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Research on Rollover Threshold Value of Tank Truck

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Abstract. The purpose of this paper is to provide reference for safety warning and accident recovery of tank truck rollover. The calculation method of critical lateral acceleration of tank truck considering liquid sloshing is studied by combining analytical method and multi-body dynamics simulation method. In this paper, three methods are presented to solve the critical lateral acceleration of tank truck rollover considering liquid sloshing, which are analytical method, step steer simulation method and tilt table simulation method respectively. The liquid sloshing is simplified to two-dimensional liquid sloshing by assuming that the lateral acceleration of the tank truck is constant. The change of liquid center of gravity is used to be equivalent to the effect of liquid sloshing on tank truck rollover. The influence data of liquid sloshing, tire ,suspension system and tank truck center of gravity on the rollover of tank truck were obtained. The research results can be applied to the safety warning and accident recovery of tank truck.

Key words. Tank truck, rollover, critical acceleration, critical velocity, ADAMS CAR

1. Introduction

When transporting dangerous chemicals such as liquefied gas by tank truck, if there is a rollover leakage, the consequences are extremely serious, which will cause great loss of life and property [1]. For example, in 2020, the "June 13" tank truck explosion accident in Wenling section of Shen-Hai Expressway caused 20 deaths, 175 people hospitalized and a direct economic loss of 9,477,815 yuan. So in order to prevent rollover accident, it is very necessary to study the critical value of rollover of tank truck.

Foreign scholars have conducted long-term and in-depth studies on vehicle rollover motion [2]. Eger Ralf et al. [3] studied the steady-state boundary problem of vehicles by using a simplified vehicle model. Hyun et al. [4] established a 14-degree-of-freedom vehicle model to evaluate the rollover threshold of the vehicle. Hegazy S [5] considered the influence of suspension and tire on steering and obtained the transient lateral acceleration. Yoon J et al. [6] predicted vehicle rollover using vehicle roll Angle velocity and roll Angle. Sankar S [7] found that reducing the center of gravity, increasing the roll center, increasing the wheel pitch and suspension stiffness can improve vehicle rollet-resistance ability. Based on lateral load transfer, Vincent

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Nguyen [8] analyzed the influence of roll moment distribution on the bifurcation characteristics of the system under and over steering. R. D. Ervin [9] pointed out that the static rolleover threshold of a fully rigid vehicle is about 0.45g, and the rolleover threshold is reduced to 0.36g due to the flexibility of the tire and suspension. Cooperrider et al. [10] found that vehicle handling frequency is related to roll stability. E. Dahlberg [11] believed that dynamic analysis was very important for the study of truck rollover stability. M. A. Saeedi et al. [12], K. N. Toosi University of Technology, Iran, based on A quasi-static liquid model And 16DOF semi-trailer model to analyze the lateral stability of semi-trailer tank truck. Venkata Ramesh Chaganti1, Dr.A.suiva Kumar, G.Hima Bindu et al. [13] Established the mathematical model of 3-DOF vehicle, studied the influence of the motion state of lateral slip and yaw on roll, effectively warned heavy vehicle rolover and optimized rollover stability.

Domestic scholars also have certain studies on vehicle rollover motion [14]. Lin Zhigui et al. [15] studied the relationship between car roll stability Angle and roll. Zhu Jun et al. [16] proposed the dynamics model of vehicle rollover. Li Shengqin et al. [17] established a three-degree-of-freedom vehicle roll model and analyzed the influence of vehicle speed and steering wheel Angle on vehicle rolover. Zhang Zhifei et al. [18] established an all-terrain vehicle model based on the software ADAMS CAR and analyzed the critical rollover threshold of all-terrain vehicles. Liu Jing used the software Adams Car to establish the roll model of the car tank car, and carried out the anti-roll attitude control of the car [19]. Xie Jin used Adams Car to establish the liquid equivalent damping model of tank truck [20]. Li Xiansheng deduced the roll dynamics equation of tank truck [21]. Li Zhen [22] established dynamic model o of automobile tank CAR based on ADAMS CAR, and studied the influence of liquid sloshing on the rollover stability of tank truck.

