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ABSTRACT

In this study, tests were performed to understand the effects of asymmetric longitudinal forces on vehicle response which may be created in certain staged partial tire tread belt detachment tests. In a very small number of tests performed by others, tires cut to simulate partial tire tread belt detachments created longitudinal drag forces at the separating tire that induced substantial vehicle yaw. This drag force and yaw response are independent of vehicle type and suspension type; they are created by the separating tire tread interacting with the road surface and/or vehicle. Similar yaw inducing drag forces are further demonstrated by applying braking to only the right rear wheel location of an instrumented test vehicle. It is shown that vehicle yaw response results from this longitudinal force as opposed to vertical axle motion.

INTRODUCTION

There have been numerous tests conducted where a rear tire is specially prepared to undergo a tread belt detachment in a controlled, experimental setting on a moving vehicle (1-6). These tests have shown that the vast majority of rear axle tread belt detachments impart small drag forces during the tread separation. These drag forces create a slight pull of the vehicle toward the side of the separating tire and can generally be compensated for with a small steering correction to maintain a straight driving path. Out of the many tread separation tests performed by different entities, the path deviations in two instances were high enough to cause the vehicle to quickly move out of its original lane of travel. Both of these tests involved a staged partially detached tire tread. A partial tread detachment is one in which the tread of the tire only "partially" separates from the casing, leaving some tread still intact. Years later, authors theorized that in one of the tests the reason for the yaw was axle tramp (7). This hypothesis was later studied and tested and it was found that pure tramp was not created during tread separation tests (8).

The data from these two case studies are analyzed. Tire preparation in both of the case studies involved circumferentially cutting the tires between the tread belts 180 degrees around the circumference in order to stage a partial tread separation, leaving half of the tire in its new, unused condition. Additionally, other testing on the case study vehicles using the same configuration and same tire preparation methodology resulted in vehicle responses that had little to no path deviation as a result of the tread belt detachment. Using the results of the case study analysis, further testing was conducted to demonstrate the cause of the path deviation.

METHODOLOGY

The existing data recorded in the two partial tread belt detachment tests that resulted in lane deviation, Case Study 1 and Case Study 2, were analyzed. The purpose of this analysis was to identify responses that were similar between the two tests, but were different from the other tests performed on the same vehicles that did not result in significant path deviation.

Additional testing was performed on a 1992 Ford Explorer two door rear wheel drive to validate what was found in the analysis. The test vehicle was modified using hydraulic valves in the brake system so that all the pressure from the master cylinder could be directed to the right rear brake. Shown in Figure 1, the test vehicle was instrumented with sensors that measured steer angle, steering torque, accelerations, translational velocities, rotational velocities, and the forces and moments at the two rear wheels. The vehicle was equipped with all terrain P235/75R15 tires at the front tires and the left rear tire and a performance drag racing P275/60R15 tire at the right rear. This tire was selected to allow for very large longitudinal forces to be created on the vehicle during the testing. This approach allowed for an analysis of vehicle response to asymmetric longitudinal forces applied at the wheels.

Figure 1. Isolated Brake Test – Test Vehicle

CASE STUDY ANALYSIS

CASE STUDY 1 (CS1) – The first case study was documented by Arndt, et al (4) in test 2030G run on November 8, 2000. The authors attempted to simulate a 180 degree partial tread separation by cutting half of the tire's circumference. This cut tire was placed on a sport utility vehicle at the right rear position and the driver accelerated to freeway speeds (approximately seventy miles per hour). As the tire tread began to detach, the vehicle was turned abruptly to the right with little or no steering input. Evidence at the site included intermittent black skid marks made by the separating tire (Figure 2).

The authors attempted to explain the outcome of the test in a recent paper (7). In their analysis, the longitudinal acceleration data was not considered and it was theorized that rear vertical forces associated with rear axle tramp was the cause of the path deviation. However, further analysis of the test data and video show that this is not the case and the rear axle was not in a pure tramp mode. The test data showed that there was a significant longitudinal deceleration present during the tread belt detachment.

