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Lateral Stability Of Heavy Trucks Under Actual Operating Conditions

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Abstract

The dynamic response of heavy vehicles may vary depending on their configuration, weight and dimensions characteristics, load distribution, cargo density and shape. A research project was conducted by the Transportation Group at the University of New Brunswick into the dynamic characteristics of heavy trucks under over-the-road operating conditions.

The research was aimed at evaluating the roll stability of heavy trucks. The field data obtained on empty and loaded truck configurations provide additional information on the influence exerted by vehicle configuration and load conditions on a vehicle's dynamic stability. Tests have been completed on an empty truck using a Data Acquisition System designed to collect information on vehicle forward speed, lateral, longitudinal and vertical acceleration along with the steering wheel angle and trailer roll angle. This paper presents results of dynamic tests performed, during in-service operation, on a 5-axle tractor semitrailer. Results are used as a baseline case for further comparisons with similar tests of vehicles under actual operating conditions with variety of load configurations. The primary objective of the research is the evaluation of the rollover threshold of heavy trucks on highway curves and ramps while in normal operation. Results on the roll stability of the vehicle and its individual units are presented along with the dynamic behaviour of each individual unit in relation to the geometric characteristics of the road section over which the testing was performed.

1.0 INTRODUCTION

The problem of truck loss-of- control has been examined by researchers over a number of years. In the light of the expansion of the trucking industry and recent changes in vehicle design new issues have emerged with respect to truck safety and accident analysis.

Statistics from the Federal Highway Administration for 1997 document that 4,871 large trucks were involved in fatal crashes which represented 8.5% of all vehicle fatal accidents in the United States (FHWA, 1998). Many of these heavy truck fatalities were associated with rollover as the primary causal factor of the accident.

A study developed at the University of New Brunswick as part of a Level III Heavy Truck Collision Study sponsored by Transport Canada investigated factors related to the frequency of occurrence of truck collisions. In that study, rollover was the most frequent event in the reported accidents accounting for a 60% of the total accidents analysed (Hildebrand and Wilson, 1997). In most cases, excessive speed was the major contributing factor for the vehicle to experience rollover.

Various studies have been conducted in the area of heavy truck dynamics through simulation. One of the studies examined the behaviour of heavy trucks in relation to road and ramp geometry as well as the height of the centre of gravity (Ervin et al., 1986). The influence of weights and dimensions on the stability and control of heavy trucks in Canada has also been addressed using simulation to analyse the performance characteristics of a variety of vehicle configurations (Ervin and Guy, 1986). The effect of horizontal-curve transition design on truck roll stability has also been studied through simulation of a vehicle moving at a constant speed (Blue and Kulakowski, 1991). A set of performance measures were presented as a function of vehicle lateral acceleration and some road design parameters.

A recent investigation on the effect of trailer axle spacing and load distribution on different dynamic performance measures evaluated the static rollover threshold of tractor semitrailer configurations for different loading and trailer's arrangement scenarios. The constant speed YAW/ROLL model developed by the University of Michigan Transportation Research Institute (UMTRI) was used to conduct the study (El-Gindy and Kenis, 1998). A comparison between the static and dynamic rollover thresholds of heavy vehicles has also been established in other research projects. Simulation results of an eight-axle A-train double showed that the last semitrailer with an A-dolly "tends to roll over first under a high-speed evasive manoeuvre due to a relatively large lateral acceleration response of the last trailer" (Liu et al., 1998).

Although highway designers are concerned about the heavy truck roll problem in the accident population, there remain a number of challenges facing designers in their effort to accommodate these large units in the traffic stream. For passenger cars, there is a greater tendency for the vehicle to slide laterally long before an unstable condition leading to rollover begins to appear, as the height of the centre of gravity is lower relative to heavy trucks. When a heavy truck enters the same curve as the automobile the moment arm produced by the centripetal force acting through the centre of gravity will be greater causing the vehicle to roll rather than slide as would be the case for an automobile or a small truck travelling at the same speed over the same section of the curve. This condition demonstrates the need for research to determine the relationship between dynamic parameters for heavy trucks, such as the lateral acceleration and roadway design characteristics.

2.0 DATA COLLECTION PROCEDURE

2.1 Data Acquisition System Features

The Data Acquisition System (DAS) is a computer-based mobile acquisition system which contains a Megatel embedded 386 microcomputer. The unit enables the recording of data through a total of 11 channels while the vehicle is in over-the-road operation. Output signals from the sensors are further processed using a Matlab program developed for the purposes of this research project.

The data acquisition is comprised of:

1. a central processing unit (acquisition unit),
2. three silicon micromachined tri-axial accelerometers (Model CXL04M3),
3. a steering wheel optical sensor to record the steering inputs,
4. a radar gun to measure forward vehicle speed,
5. a device to record the variation of the roll angle of the vehicle.

The accelerometers, radar gun, roll angle sensor and optical encoder are interfaced to the central processing unit through individual connectors on its front panel enabling data to be continuously transferred from the sensors to the DAS.

