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Investigation of when quad bikes rollover in the farming environment

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ABSTRACT

Quad bikes, referred to as All-terrain vehicles (ATVs) in North America, are the leading cause of fatalities and serious injuries on Australian farms and on–farms in many other countries. These fatal and injurious events have been associated with riding over bumps such as rocks, tree stumps, grass tufts, etc., specifically bumps positioned in-line with one wheel track of the quad bike that can result in a rollover trapping the rider.

Objectives: Earlier work presented Finite Element simulations showing how a quad bike and seated rider travelling over the bump on flat terrain can induce sudden steering and yawing that consequently triggers a rollover event. This study identifies which combination of speed, slope and bump size causes a quad bike with a seated rider to rollover.

Results: Two different rollover mechanisms occur depending on the speed, slope angle and bump height: a rear wheel impact steering induced rollover mechanism; and a front wheel impact tip-over mechanism. When quad bike speed and the slope steepness are increased to typical values (e.g. 20 km/h and 12.5°), the bump size needed to cause a rollover quickly reduces (e.g. around 100 mm).

Conclusion: Quad bikes are particularly vulnerable to a rollover event when travelling around farming environments where they traverse relatively small bumps on typical grassy slopes at moderate speeds. This suggests that a quad bike should no longer be considered as a vehicle fit for farming tasks and alternate safer vehicles should be considered.

1. Introduction

Quad bikes, referred to as All-terrain vehicles (ATVs) in North America, are the leading cause of fatalities and serious injuries on Australian farms and similarly in many other countries. Australian and New Zealand workplace health and safety regulators have adopted a 'towards zero deaths and serious injuries' objective that includes eliminating quad bike related fatalities and serious injuries in the workplace resulting from these vehicles.

McIntosh et al. (2016) identified that quad bike fatalities in the Australian workplace were characterised by rollover (85%) where a portion of the riders were pinned (68%) and asphyxiated (42%). The two most common crash mechanisms identified amongst these fatalities included riding on slopes (26%) and riding over bumps (21%), such as rocks, tree stumps, grass tufts, etc. These mechanisms as well as other surface irregularities have also been identified by other studies into workplace quad bike crashes (Milosavljevic et al., 2011; Moore, 2008; Schalk and Fragar, 1999; Wundersitz et al., 2016). Moore (2008) noted that interaction with rough ground (or uneven terrain), speed and the failure of the rider, who is concentrating on the stockwork, to predict hazards in the path of the quad bike, is a common cause of stockwork related crash events.

Grzebieta et al. (2015a, 2015b) further identified via extensive stability and handling experimental tests that quad bikes already have a particularly high propensity to rollover mainly because of the vehicle's narrow track width. Travelling on moderate slopes and speeds further exacerbates the vehicle's propensity to rollover leaving almost no margin for rider handling errors. Several studies of quad bike usage have also found that in an agricultural workplace environment these vehicles are commonly used at relatively low speeds on slopes in rough bumpy grassy terrain where rollover incidents have occurred and where riders have been seriously injured or killed (Carman et al., 2010; Grzebieta et al., 2017; Lower et al., 2012; McIntosh et al., 2016; Milosavljevic et al., 2011; Moore, 2008; Schalk and Fragar, 1999; Wundersitz et al., 2016). A recent survey of over 1564 riders in the workplace identified that around 1 in every 2 riders have had at least one crash in their riding history where around 70% of those crashes

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have involved a rollover (Grzebieta et al., 2017).

Hicks et al. (2017) determined that a quad bike traversing a bump placed in-line with one wheel track on flat terrain, under certain conditions of ground friction and approach angle towards a bump, can cause it to rollover. It was found that when the rear wheel of the quad bike struck a bump, a rider represented by an Anthropomorphic Test Device (ATD) was displaced across the seat such that it induced a sudden steering input, which led to the quad bike rolling over. However, to date no analysis has been conducted to investigate in detail which combination of speed, slope and bump height can lead to a rollover and thus what the rollover safety vulnerabilities of the quad bike are in terms of travelling over such terrain. The objective of this study was to determine whether a quad bike is at all a suitable vehicle for performing required workplace tasks on farms where slopes and surface irregularities are common.

2. Method

A finite element (FE) model of the Honda TRX500 with the ATD used by Hicks et al. (2017) that were validated against a 'bump test' procedure on flat terrain were used for this study. The non-linear explicit FE solver LS-DYNA (version R7.0.0) was used to carry out the computer simulations (LSTC, 2014) of the quad bike and rider travelling over a range of different slope angles, speeds and bump sizes. In all simulations, the ATD was placed in an upright seating position relative to the quad bike (Fig. 1). A coefficient of friction of 0.8 was used to represent the interaction between the quad bike's tyres and a grass-covered ground surface (Renfroe, 1996). Other coefficients of friction could be used; however, this study focused on simulating rollovers on sloping grass terrain, where a large portion of injuries and fatalities occur related to this type of rollover mechanism (Carman et al., 2010; Grzebieta et al., 2017; Lower et al., 2012; McIntosh et al., 2016; Milosavljevic et al., 2011; Moore, 2008; Schalk and Fragar, 1999; Wundersitz et al., 2016).

