REPEATABILITY TESTING OF A DYNAMIC ROLLOVER TEST FIXTURE

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ABSTRACT

A new dynamic rollover test fixture, the Jordan Rollover System or JRS, has been developed. This fixture has the ability of testing vehicles or bucks in a controlled manner with preset initial conditions including roll rate, drop height, roadway speed, contact yaw, pitch and roll, etc. The test vehicle is held between drop towers and dropped and rolled at a predetermined time to interact with a moving roadway. The vehicle can contact the roadway on either one or both sides of the roof. As the vehicle interacts with the roadway, the vehicle is supported laterally, in the direction of the moving roadway, and longitudinally and is free to rotate and move vertically without support. After contact with the roadway, the test specimen rotates to rest without any additional contacts. In order to examine the repeatability of the test fixture, a test buck was prepared. The test buck incorporates a replaceable roof structure approximating a production vehicle roof structure. The repeatable roof buck was tested with set parameters. During the tests, the crash pulse was measured utilizing on board instrumentation and load cells in the road way. After each test, the roof was replaced. Examining the crash pulse between the tests and the initial conditions allowed the repeatability of the JRS to be determined. The JRS fixture was found to be highly repeatable.

INTRODUCTION

Previous dynamic rollover test methods have been widely criticized as non-repeatable. All of these methods; ramp rollovers, dolly rollovers, etc, result in a vehicle moving through an entire roll sequence where small differences at the beginning of the sequence can result in large differences in the outcome of the test. For instance in dolly rollovers, the interaction between the vehicle and the dolly as the vehicle is released and interaction with the ground at the initial contact can vary which results in downstream changes in the dynamics of the vehicle. These changes can include different vehicle loadings, contact point, dummy injury measures, etc. This can be seen in studies with repeated tests on the same vehicle that result in a range of number of rolls, roll distance, etc. In these tests, even though the initial parameters are repeatable, the consequential parameters that arise in the multiple rollovers result in different downstream vehicle dynamics.

In order to design a repeatable dynamic rollover test, these consequential parameters must be removed or minimized. The consequential parameters are any test feature that can change the desired impact(s). With this in mind, two dynamic rollover test methods have been introduced that have the first vehicle/road interaction a roof contact, since this is the part of the sequence in question. One method is the Jordan Rollover System previously introduced in several technical articles [1,2,3]. This system removes the consequential parameters present in the earlier test methods allowing for repeated dynamic contacts on a test specimen at desired test parameters and prevents further contacts between the vehicle and roadway, isolating the effects of the test impacts.

DESCRIPTION OF FIXTURE

The Jordan Rollover System is designed to evaluate the performance of a vehicle's roof and rollover occupant protection system under highly controlled, dynamic conditions. The test fixture combines well-defined vertical, lateral and roll impact conditions with vehicle rotation in a single impact or sequence of impacts. The system can be used for vehicle and safety systems development, consumer information testing and regulatory purposes.

The device, shown in Figure 1, holds the ends of either a body-in-white or a complete vehicle between two drop towers that permit it to be rotated about its longitudinal axis. The impact surface moves horizontally, along tracks, below the suspended vehicle. An energy source similar to that used in an impact sled propels the roadway. In the test sequence, the vehicle is positioned at the desired pitch and yaw angles. The vehicle can be rotated at up to about 1 revolution per second.

The rotation is coordinated with the release of the vehicle and with the propulsion of the road surface so that the vehicle body strikes the road plate at a specified roll angle. After the vehicle is released, only its lateral and longitudinal motion continues to be controlled except that the vehicle's vertical motion is halted before it strikes the tracks where the impact surface moves.

Figure 1. Jordan Rollover System with vehicle mounted and ready for testing.

The test may be designed to permit impacts with both sides of the roof in a single test. The road plate moves at a speed of up to about 20 mph (32 km/hr) and moves out from under the vehicle after the impact or impacts. The inertial frame of reference for this test moves at the speed of the impact surface at the time of the initial roof contact. After the vehicle impact(s), the test specimen will be suspended as its rotation ceases without further vehicle impacts.

