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Study on Transport Safety Evaluation and Driving Stability of Hazardous Chemicals Vehicles

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Abstract

In view of the problem of the road transport safety of hazardous chemicals. This paper constructs the evaluation index system of road transport safety of dangerous goods by analyzing the impact of liquid sloshing on the transport safety and driving stability. People, vehicles, roads, environment and other factors that affect the safety of the transport vehicles are also considered. In this paper, the analytic hierarchy process (AHP) is used to give the weight of each evaluation facto and seven kinds of evaluation set of safety status are set up. This paper takes the vehicle handling stability as the object, and analyzes the influence of liquid sloshing on the handling stability of vehicle. The simulation model is constructed by the software of Trucksim, and the fishhook test is selected to carry out the simulation test. The simulation results show that forces and moments generated by the liquid sloshing significantly reduce the vehicle stability. The research method provides reference for practice and decision-making in road transport of dangerous goods safety evaluation.

Keywords

Hazardous chemicals vehicles, Transport safety evaluation, Analytic hierarchy process, Liquid sloshing, Stability.

1. Introduction

Hazardous chemical accidents have occurred in the process of road transport frequently. According to the statistics, 80% of the hazardous chemicals in our country are transported by road, and in all kinds of hazardous chemical accidents, more than 70% of the accidents occurred in the part of transportation [1, 2, 3]. Therefore, it is of great significance to conduct a reasonable safety evaluation of hazardous chemicals vehicles. At present, domestic and foreign scholars have made great progress in the research of vehicle transport safety evaluation [4, 5]. Lower et al., proposed a risk evaluation method for airfreight accidents based on fuzzy risk matrix which can quantitatively express the degree of risk[6]. Wang Xulei used Bayesian truth serum theory and expert knowledge to build the causal Bayesian network model for the influence factors of road transportation accidents of hazardous chemicals[7]. Li Changlong et al., used Mamdani fuzzy inference system to evaluate tanker transport safety[8]. Zhu Ting et al., used D-S evidence theory, expert knowledge and the conditional independence test to build the network structure. They derived the posterior probability of each factor with the inference and the expectation-maximization algorithm[9]. Using the set pair analysis principle, Wu Yanqun formed a set pair with two sets: the evaluation index of dangerous goods road transport and classification standard of safety level. He also calculated the connection degree of each evaluation index and the total connection degree of set pair[10]. Wu Jinzhong et al., analyzed the main effecting factors of dangerous goods transport from different angles and established the risk evaluation index system of dangerous goods transport and then they evaluated it[11].

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In this paper, the liquid tank semi-trailer is used as the research object, the analytic hierarchy process (AHP) is used to evaluate the safety of vehicle transport. Influences of liquid sloshing on the handling stability of vehicle are analyzed.

2. Construction of the safety evaluation index system of hazardous chemicals transport

There are many factors that cause the transport safety of hazardous chemicals vehicles. People, vehicles, roads and the environment are the four major factors that affect the safety of transport vehicles. Consider the uncertainty and complexity of these factors, as well as the safety of hazardous chemicals transport. The safety evaluation index system of transport vehicles is established which is shown in Table 1.

Table 1: Safety evaluation index system and index weight of vehicle transportation

	First-class indexes	weight	second-class indexes	weight
safety evaluation index system of hazardous chemicals transport	hazardous chemicals	35.4%	Types of hazardous chemicals	64.0%
			Packaging of hazardous chemicals	20.6%
			Quantity of hazardous chemicals	15.4%
	vehicles	2.8%	Vehicle hardware	58.2%
			Vehicle accessories	41.8%
	environment	20.1%	road condition	35.7%
			weather condition	34.7%
			Complexity of the road	29.6%
	transport	5.4%	Transport speed	61.7%
			Transport time	25.3%
			Transport route	13.0%
	personnel	13.8%	the quality of personnel	59.7%
			the body of personnel	40.3%
	management	8.3%	Laws and regulations	44.3%
			information Technology	39.8%
			Accident emergency rescue plan	15.9%
	liquid sloshing	14.3%	Acceleration	29.3%
			filling ratio	31.2%
			Medium density	28.5%
			volume	11.0%

3. Determination of index weigh

Taking into account the characteristics of the safety evaluation index system of hazardous chemicals transport, analytic hierarchy process (AHP) is used to determine the weight coefficient of each evaluation index. Assuming that B_k in the AHP is the criterion, the C_{ki}, ……, C_{km} of the next level are compared with each other to form a judgment matrix C.

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ c_{m1} & c_{m2} & \cdots & c_{mm} \end{bmatrix}$$

In the formula, C_{ij} shows the relative importance of factor C_{ki} to C_{kj} in terms of evaluation criterion B_k and its value is determined by means of “1~9” scaling method.