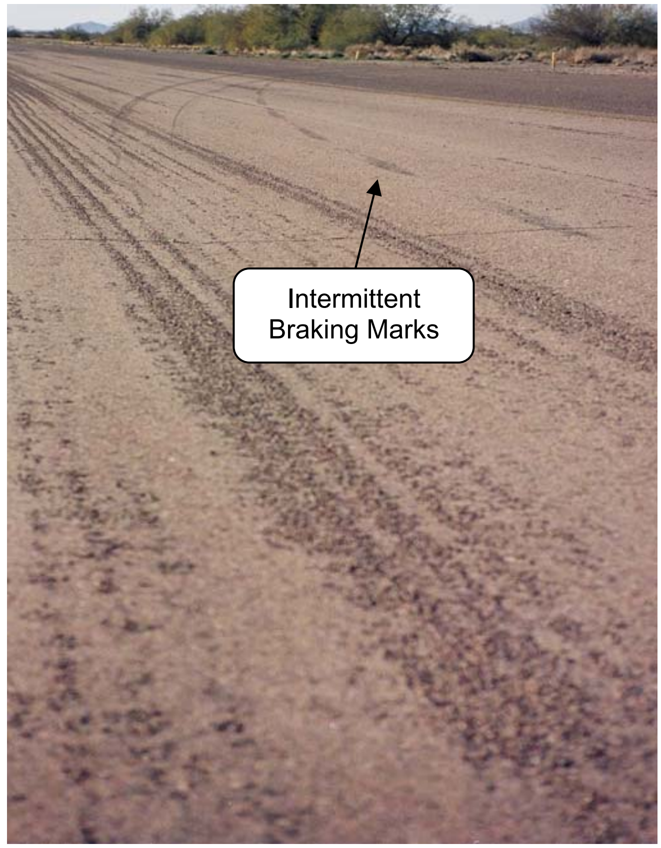

Figure 2. CS1 – Tire Marks (2030G)

In test run 2030D, a run prior to 2030G, the authors staged a partial tread separation at the right rear position on the same vehicle under the same test conditions. In this test, the vehicle continued to travel in a straight line path before, during, and after the tread separation occurred. Analysis of the test data shows that large longitudinal forces were not created, therefore no significant longitudinal acceleration or yaw rate were measured during the test. Figure 3 shows a plot of the longitudinal acceleration for both runs. Note that 2030G, the run with the large path deviation, has over double the longitudinal deceleration of 2030D.

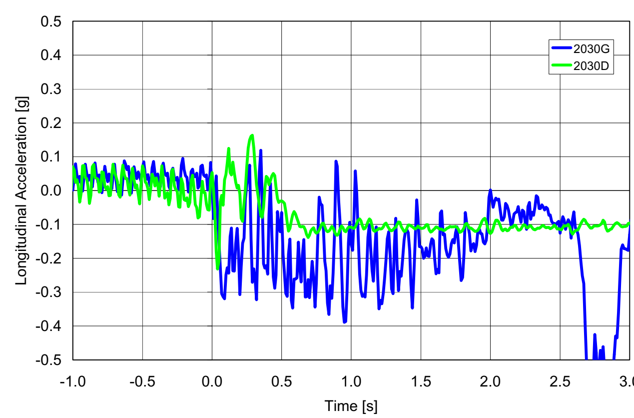

Figure 3. CS1 – Longitudinal Accelerations: 2030D and 2030G

CASE STUDY 2 (CS2) – The second example of a staged tread separation test resulting in a significant path deviation was test R10 conducted by Carr Engineering, Inc. on September 28, 2000. Before this test, the right rear tire was cut two inches inboard between the upper and lower steel belts for 180 degrees of its circumference to stage a partial tread separation event. The tread was then scored diagonally across tread surface (Figure 4). In this test, the driver accelerated to freeway speeds (approximately seventy miles per hour) and the tire began to separate. The vehicle was pulled to the right into the adjacent lane and the driver made steering corrections to stay in that lane. Even though the driver was depressing the throttle, the separating tire created a longitudinal force at the right rear position, causing a longitudinal deceleration on the vehicle and creating a moment about the center of gravity, pulling the vehicle to the right. This force dissipated when the tread belt pulled away from the tire casing. Like CS1, evidence at the test site included intermittent black tire marks created by the separating tire (Figures 5 and 6).