If it is desired, a second test can be staged on the same vehicle. The impact surface is returned to its initial position, the vehicle is lifted to the starting position and the parameters are adjusted appropriately. The test can then be repeated.

Instrumentation and cameras can record the results of the test in a myriad of configurations depending upon the variables to be examined. For instance, test dummies can be used to assess and measure the total performance of the rollover occupant protection system, or string potentiometers and accelerometers can measure the dynamic roof crush and intrusion.

DESCRIPTION OF TEST BUCK

In order to test the repeatability of the system, a test buck was created that mimicked the strength and dimensions of a production vehicle roof, but was built for ease of roof replacement, see Figure 2 and 3. With the test buck, testing was allowed to occur at an increased pace by just replacing the roof of the vehicle and not the entire vehicle in the fixture.

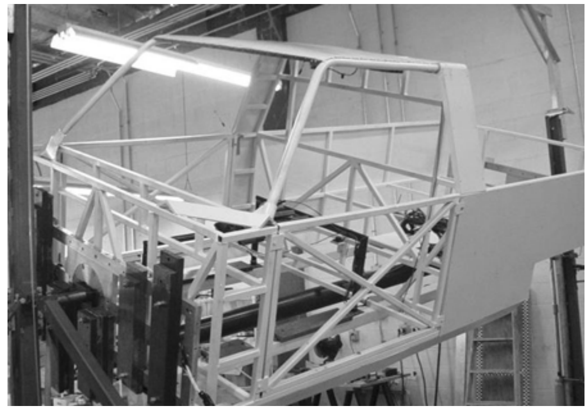

Figure 2. Pictures of the replaceable roof buck.

Figure 3. Pictures of the replaceable roof buck.

The overall dimensions of the buck and geometry were based on a small pickup truck. The roof was composed of seven components; two shaped tubes forming the A-pillars and side rails, a front and rear header, a roof panel and two side stiffeners for the roof panel, see Figure 4. The A-pillar tubes are 1 inch schedule 40 pipe (1.325 inches in outer diameter, .125 inches thick) and made of mild steel. The tubes were chosen based on an examination of cross sections of two production A-pillars in an attempt to have a similar bending stiffness. This was done in order to achieve between 4 to 6 inches of deformation in the tests and show the effects of a failing roof structure on repeatability. The headers are pieces of angled steel 1 by 1 by .125 inch thick. The roof panel was a sheet of 20 gauge (.036 inch) cold rolled steel. The edges of the roof panel were notched and formed around the .5 by .125 inch thick side stiffeners. The roof was held together by a series of spot welds 2 inches apart.

The roof is replaced by cutting the A-pillars at the top of the A-post at a set location. The remainder of the assembly can then be removed as one piece. New A-pillar tubes are then placed into the holders and the roof panel assembly is placed between the tubes. The panel is then spot welded to the side tubes and another test can be conducted. All the roofs were made by the same methods and with the same material.

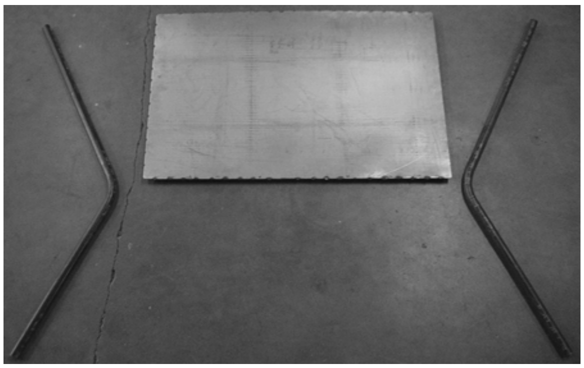

Figure 4. Replaceable roof structure.

DESCRIPTION OF TESTS

Three tests were conducted examining the repeatability of the system. Previous tests indicated that the system was very repeatable from test to test when examining road speed, angles, impact location, etc. However, multiple tests on the same structure to determine the repeatability of the test system and the repeatability of the test structure had not been done.

In all of these tests the initial conditions were kept constant and are described in Table 1.

