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Posters: TECHNIQUE AND METHODS

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structure (ROPS) or a tip-over protective structure (TOPS). Extensive discussion within the forest machine design community is currently focused on determining appropriate levels of rollover and tip-over protection for excavators. The development of new industry design standards for ROPS/FOPS/TOPS enclosures on excavators used in forestry is being hindered by a lack of information on dynamic loads that occur during rollover or tip-over accidents.

Research is needed to help determine if the current design standards for excavator operator protective structures (OPS) appropriately reflect the hazards experienced in actual construction and forestry working conditions. Specifically, research is needed to determine which variables (such as machine mass, track width, track length, height of cab, boom mass and geometric configuretion, etc.) affect the amount of energy absorbed by the ROPS/FOPS/TOPS. Further, research is needed to develop models that allow us to predict the dynamic forces applied to the OPS given these varying machine parameters. Finally, information is needed to help us revise existing OPS design standards or develop new standards so that OPS on new machines will provide appropriate levels of protection in construction and forestry applications.

The specific objectives of this project are to:

1. Develop and validate analytical and computer simulation models that will predict dynamic forces on excavator operator enclosures during rollover and tip-over accidents.
2. Conduct simulation sensitivity studies to determine which variables (such as machine mass and geometric configuration, boom mass and configuration, etc.) have a significant affect on the energy absorbed by the OPS.
3. Develop guidelines for levels of energy absorption (or force requirements) that can be used in revising or developing new standards for OPS designs.

This poster describes the development of and results from using the analytical models and computer simulation models.

Model Development

Analytical – Rigid Body Mechanics

The paper by Rummer et al. (2003) in these proceedings provides additional details on using rigid body mechanics methods. This method assumes that the vehicle is a rigid body rolling over a rigid ground surface. Allison and Mackay (1992) used the rigid body method to calculate the velocity of an armoured vehicle's centroid during a rollover accident. During a rollover event, the velocity of the vehicle centroid is a function of the angular velocity about a fixed point of rotation and the distance from the fixed rotation point to the vehicle's centroid. Equations of motion are used to calculate the velocity of the vehicle's centroid as it rotates around these various contact or impact points. Using pre- and post-impact velocity data, the amount of kinetic energy lost during the impact can be calculated.

As described in Rummer et al. (2003), the rigid body mechanics method was used to estimate levels of lateral energy absorbed during the rollover of crawler tractors, typical hydraulic excavators, excavators with 46-cm-high cab risers, and excavators with 122-cm-high cab risers. Machine masses ranged from four tonnes to 30 tonnes. The results from these analyses showed that when typical hydraulic excavators rolled down a 30-degree, 10-m-long slope, the levels of lateral energy to which the ROPS was exposed were similar to those of typical crawler tractors of equal mass. Significant increases in lateral energy levels were observed when excavators with 46-cm and 122-cm cab risers were analysed. The model was validated with data from actual field rollover tests conducted by industry groups. The poster provides further detailed results from these analyses.

Computer Simulation Methods

The rigid body analytical methods are limited in their ability to account for many aspects of the rollover event. For example, neither the ROPS nor the soil surface will behave as a perfectly rigid body. During a rollover, both the ROPS and the soil surface will deform and absorb energy. In addition, the three-dimensional shape of the excavator and its boom configuration will result in different rollover behaviour from that predicted by the simple two-dimensional model. Therefore, multiphysics computer simulation models are currently being used to model excavator rollover behaviour.

The software MSC-ADAMS was employed to simulate rollovers of the same excavators and crawler tractors discussed previously. As in the rigid body mechanics method, researchers used manufacturers' literature and field measurements to develop three-dimensional models of the excavators. Additional engineering data supplied by manufacturers were used to refine the models, especially in the area of the ROPS/FOPS on the excavators.

The soil surface was modelled as a series of non-linear spring dampers to allow it to deform and absorb energy during the rollover. Refinements are still underway to accurately model the flexibility of the ROPS/FOPS and other parts of the excavators so that they will also deform properly and absorb energy. To initiate the rollover, a flat surface under one of the excavator tracks is lifted until the excavator reaches an unstable angle and begins to roll.

Figure 1 shows an example of several frames from the simulation output of the rollover of a 20-tonne excavator. The simulation models were validated by comparing the simulation results with data from actual field rollover tests conducted by industry groups. In addition to the animation output, information on energy levels absorbed and dynamic forces experienced by the ROPS is recorded. These data are presented in the poster.

Summary

Current industry standards do not adequately address the use of and design requirements for rollover protective structures on hydraulic excavator-based forest machines. Industry groups are currently developing revisions in the ISO standards that will provide design guidelines for ROPS on excavators. The work provided in this poster presentation is being used by those industry groups. Results show that energy levels absorbed by typical hydraulic excavators during a rollover are similar to those of a crawler tractor of the same mass. However, when additional forestry features, such as extended height cab risers, are used on the excavator, energy levels can increase significantly during the rollover.

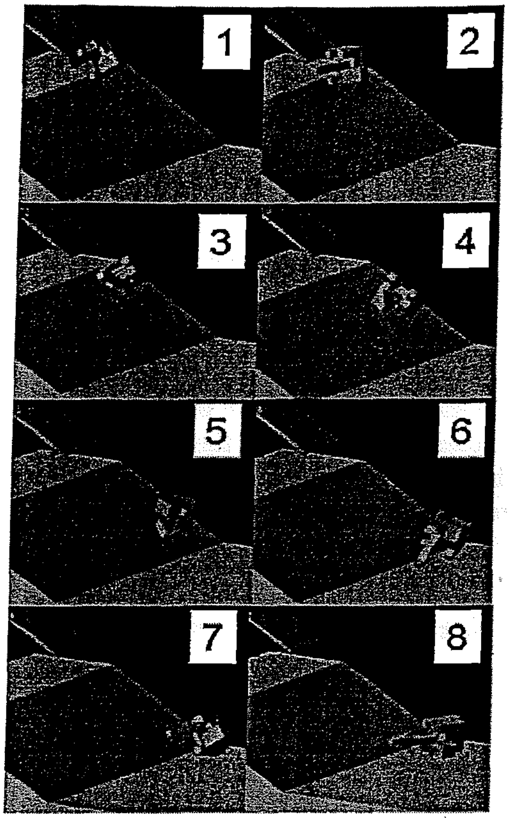

Figure 1.
Computer simulation output illustrating rollover behaviour of a 20-tonne hydraulic excavator.

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