At present, there are more researches on ordinary passenger cars, but few on tank trucks. Especially, there are fewer researches on tank trucks when liquid sloshing is combined with vehicle dynamics. At the same time, the anti-rollover performance of vehicles is more studied, but the rollover critical value is less studied. Therefore, in this paper, the critical threshold of tank truck rollover considering liquid sloshing is studied. Liquid sloshing is simplified to two-dimensional liquid slosh, and the influence of liquid sloshing on tank truck rollover is equivalent to the change of liquid center of gravity. The critical threshold of tank truck rollover is solved by combining analytical method and multi-body dynamics simulation method. The research results can be applied to the safety warning and accident recovery of tank truck.

2. Tank Truck Center of Gravity Position Calculation

Because the liquid loading capacity of the car tank truck is changing, the position of the liquid center of gravity also changes with the loading capacity. The position of liquid center of gravity is an important factor affecting the rolover stability of tank truck. The calculation method of liquid center of gravity of tank truck is discussed below.

2.1. Calculation of Center of Gravity of Liquid at Rest

When the car tank truck is stationary on the horizontal road, the liquid level remains horizontal and the liquid is a symmetrical figure, as shown in figure 1. Its center of gravity is located on the vertical axis of symmetry, that is, the abscissa of the center of gravity is 0. The vertical coordinate of the liquid center of gravity was calculated using the method of triangle and sector combination [23].

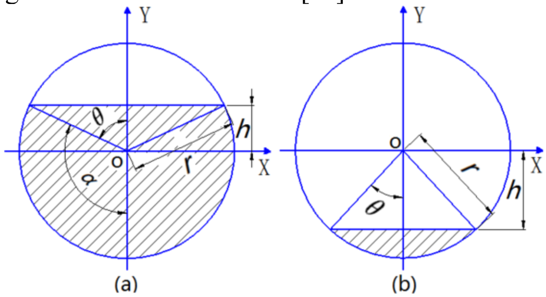

Figure 1. Liquid center of gravity

(1) When the liquid level is higher than or equal to the horizontal symmetric plane of the tank, as shown in figure 1(a), the vertical coordinate of the liquid center of gravity is calculated according to formula 1-17.

$$\theta = \arccos(\frac{h}{r}) \tag{1}$$

$$\alpha = \pi - \theta \tag{2}$$

$$S_{\text{tri}} = rh\sin(\theta) \tag{3}$$

$$S_{\text{sec}} = r^2\alpha \tag{4}$$

$$Y_{\text{tri}} = \frac{2}{3}h \tag{5}$$

$$Y_{\text{sec}} = -\frac{2r\sin(\alpha)}{3\alpha} \tag{6}$$

$$Y_{\text{static}} = \frac{Y_{\text{tri}}S_{\text{tri}} + Y_{\text{sec}}S_{\text{sec}}}{S_{\text{tri}} + S_{\text{sec}}} \tag{7}$$

Where: θ,half of the apex Angle of a triangle; h,Liquid level height; γ,Tank radius; α,Half of the Angle of a fan; Stri,Area of a triangle; Ssec, Sector area; Ytri, Vertical coordinate of triangle center of gravity; Ysec, Sector center of gravity ordinate; Ystatic, The vertical coordinate of the center of gravity at rest.

(2) When the liquid level is lower than the horizontal axis of symmetry, as shown in figure 1(b), the vertical coordinate of the liquid center of gravity is calculated according to formula 8-13.

$$\theta = \arccos(\frac{h}{r}) \tag{8}$$

$$S_{\text{tri}} = rh\sin(\theta) \tag{9}$$

$$S_{\text{sec}} = r^2\theta \tag{10}$$

$$Y_{\text{tri}} = -\frac{2}{3}h \tag{11}$$

$$Y_{\text{sec}} = -\frac{2r\sin(\theta)}{3\theta} \tag{12}$$

$$Y_{\text{static}} = \frac{Y_{\text{sec}}S_{\text{sec}} - Y_{\text{tri}}S_{\text{tri}}}{S_{\text{sec}} - S_{\text{tri}}} \tag{13}$$

Where: θ, half of the apex Angle of a triangle; h, Liquid level height; γ, Tank radius; Stri, Area of a triangle; Ssec Sector area; Ytri Vertical coordinate of triangle center of gravity; Ysec, Sector center of gravity ordinate; Ystatic The vertical coordinate of the center of gravity at rest.