Table 1.
Initial test parameters

Test Parameter	Initial Setting
Yaw Angle	10 degrees
Pitch Angle	10 degrees
Contact Roll Angle	135 degrees
Contact Roll Rate	188 deg/sec
Drop Height	4 inches
Roadway Speed	15 mph
Buck Weight	1670 lbs

The test system repeatability is shown by consistent speeds, impact locations, angular positioning, drop height, etc.

The vehicle repeatability is shown by the effects of the structure on the far side impact with the roadway, the vertical load cell results, etc.

Each test included instrumentation in both the roadway and the test buck. Roadway instrumentation included 6 vertical and 2 lateral load cells, see Figure 5. The data is recorded at 10,000 data points per second and synchronized with the other test instrumentation and the high speed cameras.

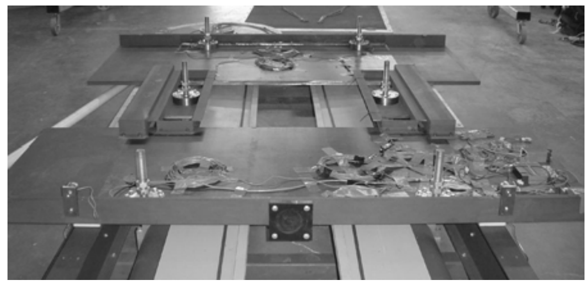

Figure 5. Roadway sled shown without the roadbed to show the instrumentation.

Vehicle instrumentation included tri-axial accelerometers near the rotational axis at about the CG and at the top of the A-pillar and string potentiometers on both the near and far side attached 4 inches inboard of the top of the A-pillar. The instrumentation was placed at the same position in the same manner in each of the tests.

TEST RESULTS

All of the tests were conducted as planned with a near and far side contact on the roof structure. After the contacts, the vehicle rotated to rest without additional contacts. All data and cameras functioned properly. Photographs of the post test condition of each test article are shown in Figures 6, 7 and 8.

Test Parameters

The majority of the test parameters are mechanically fixed and identical from test to test. The only non-mechanically fixed parameters are governed by the air pressure used to power the pneumatic drive system which in turn drives the mechanically coupled rotation of the vehicle and movement of the roadway. The measured roadway velocity in the three tests was 13.5 mph, 13.1 mph and 14.3 mph.

Figure 6. Vehicle Post Test 1.

Figure 7. Vehicle Post Test 2.

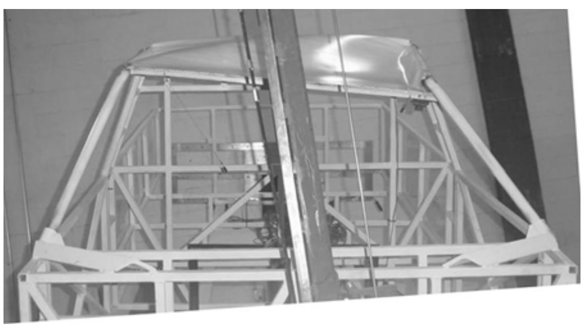

Figure 8. Vehicle Post Test 3.

Roadway Contact Locations

Figure 9 illustrates the roadway impacts for both the near and far side contacts. Figure 10 shows the near side contacts after the third test and that the contact marks coincide to the same point on the roadway and overlap. The far side contacts are dependent upon the structure and there is some small variation.

Vertical Load Cells

The crash pulse is measured by six vertical load cells with the data algebraically summed to determine the vertical load on the roadway. Figure 11 illustrates the results for each of the three tests.

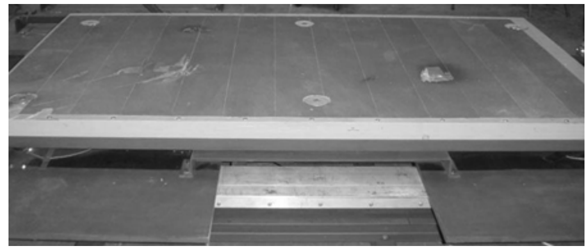

Figure 9. Roadway contact marks from the three tests. The near side contacts are on the right and far side on the left.

