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HYBRID III CORRELATION WITH HUMAN INJURY POTENTIAL IN ROLLOVERS

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ABSTRACT

In the U.S., more than 27,000 catastrophic and fatal injuries occur annually in rollovers. This study is part of an ongoing research project aimed at mitigating the likelihood and severity of such injuries.

Last year, the authors developed a dynamic rollover test methodology for replicating, predicting, and differentiating between types of real-world neck injuries using the non-biofidelic Hybrid III dummy as the human surrogate [2,3]. Based on platen drop and pendulum test results, dummy positioning for flexion injury was determined and peak neck injury measures were rejected. A new neck injury criteria, the integrated bending moment (IBM), was proposed that related human neck flexion injury to Hybrid III lower neck moment-time histories. The IBM was validated by dynamic rollover tests performed with the Jordan Rollover System (JRS) with roofs of different strength-to-weight ratios (SWR's). The measured lateral and flexion neck moments were then roughly correlated with human neck flexion injury measures proposed by Pintar, et al., in 1998 [1].

To date, real-world head injuries resulting from roof interaction and partial ejection could not be replicated in dynamic rollover tests with the non-biofidelic Hybrid III dummy because of stiffness differences between the Hybrid III and human neck.

Findings thus far suggest that improved correlations with human injury measures could be achieved with the development of a dummy neck that is biofidelic in the rollover crash mode. In this paper, the production Hybrid III neck was modified with lower durometer butyl rubber discs and nodding blocks for improved biofidelity. Pendulum tests were repeated to correlate the production and modified Hybrid III neck responses. JRS tests were performed with an increased far-side impact angle to evaluate the capability of the modified preflexed neck to replicate and predict head, neck, thoracic spine, and ejection injury potential in real-world rollovers.

Results of this study indicate the following:

- Matched-pair platen pendulum tests with the low-durometer neck were found to be repeatable.
- In JRS tests performed with an increased far-side impact angle, the low-durometer preflexed Hybrid III neck reasonably replicated head, neck, thoracic spine, and ejection injuries and kinematics of weak-roofed vehicles.
- The low-durometer neck allowed a more direct correlation with human neck flexion injury measures proposed by Pintar, et al. in 1998 [1].

INTRODUCTION

At present, the Hybrid III dummy is generally accepted as the best available human surrogate and is used in rollover tests despite its lack of biofidelity in this crash mode. However, stiffness differences between the Hybrid III and human neck limit the capability of this dummy to realistically predict human injury potential. Compared to the human cervical spine, the Hybrid III neck is 2 to 3 times stiffer in axial compression, equally stiff in tensed bending, and about 10 times stiffer in untensed bending. More importantly, the predominant rollover neck flexion injury pattern indicates that the human head-neck complex is neither aligned nor oriented with respect to the impact force in most real-world rollover crashes.

The Hybrid III neck bending stiffness, peak injury measures, and onset criteria are based on tensed volunteer musculature. Pintar, et al.'s logistic regression curves for neck flexion injury risk are also based on peak values. However, based on results of platen drop test and pendulum tests performed last year, peak neck injury measures were rejected.

Last year, the authors presented a methodology that replicated and predicted catastrophic neck injury in real-world rollovers using the non-biofidelic Hybrid III dummy as the human surrogate in dynamic rollover tests [2,3]. Because the dummy neck is much stiffer than the human neck, interaction with the roof prior to roof intrusion created kinematic and injury distortions in dynamic rollover tests. It was found that the axially aligned neck registered peak compression loading instantaneously and independent of stroke. Neck bending only occurred with an extended stroke (4 or more inches) of the roof.

Hybrid III peak neck bending moment is an indication of the speed at which the neck structure is being loaded, but the bending that produces injury is the result of the duration of the torque and/or the angle through which the torque is applied. Previous and current work by Pintar, et al. [1] related measured peak Hybrid III upper and lower neck load cell compression forces to peak human lower neck compression forces. However, injury is a momentum or energy transfer process and is poorly predicted by peak injury measures. Recent work by Paver, et al. related the probability of human neck compression and bending injury to the neck compression force and flexion moment time histories measured at the lower neck of the Hybrid III dummy [2,3].

