DISCUSSION

J. L. Atkerson[1]

Introduction

The author needs to be commended for a very timely paper on hyperhemispherical viewports. The paper presents valuable design information not only on acrylic viewports that serve as pressure-resistant conning towers with panoramic visibility for manned submersibles, but also on glass viewports that serve as pressure housings with panoramic visibility for television cameras mounted on top, below, or in the rear of the submersibles. Either way, the hyperhemispherical windows described in this paper complement the forward visibility provided to the crews of modern submersibles by the spherical sector bow windows (developed by Dr. Stachiw in 1968). The data described in this paper have already been utilized in the design of a hyperhemispherical conning tower for Mermaid VI submersible.

Discussion

Although the author covered the technical subject adequately, the physical constraints imposed by the length of the paper forced him to omit experimental data that are of great potential value to the researcher into the effect of penetrations on the distributions of strains and stresses in spheres of viscoelastic material. Thus, to complement the paper the omitted experimental data have been reviewed and are presented here in the form of a brief summary.

Penetrations as Stress Raisers in Plastic. Circular penetrations in spherical shells serve as sources of serious stress concentrations when the reinforcement around the penetration is significantly stiffer than the material of the shell that it replaces. This is particularly the case with acrylic plastic spherical shells under external pressure where the opening has been reinforced with a metallic flange that is significantly stiffer than the acrylic plastic which it replaces.

If the acrylic plastic was a perfectly elastic material with linear strain response, the magnitude of meridional stress on the interior surface of the shell in contact with the metallic flange would be 4 to 5 times higher than the nominal membrane stress measured on the interior apex of the sphere (Reference 8). Fortunately the response of acrylic plastic to biaxial compressive stresses is only linear in the 0 to 10,000 microinches/inch range under short term loading, and 0 to 5000 microinches/inch range under long term sustained loading (Reference 8). At higher strain levels the response of acrylic plastic to compressive biaxial stress becomes markedly non-linear, both with respect to imposed stress, and duration of loading.

As a result of this non-linear and viscoelastic behavior, the inner edge of the conical penetration in acrylic shell deforms at a non-linear rate without generating excessive stresses in acrylic plastic around the penetration. Figs. 13 and 14 show the results of this response to overstressing at the edge of penetration under short term loading. Thus, while the stresses on the interior surface of the sphere at the apex increase linearly with pressure under short term loading those near the penetration do not. If the graph of the meridional stress at interior edge of penetration was to be extrapolated along the slope seen at the beginning of pressurization, the maximum stress at 1000 psi pressure would have been 20,000 psi (stress concentration of approximately 5) instead of 4500 psi (stress concentration of approximately 2.25). It is only because of local deformation of the penetration's inner edge that the magnitude of stresses in acrylic plastic near the edge remains within acceptable limits.

The amelioration of peak stress near the edge of penetration is further extended under sustained long term loading. Comparison of Figs. 15 and 16 shows clearly that while the hoop and meridional strains on the interior surface of the sphere at the apex shows only a small amount of creep, the meridional strain near the edge shows a very significant amount of creep, while the hoop strain shows none. This is as it should be, since the rotation of the sphere's edge in contact with the metallic flange generates very high forces along meridional axis and none in the hoop direction.