Figure 4. CS2 – Test Tire Preparation

Figure 5. CS2 – Tire Marks (Direction of Travel View)

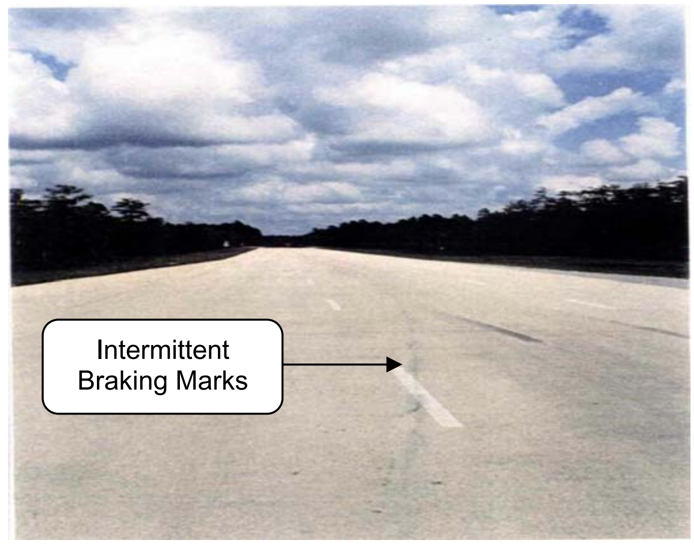

Figure 6. CS2 – Tire Marks (Opposite Direction of Travel View)

Evidence on the vehicle included marks in the inner fender well and on the brake components at the right rear position. The test data recorded deceleration of the vehicle while the driver was applying the throttle (Figure 7).

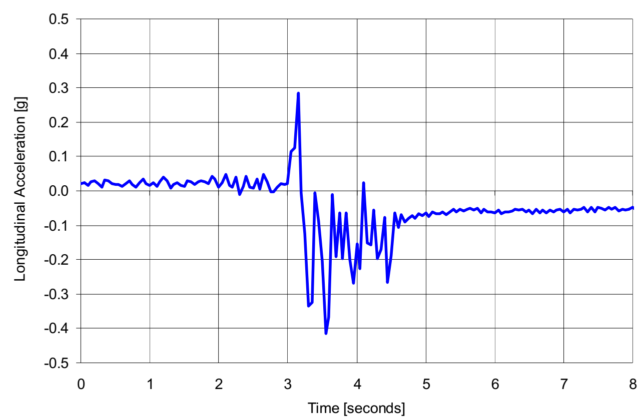

Figure 7. CS2 – Longitudinal Acceleration

Prior to the R10 test, test R08 was performed on the same vehicle with a tire modified in the same manner, using the same method. In this test, a significant longitudinal deceleration was not generated and only small steering corrections were required to maintain straight ahead driving. Figure 8 shows a comparison of the vehicle longitudinal velocity in the tests R08 and R10. Note the deceleration in test R10, but in test R08 the vehicle speed was maintained. Another observation made during the testing, and documented on videotape, is that in both these runs the rear tires underwent similar vertical vibrations.

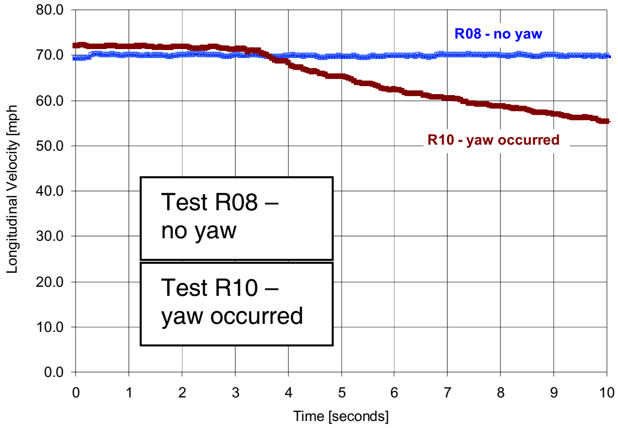

Figure 8. CS2 – Vehicle Speed in Tests R08 and R10

CASE STUDY COMPARISON – The two tread separations studied resulted in vertical vibrations at the axle during the separation, but did not excite axle tramp. The common response between these two tests that was different from other tread separation tests was the magnitude of the longitudinal deceleration. The significant and abrupt path deviation was a result of the longitudinal force applied at the rear tire. This force was created by the delaminating tire as the tread belt separated. Although some axle vibrations were present in all tread separation testing reviewed, the exact mechanism for these two tread separations to generate significantly greater longitudinal forces than others is not clear. Further study in this area is warranted.