2.2. Calculation of Liquid Center of Gravity Under Lateral Acceleration

Three-dimensional liquid sloshing is simplified to two-dimensional liquid sloshing, assuming that the lateral acceleration is stable when the tank truck is turning. By changing the position of liquid center of gravity, the effect of liquid slosh on the rolover of tank truck was simulated. The liquid surface was simplified from a curved surface to a plane, and force analysis was carried out on particle P on the liquid surface. The liquid barycenter coordinates were solved according to formula 14-22, as shown in figure 2.

$$F_{\mathrm{P}} = m_{\mathrm{P}} \frac{v^2}{x_{\mathrm{P}} + R} \tag{14}$$

$$G_{\mathrm{P}} = m_{\mathrm{P}} g \tag{15}$$

According to Newtons second law, parcle P satisfies the following formula

$$T_{\mathrm{P}} \cos\theta - G_{\mathrm{P}} = 0 \tag{16}$$

$$F_{\mathrm{P}} - T_{\mathrm{P}} \sin\theta = 0 \tag{17}$$

Deduce:

$$\tan\theta = \frac{v^2}{g\,(x_{\mathrm{P}} + R)} \tag{18}$$

Because $R >> x_{\mathrm{P}}$

$$\tan\theta = \frac{v^2}{gR} \tag{19}$$

$$\theta = \arctan(\frac{v^2}{gR}) \tag{20}$$

$$X_{\mathrm{dyn}} = -Y_{\mathrm{static}} \sin\theta \tag{21}$$

$$Y_{\mathrm{dyn}} = Y_{\mathrm{static}} \cos\theta \tag{22}$$

Where: FP,particle centrifugal force, mP particle mass, v,traveling speed, xP,particle abscissa, R, turning radius, GP, particle gravity, g, gravitational acceleration, Tp, liquid surface normal reaction, θ,liquid surface inclination Angle, Xdyn, horizontal coordinate of center of gravity when liquid is sloshing ; Ydyn,T he vertical coordinate of center of gravity when the liquid is sloshing, Ystatic, the vertical coordinate of the center of gravity when the liquid is at rest.

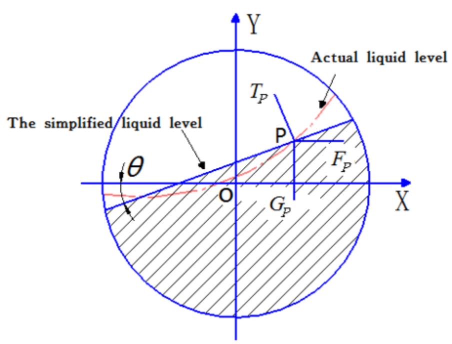

Figure 2. Liquid side angle

3. Critical acceleration calculation

3.1. Analytical Method

When the tank truck turns on the level road surface, the tank truck bears the action of lateral centrifugal force, so that the automobile tank car takes the ground point of the outside wheel as the support point and tilts outwards laterally. When the lateral centrifugal force reaches a certain level and the contact force between the inner wheel and the ground is 0, the car tank truck begins to roll over, as shown in figure 3. At this time, the torque balance equation and critical acceleration [24] are formulas 23-25.

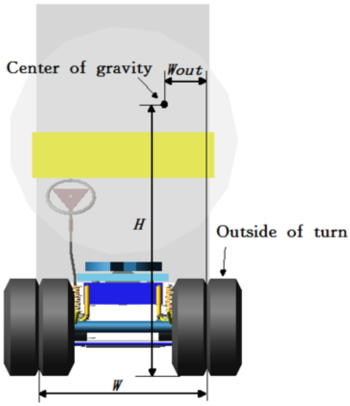

Figure 3. The model of tank truck rollover

$$ma_{\text{critical}}H = mgW_{\text{out}} \tag{23}$$

$$a_{\text{critical}} = \frac{W_{\text{out}}}{H} \times g \tag{24}$$

When the center of gravity coordinates are on the vertical axis of symmetry of tank truck

$$a_{\text{critical}} = \frac{W}{2H} \times g \tag{25}$$

$$X_{\text{all}} = \frac{m_{\text{other}}X_{\text{other}} + m_{\text{liquid}}X_{\text{dyn}}}{m_{\text{other}} + m_{\text{dyn}}} \tag{26}$$

$$Y_{\text{all}} = \frac{m_{\text{other}}Y_{\text{other}}Y_{\text{other}} + m_{\text{liquid}}Y_{\text{dyn}}}{m_{\text{other}} + m_{\text{dyn}}} \tag{27}$$

Where: m, vehicle mass; acritical,Critical acceleration; H, Gravity center height of the vehicle; Wout, The horizontal distance between the center of gravity and the outer wheel; g, Gravitational acceleration; W, Wheel span; mother, Mass outside the liquid; mliquid, Liquid mass; Xother, Horizontal coordinates of center of gravi outside the liquid; Xdyn, Ydyn Horizontal and vertical coordinates of liquid center of gravity under lateral acceleration; Xall, Yall, Horizontal and vertical coordinates of the vehicle's center of gravity.