2.1.1 Triaxial Accelerometers

The accelerometers, labelled as A1, A2 and A3, record the acceleration values at three different locations on the vehicle. The coordinate system used for their location within the vehicle is as follows:

- X-axis: Side-to-side acceleration. Positive direction toward the right side of the vehicle.
- Y-axis: Longitudinal acceleration. Positive direction toward the front end of the vehicle.
- Z-axis: Up and down acceleration. Positive direction downward to ground.

2.1.2 Radar Gun

This is a radar unit based on digital signal processing which gives good performance and ease of operation in many applications. It enables speed measurements in the range of 1 to 480 km/h with an accuracy of ± 0.16 km/h. The built-in features of the radar gun enables recording the vehicle speed and its variation over time.

2.1.3 Steering Wheel Optical Sensor

The optical encoder outputs one pulse per revolution. The actual steering angle can be derived knowing the diameter of the encoder input shaft and the diameter of the steering wheel column where the sensor is attached to.

2.1.4 Roll Angle Sensor

This consists of an oscillating pendulum with a single turn potentiometer coupled to its upper end. The electrical outputs provide a high level of accuracy in the measurement of the actual roll angle of the trailer.

3.0 FIELD TESTS

3.1 Test Procedure

An empty 5-axle tractor semitrailer was used as a test vehicle. Table 1 summarises some of the vehicle characteristics. Test runs were performed on a dry pavement with clear weather conditions. The average wind speed was 3.2 km/h. A number of highway curves and short interchange ramps were included in the test site.

The data collection unit was activated once the speed of the vehicle stabilized at 25 to 30 km/h. The dynamic variables were then continuously measured using the |Data Acquisition System.

3.2 Vehicle instrumentation

Before instrumenting the vehicle it was placed on a level surface while the initial adjustments of the accelerometers were made. Otherwise, the data recorded may not reflect the actual values of accelerations.

Accelerometer A3 was placed in the towing unit (tractor) on the floor, accelerometer A2 was located 1.83 m(6 ft) rearward of the fifth wheel kingpin. A solid aluminum frame was affixed to the top rear extremity of the trailer to support accelerometer A1 and the roll angle indicator.

The radar gun installed on the dashboard of the tractor and the steering wheel sensor attached to the steering wheel column monitored the vehicle speed and steering activity over time, respectively.

3.3 Results from Test Run

The results presented on Figure 1 show maximum values of the lateral accelerations for the empty trailer ranging from -0.08 to +0.14 g (See arrows "d" and "c"). Also on Figure 1 it can be seen that there is a slight amplification of the lateral acceleration of the trailer with respect to the side-to-side acceleration experienced by the towing unit. A peak acceleration value of -0.08 g was recorded at 280 seconds from the beginning of the test and occurred while the vehicle negotiated a short horizontal curve (See arrow "d").

On Figure 4 is shown the variation of the roll angle of the trailer from +2 degrees to the right to the same negative magnitude to the left as the trailer moved through a left turn manoeuvre and returned to its original path.

Examination of the data presented on Figure 3 and 4 shows that the magnitude of the lateral velocity of the trailer and its mass produces a momentum which results in lateral acceleration levels greater than those experienced by the tractor as measured at the fifth wheel. Note specifically the sampling times of 80 and 240 seconds.

The level of rearward amplification experienced by the empty trailer in comparison with the values recorded for the tractor unit are evident from Figure 1 at arrows "a" and "b". The variation of the roll angle, Figure 4, starting at 40 seconds describes the manoeuvre performed by the truck driver before entering an exit ramp. (See arrows "e" and "f"). No significant changes were observed in the lateral acceleration values for the subsequent time period. However, at about 240 seconds, arrow "g", a lane change manoeuvre took place prior to turning left at an intersection. A subsequent lane change manoeuvre was performed toward the end of the test run which produced a peak lateral acceleration value for the trailer of 0.14 g, arrow "h", while a roll angle of 12 degrees, arrow "i", was recorded by the tilt sensor installed on the top rear centreline of the trailer.

Examination of Figure 5 shows that the unloaded vehicle was in a stable dynamic condition at all times. As expected the disturbances produced by the dynamic manoeuvres performed during the testing did not lead to any unstable condition sufficient to initiate rollover. The acceleration levels experienced by each individual unit are within normal limits (less than 0.3-0.4 g). The peak acceleration values for the trailer are far from the rollover threshold of 0.23g to 0.31g (El-Gindy and Woodrooffe,1990), which is applicable to this type of truck configuration. A similar analysis of data from loaded trucks will help to better understand the dynamic behaviour of this a type of vehicle under over-the-road operating conditions.

4.0 CONCLUSIONS

The tests performed on the empty tractor-semitrailer unit will be used as a baseline for a further study of rollover stability of heavy truck configurations under a variety of load conditions under highway operating conditions. Test results have shown that for an empty tractor semitrailer, the trailer's sway produced peak values of lateral acceleration in the order of 0.14g. At no time during the testing procedure were critical rollover threshold values recorded. However, the lateral forces and velocities generated on each vehicle unit due to the dynamic tests performed along with the dynamic characteristics of the truck are issues to be taken into consideration when comparing the test results with those obtained for similar vehicle configurations when carrying different cargoes.

