The Effect of Gaps on the Response of Spent Fuel Transportation Package Closure Lid Bolts during an Impact Event

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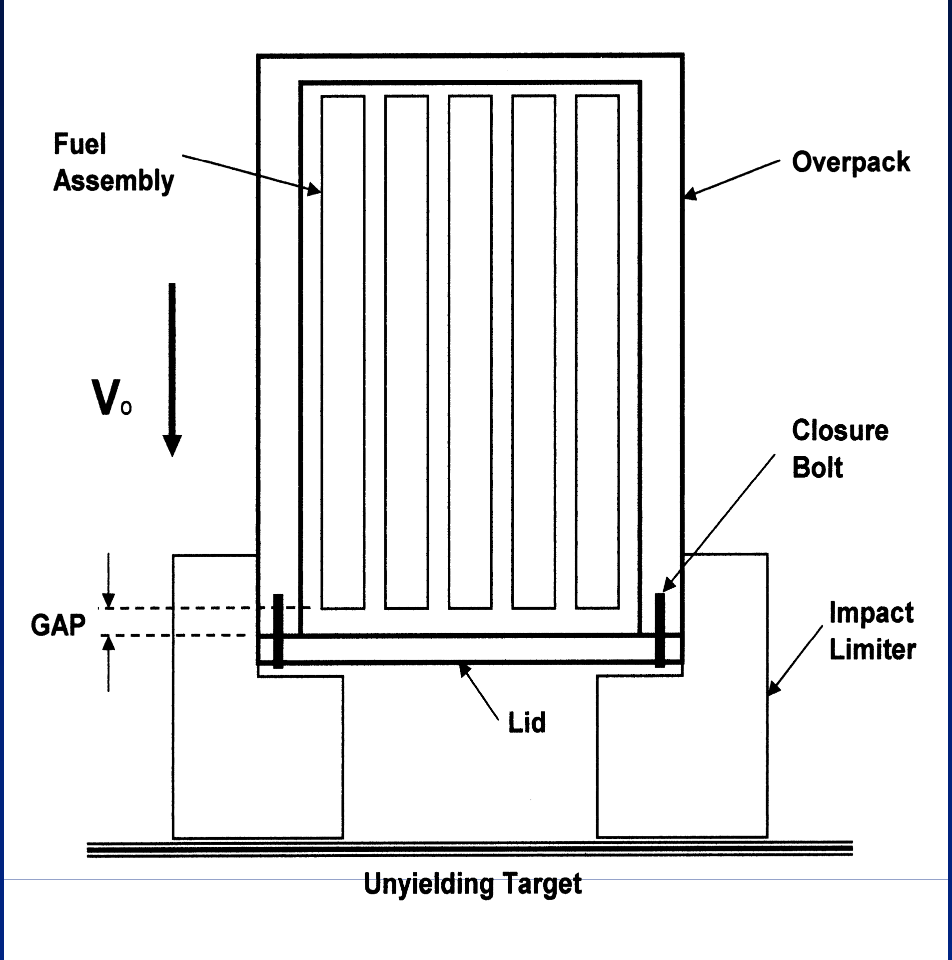
Spent Fuel Transportation Cask

During a transportation impact event, gaps between the various components of a spent fuel transportation cask may create secondary impacts that result in higher dynamic loads than would occur if the gaps had not been present.



Objective and Strategy

- Objective

- To determine when gaps are important to consider and what factors influence response?

- Strategy

- Idealize the problem as a single degree of freedom system.

- Obtain a solution for the idealized problem by treating it as an initial value problem.

