Further Improvements to the Truck Model for Roadside Safety Simulation – Suspension and Steering

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Keywords:
Suspension Modeling, Roadside Safety Simulation

ABSTRACT

Pickup trucks are commonly used for crash testing of roadside safety hardware, while nonlinear finite element analysis using LS-DYNA is commonly used to simulate that crash testing. To improve the accuracy of simulation a new front suspension and steering system was developed to replace the existing system on a pickup truck model used for roadside safety simulation. All of the critical components, such as mounting points, alignment, track width and mass, were incorporated into the new model, along with the capability to make the most important components deformable by carefully modeling the geometric details. It is believed that these modifications significantly improve the performance of simulating impacts with roadside curbs, rocks, or culvert grates, where dynamic suspension movement is essential, and with guardrail systems when deformation of the lower control arm is important

INTRODUCTION

In the United States, development and full-scale crash testing of roadside safety devices utilize two different vehicles, a 2000 kg pickup truck and an 820 kg small car; the most common being the pickup truck. In order to take advantage of the many benefits of nonlinear finite element analysis for the design of roadside devices, such as guardrails and concrete barriers, an accurate model of the truck is required.

In 1996, the National Crash Analysis Center (NCAC) released the first version of the C2500 pickup truck model. The development of roadside safety hardware is primarily concerned with the overall performance of the truck as a whole and not on the individual components of the truck; therefore the truck model has evolved over time as computers became faster and as more detail became required based on the structure being impacted.

Since 1996, various research institutions such as the University of Nebraska-Lincoln (UNL) and Worchester Polytechnic Institute (WPI), as well as the NCAC, have been working on improvements to the C2500 truck model [1], [2]. Depending on the type of roadside hardware that was being developed, different aspects of the truck have been improved, such as the addition of a steering system, refinement of the mesh on the exterior skin, and a detailed rear leaf-spring suspension [3].

One aspect that has seen some further development was the front suspension and steering system. As simulations of roadside devices become more detailed with the inclusion of items such as curbs and culvert grates, the front suspension and steering systems need to be modeled even more accurately to simulate the correct movement of the suspension [4]. Curbs and grates, cause the suspension of the truck to undergo large amounts of movement. Additionally, truck impacts with guardrail systems can cause significant deformations to the suspension components. In order to capture this behavior, deformable components for the suspension are required. Previously, these components have been modeled rather coarsely and as rigid bodies.

Front Suspension

The front suspension on a C2500 pickup is a dual a-arm independent suspension system. The main components of the front suspension include an upper control arm, lower control arm, spindle, brake caliper and brake rotor. Each of these main components are shown in Figure 1. Several additional components that attach to and have an important role in the behavior of the front suspension are the sway bar (sometimes referred to as a roll bar), the sway bar to control arm attachment, the tie rod end, the spring, and the shock absorber. These additional components are illustrated in Figure 1.

