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AN EXPERIMENTAL INVESTIGATION OF PENETRATIONS AND CLOSURES FOR GLASS-REINFORCED-PLASTIC PRESSURE HULLS WITH TITANIUM JACKETS

by

John L. Proffitt

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STRUCTURAL MECHANICS LABORATORY
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AN EXPERIMENTAL INVESTIGATION OF PENETRATIONS AND CLOSURES FOR GLASS-REINFORCED-PLASTIC PRESSURE HULLS WITH TITANIUM JACKETS

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ABSTRACT

Four models were tested under hydrostatic pressure to determine the structural behavior of ring-stiffened glass-reinforced-plastic hulls with such structural details as small cylinder penetrations and end closures. Two models incorporated cylinder penetrations; two had hemispherical end closures, one each of titanium and GRP. The results of the tests indicate that such details might be used in composite GRP hulls without a severe weight penalty. However, fatigue tests of small-scale models and further static and cyclic investigations of large-scale and complete unit models are required to fully establish the feasibility of these structures for deep-submergence applications.

ADMINISTRATIVE INFORMATION

The work described in this report was sponsored by the Special Projects Office (BUSHIPS CONFIDENTIAL letter S-F013 01 03 Serial 320-056 of 26 July 1962). The funds were administered under BuShips Subproject S-F013 01 03, Task 0214.

INTRODUCTION

In recent years, designers have become aware of the strength-weight characteristics of glass-reinforced plastic (GRP). In model and specimen tests, high strength-weight ratios have been attained. The results of an investigation initiated at the David Taylor Model Basin to determine a suitable ring-stiffened GRP geometry for the pressure hull of a deep-diving submersible are reported in Reference 1.* These results were promising and indicated that GRP pressure hulls for deep-diving vehicles are practical; indeed, they are superior to metallic hulls from a static-strength aspect. Furthermore, this series of tests indicated that composite construction is a feasible method of using glass-reinforced plastic in a deep-diving pressure hull.

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*References are listed on page 23.

Basically, composite construction employs high-strength cylindrical rings, not physically joined together, surrounded by a thin jacket. The ring material is selected for its high strength-to-weight ratio since its major function is to resist hydrostatic loading. Because the rings are not joined together, stringent welding specifications and their associated problems do not exist. Therefore, the designer can avail himself of ultra-high-strength steels, aluminum and titanium alloys, and glass-reinforced plastics, all of which are nonweldable. The thin jacket, made from a weldable material, holds the rings in place, resists salt water corrosion, and provides longitudinal strength to resist bending loads while the vehicle is surfaced.[2] The static-strength performance of composite GRP construction appears promising, but many problems still exist and must be overcome before it will be practical to construct a prototype vehicle of this type. An important question is, "Can the designer provide adequate means of closing the cylinder ends and penetrating the pressure hull?" In an attempt to answer this question and to further test the feasibility of composite construction, an investigation was undertaken at the Model Basin using structural models incorporating such design features as end closures and cylinder penetrations. The results of this study are summarized in this report.

DESCRIPTION OF MODELS

Essentially, two series of models were constructed of glass-reinforced, filament-wound plastic by H. I. Thompson Fiber Glass Co., Gardena, California. One series was designed to investigate prospective designs for small hull penetrations. The purpose of the second series was to study the problem of providing an end closure for a GRP hull. Although the ring-stiffened geometries used for these models were based on the design of Models DSRV-15 and DSRV-16,[1] the basic cylinder designs for both model series were dictated by the immediate purpose of each model; hence, some variations in design existed. Figure 1 is a diagram of the four models.

Model DSRV-17 was a ring-stiffened GRP cylinder approximately 2 diameters long with a titanium jacket having a nominal yield strength of 120,000 psi. The model had two small titanium penetrations, oriented 120 deg apart in its center bay. A replacement-of-area method was used for the design of the penetrations. The dimensions of the thin-walled penetration were chosen so that the longitudinal cross-sectional area of the titanium insert was equal to the longitudinal cross-sectional area of the hole in the fiberglass cylinder. The thick-walled penetration provided a 150-percent replacement-of-area.

The geometry used in the design of Model DSRV-17 was based on the geometry of Model DSRV-16, which, at the time of design, had not been tested. Subsequently, Model DSRV-16 failed at a pressure below design collapse pressure of 13,333 psi. Therefore, to investigate the performance of a penetration in a cylinder of improved geometry, it was decided to design a penetration model based on the geometry of Model DSRV-15. This model, a short 5-bay cylinder and designated DSRV-15.2, had a single titanium (σ_y = 120,000 psi) penetration providing 150-percent replacement-of-area in its center bay. The penetration design was selected after analysis of test data obtained from the two penetrations in Model DSRV-17. The analysis revealed that the stresses in the thick-walled penetration were not excessive at operating pressure. Because Model DSRV-15.2 had no titanium jacket, the design collapse pressure was 12,500 psi. This determination was based on an assumption used for all models of composite construction: the thin jacket increases the collapse pressure of the unjacketed model by an amount equal to the pressure (833 psi) which causes yielding in the unsupported jacket. This pressure was easily calculated by applying the Hencky-Von Mises yield criterion.

The first closure model, DSRV-18, consisted of a short, ring-stiffened, fiberglass cylinder with a thin titanium jacket and a titanium hemispherical closure at one end. The type of titanium alloy used was 6AL4V with a minimum specified yield strength of 120,000 psi. The cylinder geometry is identical to the geometry in the end region of Model DSRV-15. The cylinder-closure joint was designed to provide membrane deflection and no rotation,[3] assuming a cylinder modulus of 5.0×10^6 psi, and a titanium modulus of 17.0×10^6 psi. The titanium jacket was assumed to act monolithically with the GRP shell, and an effective thickness equal to the shell thickness plus the jacket thickness multiplied by their respective moduli was used for the deflection calculations. The hemisphere was designed to collapse at 10,000 psi, 1.5 times operating pressure.

Model DSRV-19 used a GRP cylinder and end closure, both surrounded by a titanium jacket. The closure thickness was determined by assuming an average stress of 49,000 psi at 13,333 psi pressure. The hemisphere was fabricated by laminating 69 plies of No. 1581 Volan A glass cloth impregnated with 828 resin over a male die. The warp of each ply was oriented 22 1/2 deg from that of the preceding ply to obtain a good degree of isotropy throughout the closure. The plies were applied in two stages of approximately equal numbers of plies each. After each stage was applied, the plies were vacuum bagged, void freed, and cured for 2 hr at 275 deg F. To facilitate the design of the cylinder-closure joint, the cylinder wall thickness was made equal to the closure thickness.* This arrangement and the assumption that the closure modulus was equal to one-half the cylinder modulus obviated a joint design based on membrane criterion. A simple titanium ring was inserted at the cylinder end.

