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Review

# Impact stress reduction by shell splitting in cask for transporting radioactive material

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ABSTRACT

Casks designed for transporting radioactive material are mandated to withstand drop from specific heights on hard ground. The maximum internal stress in the shell of the cask after such an impact needs to be as low as possible to ensure safety of the material being transported. This paper investigates the concept of splitting the shell of the radioactive transport container into multiple layers to reduce these stresses after impact. Different geometrical configurations which are likely to be encountered while designing such containers have been studied through plane 2D and 3D finite element analysis and the efficacy of this idea has been explored on each of them. Considerable reduction of stress has been reported and an explanation based on elastic deformation of layered beams has been suggested. Simulations on a cask with the currently prevalent design also show the benefit of implementing this idea.


**Contents**



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**Nomenclature**

| | |
|---|---|
| $D$ | outer diameter/equivalent outer diameter at point of impact |
| $\delta$ | deformation in the direction of impact |
| $S_{max}$ | maximum VM stress during impact |
| $PE_{max}$ | maximum plastic strain during impact in steel shell |
| $\Delta\delta$ (%) | difference in deformations of split shell and single shell configurations, expressed as a percentage of the latter |
| $\Delta S_{max}$ (%) | difference in maximum VM stress during impact of split shell and single shell configurations, expressed as a percentage of the latter |
| $\Delta PE_{max}$ (%) | difference in maximum plastic equivalent strain occurred impact of split shell and single shell configurations, expressed as a percentage of the latter |
| $\delta_1$ | deformation of single beam |
| $\delta_2$ | deformation of split beam |
| $L$ | length of beam |
| $F_1$ | point load applied on single beam |
| $F_2$ | force applied on split beam |
| $E$ | Young's modulus of beam material |
| $E_p$ | tangent modulus of beam material |
| $I_1$ | moment of inertia of single beam about neutral axis |
| $I_2$ | moment of inertia of split beam about neutral axis |
| $t$ | shell thickness for single shell configuration and combined thickness of both shells for split shell configuration |
| $b$ | width of beam |
| $\varepsilon_{p1}$ | plastic strain in single beam |
| $\varepsilon_{p2}$ | plastic strain in split beam |
| $\sigma_1$ | stress in single beam |
| $\sigma_2$ | stress in single beam |
| $\sigma_y$ | yield stress of beam material |
| $\sigma_{p1}$ | stress in single beam exceeding yield stress |
| $\sigma_{p2}$ | stress in single beam exceeding yield stress |

## 1. Introduction

Casks designed to carry radioactive material usually use lead as the shielding material and stainless steel as an outer casing (shell). These casks are mandated to withstand an impact which simulates an accident scenario (IAEA, 2008, 2012). Under such an impact, the cask is subjected to high local deformation. The major stresses experienced in this process are by outer shell of cask which can experience high stress and strains. Many authors have investigated the impact of a cask on a rigid target from 9 m height and on a punch from 1 m height (Teng et al., 2003; Jaksic and Nilsson, 2009; Rajendran et al., 2005; Kim et al., 2010a,b). It has been widely reported that the outer shell of the cask, which comes directly in contact with target, experiences high stress. This should not be high enough to cause failure. If experiments show or simulations predict that the stress in outer casing (shell) exceeds its limiting value, then a design modification of the cask becomes necessary. The most common approach to stress reduction has been to provide an additional layer of shock absorber near impact areas where high stresses are experienced. This can be achieved by using softer material (as shown by Rajendran et al., 2008) or some other material as cage which absorbs energy of impact before it reaches the main body of the cask. Many configurations of such a cage have been explored by different authors. One popular configuration for this is foam filled structures which has been studied by many authors for its crashworthiness (Peroni et al., 2008). Multi cell structures have also been demonstrated by some authors (Olabi et al., 2006) to be effective. However, shock absorbers add to the volume of the cask which may not be acceptable under all conditions. An alternative approach to stress reduction is to modify the cask geometry, which may include changing curvatures at some locations, to reduce local impact stresses. In this paper, an attempt has been made to understand this deformation behaviour using objects with simple geometries for impact and thereafter suggest a way to reduce stress in the outer shell. We have tried to establish that if outer shell of a cask is split in multiple parts through the thickness (without changing the total shell thickness), strains and thus stresses show considerable reduction for most of the objects. For this purpose, finite element analysis has been conducted using simple 2-D plane stress and 3-D models. The 9 m drop test was simulated since it is a regulatory requirement and is one of the more widely studied tests for simulating accidents.

It may be emphasized that shock absorbers, if designed properly, can reduce stress levels in the shell of the cask significantly. However, they are essentially an addition to the cask as they add both volume and weight to it. Reduction of volume by using these shock absorbers inside the shell is not a viable option as it will replace lead, leading to reduction in radiation shielding. The proposed approach of using split shells to reduce stress will reduce the size or can eliminate the requirement of an additional shock absorbing material. The volume and weight of the total package will be smaller compared the approach of using shock absorbers since small or no additional material is being used outside the cask. The initial study reported in this paper investigates different lead filled solids which are similar to the shapes of the cask near critical impact locations. This does not take care of all possible cask impact locations/orientations but is expected to simulate those cask locations/orientations which lead to high damage after impact.

## 2. Shell splitting

It is known that a leaf spring allows higher deformation without failure to be achieved using multiple leafs compared to a single leaf of same total thickness. In other words, a single leaf of same total thickness will experience higher stress and strain if both the configurations are subjected to the same deformation. The theory behind this has been explained in Section 8.3. This concept (henceforth called 'shell splitting') was used to reduce stress in the shell of a container. To the best of our knowledge, this method of stress reduction in container shells has not been reported in literature. Shell splitting can also be compared with de-lamination in composite plates. It can be considered as a controlled de-lamination where de-lamination is purposefully introduced to get the benefit of stress reduction. A higher level of overall deformation but lower local deformation (which avoids breakage) is acceptable in the shell since the entire container will be replaced after an accident. Prevention of shell breakage is the primary objective during an accident even at the cost of higher deformation.

In the work presented here, shell splitting is provided in steel casing part of the lead filled geometries considered here. The original shell in single layer is replaced with two layers of shells having same total thickness. Fig. 1 shows both single and split shell configurations. The gaps between the two shell layers and between shell and lead have been exaggerated. No connection is provided between two layers of shell or between the shell and lead and they move freely with respect to each other. As friction has not been considered between different layers of materials, there is no shear