When calculating the critical acceleration, it is first assumed that the tank truck is running on the horizontal road and the liquid remains level. Formula 25 is used for the initial calculation to obtain the critical acceleration without considering the liquid slosh. Then, according to the method shown in Section 2.2, the liquid center of gravity position under the critical acceleration without considering liquid slosh was calculated, and the vehicle center of gravity position was recalculated by formula 26-27. Finally, a new center of gravity position of the tank truck is adopted and formula 24 is used to recalculate the critical acceleration considering liquid slosh.

The advantage of analytical method is that the formula is simple and it is easy to calculate the critical acceleration of the tank truck especially without considering liquid sloshing. The disadvantage is that the influence of the tire and suspension system on the rollover of the automobile tank car is not considered, and the calculation result is too large.

3.2. Step Steer Simulation Method

In this paper, multi-body dynamics software ADAMS CAR is used to establish the dynamics model of the tank truck and the simulation analysis is carried out. The tank truck is a very complex mechanical system. To establish a multi-body dynamics model of the tank truck from scratch not only requires the modeler to have a good understanding of each system of the automobile and the relationship between the systems, but also needs to be very familiar with the operation of ADAMS CAR software, which is an extremely time-consuming and energy-consuming thing. In this paper, it is not suggested to build the dynamics model of the tank truck from scratch, but to modify the model of the tank truck based on the heavy truck model of ADAMS CAR.

The tank truck model established in this paper mainly includes cab, steering system, engine, tractor chassis, tank body, semi-trailer chassis, liquefied gas, control wheel, front wheel of tractor, rear wheel of tractor, front wheel of semi-trailer, semi-trailer rear wheel 1, semi-trailer rear wheel 2, suspension system and so on. As shown in figure 4.

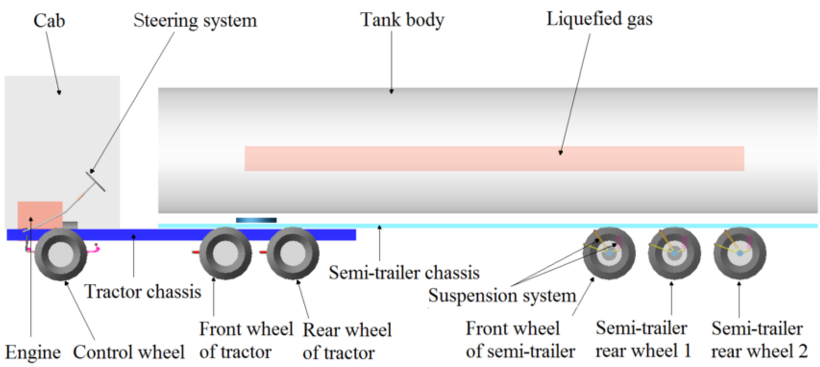

Figure 4. Tank truck model

The main influencing factors of tank truck rollover are the position of center of gravity, suspension system and tires. Focus here on the suspension and tires. The suspension system includes elastic components, shock absorbers and guiding mechanisms. The suspension system is generated by modifying the hard point position of the system template, as shown in figure 5. The elastic element is simulated by a spring, and the shock absorber is simulated by a damper. The spring stiffness parameters and damper parameters in the model are adjusted according to the stiffness and damping values of the actual suspension system. The tire model adopts Fiala model. The tire model is a classic elastic circular beam model, which is convenient and simple, easy to build and has few parameters. It can change the performance of the tire by directly editing and modifying the relevant parameters. As shown in figure 6.