TEST PROCEDURE AND RESULTS

After instrumentation with foil-resistance gages, Model DSRV-17 was placed in the TMB 17 1/2-in. high-pressure tank. Water was used as the pressurizing medium. For the first pressure run, pressure was applied in 600-psi increments to 6600 psi. Strain data were recorded at each increment by automatic recorders. Figure 2 shows strain gage locations and measured strain sensitivities. A second pressure run identical to the first was also conducted. However, at a pressure of 6600 psi during the first run the recorded strains for all inside gages jumped disproportionately whereas outside gage readings dropped to zero strain as shown in Figure 3. After pressure was released, the model was removed from the tank for examination, which revealed a longitudinal pleat in the jacket along the length of the model; see Figure 4. Since the jacket welds appeared still

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*Because of the manufacturing technique used for the closure, some variation in thickness is to be expected. As a general rule, the apex of the dome will be about 20 percent thinner than the equator.[4] Therefore, the design of Model DSRV-20 called for a minimum closure thickness. The cylinder thickness was to be determined from the measured equatorial wall thickness of the finished closure.

intact, it was decided to proceed with the collapse phase of the test as planned, omitting strain gage readings. During the third pressure run the loading rate was held as close as practicable to 100 psi/min from 6600 psi to collapse. Failure occurred at 9760 psi while pressure was being applied. Figure 5 shows photographs of Model DSRV-17 after collapse.

Test procedure for Model DSRV-15.2 was similar to that of Model DSRV-17. Two pressure runs were made to 6600 psi in 11 equal increments and strains were recorded. On the third pressure run the model collapsed at 12,600 psi after holding that pressure for approximately 1 min. This allowed time to record strain data from the outside gages. The last inside strain data were taken at 12,000 psi. Figure 6 gives strain gage locations and measured strain sensitivities for DSRV-15.2. Because all pressure-strain plots were linear up to collapse pressure for this model, no plots are presented. Maximum strains can be readily determined from the sensitivities presented. Figure 7 is a photograph of the model after collapse.

Model DSRV-18 was instrumented with foil-resistance strain gages and was placed in the TMB 17 1/2-in. pressure tank. The pressure runs were made in 600-psi increments to 6600 psi; then a final pressure run by 3000-psi increments to 6000 psi; and from there to collapse at a rate of 100 psi/min. Strain data were taken with automatic recorders. Figure 8 gives strain gage locations and measured strain sensitivities for Models DSRV-18 and DSRV-19. The model collapsed at 11,990 psi. The last strain readings were taken at 11,400 psi. Because the pressure-strain plots for Models DSRV-18 and DSRV-19 were linear up to collapse pressure, they are not presented. The same test procedure was used for Model DSRV-19. This model failed at a pressure of 14,400 psi. Figure 9 shows Models DSRV-18 and DSRV-19 after collapse.

DISCUSSION

Model DSRV-17 failed at the bay which contained the penetrations at a pressure of 9760 psi or 73 percent of design collapse pressure. There is no definite evidence of the actual cause of the premature collapse of this model. As mentioned earlier, the typical bay geometry was identical to that of Model DSRV-16, which also collapsed (11,590 psi) at less than design pressure because of high shear stresses at the metal end ring.[1] Since it is known that any discontinuity in a GRP shell, such as a frame, hatch, or other insert, produces an area of severe stress concentration known as a "hard-spot," perhaps the introduction of the penetrations into Model DSRV-17 contributed to the early failure.

Another explanation exists which is even more tenable. It is entirely conceivable that high-pressure water intruded into the penetration-cylinder interface sometime during the second or third pressure runs and lowered the strength level of the GRP.* This was possible if small cracks were present in the jacket welds after buckling of the excessively loose jacket occurred on the first run. This is graphically substantiated by the gages on the outside of the jacket (Figure 3) which returned to zero strain at 6000 psi, indicating the jacket had lost its loading.

Stresses determined from strain gages on both insert tubes of Model DSRV-17 revealed that much higher stresses took place in the thin-walled tube than the thicker tube. Figure 10a presents the stress distribution pattern for both penetrations of Model DSRV-17.

The design of the typical bay of Model DSRV-15.2 was based on the geometry of Model DSRV-15,[1] which included a shell 10 percent thicker than that of DSRV-17. Model 15, which collapsed at 14,300 psi, had a titanium jacket that was not incorporated in the shorter model (Model 15.2). The collapse pressure of Model DSRV-15.2 was 12,600 psi, 101 percent of design collapse pressure when that pressure was adjusted to account for the omission of the titanium jacket. Figure 10b gives the stresses inside the penetration at collapse pressure. Failure of the model was characterized by a circumferential fault around the entire model at the juncture of the

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*Water penetration into the glass-resin interface is an area where serious problems exist. Dramatic reductions in static strength are noted when exposed GRP surfaces, particularly those with cut fibers, are exposed to high pressure.

second bay and third frame. Because the fault is at an angle of approximately 45 deg, it was assumed to be caused by shearing at this point.

The successful static test result of Model DSRV-15.2 offers promise that properly designed small penetrations can be incorporated into GRP pressure hulls. Of course cyclic tests on small-scale models are definitely mandatory to verify this premise. If these tests prove fruitful, large-scale model tests are in order. Here, complex structural details (such as jacket weldments and penetration components) present fewer fabrication problems as the scale becomes larger. A better solution to the problem of providing hull openings, however, is to penetrate the hemispherical end closures, rather than the cylindrical section. Here, the designer is aided by symmetry, which greatly alleviates many design problems.

The first closure model, DSRV-18, failed at the cylinder-closure joint at a pressure of 11,990 psi. Even though the GRP cylinder was designed 33 percent thicker than the typical shell section of Model DSRV-15,[1] inspection of the model after collapse revealed it had failed by shearing immediately aft of the titanium support ring. Inside stress at the apex of the hemisphere was 119,480 psi at collapse; inside longitudinal stress at the cylinder-hemisphere juncture was 144,400 psi. These values were calculated by using the average strain readings and a titanium modulus of 17.0×10^6 psi and Poisson's ratio of 0.30. Maximum inside longitudinal stress in the GRP cylinder at the juncture was 51,620 psi, assuming the following material constants:

$$E_x = 5.6 \times 10^6 \text{ psi}$$

$$\nu_{\phi x} = 0.143$$

$$\nu_{x\phi} = 0.132$$

Although the nominal collapse pressure (10,000 psi) of the titanium hemisphere was only 1.5 times greater than operating pressure (75 percent of design collapse for the GRP cylinders), failure initiated in the cylinder. This can be attributed to the higher than nominal yield strength of the 6AL4V titanium used in the closure. Since no samples were tested to determine yield strength, no definitive statement can be made about it, but a good estimate would be approximately 145,000 - 150,000 psi based on other samples tested. This particular circumstance, however, proved to be somewhat advantageous. Because the joint area failed before reaching nominal collapse pressure, the need for a better design was brought to light. Subsequent designs will include a thicker shell section at the joint to resist the high imposed shear stresses in this area. Model specifications will provide for closer control over titanium yield strength, particularly those used for cyclic testing.

The glass-reinforced-plastic hemisphere of Model DSRV-19 collapsed at a pressure of 14,400 psi (107 percent of design collapse pressure). Failure was characterized by tearing of the shell along a line of about 120 deg of arc; see Figure 9. The average theoretical stress in the GRP at collapse was computed to be 50,650 psi when the titanium jacket and its effects on the collapse pressure were neglected. No rotation of the titanium insert ring was in evidence.