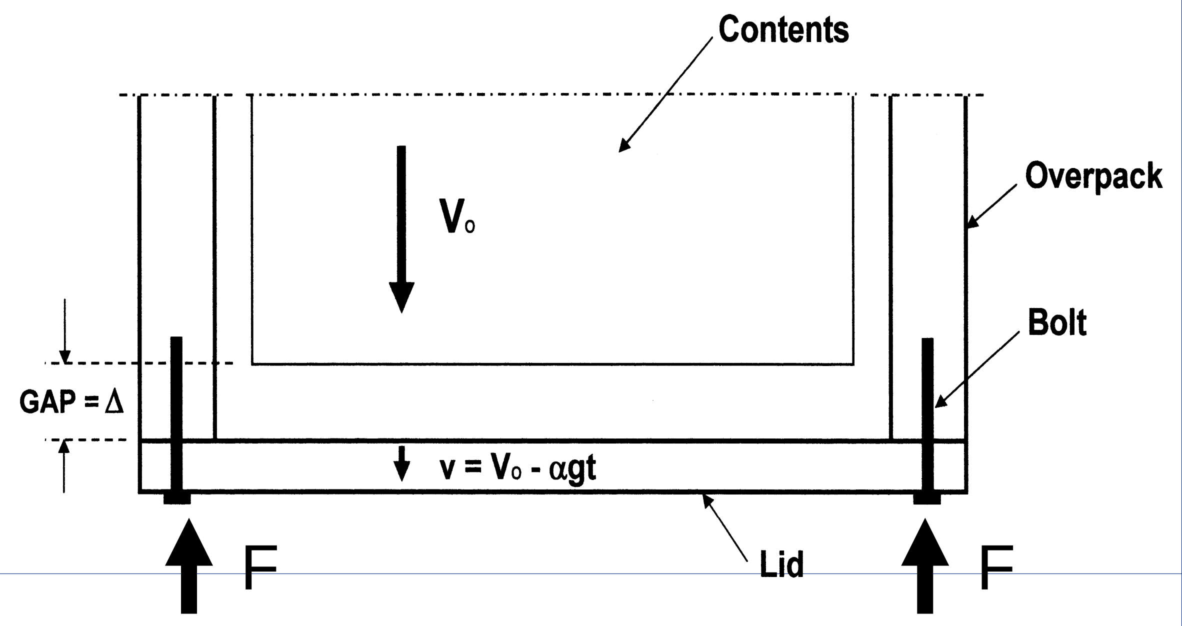
Simple Representation of the Problem Prior to Gap Closure

The crush force, F, produces a constant deceleration, αg.

