23.26	23.48	13.41	23.00
$\frac{B_p - W_p}{B - W}$	per cent	68.0	77.5	87.4	97.2	72.5	96.7
Percentage loss of lifting force	per cent	32.0	22.5	12.6	2.8	27.5	3.3
Percentage loss of volume at 150-foot depth	per cent	Not obtained	12.5	9.6	1.1	16.0	2.5
Weight in air 24 hours later, W_1	pounds	16.1	5.63	4.5	5.31	13.28	7.66
Scale reading at atmospheric pressure 24 hours later, T_1	pounds	2.94	0.50	0.00	1.00	3.81	2.43
Weight in air used to sink specimen 24 hours later, w_1	pounds	20.00	30.00	30.50	28.75	25.00	30.00
Computed buoyancy of steel weights used in test 24 hours later, b_1	pounds	2.54	3.8	3.86	3.64	3.17	3.80
Lifting force of specimen at atmospheric pressure, 24 hours later $B_1 - W_1 = w_1 - T_1 - b_1$	pounds	14.52	25.7	26.64	24.11	18.02	23.77
$\frac{B_1 - W_1}{B - W}$	per cent	86.4	97.0	100.0	100.0	97.5	100.0
Percentage loss of lifting force, measured 24 hours later at atmospheric pressure	per cent	13.6	3.0	0	0	2.5	0
Percentage permanent loss of volume, measured 24 hours later at atmospheric pressure	per cent	Negligible	Negligible	Negligible	0	1.4	0

Water absorption also equalizes the pressure around the fibers of the material being tested, and further reduces the precision of the tests on the non-watertight specimens. This phase of the experiments proved interesting, but the subject of water absorption itself was considered to be outside the scope of this report.

Suffice it to say, enough information was obtained to show clearly the importance of using a watertight material for submersion to great depths in water. For comparison, Specimen 2, the balsa wood block coated with 2 coats of linseed oil, lost 19.5 per cent of its lifting force when the pressure was increased to 150 feet of sea water, as compared to 2.9 per cent lost by Specimen 6, the balsa wood block covered with a thin watertight sheathing of brass.

Of the three watertight specimens tested, the Foamglas, Specimen 4, showed the greatest promise as an underwater buoyant material. Its advantages are:

1. Light weight. The Foamglas is slightly heavier than balsa wood, which was the lightest material tested. Considering the weight of metal sheathing required to make the balsa watertight, however, the Foamglas specimen was the lightest of all those tested.

2. Watertightness. The cellulated structure of Foamglas prevents the absorption of water into any part of the material, with the exception of the very outside surfaces.

3. Incompressibility. The Foamglas decreased in volume by only 1.1 per cent when subjected to a pressure of 150 feet of water, as compared with 2.5 per cent for the sheathed balsa wood and 16.0 per cent for the sheathed compressed cork.

The principal disadvantages of Foamglas are:

1. Low structural strength. The brittleness of the material precludes its use where structural strength is essential.

2. Low resistance to concentrated loads. The cellulated structure offers little resistance to a load applied over a small area. Its specifications state that it will withstand a uniformly distributed load of 150 pounds per square inch, which is equivalent to 337 feet of sea water.

The sheathed balsa wood stood up better than the sheathed compressed cork. So long as a watertight sheathing can be supplied, balsa makes a good buoyant material for submergence to great depths under water. However, it is considered important in using balsa to provide some type of sheathing which cannot be easily punctured.

Compressed cork has approximately twice the weight in air of either balsa or Foamglas, and does not withstand pressure as well. The cork sheathed in brass decreased 16.0 per cent in volume at 150 feet of water pressure, as compared to 1.1 per cent for Foamglas and 2.5 per cent for balsa sheathed in brass.

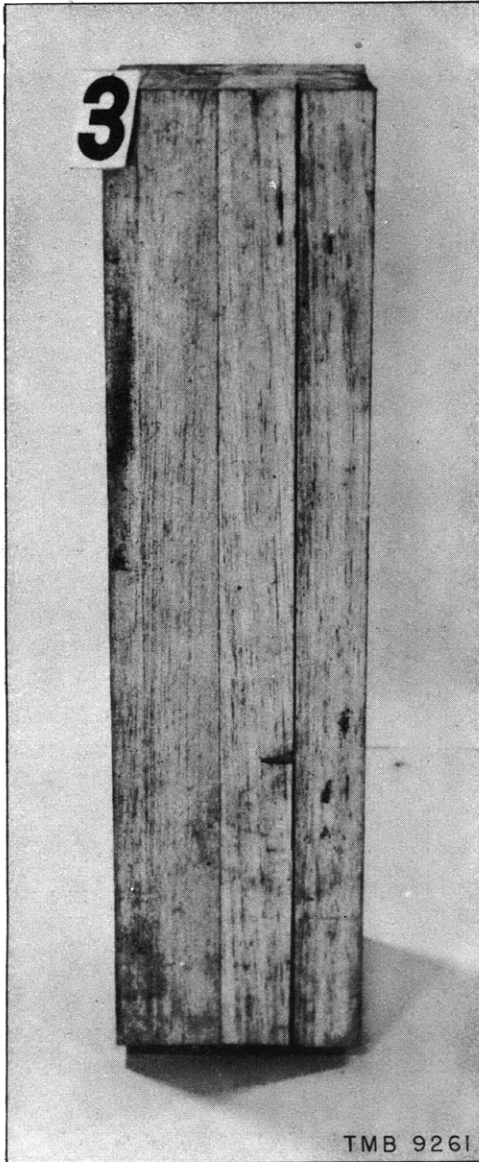


Figure 5 - Paraffin-Coated Balsa
Block after Pressure Test

The block which was built up of 4 balsa pieces failed structurally at a pressure of approximately 130 feet of water. The individual laminations were compressed unevenly, and they separated at the glued surface, as shown.