One measure of the strength-weight characteristics of a pressure hull structure is obtained by dividing its collapse pressure by the percentage of weight of material to the weight of water displaced. This method is used to compare Models DSRV-18 and DSRV-19. The closure of Model 18 weighed 63.2 percent of its displacement, and the closure of Model 19 (exclusive of insert ring) had a weight-to-displacement ratio of 0.818 (based on a thickness determined by averaging the apex and joint thicknesses). By dividing the collapse pressures by these percentages, numbers of 190 and 176 are obtained for Models DSRV-18 and DSRV-19, respectively. These "efficiencies" show one advantage of a titanium closure on a GRP hull.

The failure of Model DSRV-18 occurred in the cylinder region, and the prospects of raising the collapse pressure of the cylinder-closure unit to the desired level are good if the joint design is improved. However, there is another, perhaps more powerful, argument in favor of using a titanium closure on a hull structure of this type. It is better to penetrate the hull of a research vehicle through the end closure rather than through the cylinder. Many problems are anticipated in the design of GRP closure penetrations and viewing ports. It is relatively easy, however, to penetrate a metallic hull such as titanium because of its weldability, isotropic material properties, and the relative ease with which it can be worked. Future series of complete pressure hull models of composite construction will incorporate titanium closures.

Results of this series of tests were, on the whole, rather promising although far from conclusive. Further work is required, however, to definitely establish the feasibility of composite GRP construction for realistic deep-diving pressure hulls. Large-scale models of individual components of a complete hull configuration should be fabricated and tested. Tests should be conducted on models which are more completely representative of a complete hull structure, i.e., models incorporating penetrated end closures and cylinders in a single unit. Another important area to be thoroughly investigated is the fatigue characteristics of models of composite GRP construction. Results obtained from limited fatigue tests already conducted have been, at best, inconclusive. Three cyclic tests are described in the Appendix. Future plans call for cyclic testing of models combining the best structural details investigated.

CONCLUSIONS

1. Small metallic penetrations in the hull of a ring-stiffened cylinder of composite GRP construction can be designed to successfully resist hydrostatic loading.

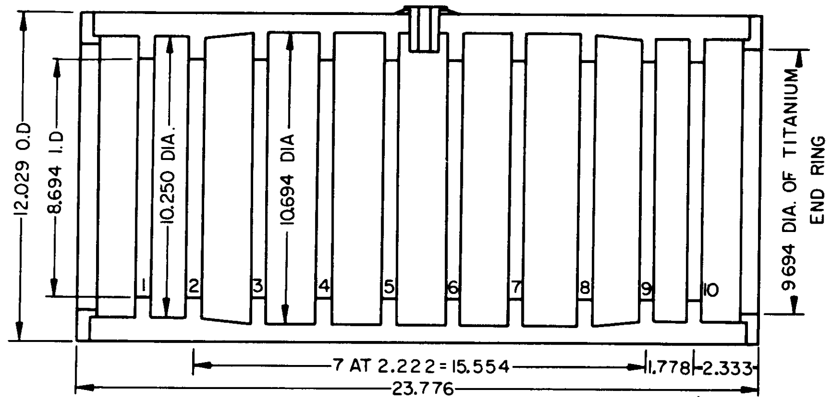
2. A titanium hemisphere used as a closure for a GRP cylinder appears to be feasible.

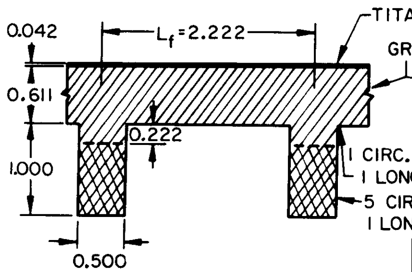
3. A GRP hemispherical closure weighs about 76 percent of its displacement when designed for a collapse depth of 30,000 ft. Although the cylinder-closure joint is more easily designed, the problems involved in penetrating such a hemisphere are complex compared to the same problems in a titanium closure.

ACKNOWLEDGMENTS

The author is indebted to Mr. W. R. Stewart for the instrumentation of the four models and his assistance in the static tests. Thanks are due also to Mr. B. W. Abbott of the IIT Research Institute for conducting the cyclic tests.

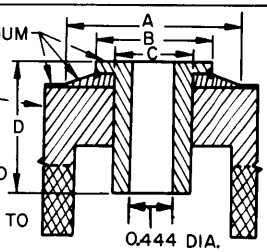
Figure 1 – Models DSRV-17, DSRV-15.2, DSRV-18, and DSRV-19