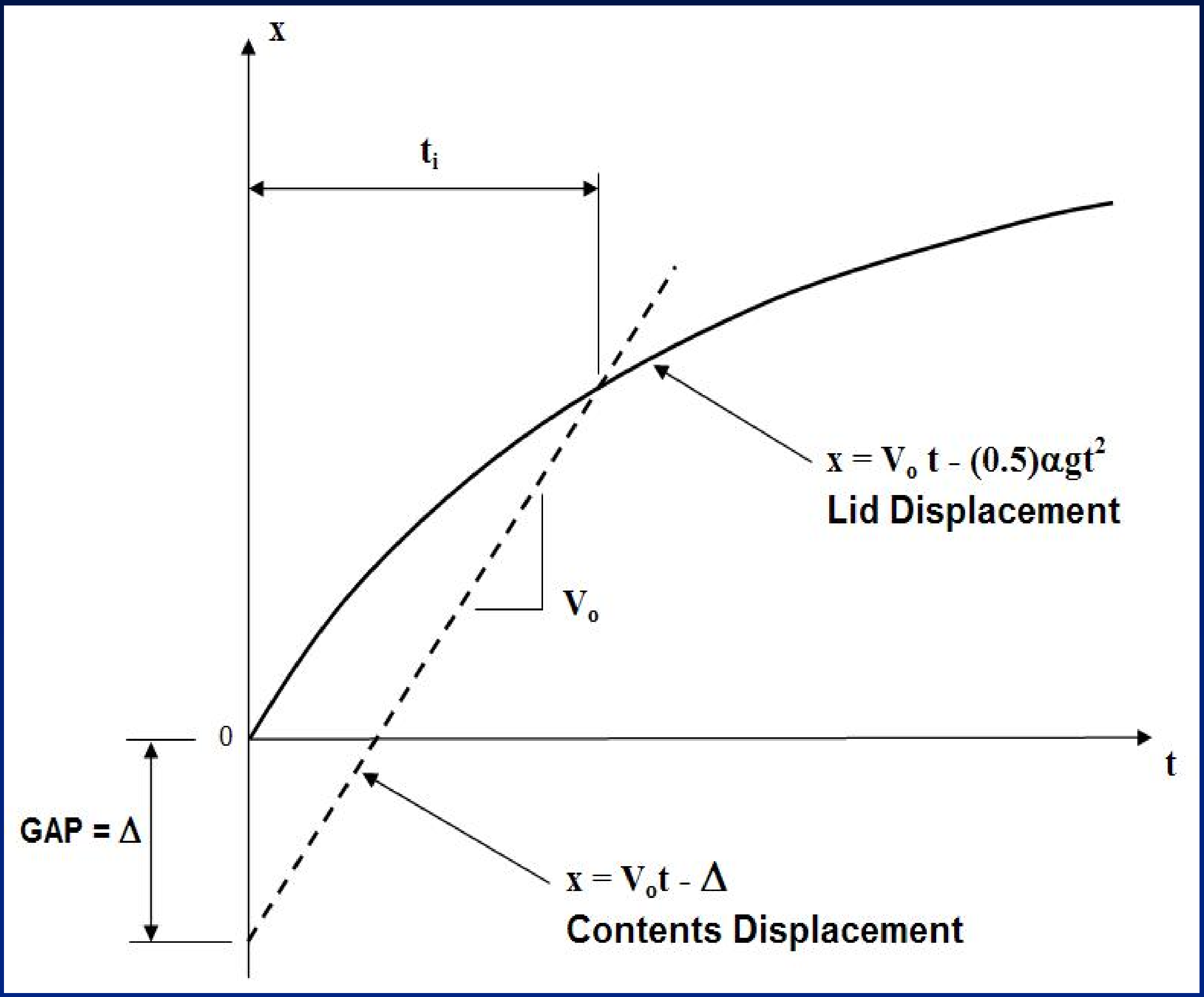
$$a = -\alpha g$$

$$v = V_o - \alpha g t$$

$$x = V_o t - \frac{1}{2}\alpha g t^2$$



Determine the Relative Velocity at the Time the Contents Impacts the Lid



Equating Lid Displacement To Contents Displacement

Time at Gap Closure

$$t_i^{\,2} = \frac{2\Delta}{\alpha g}$$

Subtracting the Lid Velocity From the Contents Velocity

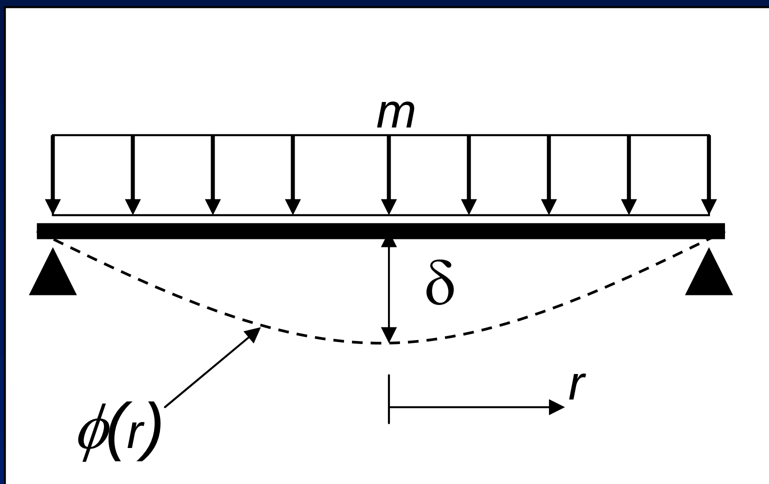
Relative Velocity

$$v_i = -\alpha g t$$

Substituting for t

$$v_i = \sqrt{2\alpha g \Delta}$$

Problem Idealized as a Single Degree of Freedom System



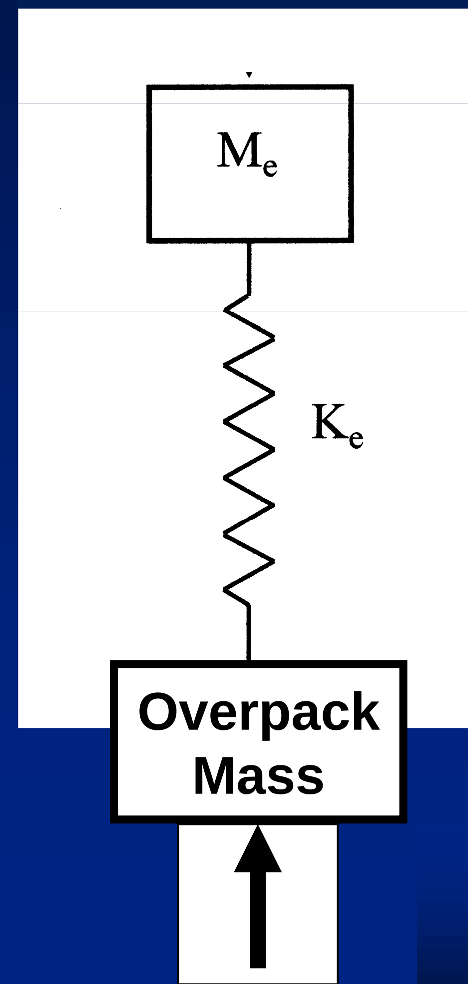
Equivalent Mass, *Me*

$$M_e = \iint m\phi(r)^2 r dr d\theta$$

$$M_e = \frac{m \pi R^2}{3}$$

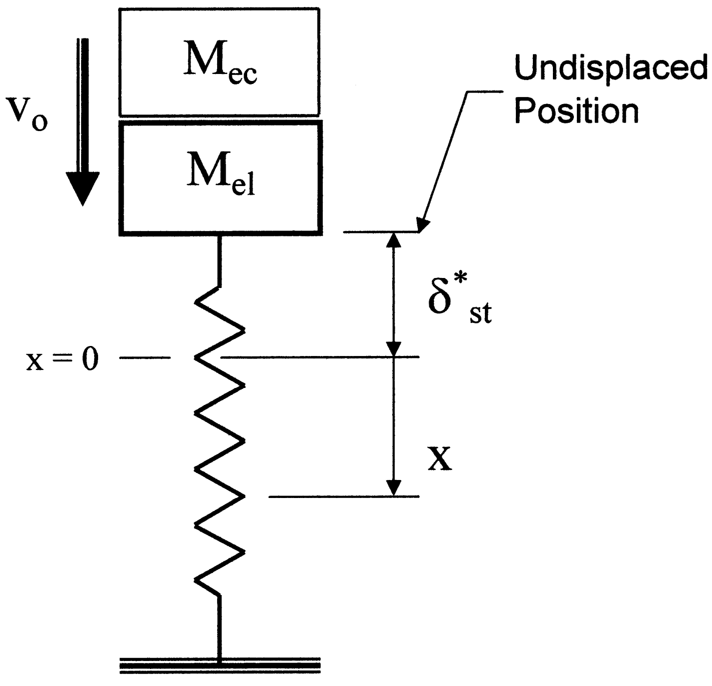
Equivalent Stiffness, *Ke*

$$\delta = \frac{M_e g}{K_e}$$



Initial Value Problem

Assumptions:
1) Fully Plastic Impact between Contents and Lid
2) Lid Response is Elastic



