COUNTERINTUITIVE RESPONSE OF LONG CIRCULAR TUBES TO AXIAL IMPACT

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Summary The dynamic transition from progressive buckling to global bending collapse of a long circular tube under an axial impact is studied in order to obtain the energy absorption characteristics. The developed theoretical modes are used to analyse the influence of various parameters on the buckling transition. The analysis reveals a specific impact velocity, which causes a counterintuitive response of a tube. An empirical criterion for the lower and upper bounds to the critical lengths for buckling transition is proposed.

INTRODUCTION

When tubes with various cross-sections are used as energy absorbing devices, the optimisation of these structures usually assumes that the particular geometry will promote a progressive buckling mechanism, which is maintained throughout the response [1]. The initiation of the desired buckling mode becomes rather complicated when long shell-like structures are to be used to absorb the impact energy as these structures can exhibit additional buckling modes leading to poor energy absorption. In particular, buckling modes similar to the Euler buckling mode characteristic for statically loaded rods or higher dynamic 'rod' modes can develop in long tubes (global bending) depending on the geometry, boundary conditions and material of the structure as reported in the experimental studies [2,3].

The mixed collapse modes - global bending with progressively developed wrinkles, which are observed experimentally and numerically [4,5], suggests that 'rod' and 'shell' buckling modes co-exist in long tubes and they can develop simultaneously during impact. It has been anticipated until recently that the increase of the impact velocity will lead to a stabilisation of the tube response due to the inertia effects. However, more comprehensive experimental studies [6] revealed that this increase is not monotonic and is accompanied by a counterintuitive response.

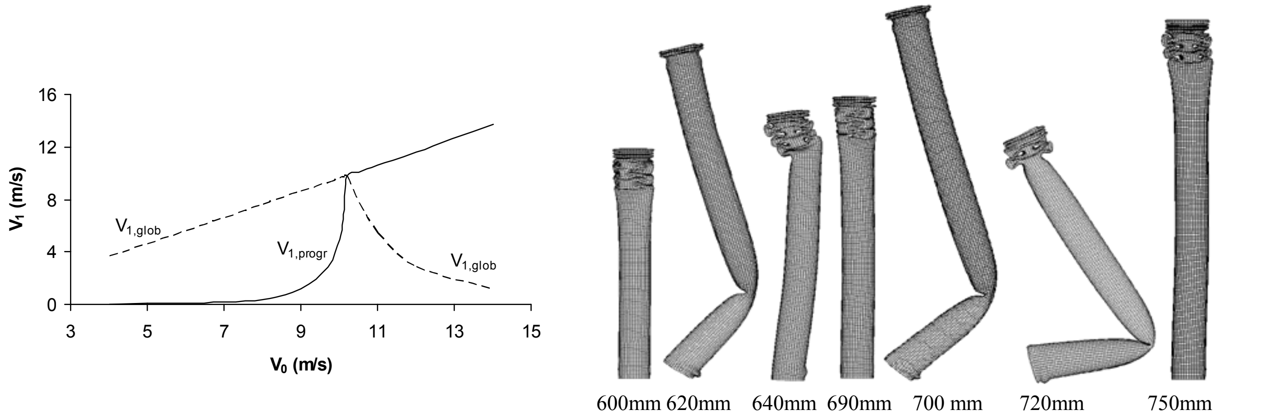
The purpose of this study is to bring an insight into the complex interaction between the two buckling modes and to analyse the predictability of the dynamic transition from progressive buckling to a global bending collapse.

THEORETICAL APPROACH

Two well distinguishing phases of deformation - initial compression and bending - characterise the response of shells that buckle in the plastic range and significant proportion of the initial kinetic energy can be absorbed during the first response phase of these structures, depending on how long the lateral inertia can support the unbuckled shape [4,5]. Thus, the compression phase can influence the initial conditions for the subsequent phase of deformation and in this way can affect the selection of the particular mode of collapse - global bending or progressive buckling (folding). This kind of response suggested to use a two-phase approach to estimate the speeds of the development of the two buckling modes during the initial compression and subsequent post-buckling response depending on the material properties and loading parameters. Due to the compressibility of the shells made from ductile materials, the initial displacements and velocities at the end of the compression phase at $t = t^*$ are functions not only of the loading parameters but also depend on the geometric and material properties of the shell. The numerical simulations show that bending deformations with small amplitudes associated with the global bending and progressive buckling modes start to develop during the compression phase. Therefore, different initial conditions can be set in the shell at the outset of the subsequent phase of deformation, which can be progressive buckling or global bending. These initial conditions determine the speeds of the development of the corresponding buckling mode and a relationship between the displacements and velocities at $t = t^*$ and the various parameters that characterise the dynamic buckling transition phenomenon exists.

RESULTS

The initial conditions for the development of the global bending mode and progressive buckling mode are obtained as functions of the loading parameters, geometrical and material characteristics of a shell when using separate structural models for the two deformation phases. The axial velocities $V_{glob}(t^*)$ and $V_{progr}(t^*)$ at $t = t^*$ for the initiation of the post-buckling development of global bending and a local wrinkle calculated according to the theoretical models are shown in Fig. 1(a) as functions of the initial impact velocity V_0 for a particular shell geometry. One can see that there is a specific impact velocity, $V_{0,cr}$, which causes equal speeds of the development of the two buckling modes ($V_{progr}(t^*) = V_{glob}(t^*)$). In this case, there is no obvious leading mode at $t = t^*$, which could determine the buckling pattern in a unique way causing its development during the bending phase. The axial velocities V_1 associated with the two buckling modes become incomparable away from the critical impact velocity $V_{0,cr}$ thus corresponding to the selected preferable mode associated with the higher speed. Impact velocities around the critical value cause a counter intuitive response as shown in Fig. 1(b) when identical impact loads are applied to shells with equal cross-section characteristics and made from the same materials but the shell length increases.



(a) (b)

Figure 1 (a) Velocities $V_1(t^*)$ at the end of the compressive phase: —— progressive buckling mode, ---- global bending mode, L = 550 mm, h = 2.19 mm; (b) Buckling shapes of tubes made of an aluminium alloy ,V_0 = 10.4 m/s and G = 209 kg.

An empirical criterion for the lower and upper bounds to the critical lengths for buckling transition depending on the impact velocity and the striking mass is proposed in this study. This criterion is based on the absorbed energy during the development of a single wrinkle and the vertical velocities of the proximal end of a shell, which are associated with the two buckling modes.
The analysis of the buckling process of relatively long circular tubes suggests that an introduction of an appropriate trigger (either mechanical dent or altering locally the material properties) will improve the energy absorbing characteristics of the device by promoting the initiation of progressive buckling. However, in the case of large impact energy when a large number of wrinkles are necessary to absorb the initial kinetic energy, the buckling initiation into the desirable buckling mode will not promote entirely progressive buckling.

CONCLUSIONS

The present study reveals that, for practical purposes, it is advisable to analyse the response of relatively long tubes when subjected to the actual mass. The velocities causing comparable initial conditions for the buckling/bending phases and therefore counterintuitive deformation of the energy absorbers can be avoided by a variation of the cross-sectional characteristics of the tubes. If certain geometry is required, different materials can be selected to assure a predictable response of the energy absorber.

References

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