An example of the model setup for the range of investigated scenarios is shown in Fig. 1. To reduce the computer processing time, in all simulations, the FE model of the quad bike with the ATD was assigned the desired initial velocity and positioned so that the front right wheel was about to traverse the semi-cylindrical bump in a perpendicular direction to the bump. The bump's longitudinal axis was aligned with the slope and positioned in-line with the uphill wheel track. Placing the bump on the uphill side wheels of the quad bike, was deemed to be the worst-case scenario for any particular combination of slope, bump height and speed since it amplified the rollover event.

Ten bump heights (i.e. radius of the semi-cylindrical bump) were considered, ranging from 50 mm to 500 mm in increments of 50 mm. The maximum bump height of 500 mm was chosen as it represents the tallest bump required to induce a rollover of this vehicle on flat ground at an approach angle that was perpendicular to the bump at each speed tested.

Previous tilt-table testing performed by Grzebieta et al. (2015b) identified that the static lateral rollover threshold of a Honda TRX500 with a seated 95th percentile ATD was 30.8°. The FE model of this quad bike with the ATD was previously validated using the experimental static test results (Mongiardini et al., 2014). Therefore, taking into consideration this rollover threshold value, six different slope angles were modelled ranging from 0° to 25° in increments of five degrees.

Previous studies of in-field use of quad bikes in the agricultural workplace environment indicate that these vehicles are commonly ridden at speeds of 35 km/h or less (Carman et al., 2010; Grzebieta et al., 2017; Wundersitz et al., 2016). Thus, based on these studies, an initial speed of either 10, 20, 30 or 40 km/h was considered for each investigated combination of slope angle and bump height.

The variations of slope, bump height and speed, which were selected to represent a comprehensive range of riding conditions, are shown in Table 1. This would have resulted in a total of 240 simulations needing to be run if every combination of speed, slope and bump height were modelled. However, 60 simulations were not carried out after observing that the quad bike would rollover at 30 km/h or more when traversing bumps of 300 mm or higher. This resulted in reducing the total number of simulations to 180.

As a final step in the analysis, a multivariate logistic regression model was used to identify associations with the independent variables (i.e. speed, slope angle and bump height) and the binomial dependent variable 'rollover'.

3. Results

It was observed from all the simulations that there were two distinct types of rollover mechanism resulting from the quad bike's interaction with the bump. In one of the mechanisms the front wheel passes across the bump smoothly and the rear wheel interacts violently with the bump causing a rollover (rear-wheel impact mechanism), whereas in the second mechanism the front wheel interacts violently with the bump causing a rollover (front-wheel impact mechanism). Images of the simulations that exemplify the sequence of events for these two different rollover mechanisms are shown in Fig. 2. In each case the quad bike is traversing the bump on a 15° slope at 20 km/h. However, Fig. 2 shows the quad bike in the left column is traversing a 300 mm bump whereas in the right column it is traversing a 450 mm bump.

In the case of the quad bike traversing the smaller 300 mm bump, the

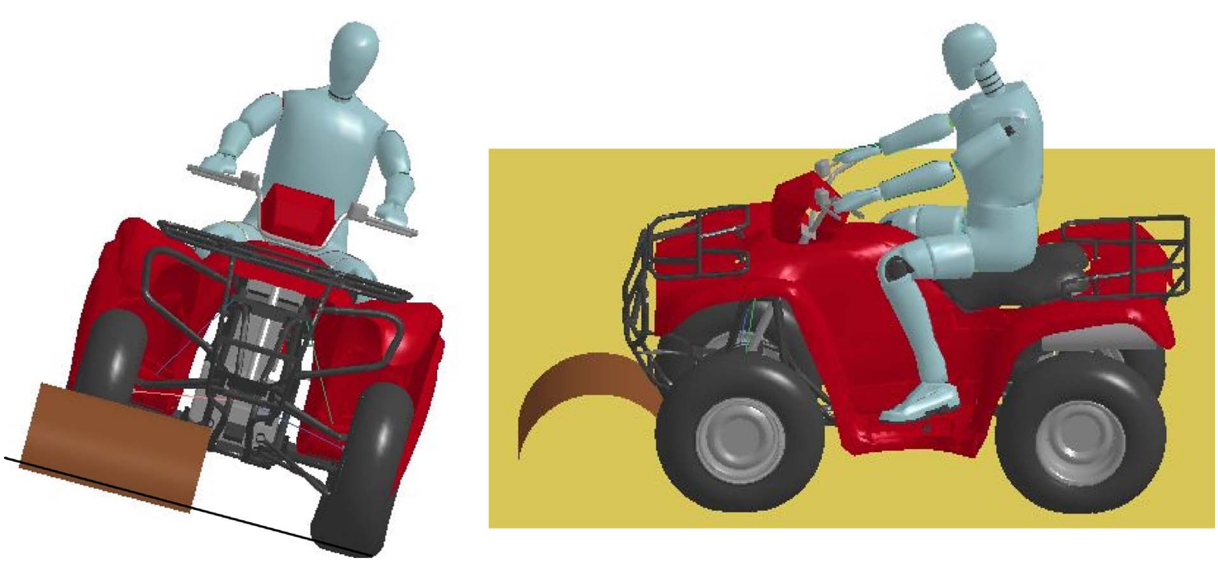

Fig. 1. Initial position of the quad bike and ATD FE models on a 15° slope and 300 mm high bump.