Solution of the Free Vibration Problem With Initial Conditions

$$x = x_o \cos(\omega t) + \left(\frac{v_o}{\omega}\right)\sin(\omega t)$$

Initial Velocity (v_o) of Contents and Lid

$$v_o = v_i \frac{M_{ec}}{M_{ec} + M_{el}}$$

Initial Displacement

$$x_o = \delta_{st}^* = \alpha\delta_{st}$$

Frequency

$$\omega^2 = \frac{K_e}{M_e} = \frac{\frac{M_e g}{\delta_{st}}}{M_e} = \frac{g}{\delta_{st}}$$

Solution of the Free Vibration Problem With Initial Conditions

$$x = x_o \cos(\omega t) + \left(\frac{v_o}{\omega}\right)\sin(\omega t)$$

The Maximum Amplitude of the Displacement, x, Measured from the Static Equilibrium Position, x = 0

$$x_{\max} = \sqrt{x_o^{\,2} + \left(\frac{v_o}{\omega}\right)^2}$$

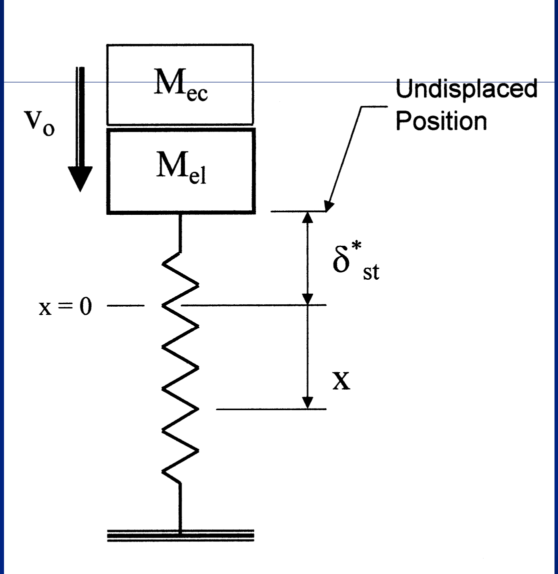
Substituting Results from Previous Slide

$$x_{\max} = \alpha\delta_{st}\sqrt{1 + \left(\frac{2\Delta}{\alpha\delta_{st}}\right)\left(\frac{M_{ec}}{M_{ec}+M_{el}}\right)^2}$$