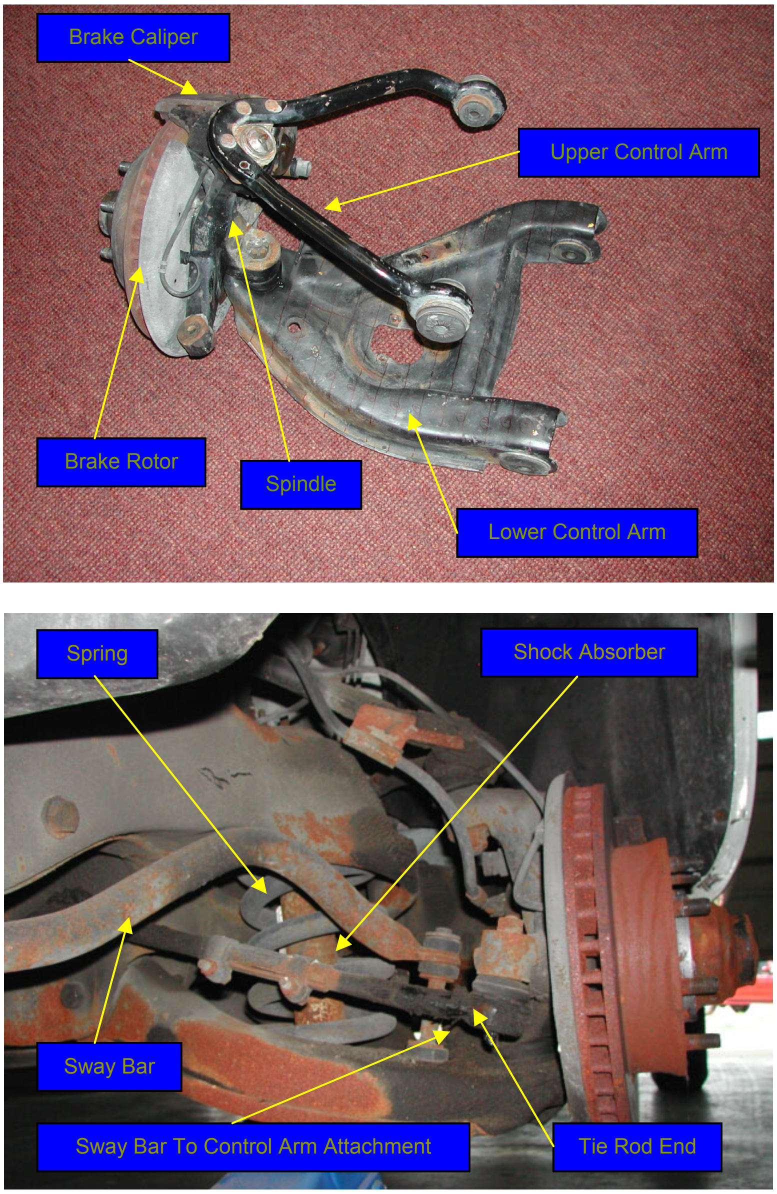


Figure 1. C2500 Front Suspension Components

Attachment of the upper and lower control arm to the frame rail of the pickup is accomplished through the use of bolts, which create revolute joints. The upper and lower control arms are attached respectively to the top and bottom of the spindle. Both of these connections are made through the use of ball joints, which are ball and socket joints. The tie rod is attached to the steering mechanism on one end and the portion of the spindle referred to as the steering arm on the other end. Steering of the vehicle occurs when the tie rod end transfers the motion from the steering mechanism to the spindle. The tie rod end and spindle are attached using a ball joint. The spindle plays an important roll in the front suspension. Not only does it connect the upper and lower control arms and allow for turning of the vehicle, but the components that allow the wheel to rotate, as well as braking components, are attached to the spindle.

As the truck maneuvers over terrain, such as bumps, the front suspension allows the wheel and tire to move up and down with respect to the frame of the truck. The specific direction of this movement is controlled through the geometry and mounting points of the upper control arm, lower control arm, and tie rod end. The spring and shock absorber are attached to the lower control arm and the frame of the truck. As the wheel and tire try to move upwards, the spring generates an opposite direction force to resist the motion. This motion is damped by the shock absorber. The sway bar connects both the left and right lower control arms together and mounts through revolute joints on the frame of the truck. The sway bar increases load transfer from one side of the truck to the other to resist roll motions.

Old and New Suspension

Each of the suspension components was modeled to replace an existing, limited detail model. Shell elements were used to model the lower control arm, while solid elements were used for the upper control arm, spindle, brake rotor, and tie rod end. Discrete elements were used to model the spring and shock absorber. These components are shown in Figure 2. For comparison, the original suspension is shown in Figure 3. The sway bar, which is not shown, was also modeled with discrete beam elements. Upper and lower control arms were attached to the frame rails using revolute joints and to the spindle using spherical joints. Similarly the tie rod end is attached to the spindle with a spherical joint. The brake rotor attaches to the spindle using a revolute joint.