The objective of this paper was to design and test a more biofidelic neck for the Hybrid III dummy in pendulum and JRS tests:

- to replicate, predict, and differentiate between human neck compression and the more predominant flexion injuries; and
- to characterize and demonstrate the more frequent head injuries due to roof rail interaction and/or partial ejection, and shoulder loading creating thoracic spinal injuries.

METHODS

In this study, the Hybrid III neck was modified by replacing the stiff with softer butyl rubber discs and nodding blocks.

The pendulum test fixture has been described in earlier papers. The Hybrid III dummy was initially suspended above a production vehicle seat. A weighted pendulum platen, initially suspended above the dummy's head at a preset height, was dropped. At the instant the dummy's head was struck, the dummy was released and it fell several inches into the seat. Inverted 180º, these tests approximated the impact conditions of a rollover, where the occupant is upside down below the seat at the time of roof interaction.

Matched-pair tests were performed with the modified dummy neck preflexed relative to the roof intrusion at an angle that approached the limit of neck's free range of motion in flexion (approximated here as 35° to the horizontal), where the effects of musculature, the disc, and stretched ligaments dictated the neck bending stiffness. The platen was permitted to drop an additional 2, 4 and 6 inches after head impact.

JRS dynamic testing of production vehicles was performed with an altered far-side impact angle and the low-durometer neck preflexed.

RESULTS

In the pendulum tests, the amplitude of peak neck force was dependent upon the change in speed experienced by the dummy. Altering the stroke of the platen (i.e., the distance it continues to fall after the initial head impact) did not alter the peak compressive neck load. However, the duration of the lower neck moment and bending varied with stroke from 40 to 95 ms increasing the probability of neck flexion injury. Tests performed with the low-durometer neck more closely replicating the human neck.

JRS dynamic testing with altered far-side impact angle of production vehicles has verified the effect of the low-durometer neck to characterize head injury, partial ejection and thoracic spinal injury results.

The IBM neck flexion injury criteria, which calculates the extent of bending by integrating composite lateral and flexion moments over the duration of neck loading [3, was validated by a series of dynamic JRS rollover tests with roofs of different strength-to-weight ratios (SWR's). The measured lateral and flexion moments were roughly correlated with human injury measures proposed by Pintar, et al., in 1998 [1]. The IBM was compared to real-world injury patterns and the following generic injury measures: post-crash negative headroom; SWR; and the 11.3 kph (7 mph) head impact speed and 7,000 N (1,574 lbs) peak upper neck Fz compression load consensus serious injury measure for humans and dummies.

DISCUSSION

The more humanlike modified Hybrid III neck allows the investigation of the experimental injury potential for partial ejection, head, neck, and thoracic spine injuries in rollovers. The hypothesis for the ejection, head and spine investigation is associated with the pre-trip motion in yaw of the vehicle, the trip delta V, the associated occupant kinematics, the neck stiffness, and the far-side roof touchdown angle. Due to the pre-trip vehicle motion in yaw at the beginning of the roll, the far-side occupant moves laterally inboard and forward toward the near-side with his head and neck preflexed relative to his torso. This motion places the head approximately 18 to 24 inches from the far-side roof rail. During the roll, the far-side occupant traverses that distance to the roof rail rapidly. In conjunction with the intrusion velocity of the far-side roof, the closing speed at impact can be well above the 12 to 20 mph head concussion speed criteria proposed by Viano based on NFL football injury studies. Depending on the far-side roof touchdown angle, the timing of the head motion, and the vertical and lateral roof intrusion, the head, with the modified more biofidelic neck, may go out the window (i.e., partial ejection) or result in shoulder loading and upper thoracic spine injury.

CONCLUSIONS

This paper is part of an ongoing research project aimed at differentiating between axial compression and neck flexion injuries, characterizing head and thoracic spine injuries and ejections.

The dummy data measured in the matched-pair platen pendulum tests with the low-durometer neck were found to be repeatable.

In conjunction with the adjusted JRS protocol of increased far-side impact angle, the low-durometer Hybrid III neck with its preflexed orientation reasonably replicated head, thoracic spine and ejection injuries and kinematics of weak-roofed vehicles.

The low-durometer neck allows a more direct correlation with Pintar's logistic regression curves for flexion injuries.

REFERENCES

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