TESTING AND RESULTS

ISOLATED BRAKE TEST (IBT) - To isolate and study the effects of a longitudinal force at a rear wheel position, testing was conducted on a 1992 Ford Explorer 4x2 two door with the hydraulic brake system modified to allow isolated application of the right rear brake through the application of the service brake. In addition to traditional instrumentation to record speed, yaw, accelerations, and steering, wheel force transducers were utilized to measure the forces and moments at the rear wheels (Figure 9). The brake controls are shown in Figure 10.

The test procedure for the isolated brake tests involved accelerating the vehicle to a speed of approximately sixty miles per hour in a straight line vehicle path. The throttle was then released and the modified service brake applied by the driver, with brake pressure only going to the right rear. During the test, the steering wheel angle was held constant. In order to obtain high longitudinal forces, a special performance tire was used at the right rear position. Several runs were made and all resulted in a longitudinal deceleration rate of between 0.25 and 0.3 g's. The longitudinal acceleration for test R04 is shown in Figure 11. Isolated application of the right rear brake created a peak longitudinal force of approximately 1250 pounds at the braked wheel (Figure 12). Using Newton's Second Law of Motion, a vehicle that weighs approximately 5000 pounds should decelerate at about 0.25g's when subjected to that force. The resulting yaw is due to the moment created by a longitudinal force applied to the right of the center of gravity (Figure 13). Note the rapid buildup in yaw rate at approximately 2 seconds into the test, climbing until approximately 3.5 seconds at which point the driver steered to correct (Figure 14).


