

Assessing the Effect of Chassis Torsional Stiffness on Tractor Semi-trailer Rollover

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Abstract: The semi-trailer chassis was usually treated as rigid body in many existing literature, which would lead to larger deviation from actual situation. A rigid semi-trailer chassis model was built and flexibilized based on the modal test results in this paper. The tractor semi-trailer with flexible chassis was utilized to simulate the rollover scenarios on high speed obstacle avoidance under emergency based on virtual prototyping. The simulation results were compared to the simplified 5-DOF, 3-wheel linear vehicle model. It was revealed that the wheels on flexible chassis are more inclined to be got pushed up and away from the road, which is likely to occur rollover. The actual roll angle of semi-trailer is proposed to be measured from several positions, and it should be a weighted value.

Keywords: Tractor semi-trailer, torsional stiffness, obstacle avoidance, rollover

1. Introduction

A tractor semi-trailer, also known as articulated vehicle is an articulated truck consisting of a tractor and a semi-trailer that carries the freight [1]. Tractor semi-trailers on high speed obstacle avoidance under emergency are likely to arise rollover, which is a serious risk for motorists. Handling behaviour of articulated vehicles is more complex and less predictable than that of non-articulated vehicles. The ability of the semi-trailer to articulate relative to the tractor through the fifth wheel contributes an additional mass with which the driver must be concerned. In addition, the response of the semi-trailer to inputs from the tractor, such as steering manoeuvres, is typically amplified and lags behind the response of the tractor making it difficult to control. This often causes stability problems and a semi-trailer may start to roll excessively before the driver is aware of the problem and, therefore, may not have time to take corrective action [2-4].

There are many methods or strategies designed for tractor semi-trailer chassis control system for rollover prevention and roll stability improvement. Among the existing literature, the semi-trailer chassis was usually treated as rigid body, which would lead to larger deviation from actual situation. As shown in Fig. 1, the tractor semi-trailer

was performed rollover test. The rear part of the semi-trailer can be found a large torsional deformation relative to the front part. Therefore the flexible chassis of semi-trailer is more likely to rollover comparing to desired rigid chassis. And different position of roll sensor on the semi-trailer may get different roll information, which will affect the vehicle stability control or roll support control function.



Figure 1 Tractor semi-trailer rollover test

In this paper, a rigid semi-trailer chassis was built based on the modal test results and flexibilized. The tractor semi-trailer with flexible chassis was utilized to simulate the rollover situation on high speed obstacle avoidance under emergency based on virtual prototyping.

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2. Kinematics model of tractor semi-trailer

Most of the kinematics models of the motion of tractor semi-trailer combinations which have been developed so far have dealt with tracking of trailers in a turn. In developing the equations of motion for the yaw-roll model, the tractor and semi-trailer units are assumed to have no pitch or bounce. Also, the tractor semi-trailer is assumed to travel at a constant forward velocity. A simplified 5-DOF, 3-wheel linear vehicle model was usually used to design the control strategy (Fig. 2 and Fig. 3) [5-7].

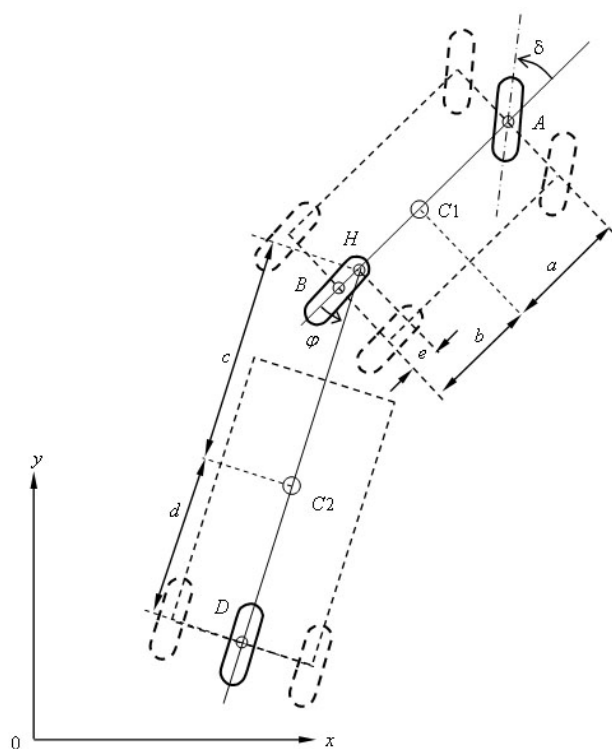


Figure 2 Tractor semi-trailer model

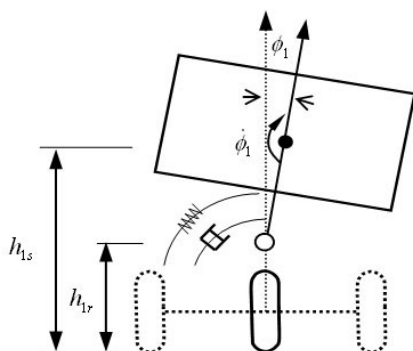


Figure 3 Rear view of tractor roll

The articulated vehicle was modeled using two rigid bodies: tractor and the semi-trailer. The tractor unit had freedom to side-slip, yaw and roll; while the semi-trailer had freedom to yaw relative to the tractor and to roll.

