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Denting Analysis of Ring Stiffened Cylindrical Shells

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ABSTRACT

The objective of this paper is to assess the effect of ring stiffeners on the local response of cylindrical shells subjected to large deflections caused by transverse concentrated loads. A new model has been developed to account for the strengthening of the shell in the circumferential direction as the deformation zone spreads away from the load application point. The model is general and can be applied to shells with any type of stiffeners. Strains and rotations were also determined in the dent-affected zone near the stiffeners. It was found that ring stiffened shells are more susceptible to fracture than similar shells with uniform thickness.

INTRODUCTION

The objective of this study is to extend the plastic analysis of local denting of unstiffened cylindrical shells developed by Wierzbicki and Suh (1987) to ring stiffened shells. Observations show that, while the ring stiffeners increase the strength of the shell, they may cause premature fracture in the case of extreme loads. The fracture process is driven by the local stress and strain fields, and these local fields depend on the global deformations and forces in the structure. Therefore, it is important to formulate and analyze the global denting response of the stiffened shell.

The present analysis can also be applied in damage assessment of offshore installations collided into by supply boats or moving ice floes; hydrodynamic wave impact on tubular members; impact caused by accidentally dropped objects; and ice scouring of Arctic pipelines. There has been increasing concern in the area of collision and damage of these structures. A comprehensive review of the state of the art in the study of collisions and damage of offshore structures was published by Ellinas and Valsgard (1985) and more recently by Moan and Amdahl (1988).

The approach taken in this research is based on the methodology developed by Wierzbicki and Suh (1987), which analyzed the problem of large plastic deformation of an unstiffened tube subjected to lateral concentrated load, axial force, and bending moment. This methodology was derived from an approximate theoretical model by de Oliveira et al. (1982), developed to obtain a relationship between the load and dented depth of unstiffened cylinders under lateral concentrated loading. Walker and Kwok (1986) also used an energy approach in conjunction with a different plastic mechanism to provide the relationship between the load and residual depth of an unstiffened cylindrical shell under a transverse punch load. Furthermore, some experimental and analytical research has also been carried out on ring and orthogonally stiffened cylinders (Onoufriou and Harding 1985; Ronalds and Dowling, 1987; Frieze and Sachinis, 1983]. In particular, Ronalds and Dowling analyzed the denting process of short, orthogonally stiffened shells under a transverse punch load by using a local equilibrium approach. They reported good agreement with experimental data on short, orthogonally stiffened tubes. Other approaches taken to solve this class of problem include the use of nonlinear finite element and finite difference programs such as ABAQUS, ADINA and PAM-CRASH. These programs are particularly suited for detailed analysis of the problem such as the determination of stresses and strain fields in the shell. Onoufriou et al. (1987), for example, studied the denting process of ring stiffened cylinders using a finite element method.

In this analysis, the energy approach is adopted to solve the local denting of a shell with evenly spaced ring stiffeners. The equilibrium condition is expressed through the principle of virtual velocities. A key element in deriving a closed-form solution is the assumption that the bending strength of the ring stiffened shell in the circumferential direction depends on the length of the deformed region. Stiffeners are treated as discrete entities, each strengthening the shell in the circumferential direction as it deforms. Results obtained from experiments and other approximate techniques are used to compare to theoretical predictions. Finally, the deformed profiles and strain distributions are derived for the ring stiffened cylindrical shell. Using this model the maximum strains are determined at critical locations in the shell.

PROBLEM FORMULATION

Consider a ring stiffened cylindrical shell that experiences large deflections and sectional collapse under the action of a rigid indenter. The parameters that describe the shell geometry during indentation are shown in Fig. 1. Additional parameters that describe the stiffener geometry will be discussed later. The length of the deformed zone ξ varies during the deformation process and is taken as one of the variables to describe the deformed geometry. The depth of the dented zone δ is not restricted and can get as large as the diameter of the cylinder.

Experimental observations show that the cross-sectional shape of the cylinder under a rigid punch load has a flat upper part in the damaged zone. A cross-sectional profile consisting of four moving plastic hinges has been proposed by Wierzbicki and Suh (1987) to realistically describe the deformation profile of the shell. This profile is also shown in Fig. 1.

Theoretical Background

The equilibrium equation is derived from the principle of virtual velocities:

$$\dot{E}_{ext} = \dot{E}_{int} \tag{1}$$

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