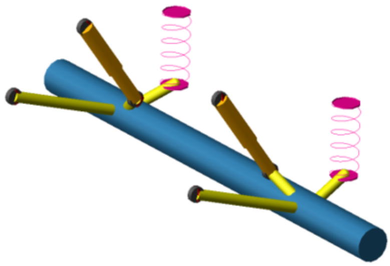

Figure 5. Suspension system

Figure 6. Tire system

Build a component that represents the center of mass of the tank truck. The mass of the mass component is set to a small value, such as 1kg. The position of the component is driven by a hard point. Create a request to output the lateral acceleration of the vehicle's center of mass. Before each simulation calculation, adams car was used to calculate the position of the vehicle's centroid, and then the hard point position of the car tank truck centroid components was modified. In this way, the lateral acceleration of the vehicle can be obtained in the simulation post-processing.

Step steer simulation refers to that the tank truck is driving at a certain constant speed, and an angular step input is applied to the steering wheel at a certain moment, and then the Angle remains unchanged. The simulation can obtain the lateral acceleration, speed, yaw speed and side Angle of the tank truck.

When calculating the critical acceleration, it is first assumed that the tank truck is driving on the horizontal road and the liquid remains level. The input parameters of the step steer simulation, such as speed and steering Angle, are adjusted continuously to carry out the step steer simulation until the tank truck rolls over In the simulation post-processing, the normal contact force curve of the innermost tire of the last row of the semi-trailer with the ground and the lateral acceleration curve of the tank truck's center of mass with time are shown, as shown in figure 7 and 8. Confirm the moment when the tire force is 0 in figure 7, and confirm the lateral acceleration under this moment in figure 2. This acceleration is the critical acceleration without considering liquid sloshing. Figure 9 shows the rollover moment. At this moment, the normal contact force between the innermost tire of the last row and the ground is 0.

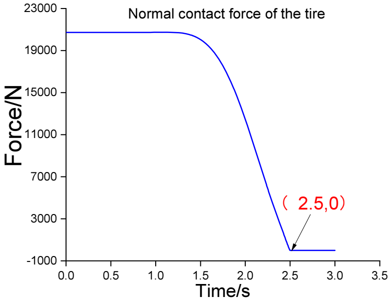

Figure 7. Normal contact force of the tire

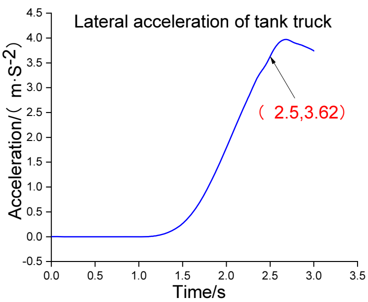

Figure 8. Lateral acceleration of the tank truck

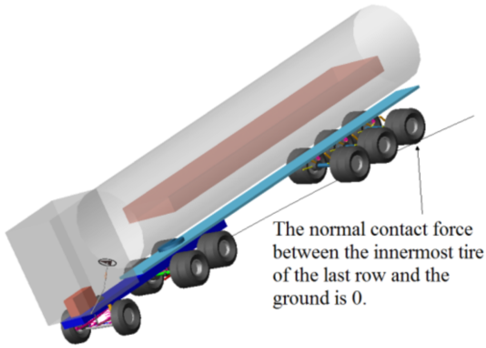

Figure 9. Moment of rollover

According to the method shown in Section 2.2, the position of gravity center of liquid considering the critical acceleration of tank truck was calculated, and then formula 26-27 was used to recalculate the position of gravity center of the tank truck. Adjust the center of gravity position of the liquefied gas model in the tank truck model, adjust the hard point position of the tank truck centroid component, and carry out step steer simulation to recalculate the critical acceleration of tank truck.

The advantage of the step steer simulation method is that it fully considers the influence of tire system, suspension system and liquid sloshing on the rolover of tank truck, and the results are more accurate.

3.3. Tilt Table Analysis

Tilt table analysis means that the tank truck is placed on the steel plate stationary, and one end of the steel plate rotates around the other end until the tank truck is about to roll over, as shown in figure 10.

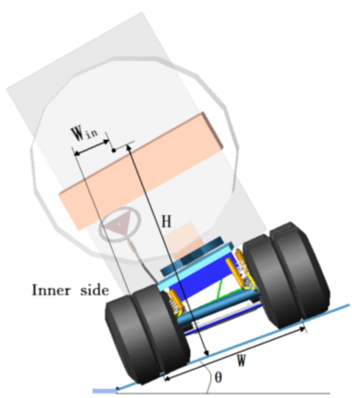

Figure 10. Tilt table analysis

The balance equation was established at the moment of rollover in the roll motion and derived as follows:

$$mg\sin\theta \times W_{\text{in}} = mg\cos\theta \times H \tag{28}$$

$$\tan\theta = \frac{W_{\text{in}}}{H} \tag{29}$$

When the center of gravity coordinates are on the vertical axis of symmetry of tank truck

$$\tan\theta = \frac{W}{2H} \tag{30}$$

Compare formulas 24 and 29, and formulas 25 and 30

$$a_{\text{critial}} = \tan\theta \times \text{g} \tag{31}$$

Where: m, vehicle mass; g, Gravitational acceleration; θ, Roll Angle; Win, Distance from center of gravity to inner wheel; H, Gravity center height of the vehicle; acritical, Critical acceleration; W, Wheel span.