Equations of motion are given by following:

$$m_1 u (\dot{\beta}_1 + \dot{\psi}_1) - m_1 s u (h_{1s} - h_{1r}) \ddot{\phi} = Y_{\beta_1} \dot{\beta}_1 + Y_{\psi_1} \dot{\psi}_1 + Y_{\phi_1} \dot{\phi}_1 + Y_{\delta} \delta - F_H \tag{1}$$

$$I_{1zz} \ddot{\psi}_1 - I_{1xz} \dot{\phi}_1 = N_{\beta_1} \dot{\beta}_1 + N_{\psi_1} \dot{\psi}_1 + N_{\phi_1} \dot{\phi}_1 + N_{\delta} \delta + e F_H \tag{2}$$

$$I_{1x'x'} \ddot{\phi}_1 - I_{1x'z'} \ddot{\psi}_1 = m_1 s g (h_{1s} - h_{1r}) \phi_1 + m_1 s u (h_{1s} - h_{1r}) (\dot{\beta}_1 + \dot{\psi}_1) - (C_{1f}^* + C_{1r}^*) \phi_1 - (k_1 + k_2) \dot{\phi}_1 + K_{12} (\phi_1 - \phi_2) + h_{1cr} F_H \tag{3}$$

where,

$$\frac{1}{C_{1f}^*} = \frac{1}{C_{1f}} + \frac{1}{C_{1rf}}$$

$$\frac{1}{C_{1r}^*} = \frac{1}{C_{1r}} + \frac{1}{C_{1tr}}$$

Including the additional force and torque,

$$m_2 u (\dot{\beta}_2 + \dot{\psi}_2) - m_2 s u (h_{2s} - h_{2r}) \ddot{\phi} = Y_{\beta_2} \dot{\beta}_2 + Y_{\psi_2} \dot{\psi}_2 + Y_{\phi_2} \dot{\phi}_2 + F_H \tag{4}$$

$$I_{2zz} \ddot{\psi}_2 - I_{2xz} \dot{\phi}_2 = N_{\beta_2} \dot{\beta}_2 + N_{\psi_2} \dot{\psi}_2 + N_{\phi_2} \dot{\phi}_2 + c F_H \tag{5}$$

$$I_{2x'x'} \ddot{\phi}_2 - I_{2x'z'} \ddot{\psi}_2 = m_2 s g (h_{2s} - h_{2r}) \phi_2 + m_2 s u (h_{2s} - h_{2r}) (\dot{\beta}_2 + \dot{\psi}_2) - C_{2r}^* \phi_2 - k_3 \dot{\phi}_2 - K_{12} (\phi_2 - \phi_1) - h_{2cr} F_H \tag{6}$$

where,

$$\frac{1}{C_{2r}^*} = \frac{1}{C_{2r}} + \frac{1}{C_{2tr}}$$

The kinematic constraint equation between the tractor and semi-trailer:

$$\dot{\beta}_2 = \dot{\beta}_1 + \frac{h_{1s} - h_{1a}}{u} \dot{\phi}_1 - \frac{h_{2s} - h_{2a}}{u} \dot{\phi}_2 - \frac{l_{1a}}{u} \dot{\psi}_1 - \frac{l_{2a}}{u} \dot{\psi}_2 + \dot{\psi}_1 - \dot{\psi}_2 \tag{7}$$

Lateral velocity of the semi-trailer

$$y_2 = u \beta_2 + u \psi_2 \tag{8}$$

These above equations can be expressed in state-space:

$$\dot{X} = AX + B\delta \tag{9}$$

where,

$$X = [\psi_1 \quad \beta_1 \quad \dot{\phi}_1 \quad \phi_1 \quad \psi_2 \quad \psi_2 \quad \beta_2 \quad \dot{\phi}_2 \quad \phi_2 \quad y_2]$$

The desired yaw rates, slip angles and roll angles of tractor and the semi-trailer can be calculated by equation (9). By comparing the desired yaw rates, roll angles with the actual measured values from sensors, the electronic control unit can detect the vehicle operating status, such as oversteer, understeer, jackknife or rollover.