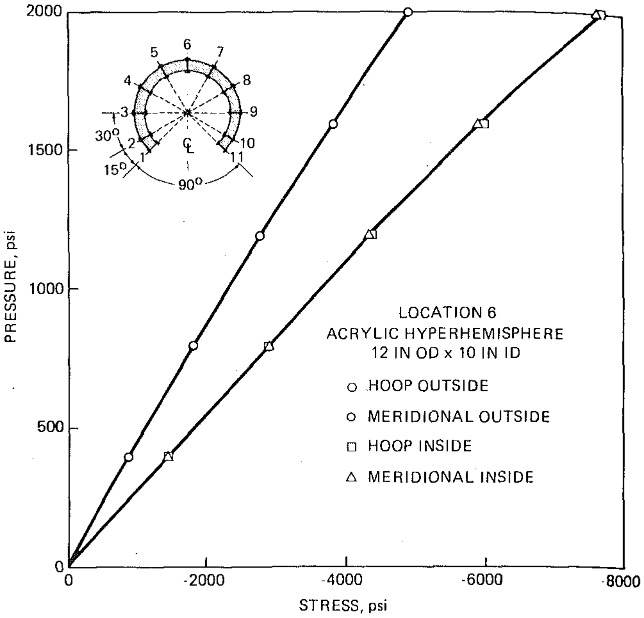

Fig. 13 Membrane stresses at the apex of the acrylic hyper-hemisphere under short term hydrostatic loading. Note the linearity of stress on both exterior and interior surfaces.

Although the high modulus of elasticity commonly found in transparent brittle materials (glass, sapphire, quartz, etc.) makes it easier to match the membrane strains in the window with the hoop strains in the metallic mounting extreme care must be taken that this match is perfect, or if this is not feasible, that the hoop strains in the mounting are higher than the membrane strains in the hyperhemispherical window. If this is not done, the meridional compressive stress on the interior surface of these perfectly elastic and brittle windows at the edge of penetration will be 4 to 5 higher than the membrane stress. As a result of this high stress concentration the safe operational

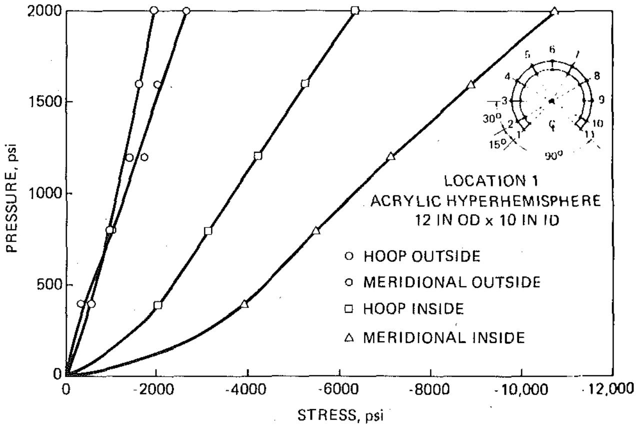

Fig. 14 Combined stresses at the edge of penetration in acrylic hyper-hemisphere under short term hydrostatic loading. Note the nonlinearity of stresses on the interior surface, indicating local, nonlinear, elastic deformation at the inner edge due to large bending movement.

---

[1] P.O. Box 2343; El Cajon, CA. 92021.

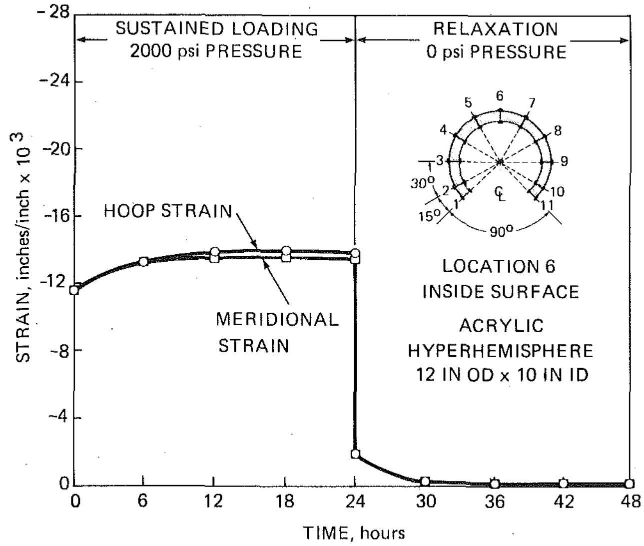

Fig. 15 Membrane strains at the apex of the acrylic hyperhemisphere under long term hydrostatic loading. Note that there is very little creep at this location, and that it is of the same magnitude in both meridionial and hoop directions.