TYPICAL LONGITUDINAL CROSS SECTION

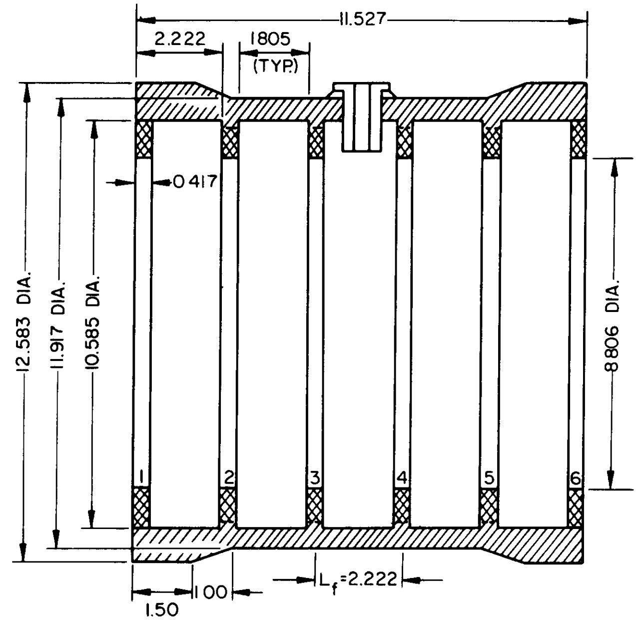
ALL DIMENSIONS ARE IN INCHES

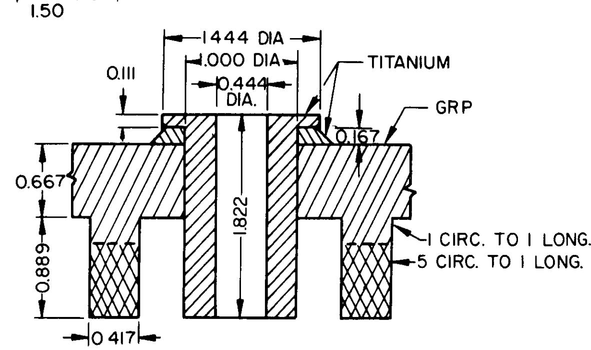


ORIENTATION	A	B	C	D
60°	1.833	1.278	0.833	1.433
30.0°	2.000	1.444	1.000	1.822

PENETRATION DETAILS

Figure 1a – Model DSRV-17





LONGITUDINAL SECTION AT PENETRATION

Figure 1b – Model DSRV-15.2

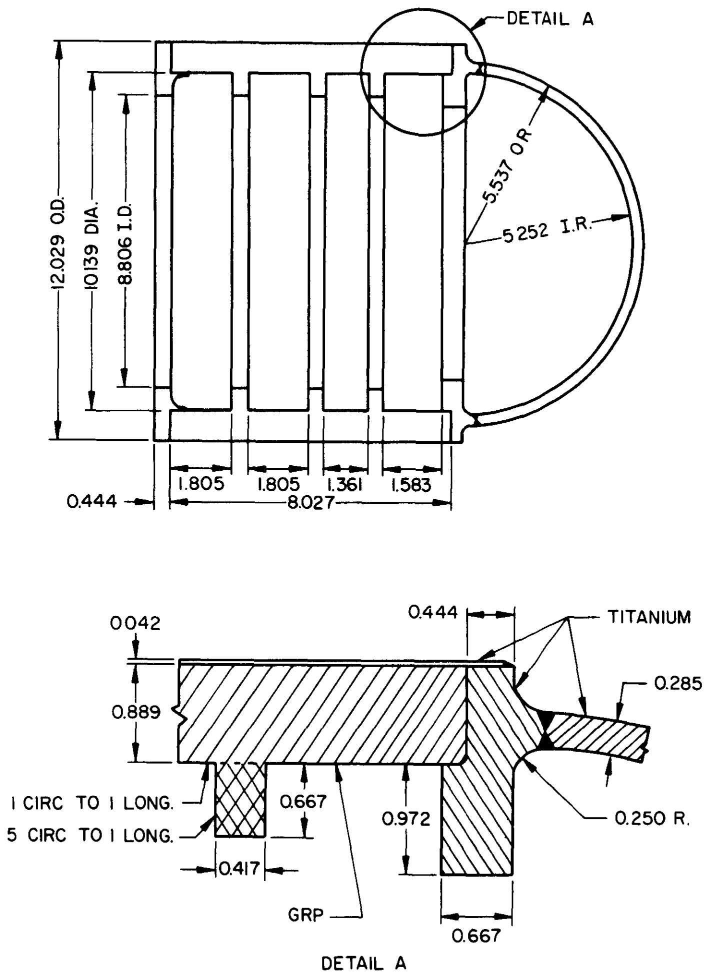


Figure 1c — Model DSRV-18

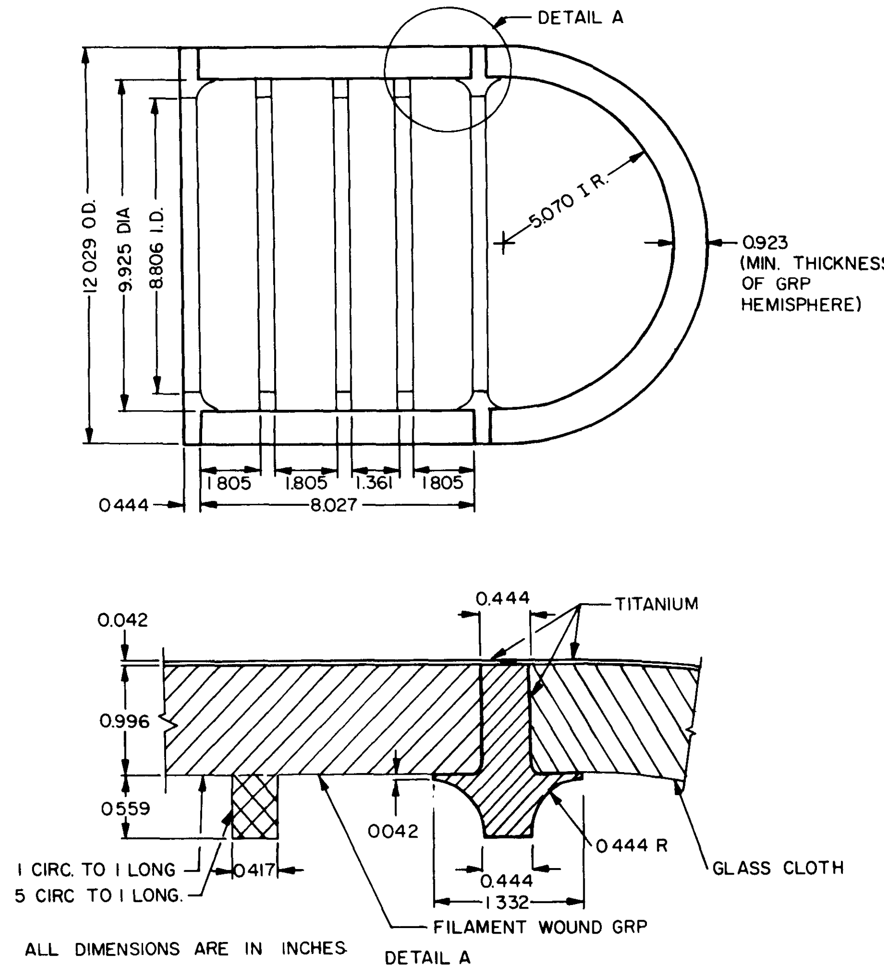


Figure 1d — Model DSRV-19

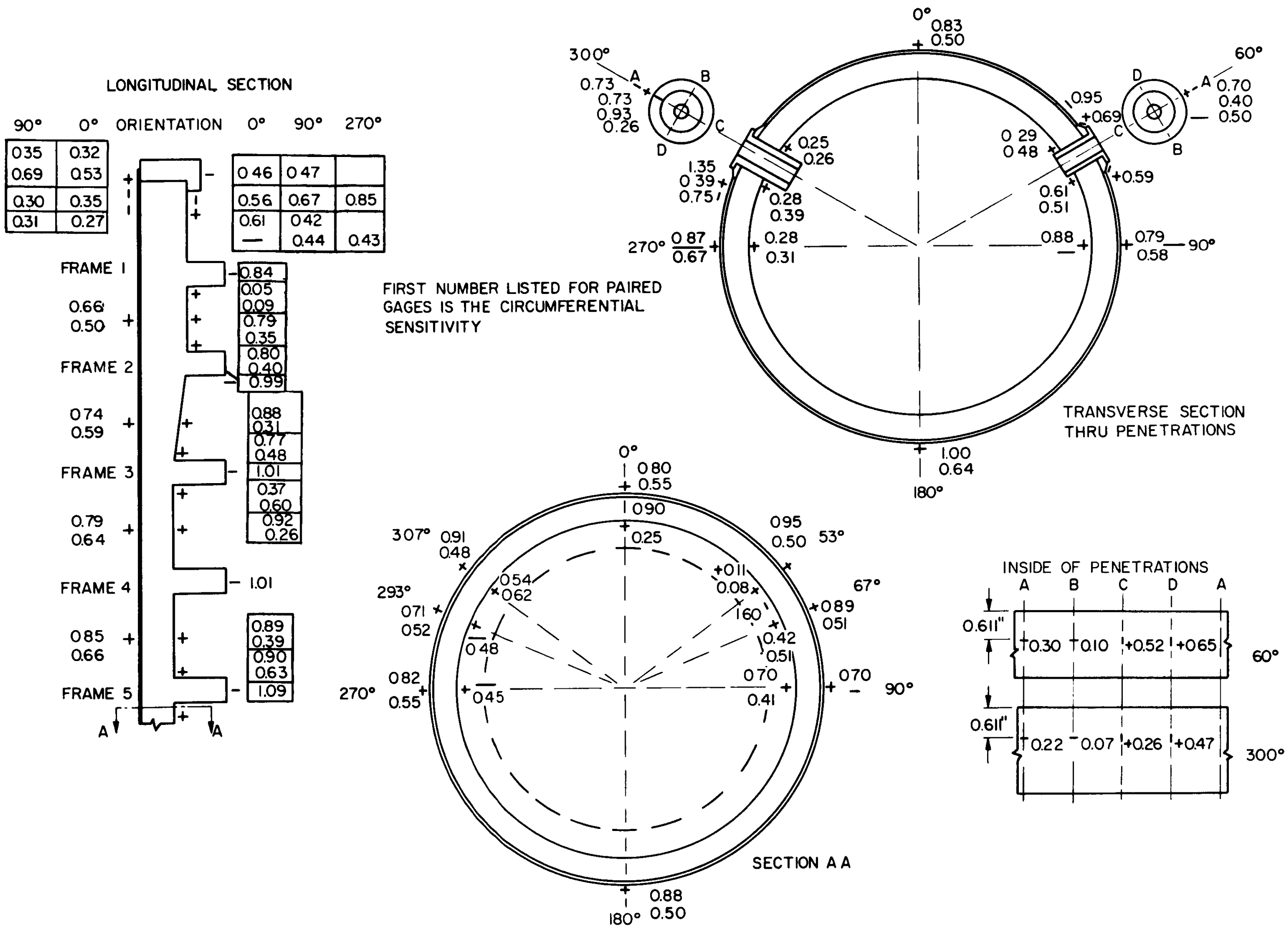


Figure 2 – Strain Gage Locations and Measured Strain Sensitivities for Model DSRV-17