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3.1. Calculation of index weight

Taking the judgment matrix $A = (a_{ij})_{m\times m}$ as an example, the maximal eigenvalue and its eigenvector are calculated by the square root method, and the eigenvector is the weight vector of the evaluation index. The steps are as follows:
Calculate each line of the matrix of the product M_i judgment matrix.

$$M_i = \prod_{j=1}^{m} a_{ij}, i = 1,2,\dots,m \tag{1}$$

Calculating the m root $\overline{W_i}$ of M_i.

$$\overline{W_i} = \sqrt[m]{M_i} \tag{2}$$

Normalizing the vector $\overline{W_i} = [\overline{W_1}, \overline{W_2}, \dots \overline{W_m}]^T$.

$$w_i = \frac{\overline{W_i}}{\sum_{j=1}^{m} \overline{W_j}}, i = 1,2,\cdots,m \tag{3}$$

In the formula, $W = [w_1, w_2, \dots w_m]^T$ is the calculated eigenvector, and the eigenvector is the weight vector of elements C_{k1},C_{k2},... C_{km} under B_k criterion.
Calculating the maximal eigenvalue λ_{max} of the judgment matrix.

$$\lambda_{\max} = \frac{1}{m}\sum_{i=1}^{m}\frac{(AW)_i}{W_i} \tag{4}$$

Where $(AW)_i$ represents the i^{th} element of vector AW.

$$AW = \begin{bmatrix} (AW)_1 \\ (AW)_2 \\ \vdots \\ (AW)_m \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{bmatrix} \tag{5}$$

3.2. Consistency test for index

The consistency and randomness test are also needed after getting the weight , the formula is

$$CR = CI/RI \tag{6}$$

In the formula, CR is the random consistency ratio of judgment matrix, and CI is the consistency index of judgment matrix.

$$CI = \frac{1}{m-1}(\lambda_{max} - m) \tag{7}$$

Where m is the order of matrix, RI is the mean random consistency index of the judgment matrix, and they are generally obtained from the table.

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When CR<0.1, it is considered that the judgment matrix has a satisfactory consistency, and it is also indicated that the weight distribution is reasonable.

The expert scoring method (1-9 scaling method) is used to score the relative importance of each element in the target layer and the criterion layer, and the weight coefficients of index are obtained from the formulas (1)-(7), as shown in Table 1.

As can be seen from Table 1, the influence coefficient of liquid sloshing on the transport safety evaluation is 14.3%. In the process of driving, the sloshing of liquid has a certain transient impact on the tank so that the stability of the vehicle dropped significantly, and it can easily lead to vehicle rollover. Therefore, it is of great theoretical significance and engineering value to study the influence of liquid sloshing on the stability of the vehicle.

4. Influence of liquid sloshing on the stability of hazardous chemicals vehicles

Trucksim software is mainly composed of graphical database, vehicle mathematical model, solver, simulation animation display and plotter. Taking the six-axle liquid tank semi-trailer as the research object, The parameters of vehicle modeling are shown in Table 2, a simulation model is established by the software of Trucksim, as shown in Figure 1. Simulation models include tractor model, semi-trailer model, steering system model, tire model, suspension system model, rigid vehicle axle model, brake system model, powertrain system model and load model. Through setting the sub-system parameters and property curves, simulation analysis can be carried out.

Table 2: Parameters of vehicle modeling

Name	Symbol	Numerical value	Unit
Height of towing vehicle	H_1	3200	mm
Height of semi-trailer	H_2	180	mm
Width of towing vehicle	W_1	2438	mm
Width of semi-trailer	W_2	2438	mm
Distance between mass center and front shaft of towing vehicle	L_1	2000	mm
Distance between mass center and front shaft of semi-trailer	L_2	5500	mm
Distance between mass center and ground of towing vehicle	h_1	1173	mm
Distance between mass center and ground of semi-trailer	h_2	1000	mm
sprung mass of towing vehicle	M_1	4455	kg
sprung mass of semi-trailer	M_2	5925	kg

Figure 1: Simulation model of heavy liquid tank semi-trailer

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4.1. Setting of simulation conditions

In order to verify the impact of liquid sloshing on tank, a certain lateral force and roll moment are applied to the vehicle to simulate the impact of liquid, as shown in Figure 2.

According to the regulations of NCAP in the United States, dynamic tests mainly include J-type steering test and fishhook test, and the fishhook test was adopted as dynamic test by NCAP because of its similarity to the actual situation. The simulation speed is 40km/h, the adhesion coefficient of road surface is 0.85, and the simulation time is 14s. The steering wheel angle is set as shown in Figure 3.