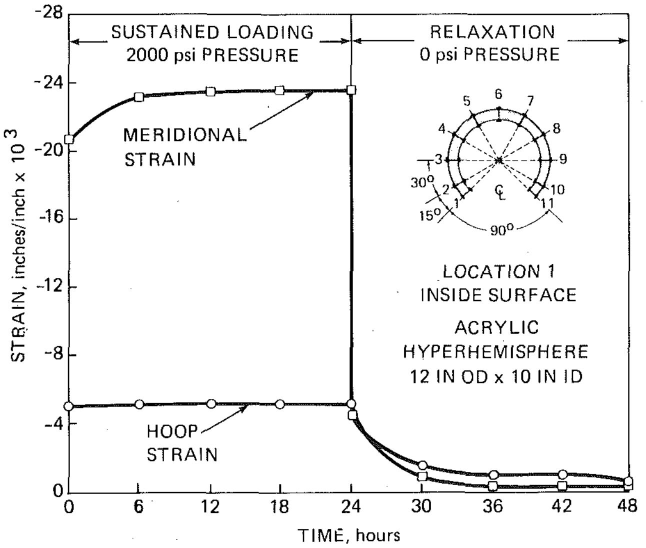

Fig. 16 Combined stresses at the edge of penetration in acrylic hyperhemisphere under long term loading. Note the large elastic creep in meridional direction and the total absence of creep in hoop direction indicating local, elastic creep of the inner edge due to large bending moment.

depth of the glass window would not be significantly higher than of an acrylic window with identical dimensions even though the compressive strength of glass is an order of magnitude higher than of acrylic plastic.

It is only because the titanium mounting, shown in Figs. 3 and 4, had a higher circumferential strain than the membrane strain in a glass hyperhemisphere that Dr. Stachiw was able to reach 10,000 psi pressure without failure or initiation of cracks. If steel (which has a modulus of elasticity twice as large as titanium) is substituted for titanium in that mounting implosion of the window would occur below 10,000 psi. If a material with modulus of elasticity in the 30×10^6 to 50×10^6 psi range (i.e., sapphire) was substituted for glass in the hyperhemisphere a steel mounting would probably be found to be just right.

Conclusion

Acrylic plastic is well suited for construction of hyperhemispherical windows in manned submersibles as the nonlinear, but still elastic, response of acrylic plastic to compressive stresses allows the use of metallic mountings, which are *significantly* stiffer than acrylic plastic hyperhemispherical windows because the peak compressive stress in the acrylic plastic at the edge of penetration rises only about 100 *percent above the membrane stress on the interior of the window at its apex.*

The use of mountings that are significantly stiffer than the windows provides the designer of the submersible with more design options, and requires simpler calculations than mountings whose stiffness has to match the stiffness of the window exactly. This reason, in addition to the lower cost of acrylic plastic, make the acrylic plastic rather than glass hyperhemispheres a cost-effective solution to applications where a pressure-resistant dome of transparent material is required for depths less than 1000 meters (3280 feet).

Author's Closure

The discussion presented by J. L. Atkerson is a very valuable con*tribution to the paper as it highlights the difference in responses of* acrylic and glass hyperhemispheres to penetrations supported by rigid mountings with conical seats. The discussion reinforces well the main point of the paper; the radial displacement of the mounting for acrylic hyperhemisphere must be *equal to or less* than that of the plastic that is replaces, while the displacement of the mounting for a hyperhemisphere made of brittle material (i.e., glass, quartz, saphire, germanium etc.) must be *equal to or larger* than that of brittle material that it replaces. Since it is easier and less expensive to design and fabricate such mountings for acrylic plastic hyperhemispheres the use of acrylic plastic for hyperhemispheres with maximum design depth of less than 3280 feet (1000 meters) is a more cost effective solution than the application of brittle material like glass.

The author deeply appreciates the time and effort expended by J. L. Atkerson in preparation of this excellent discussion.