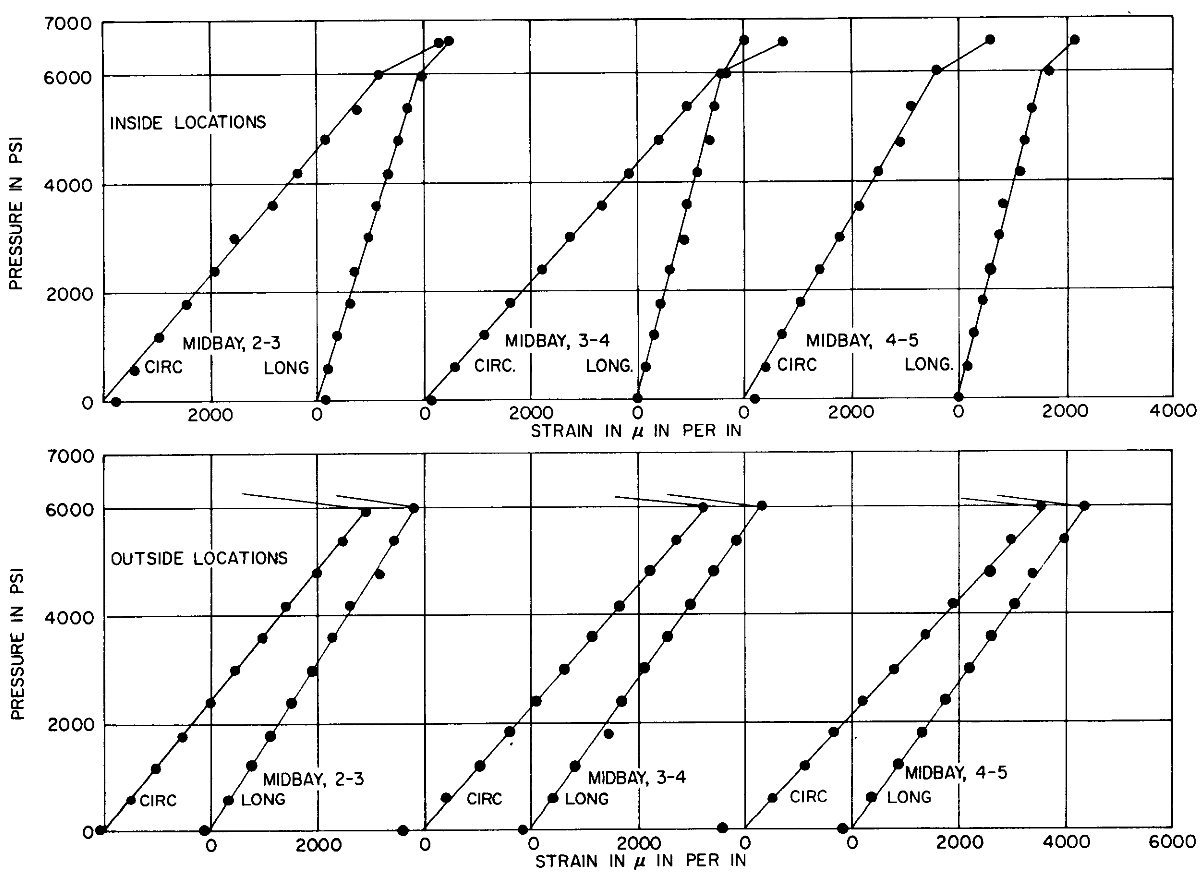


Figure 3 – Pressure-Strain Plots for Model DSRV-17 Run Number 1

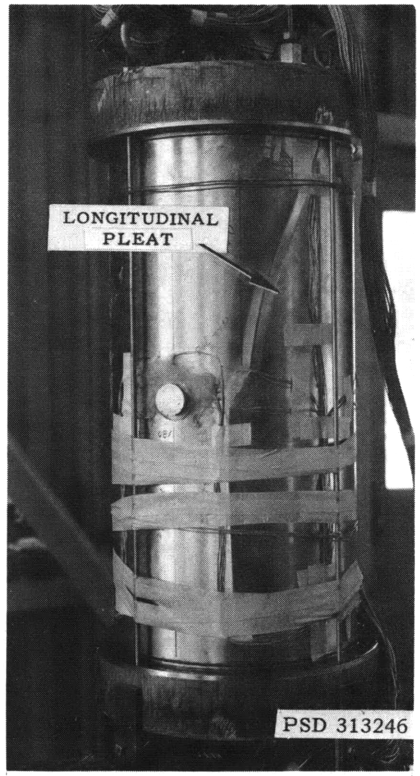


Figure 4 – Model DSRV-17 after Subjection to 6600 PSI Pressure

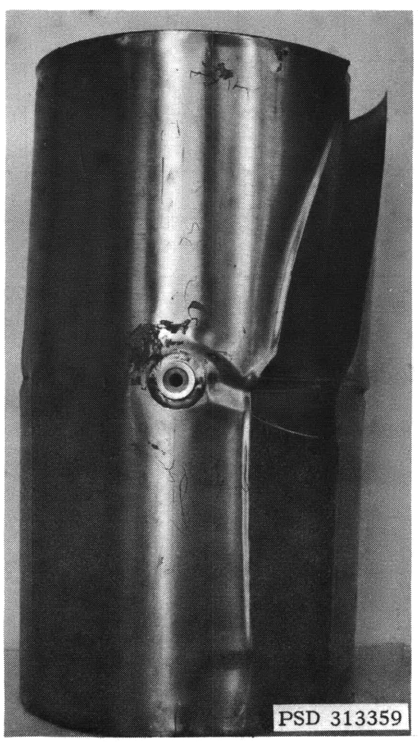


Figure 5a – Thin-Walled Penetration

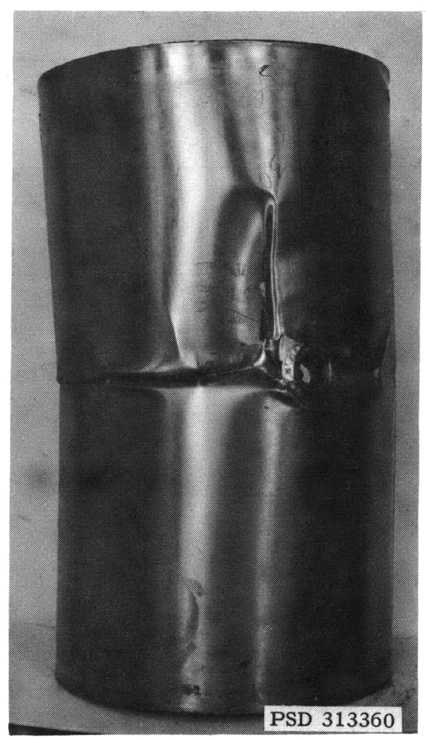


Figure 5b – Thick-Walled Penetration

Figure 5 – Model DSRV-17 after Collapse

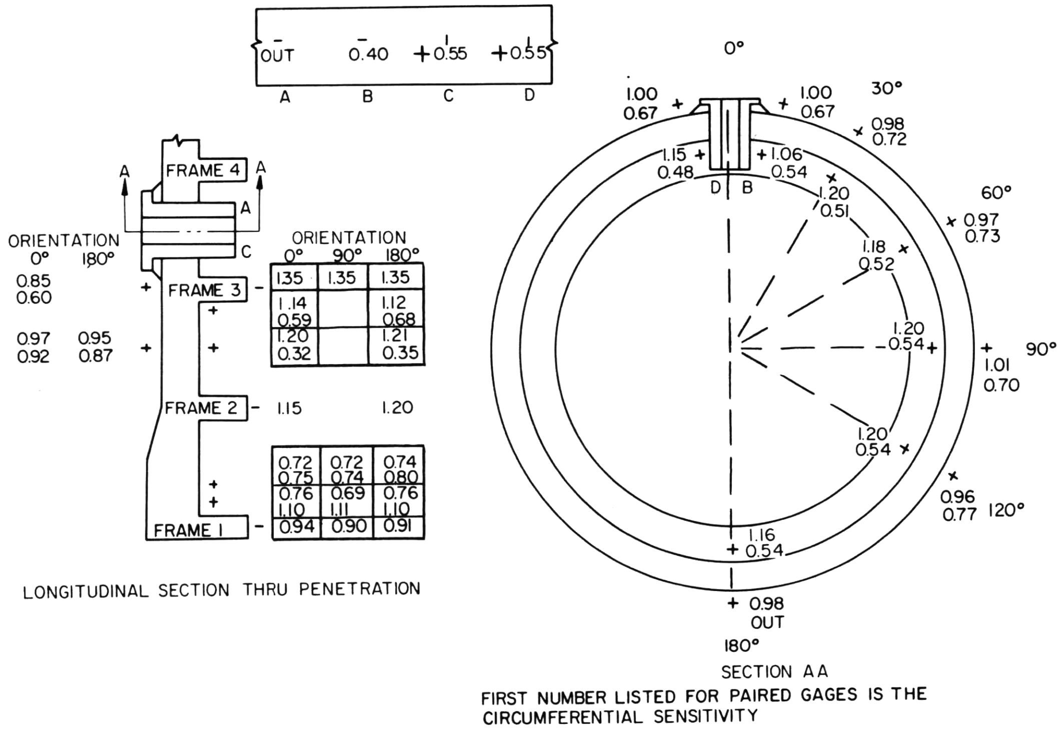
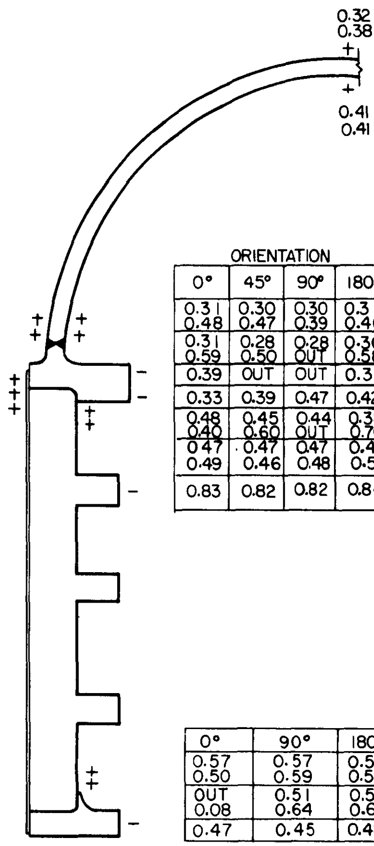


Figure 6 – Strain Gage Locations and Measured Strain Sensitivities for Model DSRV-15.2