The test results confirmed that data with a high level of accuracy can be achieved using the Data Acquisition System while the vehicle is in over-the-road service.

5.0 ACKNOWLEDGEMENTS

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Table 1- General characteristics of the test vehicle

Vehicle Configuration	5-axle tractor semitrailer
Tractor Suspension Type	Leaf / Air Ride
Tire Type and Dimensions	Michelin/Goodyear 11R 22.5
Tractor Wheelbase	4.26 m (14 ft)
Tractor Rear Axle Spacing	1.22 m (4 ft)
Trailer Suspension Type	Air Ride
Tire Type (trailer)	Michelin 11R 22.5
Trailer Wheelbase	13 m (43 ft)
Trailer Length	16.15 m (53 ft)
Trailer Rear Axle Spacing	1.22 m (4 ft)
Trailer Height(from trailer's floor)	3.04 m (9.97 ft)
Trailer Track Width	2.01 m (6.6 ft)
Trailer Width	2.74 m (8.98 ft)

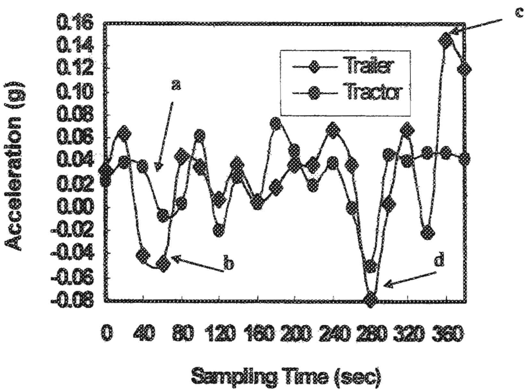

Fig. 1: Lateral Acceleration (Tractor/Trailer

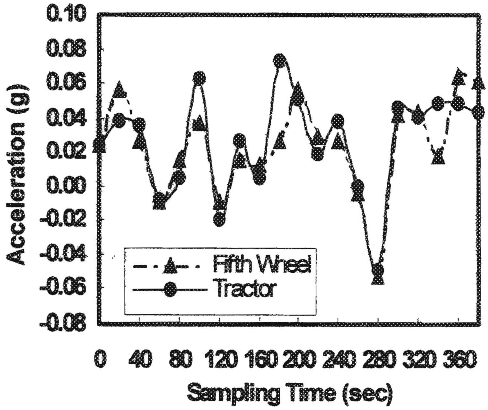

Fig.2: Lateral Accelerations (F. Wheel/Tractor)

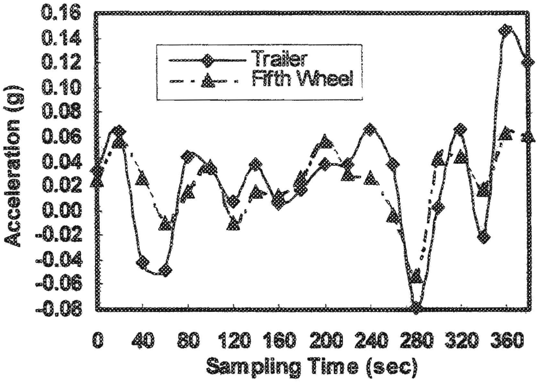

Fig. 3: Lateral Accelerations (Trailer/F. Wheel)

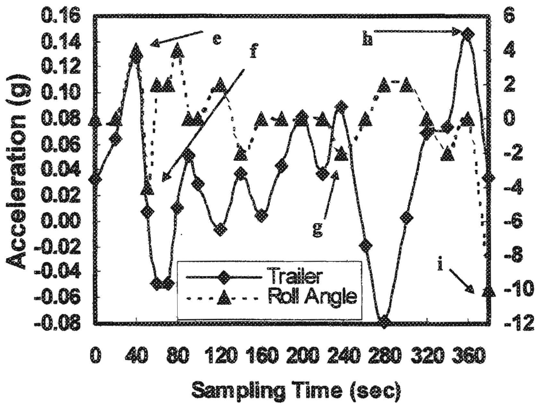

Fig.4: Trailer Roll Angle and Lateral Acceleration

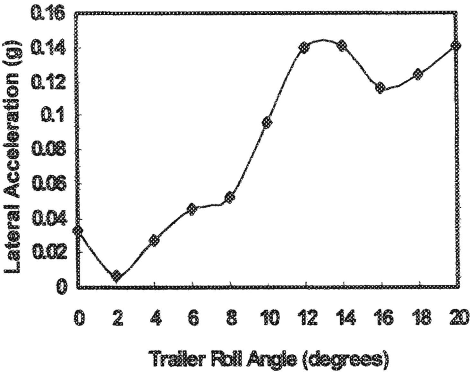

Fig. 5: Variation of trailer lateral accelerations with roll angle