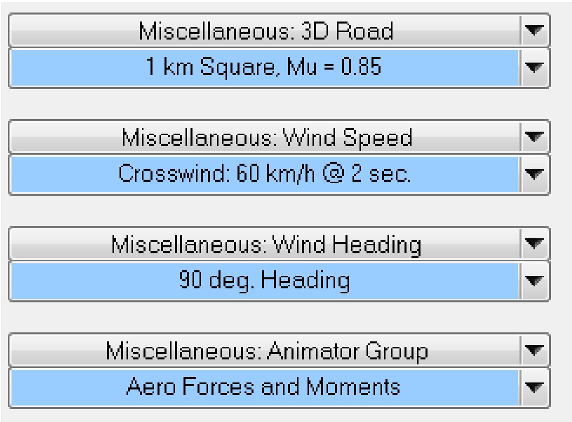

Figure 2: Setting of lateral force and roll moment

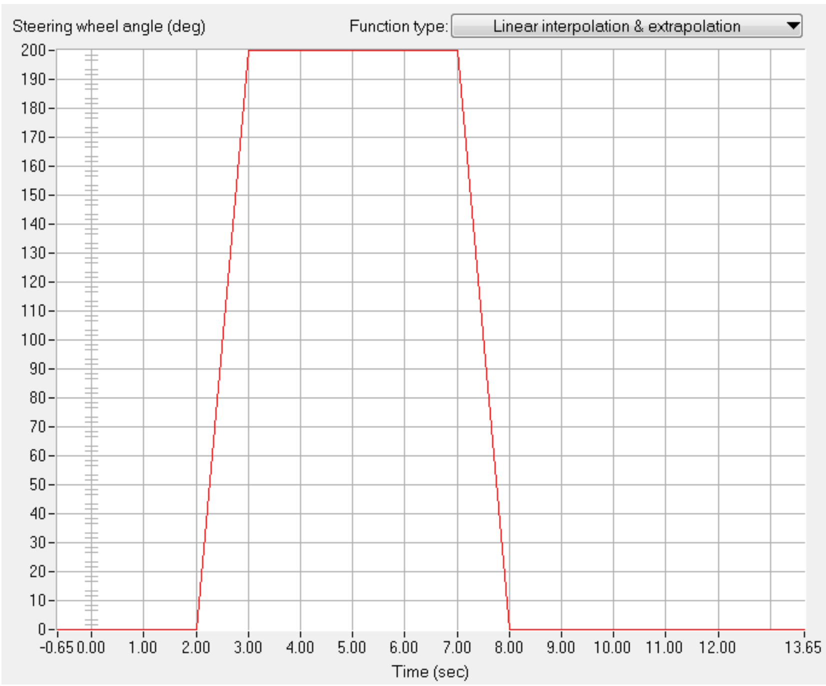

Figure 3: Steering wheel angle under fishhook condition

4.2. Analysis of simulation results

Figure 4-Figure 7 show the variation curves of the semitrailer inclination angle, lateral acceleration, yaw angle, and yaw rate. Test2 considered the liquid sloshing and Test1 without force and moment is not considered for liquid sloshing.

It can be seen from Figure 4 that the inclination angle of semi-trailer is negative from 0s to 2s. After that the maximum angle of the semi-trailer without force and moment is 1.12 deg which

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appears at 5.10s, and the maximum inclination angle of semi-trailer with force and moment is 1.17 deg that appears at 5.05s in the process of turning. From 7s to 8.5s, the inclination angle of the semitrailer without force and moment is slightly larger than one with force and moment. This is because the lateral force and inclination moment caused by liquid sloshing have great influence on the tanker body. After 9.5s, the inclination angle of semi-trailer tends to be stable with the steady state of the vehicle.

It can be seen from Figure 5 that the lateral acceleration produced by semitrailer is smaller than that of tractor. This is because the mass and inertia of semitrailer is large. The maximum lateral acceleration of semi-trailer without force and moment is 0.243g and that of semitrailer with force and moment is 0.251g. Both appear at 4.9s. From 7s to 8s, the vehicle returns to normal driving. At this moment, both of the lateral accelerations decrease sharply. After the vehicle returns to normal driving, the liquid sloshing condition is stable, and the excitation to the tank reduces drastically. Then both of the values return to near zero.