For the desired roll angle of semi-trailer is computed from the rigid chassis, it may deviate largely from the actual roll angle measured from different position of the semi-trailer, which may deteriorate the tractor semi-trailer rollover.

Therefore, the actual roll angle should be measured from several positions of the semi-trailer, and it should be a weighted value. The weighting factors may be determined by theoretical and experimental methods.

3. Dynamic analysis using Adams/Car

In order to assess the effect of chassis torsional stiffness on tractor semi-trailer rollover, we perform a dynamic analysis using ADAMS/Car. One drawback of the ADAMS program is that all components are assumed to be rigid. Fig. 4 is tractor semi-trailer based on rigid body. In the ADAMS program, tools to model component flexibility exist only for geometrically simple structures. To account for the flexibility of a geometrically complex component [8-9], ADAMS relies on data transferred from finite-element programs such as ANSYS. The ANSYS-ADAMS Interface is a tool provided by ANSYS, Inc. to transfer data from the ANSYS program to the ADAMS program.

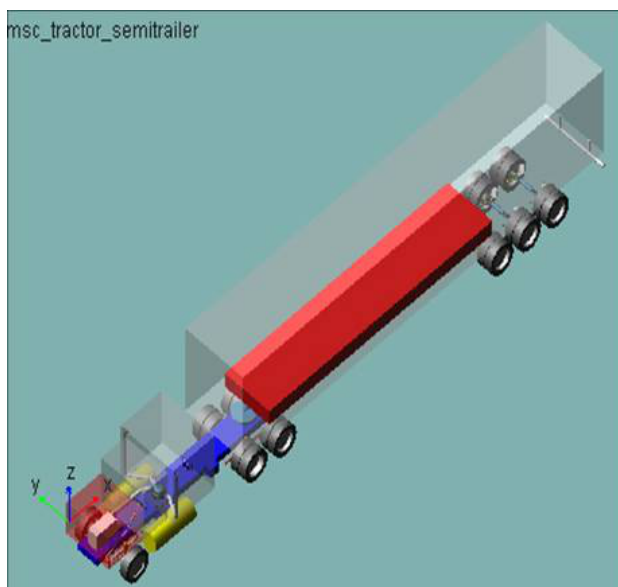


Figure 4 Tractor semi-trailer based on rigid body

To analyze the chassis torsion, we need flexible chassis in ADAMS. Obviously, the semi-trailer chassis can't belong to geometrically simple structures in any sense. It

will produce wrong result if using a box part to act as the arm. So we have to create the flexible chassis using ANSYS. Fig. 5 is the flexible semi-trailer chassis built in Pro/ENGINEER and meshed in ANSYS8. The chassis is divided into many parts with workplane. The regular parts are map meshed with SOLID45 element while the others are free meshed with SOLID92 element. The flexible semi-trailer chassis was modified based on the modal test (as shown in Fig. 6) several times.



Figure 5 Flexible semi-trailer chassis



Figure 6 Modal test on the semi-trailer chassis

Master node is the joint between the flexible semi-trailer chassis and other parts, such as damper, air suspension, and fifth wheel king pin. According to the constraint, load and driving force on the chassis, 25 master nodes are defined in ANSYS. These master nodes use MASS21 element, a tiny real constant and a huge elastic modulus.

In ADAMS, flexible bodies are defined by importing modal data as calculated by an external Finite Elements (FE) program. A special data file (the mnf file) is used to transfer frequency and amplitude data for a selected number of vibration modes from a FE code to ADAMS. Craig Bampton modes, required for defining constraint connections to flexible bodies are transferred from the FE code by defining master nodes. For each master node, constraint mode information is stored in the mnffile. Fig. 7 is the flexible semi-trailer chassis assembly in ADAMS/Car.

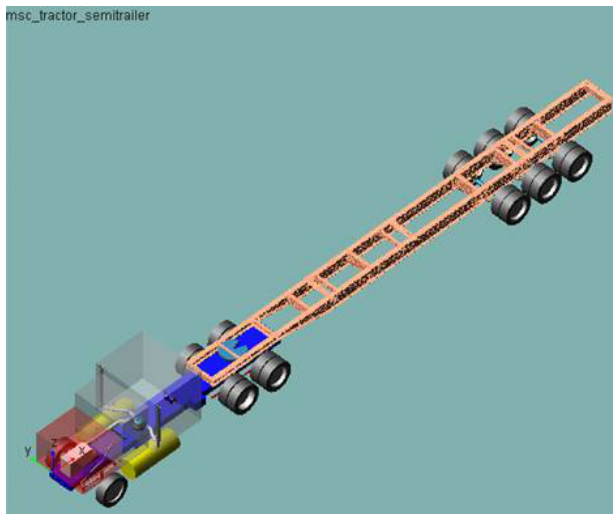


Figure 7 Flexible semi-trailer chassis assembly

4. Simulational result

A flexible semi-trailer chassis was created in ADAMS/Car with the neutral file exported from ANSYS to replace the rigid one. In order to simulate the high speed obstacle avoidance under emergency and achieve more realistic simulation results, a single lane change simulation was performed in ADAMS/Car using an assembly grouped with several subsystems, a test rig and the flexible semi-trailer chassis, as shown in Fig. 8.