Tilt table analysis was carried out on the tank truck, and the normal contact force curve of a outside tire changing with Angle was obtained in the simulation post-processing, and the Angle when the normal contact force was 0 was determined, as shown in Figure 11. The critical acceleration of tank truck without considering liquid sloshing was obtained by formula 31.

According to the method shown in Section 2.2, the position of gravity center of liquid considering the calculated critical acceleration of tank truck was calculated, and then formula 26-27 was used to recalculate the position of gravity center of the tank truck. The final critical acceleration considering liquid slosh is obtained by adjusting the center of gravity of the liquefied gas model in the car tank car model and re-calculating the roll simulation.

The Tilt table analysis method considers the influence of tire system, suspension system and liquid sloshing on the rolover of tank truck, and the results are more accurate than the analytical method. Compared with the step steer simulation method, it ignores the influence of the transition state in the motion process, and its accuracy is inferior to that of the step steer simulation method.

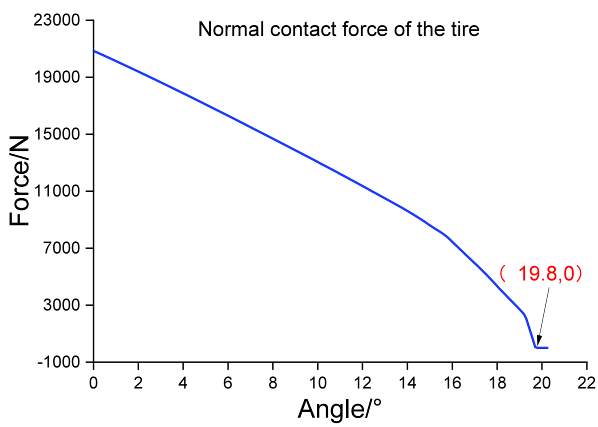

Figure 11. Normal contact force of the tire

3.4. Compare the Three Methods

In this paper, the "June 13" tank truck explosion accident in Wenling section of Shenzhou-Hai Expressway in 2020 is taken as the background for research, and the critical acceleration of the tank truck in this accident is calculated respectively according to the three methods above. The maximum load capacity of the tank truck is 26 tons. It is assumed that the liquid is just full when the tank is fully loaded. The critical accelerations of the tank truck of different liquid filling ratios are calculated, and the results are shown in table 1 and figure 12-14.

Table 1. Critical acceleration

Critical acceleration	**Analytical method m/s2**	**Step steer simulation m/s^2**	**Tilt table analysis m/s^2**	**Contrast between analytic method and Step steer simulation**	**Contrast between tilt table analysis and Step steer simulation**
Without considering liquid sloshing					
Full load	4.46	3.38	3.28	24.22%	-3.05%
90%	4.66	3.52	3.48	24.46%	-1.15%
70%	5.06	3.8	3.99	24.90%	4.76%
50%	5.49	4.14	4.48	24.59%	7.59%
40%	5.7	4.25	4.88	25.44%	12.91%
20%	6.10	4.53	5.11	25.74%	6.85%
10%	6.24	4.78	5.25	23.40%	8.95%
No-load	6.29	4.83	5.29	23.21%	8.70%
considering liquid sloshing					
Full load	4.46	3.38	3.28	24.22%	-3.05%
90%	4.52	3.44	3.37	23.89%	-2.08%
70%	4.66	3.54	3.67	24.03%	3.54%
50%	4.86	3.75	3.94	22.84%	4.82%
40%	5.00	3.82	4.26	23.6%	10.33%
20%	5.45	4.29	4.55	24.22%	9.23%
10%	5.80	4.48	4.85	22.76%	7.63%
No-load	6.29	4.83	5.29	23.21%	8.70%
Comparison of results without and with the effect of liquid sloshing					
Full load	0.00%	0.00%	0.00%	--	--
90%	3.0%	2.27%	3.16%	--	--
70%	7.91%	6.84%	8.02%	--	--
50%	11.48%	9.42%	12.05%	--	--
40%	12.28%	10.12%	12.70%	--	--
20%	10.66%	8.83%	10.96%	--	--
10%	7.05%	6.28%	7.62%	--	--
No-load	0.00%	0.00%	0.00%	--	--