Lower Control Arm Deformation

Testing of roadside safety hardware has resulted in various forms of failure in the front suspension on the C2500 pickup, most commonly occurring in the lower control arm. Failure mostly occurs in two main ways, joint failure, either of the ball joint or the revolute joint where the control arm mounts to the frame, or through lower control arm deformation. Joint failure is incorporated into the current UNL truck model. Lower control arm deformation has an increased chance of occurring when the impact occurs with roadside hardware that includes a concrete member, such as a concrete temporary barrier or a concrete bridge rail. Deformation is also observed in impacts with guardrail systems when severe snagging of the wheel and tire occurs on one or more posts in the system. Photographs of deformed lower control arms are shown in Figure 4. The photo on the left, from a crash cushion test, illustrates joint failure, while the right, from a concrete barrier test, depicts lower control arm deformation.

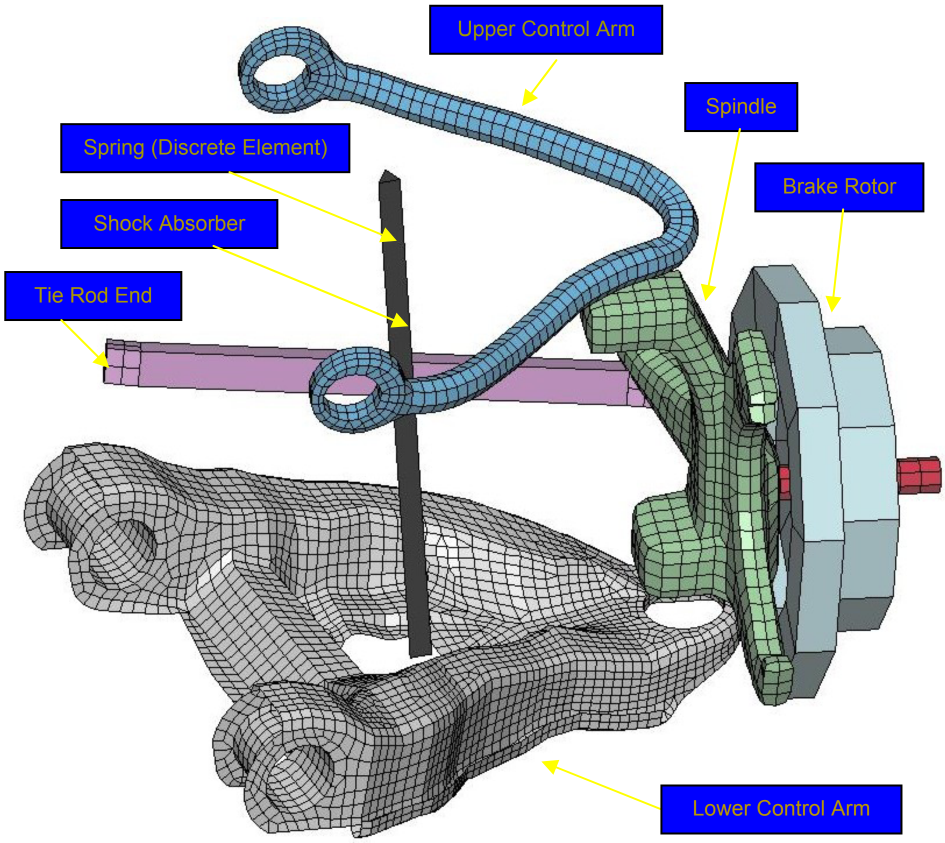


Figure 2. New Front Suspension Model Components

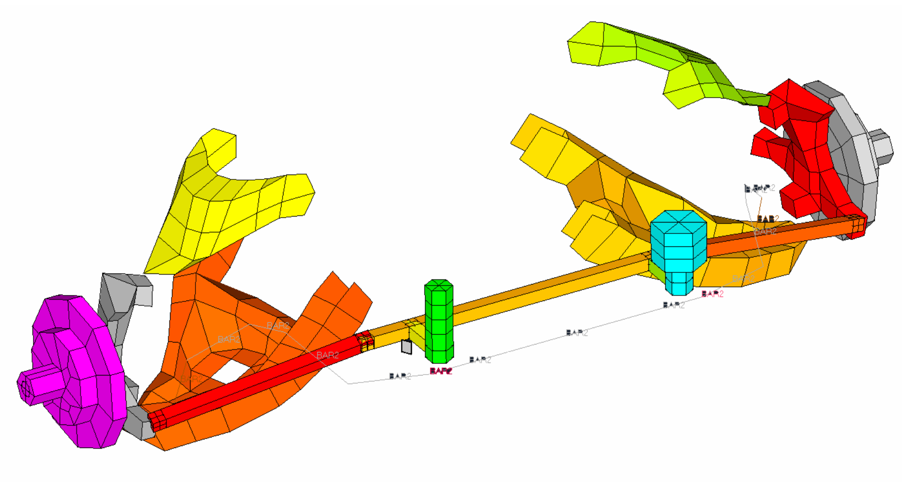


Figure 3. Old Front Suspension/Steering Subsystem Models

Figure 4. Lower Control Arm Deformation That Occurs During Crash Testing

The previous suspension model, shown in Figure 3, used a coarse mesh on the lower control arm as well as a rigid material so no deformation of the lower control arm occurred. Simulations were performed on the new lower control arm to illustrate its ability to deform under loads from various directions. Sequential photos of a lower control deformation simulation are shown in Figure 5. No laboratory testing was done to validate the simulation.

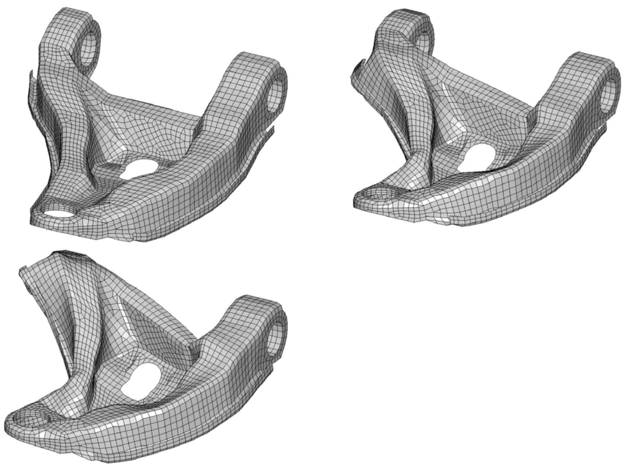


Figure 5. Lower Control Arm Deformation Simulation

Mounting Points