Figure 7 – Model DSRV-15.2 after Collapse



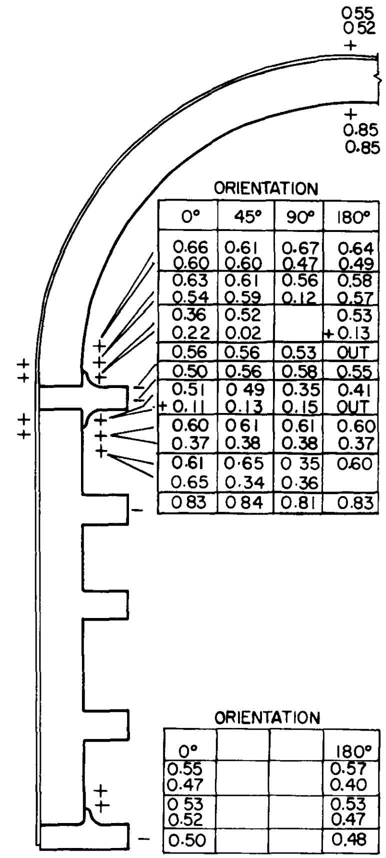
ORIENTATION

0°	45°	90°	180°
0.25 0.29	0.27 0.34	0.28 0.37	0.29 0.37
0.25 0.28	0.29 0.25	0.26 0.33	0.29 0.34
0.27 0.19	0.27 OUT	0.21 0.13	0.22 OUT
0.30 0.37	0.29 0.47	0.28 0.55	0.31 0.42
0.37 0.46	0.32 0.32	0.36 0.35	0.35 0.30

ORIENTATION

0°	45°	90°	180°
0.31 0.48	0.30 0.47	0.30 0.39	0.31 0.46
0.31 0.59	0.28 0.50	0.28 OUT	0.30 0.58
0.39	OUT	OUT	0.31
0.33	0.39	0.47	0.42
0.48 0.40	0.45 0.60	0.44 OUT	0.38 0.70
0.47 0.49	0.47 0.46	0.47 0.48	0.48 0.54
0.83	0.82	0.82	0.84