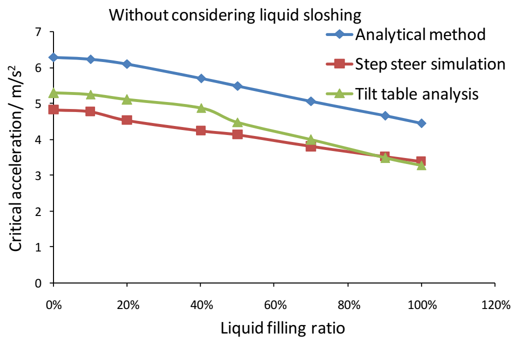

Figure 12. Critical acceleration without considering liquid sloshing

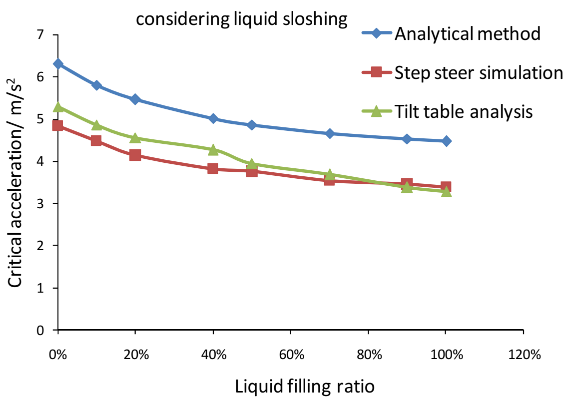

Figure 13. Critical acceleration considering liquid sloshing

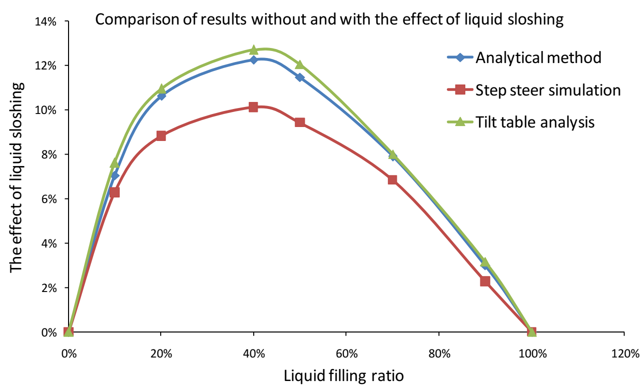

Figure 14. Comparison of results without and with the effect of liquid sloshing

Because the step steer simulation method not only considers the influence of the tire and suspension system, but also considers the influence of the transition response of the tank truck before rolling over, the results of the step steer simulation method are relatively accurate. As can be seen from Table 1, the critical acceleration obtained by the analytical method is 24.49% larger on average than that obtained by the angular step method without considering the influence of liquid sloshing, which is mainly caused by the fact that the analytical method does not consider the influence of tire and suspension system on the critical acceleration of rollover of the tank truck. It can be seen that the tire and suspension system have great influence on the critical acceleration of rollover for tank truck. Compared with the step steer simulation method, the maximum error of the critical acceleration obtained by the roll method without considering liquid sloshiness is 12.91%, in which the error is less than 4.76% when the liquid filling ratio is over 70%. The tilt table analysis method is an approximate and feasible method to calculate the critical acceleration without considering liquid sloshing. The critical acceleration of tank truck without considering liquid sloshing can be obtained easily by using tilt test.

The critical acceleration obtained by the analytical method is 23.60% larger on average than that obtained by the step steer simulation method when considering the effect of liquid sloshing. This is mainly because the analytical method does not consider the influence of the tire and suspension system on the critical acceleration of rollover.of the tank truck. Compared with the step steer simulation method ,the maximum error of the tilt table analysis method is 10.33% when the loading capacity of the car tanker is 40%,and the error is less than 4.76% when the liquid filling ratio is over 70%.The roll method is an approximate and feasible method to calculate the critical acceleration considering the influence of liquid sloshing. The critical acceleration considering liquid sloshing can be obtained easily by using tilt test.