Each of the main suspension components were modeled individually. Assembling the pieces with the proper geometry was essential to capture the dynamic performance of the suspension. The parts had to be placed in the right position with respect to each other as well as at the correct mounting locations. Measuring where each component mounts is not an easy task since there are many components that inhibit easy measurement. In order to obtain these locations, a rigid structure was created under the vehicle that essentially pointed to each mounting location. This structure is shown in Figure 6.

Figure 6. Structure to Find Front Suspension Mounting Points

After the structure was fully constructed under the vehicle, it was carefully removed for measuring. Measurement of the mounting points was then easily accomplished using a level and tape measure. The modeled suspension components were then oriented to these positions. The mounting point locations provide good overall suspension geometry, however each vehicle is fine tuned with more detailed measurements than just these mounting points.

Suspension Details

In addition to the proper mounting points and geometry of the components, other small details in the front suspension can make the difference between being able to let go of the steering wheel while driving 60-mph down the road and needing to hold onto the steering wheel at all times. Alignment of the vehicle, steering system geometry, and the mass of the suspension components are all very critical.

Vehicle Alignment

Adjustment of the angles in the front suspension is often referred to as the alignment of the vehicle. Alignment consists of four primary angle measurements: caster, camber, king pin, and toe. Differences of less than one degree in these angles can severely alter how the vehicle drives. Caster is the angle observed between the upper and lower ball joint when the vehicle is viewed directly from the side. Camber is the angle between the tire and the ground when the vehicle is viewed directly from the front. King pin is the angle between a line drawn from upper to lower ball joint and the ground line. When the vehicle is viewed directly from the top, the toe angle is measured as the difference between the tires pointed straight forward and angled in or out.