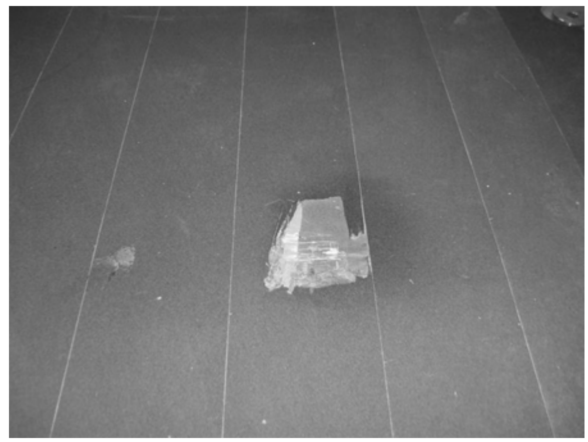

Figure 10. Close up of the near side contact marks from the three tests.

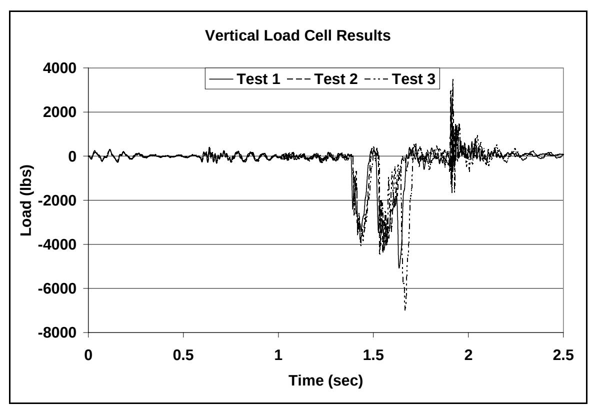

Figure 11. Vertical load cell results for each of the three tests.

In Figure 11, it can be seen that in every test the first contact between the vehicle and the road occurs just prior to 1.4 seconds after the triggers are actuated. This contact is the near side of the roof, the passenger side in these tests, striking the roadway. All three curves are very similar through the entire first contact from approximately 1.38 seconds to 1.5 seconds and until near the end of the far side contact at approximately 1.62 seconds. At that point, the data traces differ due to the interaction between the body structure at the base of the A-pillar and the roadway. This structure, shown in Figure 12, is strong enough to support the weight of the test buck and results in a higher load. The marks from this structure striking the ground are evident on the roadway, see Figure 13.

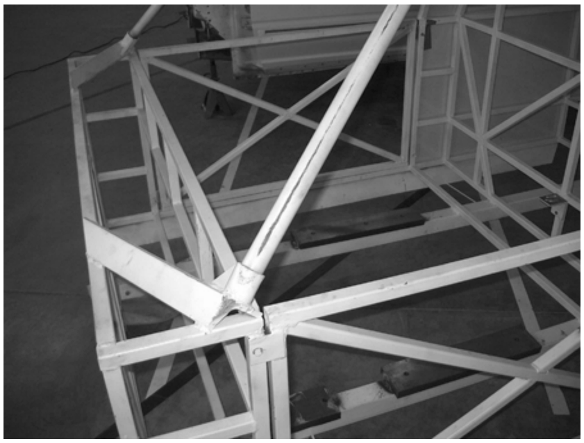

Figure 12. Photograph of the body structure at the base of the A-pillar.

Figure 13. Photograph of the roadway illustrating the contacts with the structure at the base of the A-pillar.

The roof impacts during the contacts on the first side are very similar for the three tests with overlapping contact locations on the roadway and similar load levels. The average maximum load during this contact for the three tests is 3800 lbs with a maximum percentage variation of 10% and a standard deviation of 350 lbs.

For the second contact, the loads on the roof structure are also similar. The only difference is after the roof contact when the body of the vehicle can come into contact with the roadway. For the roof portion of the second contact, the loads are very consistent from test to test with an average maximum load of 4270 with a maximum percentage variation of 4.5% and a standard deviation of 180 lbs.