Whether considering the effect of liquid sloshing or not, the calculation results of the three methods are large in the middle and small at both ends, as shown in figure 14. When the liquid filling ratio is about 40%, liquid sloshing has the greatest influence on the critical acceleration. When the liquid filling ratio is 40%, the difference between the results of the step steer simulation method considering the effect of liquid sloshing and those without considering the effect of liquid sloshing is 10.12%. It can be seen that the influence of liquid sloshing on critical acceleration is a factor that cannot be ignored.

4. Accident recovery

The calculation method of the critical acceleration of rollover of the tank truck described in this paper can provide reference and basis for the recovery of the tank truck rollover accident.

In this paper, the accident recovery of the "June 13" tank truck explosion accident in Wenling section of Shen-Hai Expressway in 2020 is conducted. The tank of the tank truck in the accident was filled with a density of about 529.50kg/m3 and a capacity of 25.36 tons of liquefied petroleum gas. The volume of the tank is 61.90 m3 and 32.78 tons when fully filled. The volume of filled liquefied petroleum gas is 77.37% of the total volume. Based on this, the liquid level height of the liquefied petroleum gas is calculated, and then the liquid center of gravity height is calculated using the method described in Section 2.1. The step steer simulation method in section 3.2 was used to calculate the critical acceleration, and the critical acceleration considering the influence of liquid sloshing was obtained to be 3.466m/s2.

Lateral acceleration occurs when the tank truck turns, which satisfies formula 32-33. The radius of the road where the accident occurred is about 60m. According to Formula 33, the critical speed of turning and rollover of the tank truck can be obtained as 14.42m/s, that is, 51.91 km/hour. According to the judicial authorities, the tank truck was traveling at 52 to 57 kilometers per hour before it rolled over, exceeding the critical speed. Therefore, it is determined that the cause of the accident is that the tank truck speed exceeded the critical speed and rolled over, resulting in the accident. The accident recovery shows that the results of step steer simulation are basically consistent with the actual results.

$$a_{\text{critical}} = \frac{v_{\text{critical}}^2}{R} \tag{32}$$

$$v_{\text{critical}} = \sqrt{a_{\text{critical}} R} \tag{33}$$

Where : acritical , critical acceleration; R , Turning radius; vcritical ,Indicates the critical speed.

5. Safety warning

The calculation method of the critical acceleration of rollover of the tank truck described in this paper can provide reference and basis for the safety warning.

Take the "June 13" tanker explosion accident at Wenling section of Shen-Hai Expressway in 2020 as an example. It is assumed that the tank truck speed before entering the accident curve is 57.00km/hour, and the critical speed of the tank truck has been calculated as 51.91km/hour. If the driving speed is higher than the critical speed, the warning system will warn the driver to reduce the speed in advance through voice, alarm or image, so as to avoid the occurrence of accidents.

6. Conclusion and prospect

In this paper, three methods are presented to solve the critical acceleration of tank truck, which are analytical method, step steer simulation method and tilt table analysis method. The analytical method uses mathematical formula to calculate the critical acceleration. Both the step steer simulation method and the tilt table analysis method use the software ADAMS CAR to simulate the multi-body dynamics to obtain the critical roll acceleration. The three methods all consider the effect of liquid roll on rollover. The critical acceleration results calculated by the three methods were compared, and the influence data of liquid sloshing, tire and suspension system and center of gravity position on the rollover of tank truck were obtained.

In this paper, the step steer simulation method is used to solve the critical acceleration of tank truck, and the accident recovery of the "June 13" explosion of tank truck in Wenling section of Shen-Hai Expressway in 2020 is carried out.

This paper provides an approximate solution to the effect of liquid sloshing on the rollover of the tank truck, which is only applicable to the case that the tank truck is driving stably with constant lateral acceleration and the liquid is tilting steadily. The actual situation is that when the tank truck turns, the liquid will shake violently due to the constant change of lateral acceleration. This method can not reflect the effect of liquid sloshing truly. In the future, ADAMS CAR and FLUENT can be used to jointly simulate the liquid sloshing of tank truck, CAR. ADAMS CAR provides real-time motion data to FLUENT, and FLUENT provides mechanical data of liquid sloshing to ADAMS car to more truly simulate the actual situation of tank truck rollover.

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