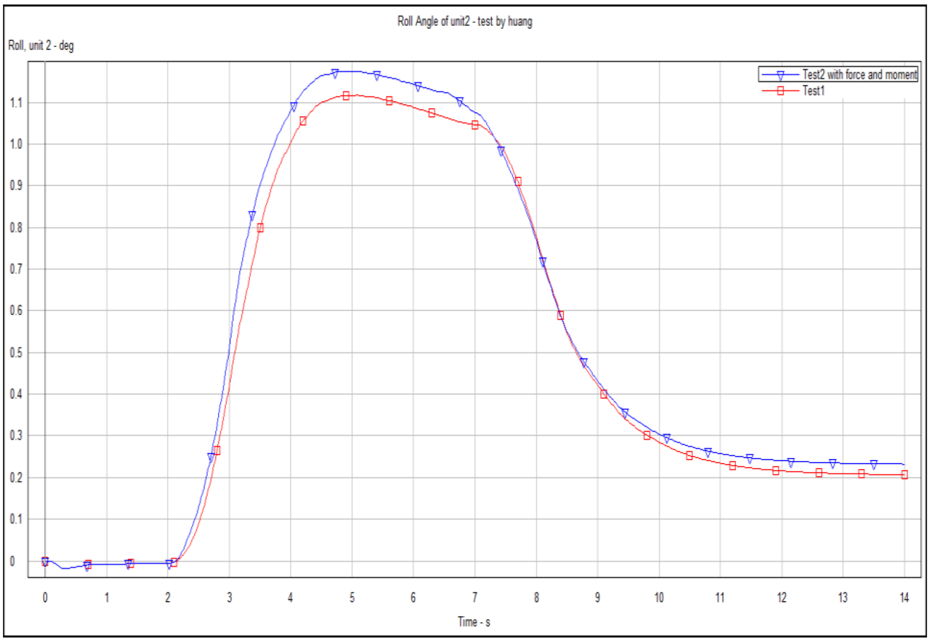

Figure 4: Inclination angle of semitrailer

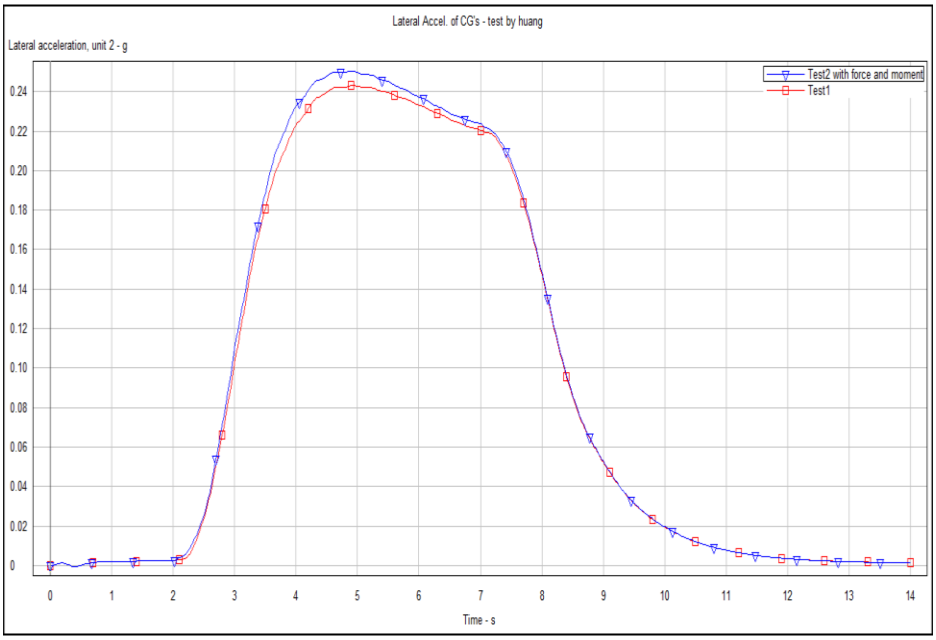

Figure 5: Lateral acceleration of semitrailer

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From Figure 6, it can be seen that the yaw angle of semitrailer starts to change from about 2.6s because of its large mass and inertia coupled with the steering wheel of tractor. After 10s, it tends to be stable, with a delay of about two seconds compared to the tractor. The maximum yaw angle of semitrailer without liquid sloshing is 83.3deg, and that of semitrailer with liquid sloshing is 85.6deg.

From Figure 7, it can be seen that the yaw rate of semitrailer without force and moment increases gradually from 2s to 5.4s and then reaches its maximum value at 5.7s, the maximum value is 15.6 deg/s. The maximum yaw rate of semitrailer with force and moment is 16.2deg/s which appears at 5.4s. In the period of 5.7s to 8s, the yaw rate curves of the two groups gradually begin to overlap as the vehicle recovers to normal driving condition.