Total Displacement = $\alpha\delta_{st} + x_{max}$

Dividing the Total Displacement by the Static Displacement, $\alpha\delta_{st}$, one Obtains The Dynamic Load Factor, DLF.

$$DLF = 1 + \sqrt{1 + \left(\frac{2\Delta}{\alpha\delta_{st}}\right)\left(\frac{M_{ec}}{M_{ec}+M_{el}}\right)^2}$$

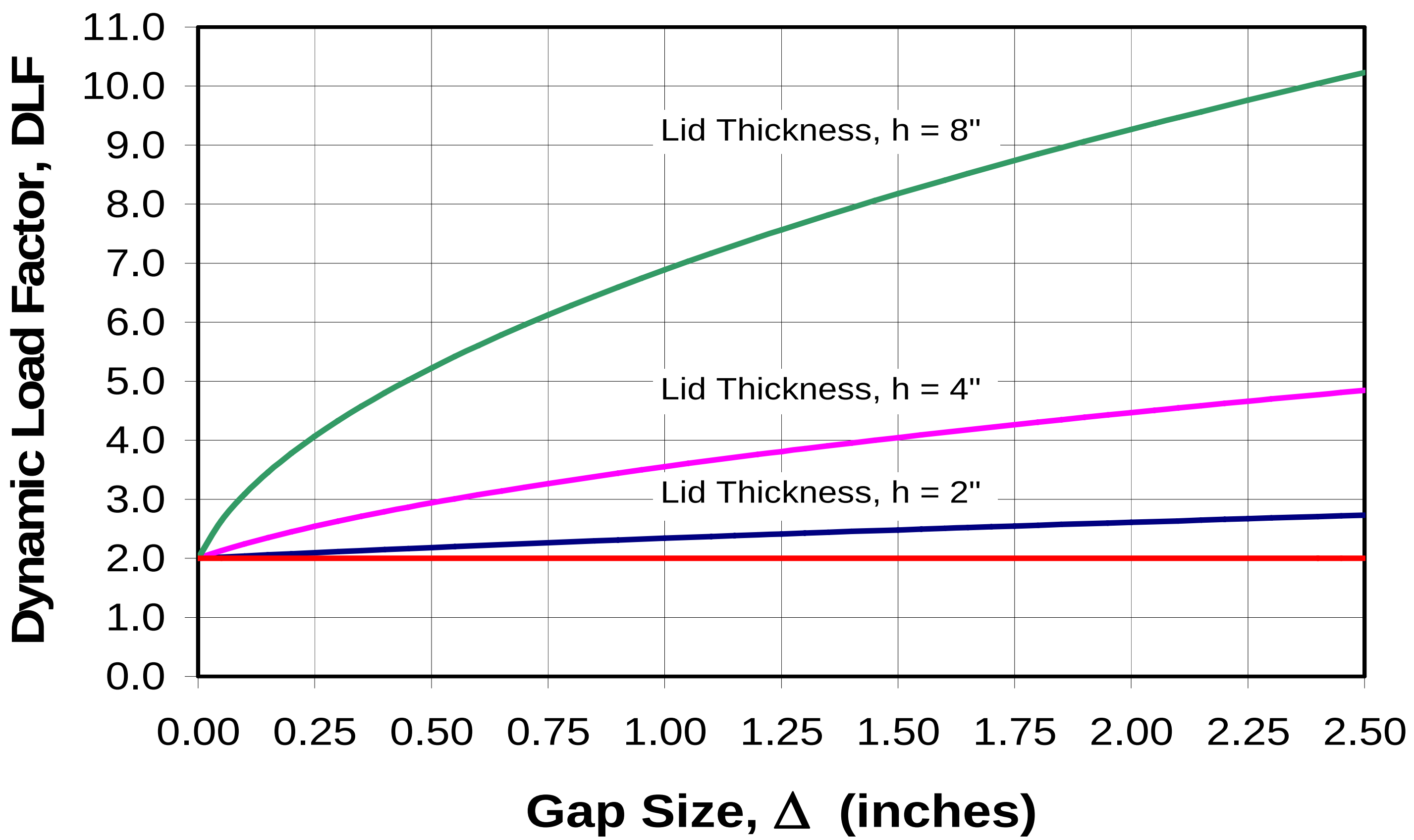


Dynamic Load Factor Plotted as a Function of Gap Size, Δ, for Three Lid Thicknesses

DLF = 1.0, Static Response

DLF = 2.0, Dynamic Response with NO Gap

Lid Bolt Response



Results from an Actual Package Drop Impact Evaluation using a Detailed LS-DYNA Model