0°	90°	180°
0.57 0.50	0.57 0.59	0.58 0.55
OUT 0.08	0.51 0.64	0.54 0.66
0.47	0.45	0.48



ORIENTATION

180°	90°	45°	0°
0.45 0.28	0.44 0.32	0.44 0.31	0.50 0.33
0.39 0.10	0.41 0.06	0.44 0.14	0.43 0.20
0.42 0.17	0.37 0.34		0.45 0.52
0.45 0.32	0.44 0.23	0.26 0.41	0.42 0.11

ORIENTATION

0°	45°	90°	180°
0.66 0.60	0.61 0.60	0.67 0.47	0.64 0.49
0.63 0.54	0.61 0.59	0.56 0.12	0.58 0.57
0.36 0.22	0.52 0.02		0.53 +0.13
0.56	0.56	0.53	OUT
0.50	0.56	0.58	0.55
0.51 +0.11	0.49 0.13	0.35 0.15	0.41 OUT
0.60 0.37	0.61 0.38	0.61 0.38	0.60 0.37
0.61 0.65	0.65 0.34	0.35 0.36	0.60
0.83	0.84	0.81	0.83

ORIENTATION

0°			180°
0.55 0.47			0.57 0.40
0.53 0.52			0.53 0.47
0.50			0.48

FIRST NUMBER LISTED FOR PAIRED GAGES IS THE CIRCUMFERENTIAL SENSITIVETY

Figure 8a – Model DSRV-18

Figure 8b – Model DSRV-19

Figure 8 – Strain Gage Locations and Measured Strain Sensitivities for Models DSRV-18 and DSRV-19

Figure 9a – Model DSRV-18

Figure 9b – Model DSRV-19

Figure 9 – Models DSRV-18 and DSRV-19
after Collapse

APPENDIX

CYCLIC LOADING TESTS OF GRP CYLINDERS WITH PENETRATIONS

As an increasing number of models are tested, more information on the static strength capabilities of glass-reinforced-plastic hulls becomes available. The results of such tests have spurred interest in this type of construction, triggering more intensive investigation and further static model tests. Attention must be directed toward other aspects of the structural characteristics of GRP hulls, however. Probably the most important area where little is now known is that of response to cyclic loading. As future models are designed and fabricated, it is planned to roughly parallel the static test program with cyclic tests on similar or comparable models. Several cyclic tests have been completed, and although the results are inconclusive and limited in scope, they are discussed here.

The first GRP titanium model to be subjected to cyclic testing was designated DSRV-17(F). It was identical to Model DSRV-17 (Figure 1) with one exception; it included a cylinder joint like that of Model DSRV-15(F), Figure 11, to be described later. The facilities of the Illinois Institute of Technology (IIT) Research Institute were used for the test because of their capability to pressurize the medium surrounding the model while keeping the interior dry. The loading schedule specified a pressure variation from 200 psi to 6700 psi with a hold time of 1 min at both minimum and maximum pressures. The model was to be cycled until 10,000 repetitions were reached or failure occurred. The model would be inspected visually at each 2000 cycles.

Model DSRV-17(F) experienced catastrophic failure after 129 pressure cycles. Failure occurred in the bay which contained the two penetrations. The suspected cause of failure was shearing of the cylinder wall because of the stresses imposed by the inclusion of the two tubes. Because the static performance of penetrated GRP cylinders was improved by increasing the wall thickness, the design of subsequent models for cyclic tests was based on the same approach.

The next model to be cyclically tested was a short, ring-stiffened cylinder identical to Model DSRV-15.2 (Figure 1) and designated DSRV-15.2 (F). No jacket was included on this model for two reasons. It was desired to fabricate a model with the improved DSRV-15 geometry in the shortest possible time, and further, to eliminate the jacket-oriented problems encountered during the test of Model DSRV-17(F). Model DSRV-15.2 (F) failed after 1587 cycles. Water penetration into the tapered end section is the suspected cause for failure, even though the model had been completely covered with a rubber-based protective seal before testing. This premature failure was rather disappointing since it gives no indication of the structural response of the cylinder to cyclic loading in the immediate vicinity of the penetration. Examination of this area after collapse indicated that it was intact at the time of failure, but no definite conclusions can be drawn regarding structural integrity at a greater number of cycles. Figure 12 shows photographs of Models DSRV-17(F) and DSRV-15.2(F) after failure.

These two tests are good examples of the difficulties experienced in testing small-scale GRP cylinders under cyclic loading. There is one test in progress at this time from which significant results are anticipated, however. At about the same time as testing began on Model DSRV-15.2(F), Model DSRV-15(F) was shipped to IIT Research Institute for cyclic loading. This model was a 4-diameter long, GRP cylinder with a titanium jacket and two cylinder penetrations. Details are given in Figure 11. The loading schedule for this model specifies a 12-hr cycle of which 2 hr consists of rise from 200 psi to 6700 psi at a constant rate, a 6-hr hold at 6700 psi, a drop in pressure to 200 psi over a 2-hr period, and a hold at 200 psi for 2 hr. Thus, the model experiences 2 cycles per day (a closer approach to actual loading conditions). The test will last for a 1-yr period. At this time, the model has withstood 500 pressure cycles successfully. This is an interesting, if not a hopeful sign; it probably indicates the importance of keeping water away from the GRP surfaces.

