Numerical and Experimental Investigation of Buckling Behaviour of Metallic Dished Shells under Uniform External Pressure

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by

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ABSTRACT

The dished shells are similar to conical frustum with a closed circular top on the smaller diameter end. Due to the discontinuity in the geometry of these shells, they become very special in nature. Metallic dished shallow shells are used as actuator elements in fluid control components working at very low temperatures of the cryogenic engines of spacecraft launch vehicles. These types of shells exhibit a special type of buckling behaviour as noticed in the case of arches and shallow spherical caps. This phenomenon needs to be studied in detail for dished shells. To study the buckling behaviour of dished shells we have carried out Finite Element (FE) based numerical analysis and experimental investigation on a uniform thickness shell to validate the numerical results and material model. A study is also carried out to study the effect of imperfections on the critical buckling pressure of these shells. Based on these results a statistical cum mathematical model using Response Surface Methodology (RSM) is proposed for the estimation of the critical buckling pressure of these shells.

In the present study, two types of dished shells are considered based on the rigidity of the top circular region: uniform thickness (with a flexible top region) and dual thickness (with a stiff top region). Initially, an FE based elastic linear Eigenvalue buckling analysis on dished shells is carried out to evaluate the effect of various geometrical parameters of the dished shells such as shell thickness, height and radius of the flat top circular region under uniform external pressure. The effect of two types of boundary conditions on the mode shape and critical buckling pressure is also studied. It is found that dished shell buckling modes and critical buckling pressure significantly depend on the geometrical parameters of the shells. The buckling modes of uniform thickness shells and dual thickness shells are different in nature. In the case of uniform thickness shells predominant buckling modes are the deformation in the central top flat region, in contrast to the wavy pattern in conical region for the dual thickness shells. It is also observed that dual thickness shells exhibit different harmonics in the conical region for different modes of deformation. However, the values of the critical buckling pressure for the dual thickness shells for different modes are very close to each other. Whereas, the values of the critical buckling pressure for the uniform thickness shells are significantly different for the various modes except for the conjugate modes.

Subsequently, a non linear FE analysis with elastic and elastic-perfectly-plastic material

behaviour of dished shells is carried out for the different geometrical parameters such as shell thickness, height and top flat region radius under similar boundary conditions as used for the mode shape analysis. This analysis is carried out to find out the effect of various geometrical parameters and boundary conditions on the post buckling behaviour of the dished shells. The analysis result indicates that snapping of the shells occurs at a critical pressure, which depends on the values of shell characteristic parameters. In general, the critical buckling pressure is seen to increase with decrease in characteristic parameters. A study for imperfection sensitivity is also carried out to see the effect of the presence of axisymmetric imperfections on the critical buckling pressure. The imperfections are introduced in the form of percentage reduction in the shell thickness as a linear combination of first three Eigen modes in the conical region.

The critical buckling pressure obtained from these studies are higher in comparison to the values obtained using literature on equivalent spherical shells. Towards this an experimental investigation is also carried out using Differential Image Correlation (DIC) technique to capture the buckling and post buckling behaviour on a dished shell of uniform thickness under fixed boundary condition. To determine the reason for the difference in critical buckling pressure an elastic-perfectly-plastic material model is chosen and non-linear FE analysis is repeated and results are very convincing.

Finally analysis results were used to provide a statistical design tool based on Response Surface Methodology (RSM) for predicting the critical buckling pressure of such shells. In the future it is possible to use this technique to give an empirical relationship between the design variable and critical buckling pressure of the shell.