Although the wood failed structurally and lost considerable buoyancy when the pressure was applied, the actual permanent loss of volume was found to be negligible. In its present state, however, the absorption of water would be exceedingly rapid.

All of the materials tested appeared to withstand the increased pressure without failing structurally, with the exception of the two balsa blocks coated with paraffin and linseed oil, respectively. These blocks were built up of 4 smaller blocks glued together. When the pressure reached 100 feet for the linseed oil covered block and 130 feet for the paraffin-coated block, the blocks yielded structurally and took a permanent set as illustrated in Figure 5, which shows the paraffin-coated balsa block after the pressure test. Although the block itself failed structurally when the pressure was applied, the actual permanent loss of volume was negligible. A failure of this nature did not occur in the balsa block sheathed with brass.

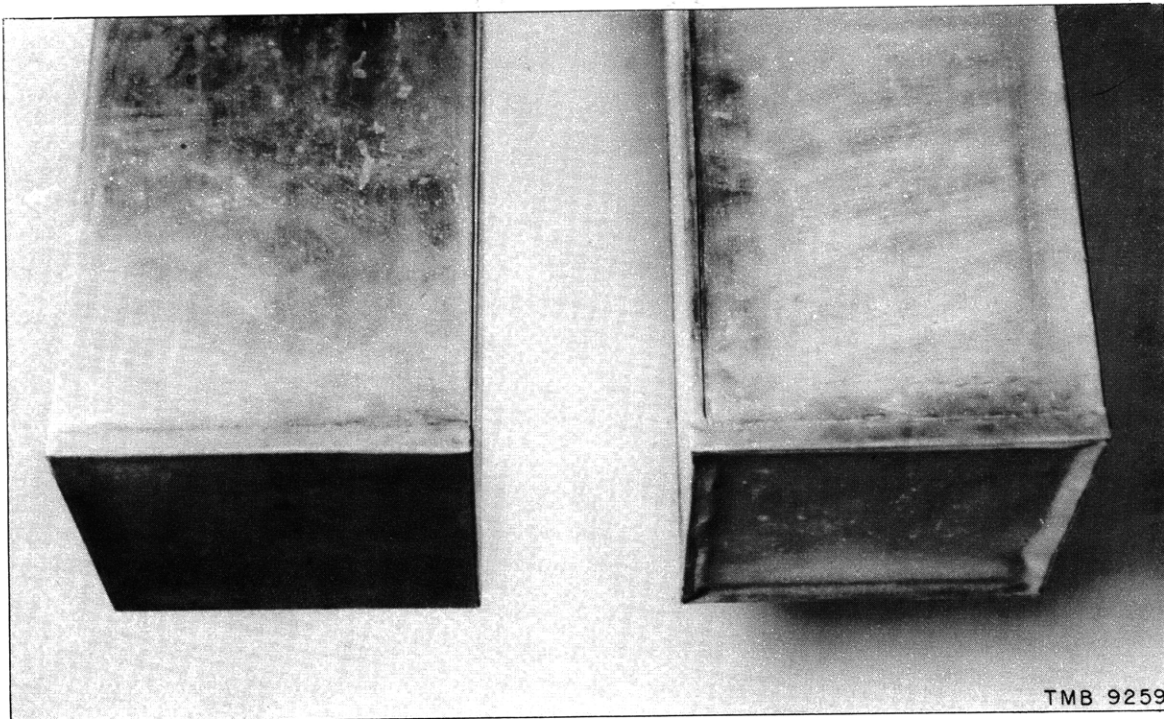


Figure 6 - End Views of the Sheathed Cork and Sheathed Balsa Specimens after Pressure Test

The permanent set taken by the compressed cork at the right is clearly illustrated. The sheathed balsa specimen at the left stood up much better than the unprotected balsa specimens; see Figure 5.

The sheathed compressed cork took a decided permanent set, as illustrated in Figure 6. This, however, was due to compression rather than to structural failure.

The white pine block, the Foamglas, and the sheathed balsa block showed no structural failure whatsoever and only negligible permanent set.

CONCLUSIONS

As a result of the tests, it was decided that Foamglas offered the best combination of incompressibility, watertightness, and light weight.

The basic conclusions of the test were:

1. None of the materials tested, except Foamglas, is recommended as a buoyant material where great depths of immersion are involved, unless some type of watertight and puncture-proof sheathing is employed.

2. Where structural strength is not essential, Foamglas is the best all-around buoyant material of those tested for submergence to great depths.

3. Balsa wood without a protective sheathing fails structurally at a depth of about 100 feet. All of the other materials tested may be expected to withstand the pressure at 150 feet without failing structurally.

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