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Crash performance of notch triggers and variable frequency progressive-triggers on patterned box beams during axial impacts

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ABSTRACT

Embedding complex sinusoidal patterns on the wall surfaces of box beam impact absorbers has been recently proposed in literature and demonstrated to significantly improve energy absorption capability of box beams during axial impacts. However, no suitable trigger has yet been devised for these absorbers. This paper evaluates the viability of using conventional notch triggers on patterned beams. A progressive triggering mechanism on box beams with embedded patterns is also proposed by a novel idea of using a variable pattern throughout the length of the beam. In the proposed progressively triggered beams, the reaction force slightly increases with each progressive collapse buckle formation throughout the collapse. An extensive FEM study is performed using the commercial pre-processor HyperCrash^{TM} and the commercial explicit FEM solver RADIOSS^{TM}. It is found that, as opposed to point triggers, progressive triggering through variable pattern formulation effectively triggers and initiates a more stable collapse. More importantly, progressive triggers cause less stray deformations elsewhere along the beam and are consequently much more robust against global bending.
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1. Introduction

This paper is a continuation of the previous work published by the authors [1] regarding embedding of sinusoidal patterns on box section beams for use in crash absorbers.

A well designed crash absorber needs to be lightweight and must be able to absorb a high amounts of energy during an accident so that minimal damage occurs to the passenger cabin. They should also be effective in case the crash is misaligned rather than perfectly axial.

Thin walled beam sections are widely used as frontal crash absorbers in automotive applications. Their collapse behavior was first studied and mathematically formulated by Alexander [2] in the 1960s. Since then many authors, importantly, Jones, Wierzbicki, Abramowicz and Kecman [3–8] have made contributions in understanding the collapse behavior of thin walled box and circular beams through numerical and analytical studies.

Configurations such as using foam filled beams [9–11] and multi cellular beams [12,13] have been studied in the past. Adding triangular perturbation patterns on beams surfaces was first proposed by Zhang et al. [14] and proven using FE analysis to greatly improve energy absorption during an axial crash. They were able to control and reduce the buckle wavelength. In a study by Jiang and Yang [15], bi-dimensional sign wave patterns were also proposed. Their study concluded that the buckling could be regularized by inducing a double sign wave but there was a slightly detrimental effect on the total dissipated energy value. Recently, Qureshi and Bertocchi [1] tested various complex sinusoidal patterns on box section beams and showed them to improve the energy absorption capability by almost 42%.

New triggering mechanisms have been designed by Zhang et al. [16] by using a pre-hit column and pulling strips for initiation. Gumruk and Karadeniz [17] studied bump type triggers on top hat, rectangular cross-sections and showed through numerical studies that the crash response also varied greatly with the placement and the size of the trigger. An experimental study on cross-sections with triggers was also done by Minoru et al. [18]. Cho [19] carried out numerical studies on hole-and-dent triggers to optimize dent geometry and positioning of triggers.

However, all studies on triggers or buckling initiators have been done on plain surface beams. The viability of such triggers on pattern embedded beams mentioned in [13–15] has not been previously tested. In patterned beams, folding only initiates on predetermined hinge lines rather than anywhere along the length, therefore the use of the same triggering mechanism used for plain surface beams may not be as effective.

Triggers or buckling initiators are designed to serve the following purposes:

1. The initial force spike during the beginning of the collapse should be lowered.
2. The buckling has to start at a desired location (preferably close to the frontal tip) and nowhere else.

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3. Buckling must commence into a subsequent regular and stable collapse mode.

In the first part of this work, the effectiveness of using conventional notch type triggers for patterned beams mentioned in [1] is tested. In the second part, an alternate triggering mechanism for the patterned beams is proposed in which the sinusoidal pattern formulation is slightly altered along the length of the beam to make frontal zones more predisposed towards a collapse. Since progressive triggers have a continuous variation in pattern rather than a point base trigger, these beams are purported to be more robust against forming unwanted stray deformations elsewhere along the length of the beam during collapse. This property is especially useful in the performance of impact absorbers during oblique impacts where globalized bending or kneeing-out is a common undesired failure mode.

A FEM study is performed using the commercial pre-processor HyperCrash™ and the commercial explicit FEM solver RADIOSS™ to test the hypothesis. Patterned beams with notch type triggers were simulated for frontal impacts and analyzed. The proposed progressive triggers are studied comprehensively for frontal impacts in the second part.