Figure 9. IBT – Wheel Force Transducer at Right Rear Tire Position

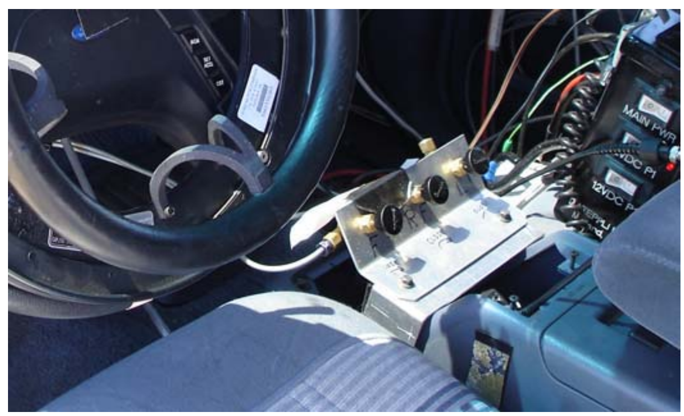
Figure 10. IBT – Brake Controls

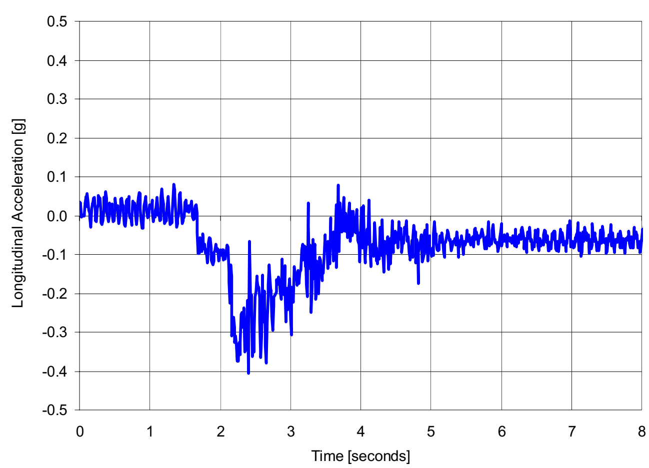

Figure 11. IBT R04 – Longitudinal Acceleration

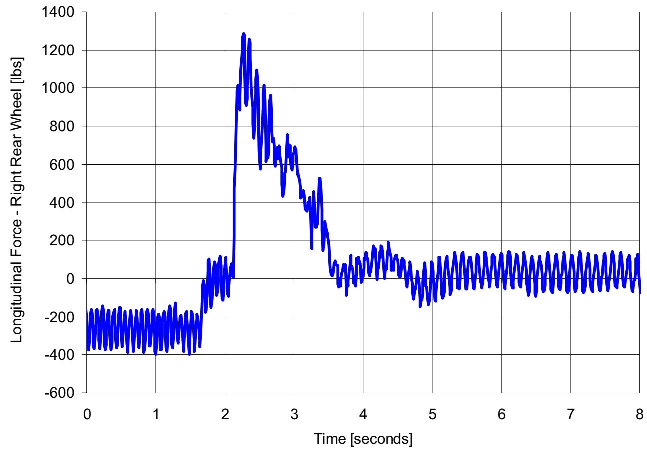

Figure 12. IBT R04 – Longitudinal Force at Right Rear Wheel

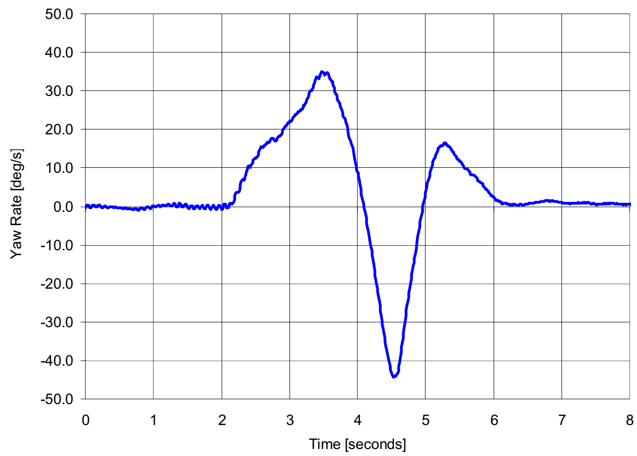

Figure 13. IBT R04 – Yaw Rate

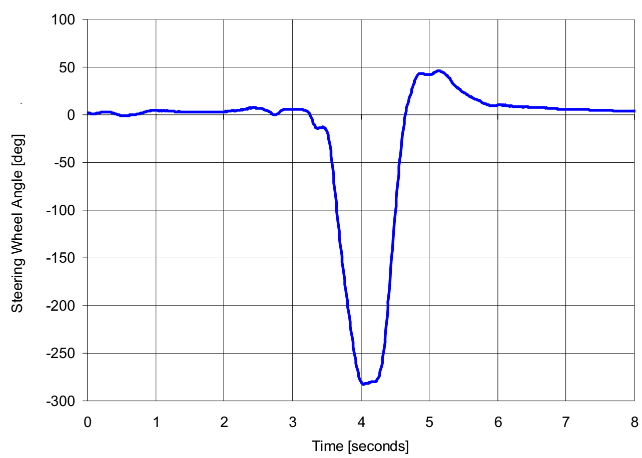

Figure 14. IBT R04 – Steering Wheel Angle

ANALYSIS

Comparison of the isolated brake test (R04) to the two staged partial tread separation tests (CS1-2030G and CS2-R10) shows significant similarities in the responses of the vehicles (Figure 15). The differences between the measured responses are a result of the steer inputs from the drivers. Note the similarities in the measured lateral acceleration, but the yaw rate for test CS2-R10 begins to lessen as a result of the quicker steer response. The longitudinal accelerations are shown in Figure 16. In all three tests, longitudinal accelerations on the order of approximately 0.25 g's were observed. The vehicle yaw rates are also similar for the portion of the test before it is heavily influenced by driver input (Figure 17). Yaw Angles were calculated by integrating the yaw rate signals, with the assumption that the vehicle heading was approximately straight just prior to tread separation or brake application. The yaw angles for the first second of data are further compared in Figure 18. Review of the videotape recordings confirms the vehicle paths and yaw angles were similar.