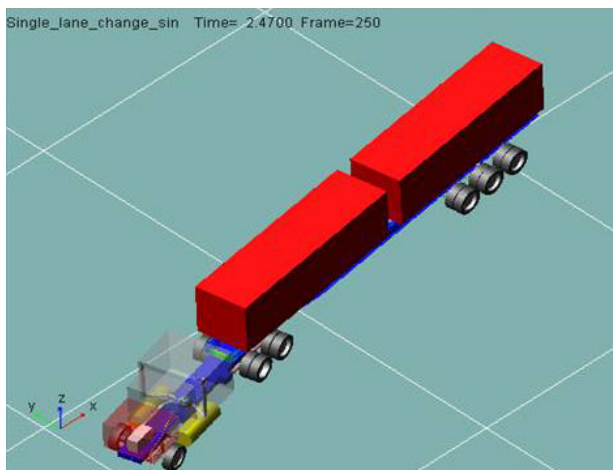


Figure 8 Simulation of flexible chassis

Fig 9 is the roll angle of both front and rear end on the flexible chassis in the single lane change simulation. As shown in Fig. 9, the roll angle of rear end is bigger than the front one, while they are the same values using rigid semi-trailer chassis.

The simulation results reveal that the wheels on flexible chassis are more inclined to be got pushed up and away from the road, which is likely to result in rollover.

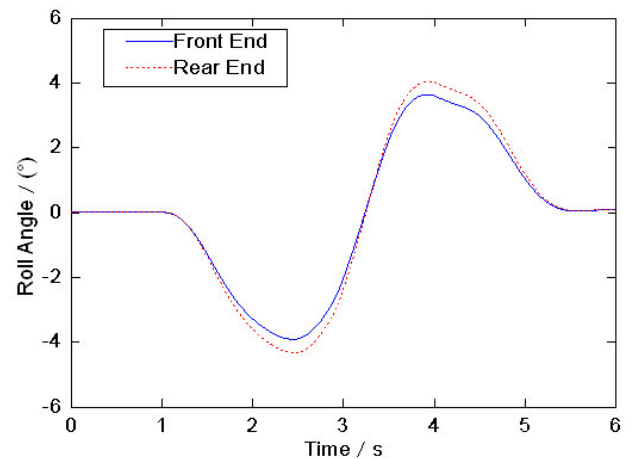


Figure 9 Roll angle of both front and rear end on the flexible chassis

Since the semi-trailer chassis is doomed to twist on high speed obstacle avoidance under emergency, any roll angle measured from a single sensor can not certainly represent the actual roll information. Therefore, the realistic roll angle should be measured from several positions of the semi-trailer, and it should be a weighted value. The realistic roll angle can be obtained from equation (10).

$$\phi_r = k_f \phi_{rf} + k_c \phi_{rc} + k_r \phi_{rr} \quad (10)$$

where ϕ_{rf} , ϕ_{rc} , ϕ_{rr} are the roll angle measured from the front end, centroid and rear end of the semi-trailer chassis respectively. k_f , k_c , k_r are the weighting factors.

5. Conclusion

Tractor semi-trailers on high speed obstacle avoidance under emergency are likely to arise rollover, which is a serious risk for motorists. Nowadays there are many methods or strategies designed for tractor semi-trailer chassis control system for rollover prevention and roll stability improvement. Among the existing literature, the semi-trailer chassis was usually treated as rigid body, which would lead to larger deviation from actual situation. In this paper, a semi-trailer chassis was built and flexibilized using ANSYS software. The tractor semi-trailer with flexible chassis was utilized to simulate the rollover situation on high speed obstacle avoidance under emergency based on virtual prototyping. The simulation results reveal that the rear part of the semi-trailer can be found a large torsional deformation relative to the front part. And different position of roll sensor on the semi-trailer may get different roll information, which will affect the vehicle stability control or roll support control function.

Acknowledgement

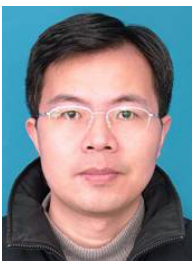
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