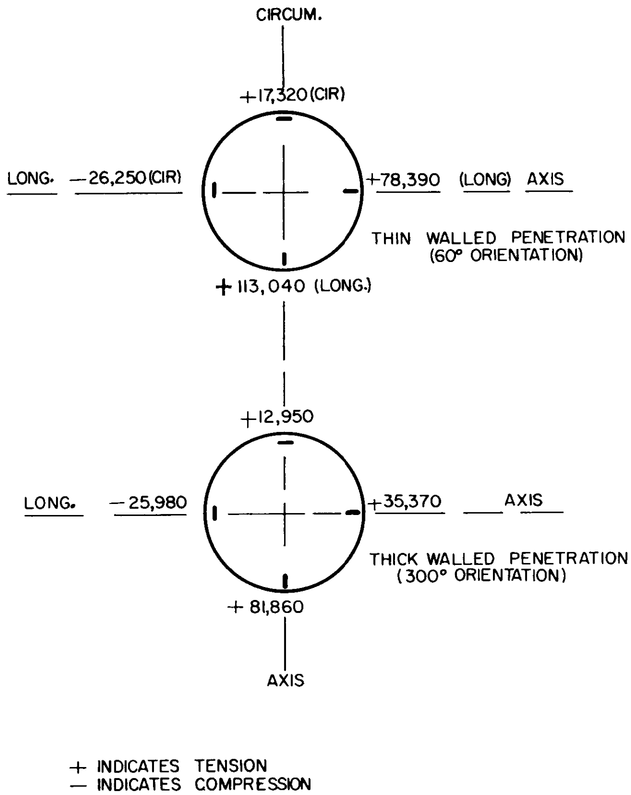


Figure 10a – Model DSRV-17

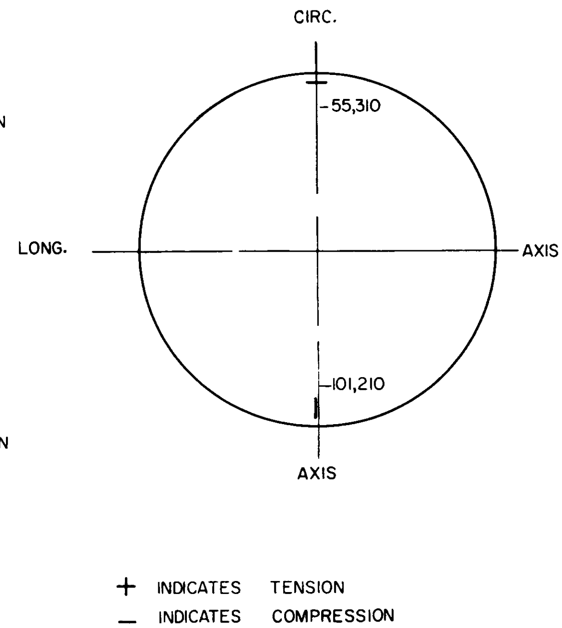


Figure 10b – Model DSRV-15.2

Figure 10 – Stresses on Inside Surfaces of Penetrations at Collapse

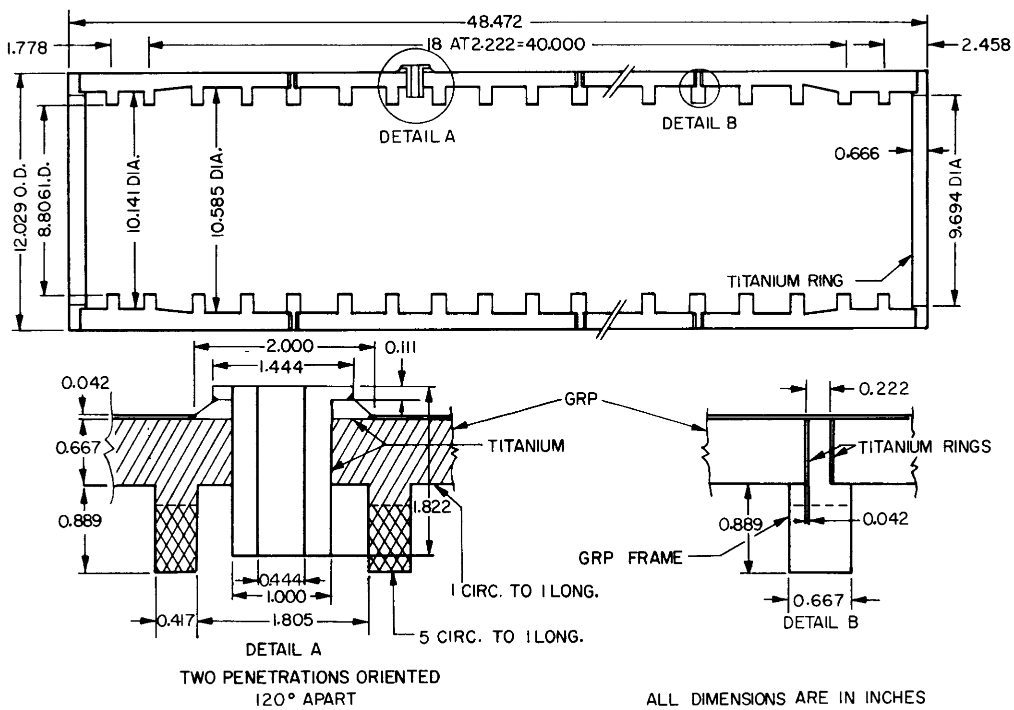


Figure 11 – Model DSRV-15(F)

Figure 12 – Models DSRV-15.2(F) and DSRV-17(F) after Cyclic Testing

Figure 12a – Model DSRV-15.2(F)

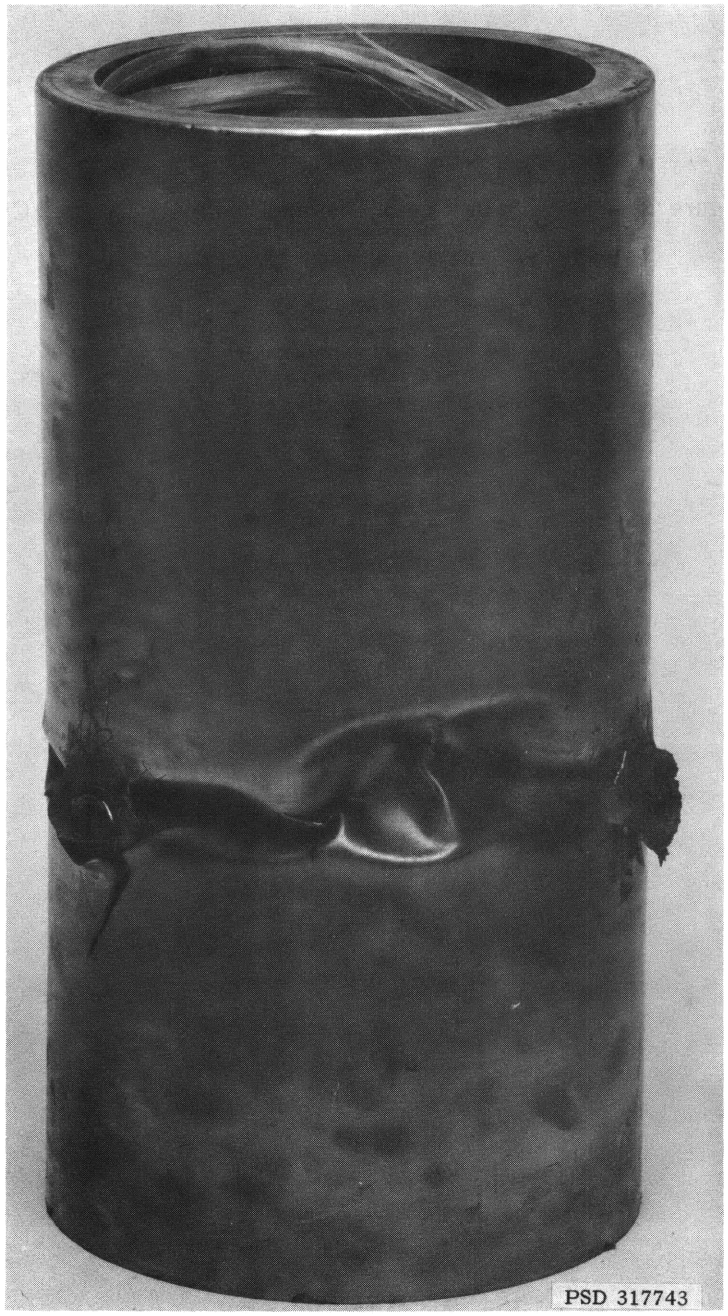


Figure 12b – Model DSRV-17(F)

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13 ABSTRACT

Four models were tested under hydrostatic pressure to determine the structural behavior of ring-stiffened glass-reinforced-plastic hulls with such structural details as small cylinder penetrations and end closures. Two models incorporated cylinder penetrations; two had hemispherical end closures, one each of titanium and GRP. The results of the tests indicate that such details might be used in composite GRP hulls without a severe weight penalty. However, fatigue tests of small-scale models and further static and cyclic investigations of large-scale and complete unit models are required to fully establish the feasibility of these structures for deep-submergence applications.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Hydrostatic Testing						
Cyclic Testing						
Titanium						