Prior to crash testing, each test vehicle is taken to an alignment shop where the caster, camber and toe angles are set. Target alignment values for the test vehicle are shown in Table 1. The suspension model was modified to obtain the proper alignment angles. These angles were measured on the previous model of the front suspension and are shown in Table 1, along with the angles on the new suspension model.

Table 1. Alignment Angles - Test Vehicle, New Model, Previous Model

Front Suspension Angles (Degrees)					
Angle Side	Test Vehicle Left	Right	Average	New Model Both Sides	Current Model Both Sides
Caster	2.500	2.750	2.625	2.625	1.257
Camber	0.450	0.180	0.315	0.315	0.1085
King Pin	N/A	N/A	N/A	14.26	12.25
Toe	0.03125	0.03125	0.03125	0.03125	0.0056

Steering System

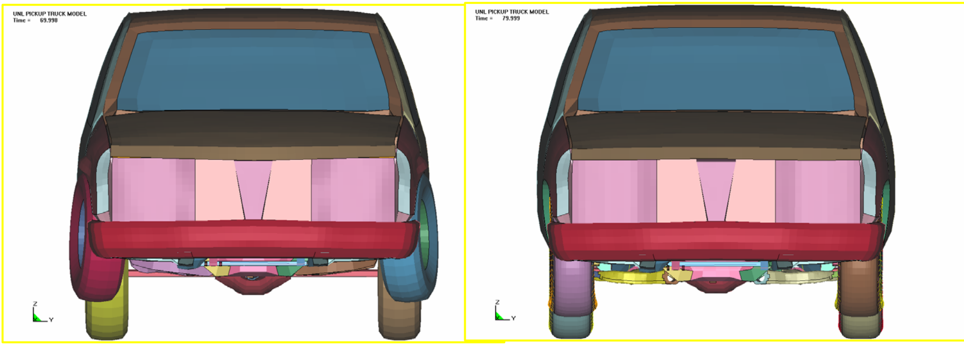
In addition to the alignment of the front suspension, the layout of the steering system is critical. Ackerman steering is a principle that refers to the geometry of the steering system. As a car maneuvers around corners, both the inside and outside wheel encounter different radii. These radii will vary based on vehicle dimensions and how tight of a corner the car is trying to turn. Both wheels need to be pointing straight forward when no steering is acting, and the inner wheel needs to turn progressively more the tighter the turn that is being made. This is accomplished by changing the geometry and angle of the steering arm on the spindle.

Ackerman steering was checked on the new front suspension model. If the geometry of the components, the mounting locations, and the suspension alignment were correct, Ackerman steering would be present. A line was drawn from the steering arm on the front spindle to the center of the rear axle. This line passed very close to a line drawn between the upper and lower ball joint. This is an indication that Ackerman Steering was accomplished.

The steering linkage lengths are equally as important. If the tie rod ends are too long, the inside mounting point, where the pivot occurs as the suspension travels up and down, the toe angle will change as the suspension travels up and down. The affects of this are illustrated in Figure 7 where the tires on the previous model toe in. This is sometimes referred to as bump steer. With the proper geometry and mounting locations for the steering and suspension systems, the new model did not exhibit bump steer.

Component Masses

Maintaining proper mass in a computer model with respect to the actual vehicle can be very important. Rotating and translating masses can play an important role in the behavior of the test vehicle as it impacts a roadside device and gets redirected. When the vehicle suspension encounters an obstacle such as a curb, the component masses effect suspension movement. The components were first modeled using a standard density of steel for all the suspension parts that was then modified on a component-to-component basis to get the proper mass. A comparison of masses for major front suspension components between the previous truck model, new truck model, and the actual truck is shown in Table 2. Note that since the brake caliper was not modeled, it was combined with the spindle since it bolts to the spindle.