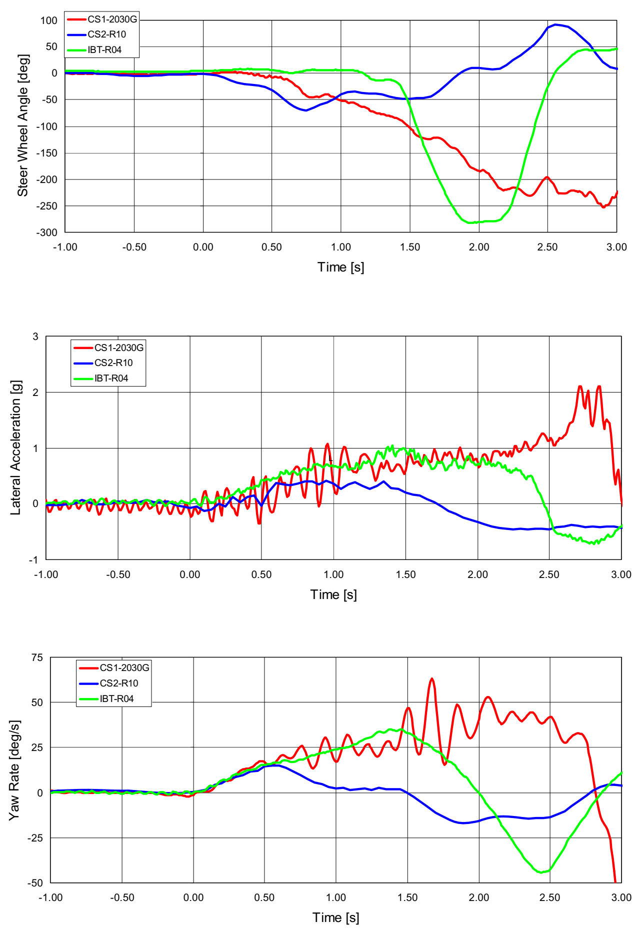

Figure 15. Test Comparison – Input and Responses

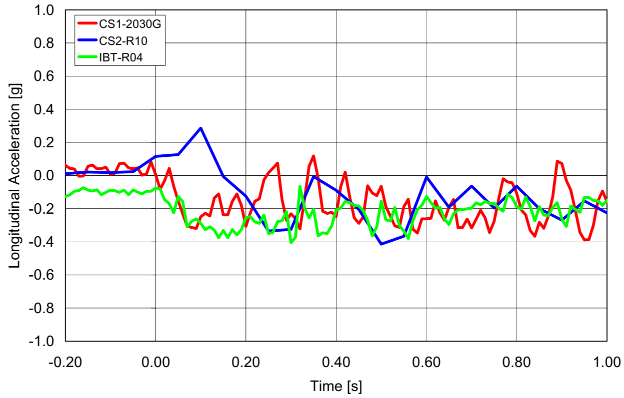

Figure 16. Test Comparison – Longitudinal Acceleration

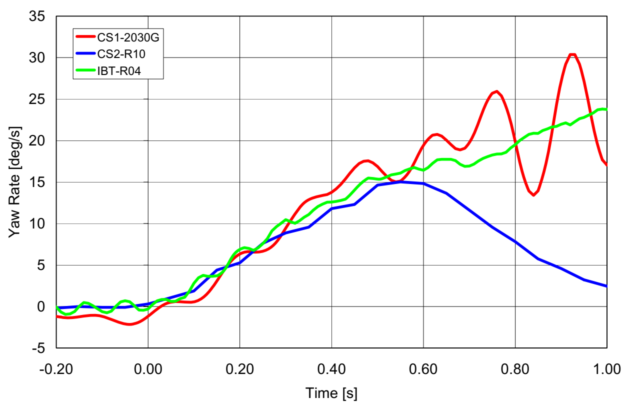

Figure 17. Test Comparison – Yaw Rate

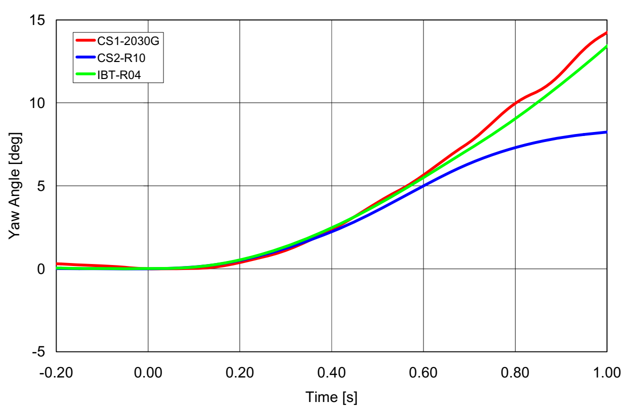

Figure 18. Test Comparison – Yaw Angle

In another isolated brake test, R08, the service brake was modulated by the driver so that two brake pulses were input to the vehicle. This can be seen in longitudinal force data (Figure 19). The corresponding yaw response is shown in Figure 20. Note that the vehicle yaw rate changes in response to the longitudinal force pulses. This indicates that vehicle path deviation is due to the moment created by a longitudinal force applied to the right side of the center of gravity.