Lateral Load Cells

Lateral load cells were included in the roadway to determine the loads on the roadway in the direction of the roadway's motion due to the acceleration phases and the vehicle contacts. It was determined after the first test that the cells were improperly attached. This allowed for a limited measurement only and was continued in the following two tests as a means for comparison between these tests. These traces, see Figure 14, are very similar from test to test and illustrate the acceleration pulse as the roadway comes to rest against the decelerator.

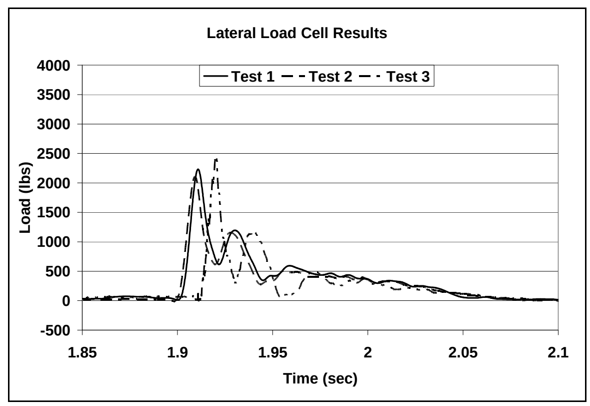

Figure 14. Lateral load cell data from the three tests.

String Potentiometers

The passenger (near) and driver (far) side string potentiometers results are graphed below in Figures 15 and 16. The deformation is similar in the tests with the exception of a greater deformation on the third test due to the header beam moving below the A-pillar tube as the result of a weld failure.

In Figure 15, the near side impact is clearly seen beginning in all three tests at approximately 1.4 seconds. For tests 1 and 2, the peak displacement is approximately 1.9 inches. As the load is removed from this side of the roof, the deformation is reduced to less than .5 inches at approximately 1.5 seconds. Differences in the header deformation due to the second impact result in a residual deformation of 1 inch in test 1 and .6 inches in test 2. For test 3, the peak displacement is 2.6 inches during the near side contact. The additional displacement is due to spot weld failure allowing the header to move below the A-pillar tube. This also causes a second peak in the data trace as the far side contact pushes the beam down further displacing the near side header/A-pillar. The residual deformation for this test is 1.5 inches on the near side.

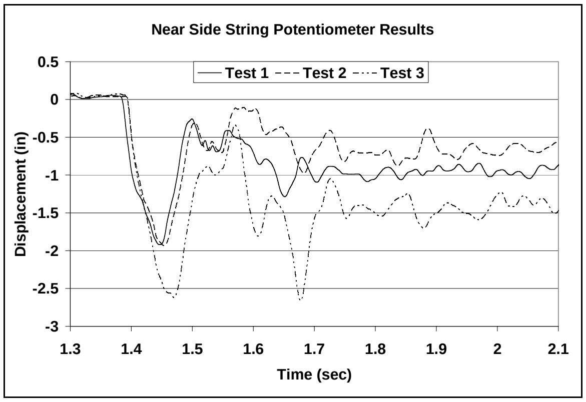

Figure 15. Passenger's (Near) side string potentiometer data.

In Figure 16, the near side impact, from approximately 1.4 to 1.5 seconds, can be seen by a slight outward motion of the roof structure in all three data traces. After this motion, the far side of the roof strikes the ground at approximately 1.5 seconds. As described previously, tests 1 and 2 have similar data traces with differences only due to the structural

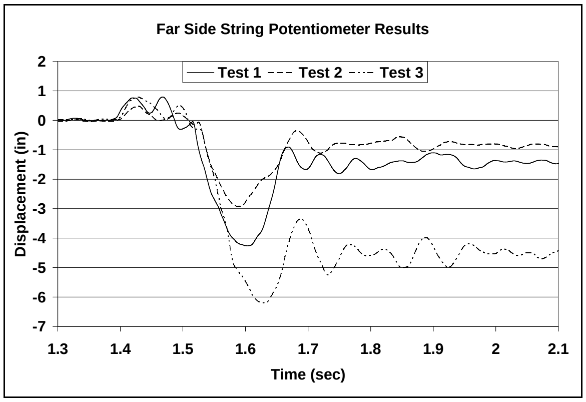

Figure 16. Driver's (Far) side string potentiometer data.

performance and tenting of the header structure. For test 1, the peak deflection is 4.25 inches with a residual deformation of 1.4 inches. For test 2, the peak deflection is 3 inches with a residual deformation of .9 inches. Test 3 has greater deformation due to a weld failure connecting the header to the roof panel. For test 3, the peak deflection is 6.2 inches with a residual deflection of 5 inches.