previous model new model

Figure 7. Improper Steering System Geometry Fixed

Table 2. Front Suspension Component Masses

Front Suspension Masses (kg)					
Component	Test Vehicle	New Model	% Difference From Actual	Current Model	% Difference From Actual
Lower Control Arm	10.89	10.89	0.00	7.51	-31.04
Upper Control Arm	4.08	4.08	0.00	2.14	-47.55
Rotor	16.33	16.33	0.00	22.19	35.88
Brake Caliper	5.89	N/A	N/A	N/A	N/A
Spindle	9.98	15.86	N/A	5.44	N/A
Spindle and Brake Caliper Combination	15.87	15.86	-0.06	5.44	-65.72
Lower Arm, Upper Arm, Rotor, Brake Caliper and Spindle	47.17	47.16	-0.02	37.28	-20.97

Application

In order to test abilities of the new suspension, a simulation was performed where the truck was driven over a rocky ground, consisting of rocks 100-mm in height, at 40-mph. Rocks of this size would put a sizeable force into the suspension causing it to travel upward. Sequential photos of the simulation are shown in Figure 8. Notice the movement of the right front suspension as the bumps are encountered.

Conclusions

Using LS-DYNA [5], a new front suspension and steering system was developed that replaced the existing system on a pickup truck model used for roadside safety simulation. All of the critical components, such as mounting points, alignment, track width and mass, were incorporated into the new model, along with the capability to make the most important components deformable by carefully modeling the geometric details. Because of the relatively small mesh size, thus small time step, it is recommended that the deformable components be made rigid when deformation of those components is not imminent. It is believed that these modifications significantly improve the performance of simulating impacts with roadside curbs, rocks, or culvert grates, where dynamic suspension movement is essential, and with guardrail systems when deformation of the lower control arm is important.

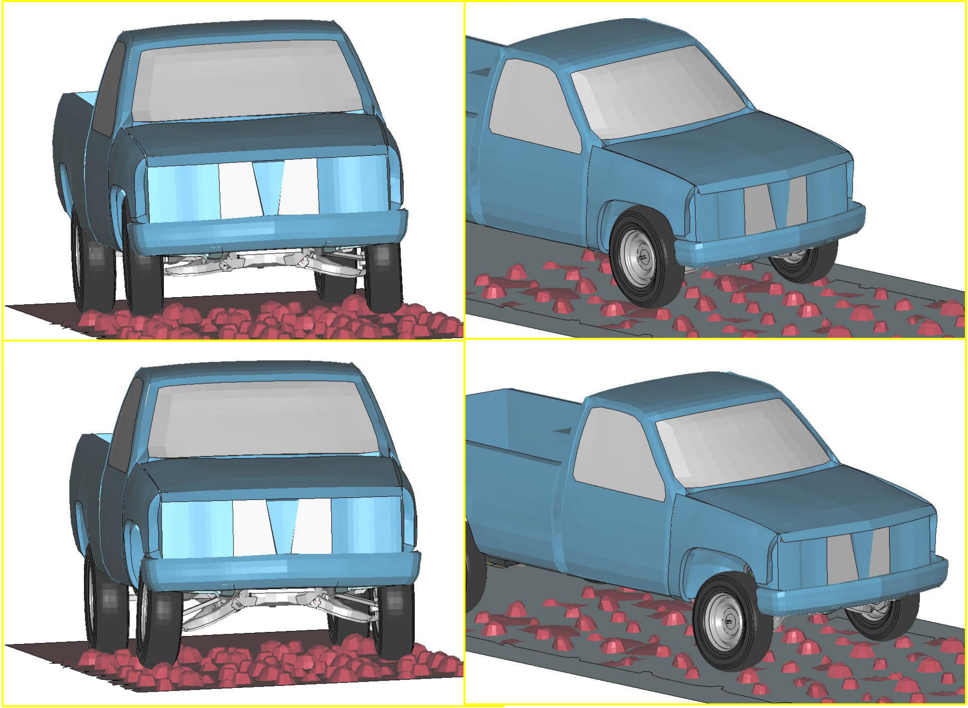


Figure 8. Rocky Ground Simulation Sequential Photos

Acknowledgments

The authors wish to acknowledge the Midwest Roadside Safety Facility and Livermore Software Technology Corporation for their support. The simulation work performed during this project was completed utilizing the Research Computing Facility of the University of Nebraska – Lincoln.

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