SHALLOW SPHERICAL CAPS UNDER EXTERNAL PRESSURE

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Summary This contribution details buckling tests and corresponding numerical results for shallow spherical caps subjected to static and uniform external pressure. Six mild steel caps were carefully CNC-machined from a solid billet of 245 mm diameter. Shallowness parameter, λ, varied from 3.5 to 5.5.

BACKGROUND

Buckling of spherical caps subjected to uniform and static external pressure has been researched for decades. Reference [1] lists most of the relevant work spanning a century or so. When reviewing the experimental work on buckling of spherical caps it becomes transparent that only small number of tests was carried out on metallic caps. One specific set of tests is reported in Ref. [2]. They were small diameter, 50mm – 70mm, aluminium models. A drop in the buckling strength was confirmed in these tests for small magnitude of caps' slenderness parameter lambda, i.e. for $\lambda \approx 4.0$.

A number of subsequent tests did not follow the same trend. Various reasons were given in order to explain this scatter of results around lambda = 4.0. By-and-large there appears to be no definitive answer to this dilemma.

This limited experimental/numerical study aims at exploring spherical caps' static stability around $\lambda = 4.0$. This is to be achieved through careful manufacturing of caps with well defined boundary conditions. Experiments have already been carried out and results of initial numerical runs are given here.

SUMMARY OF EXPERIMENTAL AND NUMERICAL RESULTS

A series of six cups, designated here as D1, …, D6, were CNC-machined from 245mm diameter mild steel billet. Shells had a heavy edge ring (integral with the wall). Its role was to model the fully clamped boundary conditions. The shallowness parameter, λ, was chosen to be between 3.5 and 5.5. The sequence of manufacturing for these caps was the same as in Ref. [3]. After final machining caps were stress-relieved in a vacuum furnace. Next, shape and wall thickness were measured. Shape was measured using an (XYZ)-co-ordinate measuring table. Measurements were taken along 14 equally spaced meridians and at 10 mm arc-length intervals. Table 1 contains average values for geometry (columns 2 – 5). It is seen from Table 1 that the height-to-wall thickness ratio varied approximately from 2.5 to 4.0 and the radius-to-thickness ratio varied from 300 to 1800. Examining the scatter of wall thickness, and radial deviations from perfect geometry it can be concluded that they all were, geometrically, nearly-perfect. Further details are to be published separately.

Mechanical properties of mild steel were the same as reported in Ref. [3]. That paper should be consulted for further details. Average mechanical properties of the mild steel were found to be: Young's modulus, E = 207.0 GPa, Yield point of material, $\sigma_{yp} = 303.5$ MPa; and Poisson's ratio, $\nu = 0.28$.

The above models were buckled through the application of quasi-static external pressure in a small pressure vessel opened to atmosphere (again, further details are to be published separately). All caps failed suddenly through a snap-through mechanism. Values of experimental buckling pressures are given in Table 1 (column 6). The initial numerical predictions of buckling loads were carried out using axisymmetric modelling of geometry and elastic perfectly-plastic modelling of the stress-strain curve. The latter corresponded well to steel which was used for manufacturing models D1, …, D6. Table 2 contains comparison of experimental and numerical results. Comparison of experimental failure pressures with numerical predictions is found to be good (with the ratio of, p_{expt}/p_{num}, varying from 0.92 to 1.04). Also, the trend of experimental data on load versus the slenderness parameter, λ, confirms a sudden dip in the load carrying capacity around $\lambda = 4.0$.

Model	D_i (mm)	H (mm)	t (mm)	R (mm)	p_{expt} (MPa)
D1	166.12	1.90	1.0	1816.5	0.0458
D2	166.13	2.15	1.02	1605.7	0.0523
D3	166.10	3.93	1.03	878.6	0.211
D4	166.12	2.96	1.76	1166.7	0.330
D5	166.10	4.56	1.76	759.3	0.650
D6	166.18	6.20	1.76	563.4	1.172

Table 1. Average experimental dimensions (mid-surface where appropriate). Also, experimental buckling pressures.

Model	λ	p_{cl}	p_{expt}/p_{cl}	p_{num}/p_{cl}	p_{expt}/p_{num}
D1	3.56	0.0755	0.61	0.59	1.04
D2	3.74	0.101	0.52	0.57	0.92
D3	5.04	0.342	0.62	0.61	1.01
D4	3.35	0.567	0.58	0.59	0.98
D5	4.11	1.338	0.49	0.450	0.98
D6	4.8	2.430	0.48	0.49	0.99

Table 2. Comparison of experimental buckling pressure, p_{expt}, with classical, p_{cl}, and numerical, p_{num}, predictions.

References

[1] J. Singer, J. Arbocz, T. Weller, “Buckling experiments – Experimental Methods in Buckling on Thin-Walled Structures – Volume 2”, John Wiley & Sons, NY, Chapter 9, 2002.

[2] M.A. Krenzke, T.J. Kiernan, “Elastic stability of near-perfect shallow spherical shells”, AIAA J., vol. 1, 2855-2857, 1963.

[3] J. Blachut, G.D. Galletly, D.N. Moreton, “Buckling of near-perfect steel torispherical and hemispherical shells subjected to external pressure”, AIAA J., vol. 28, 1971-1975, 1990.

Notation

t – uniform wall thickness

p_{cl} – linear classical buckling pressure ($p_{cl} \equiv 2\left[3\left(1-\nu^2\right)\right]^{-1/2} E\left(t/R\right)^2$)

D_i - base diameter of spherical cap

H – rise of spherical cap

R - radius of spherical cap

λ - geometric parameter ($\lambda \equiv 2\left[3\left(1-\nu^2\right)\right]^{\frac{1}{4}}\left(H/t\right)^{1/2}$)

ν - Poisson’s ratio

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