2. Brief description of SLD pattern beams

SLD pattern beams were proposed in [1]. These patterns are formed by embedding complex sinusoidal perturbations upon box beam surface by trigonometric mathematical expressions given in Eq. (2.1). The $\pm$ are set according to the wall position and to invert the phase difference amongst each other. Fig. 1 shows a depiction of FE meshed SLD beam.

$$t = \pm C/2 \pm \cos\left(x \times \frac{2\pi}{\lambda_1}\right) \times \left(\left(\cos\left(z \times \frac{2\pi}{\lambda_2}\right)\right) + 1\right) \times a_{1,2}\right) \pm \sin\left(z \times \frac{2\pi}{\lambda_3}\right) \times a_3 \quad (2.1)$$

where C is the section width, λ_1, λ_2, and λ_3 are characteristic pattern wavelengths while $a_{1,2}$ and a_3 are their respective amplitudes. A brief description of some of the patterns and their increase in energy absorption and energy efficiency factor φ is given in Table 1.

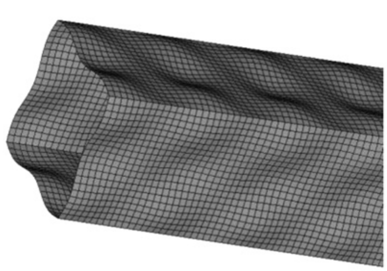

Fig. 1. SLD pattern depiction.

The energy absorbing effectiveness factor, φ, as defined by Jones [20] is used for benchmarking the results. This dimensionless parameter allows comparisons to be made of the energy absorption effectiveness among crash absorbers of various geometrical shapes and materials and is defined in Eq. (2.2).

$$\varphi = \frac{3P_m}{4A\sigma_0\varepsilon_r} \quad (2.2)$$

where ε_r is the rupture strain of the material, A is the cross-section area, P_m is the average collapse force and σ_0 is the flow stress.

The reference model mentioned in Table 1 is an un-patterned beam given for comparison. E indicates the energy absorbed after 900 mm of collapse.

The previous work [1] observed through that the relief patterns could be used effectively to change the buckling modes and reduce the buckle wavelength. A maximum of 42% increase in the amount of total energy absorbed and an increase in the energy efficiency factor, φ, from 1.08 to 1.54 was observed. Fig. 2 shows the collapse behavior comparison between SLD16 and reference model.

3. Model setup

The same testing criteria was adopted from the preceding work in which the patterned beams were proposed [1]. A box beam with cross-sectional dimensions of 100 × 100 mm with a wall thickness of 1.7 mm and a length of 1200 mm has been employed.

A load of 500 kg was fixed on an axial guiderail perpendicular to the wall. Both the load and the beam were given an initial velocity of 15.6 m/s and impacted upon a rigid wall.

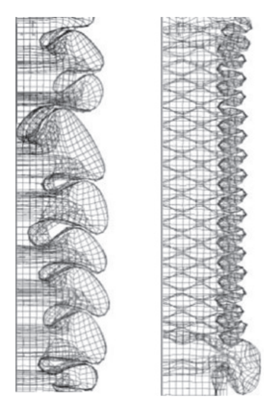

Fig. 2. Comparison between axial collapse of reference model and SLD16 patterned beam.

Table 1
SLD beams frequency description and their performance indicators.

Name	λ_1 (mm)	λ_2 (mm)	$a_{1,2}$ (mm)	λ_3 (mm)	a_3 (mm)	E (kJ) at 900 mm	P_m (kN) at 900 mm	φ	% age Inc. in E & φ
Ref. model						36.86	40.95	1.08	0.00
SLD8	34	40	2	68	0.3	38.42	42.69	1.13	4.25
SLD10	30	40	2	60	0.3	43.53	48.37	1.28	18.11
SLD11	30	40	2	60	0.15	43.60	48.45	1.28	18.30
SLD12	26	40	2	52	0.3	48.17	53.52	1.41	30.68
SLD13	26	28.57	2	52	0.3	50.16	55.73	1.47	36.09
SLD14	20	28.57	2	40	0.3	47.76	53.06	1.40	29.57
SLD16	25	28.57	2	50	0.1	52.43	58.26	1.54	42.27

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