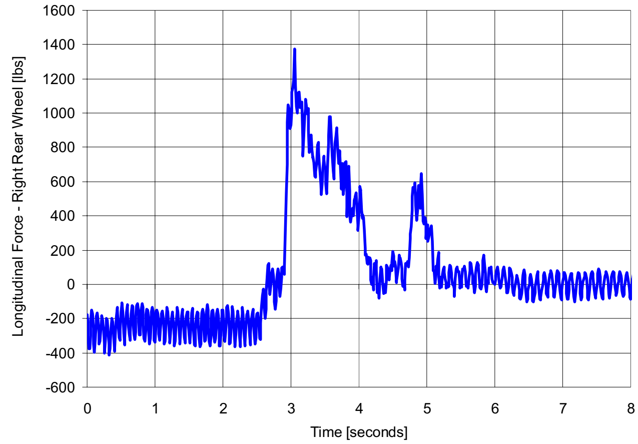

Figure 19. IBT R08 with Pulsed Braking – Right Rear Longitudinal Force

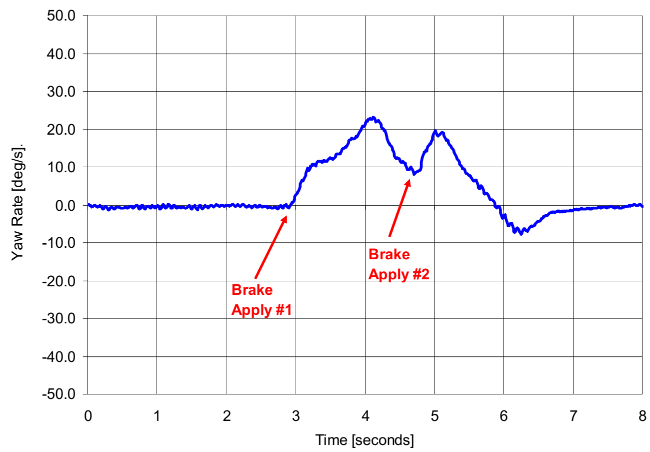

Figure 20. IBT R08 with Pulsed Braking – Yaw Rate

CONCLUSIONS

The data from two known staged tread separation tests where the test vehicle moved abruptly to an adjacent lane without driver steering in that direction were analyzed. The common response between these two tests that was different from other tread separation tests was the magnitude of the longitudinal deceleration. The drag forces and vehicle response during a tire tread belt detachment were studied through analysis of testing performed by others and additional testing. While analysis shows that most tread belt detachments result in drag forces that only have a minor effect on the vehicle path, in two circumstances the forces were large enough to cause a yaw response that required significant steering input to correct the path deviation. In these situations, intermittent black tire marks may be present at the crash site. However, this does not mean that the presence of intermittent black tire marks necessarily indicate a partial tread separation with a yaw inducing drag force.

The cause of the vehicle yaw response in a few partial tread separation tests was determined by comparing these tests to testing where only the right rear brake was engaged. It was found that a tire undergoing a tread belt detachment created a drag force which acted to slow down the vehicle and create a moment that pulls the vehicle to the side of the separating tire. Although many tests have been run which confirm that in typical tread separations this pull can be overcome with small steering corrections so that a straight ahead path can be maintained, two known staged partial tread separation tests have resulted in a large path deviation. In studying the underlying data of those tests, it was observed that there was a significant longitudinal deceleration created by the separating tire. Large, asymmetric longitudinal forces created at a rear tire position on a moving vehicle will induce the vehicle to yaw. The amount of yaw angle and yaw rate are dependent on the magnitude and rate of the deceleration force. Vehicle yaw response and path deviation during a tread belt detachment were due to the longitudinal forces created during the detachment, they are not due to rear axle vibration.

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