Accelerometers

In this analysis, we focused on the direct measurements of force and deflection. However, the system is capable of taking accelerometer data. For example, the following trace, Figure 17, is the resultant acceleration data from the three tests as measured near the CG of the vehicle.

DISCUSSION

Repeatability

The test system is very repeatable. An examination of the roadway loads illustrate that the loading environment is almost identical from test to test. The only variation is due to differences in the vehicle as shown by the differences in the string potentiometer readings and the post test appearance of the roofs. These slight variations would also be present in testing of production cars where some variation would occur due to differences in spot welds, windshield failure points, etc. However, the loading environment would be very similar from test to test and it would be hoped that the overall performance of a vehicle would not be contingent on a spot weld or the windshield failure characteristics.

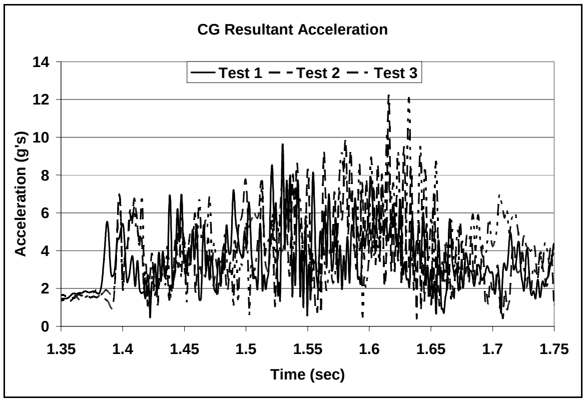

Figure 17. Resultant CG acceleration.

With the repeatability seen here, testing can be conducted at either the component or compliance level to determine the performance of the variable in question with assurance that the loading environment from test to test was consistent while isolating the damage to a particular impact or impacts as desired.

Load Cells

The lateral load cell mounting issue in these tests was corrected for future tests. The data traces in Figure 18 are the vertical and lateral load cell results for a subsequent test illustrating the performance of the system and typical data traces for a production vehicle test. In the test illustrated here, the vehicle test weight was approximately 2800 lbs. Similarly to the test bucks, the far side peak load, at approximately 1.7 seconds, is due to interaction of the top of the A-post and the roadway. Resolving the lateral load cell issue allows the direct measurement of forces during a dynamic rollover event.

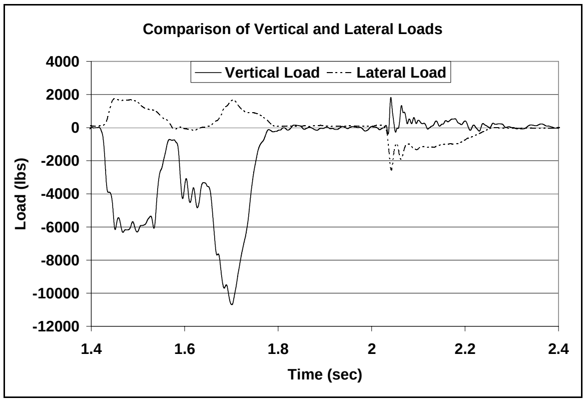

Figure 18. Comparison of vertical and lateral load cell results for a production vehicle.

CONCLUSIONS

The system has been shown to be repeatable. The majority of the parameters are fixed from test to test where the only variable is the air pressure in the system prior to testing. For these tests with identical test bucks, the roadway speed was within 5% for the three tests. The other setup parameters are either dependent upon this speed or fixed.

The loading environment on the vehicle was very consistent from test to test with only small variations, less than 10%, in the peak vertical load values seen during the roof contacts.

ACKNOWLEDGEMENTS

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