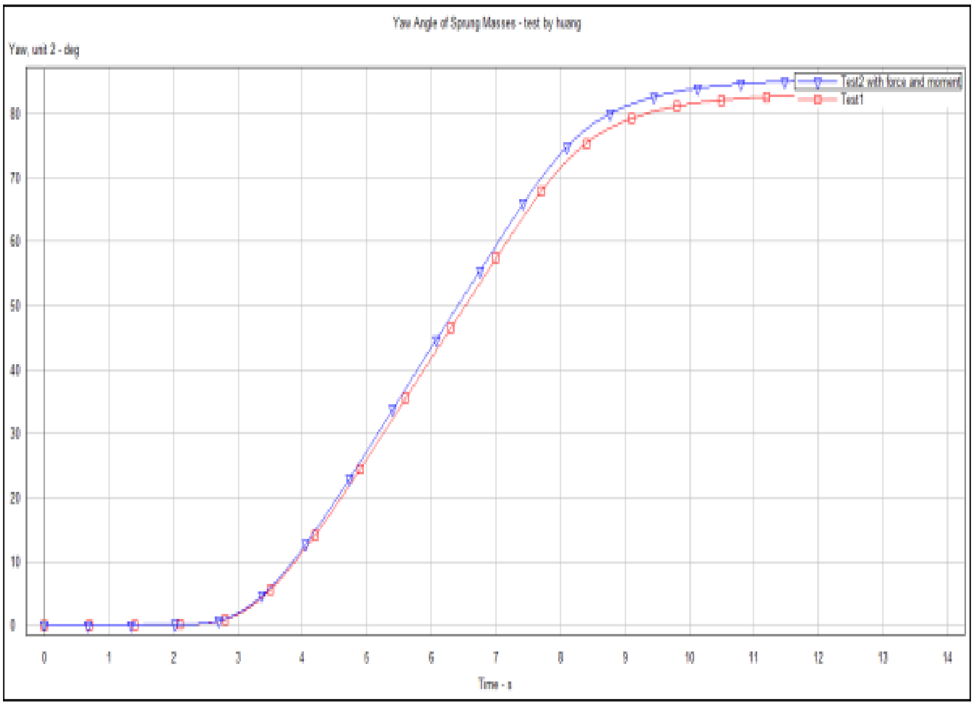

Figure 6: Yaw angle of semitrailer

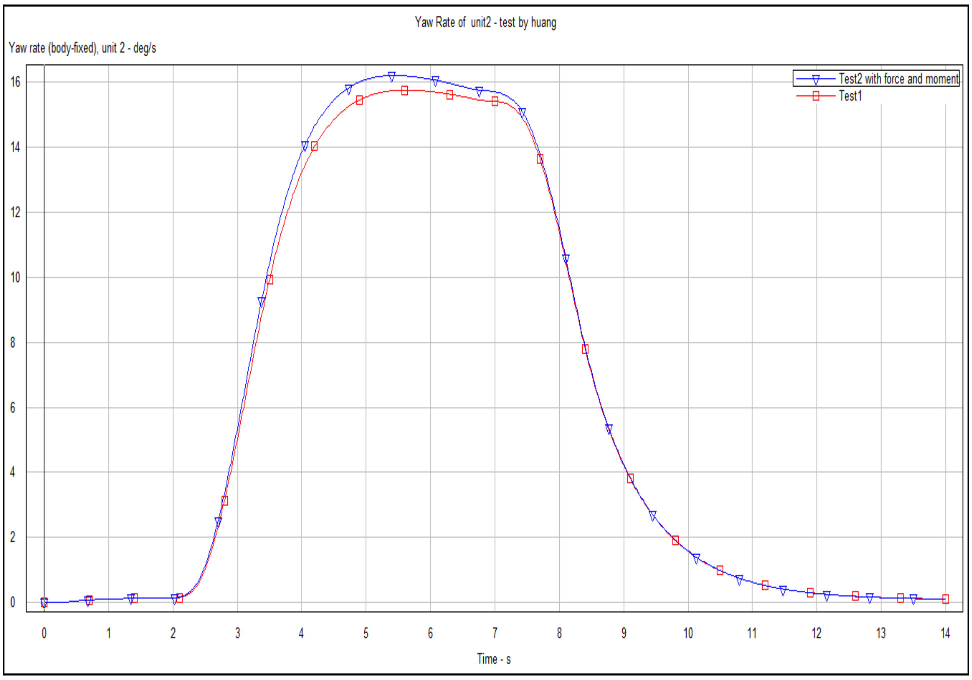

Figure 7: Yaw rate of semitrailer

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5. Conclusion

a) Considering the influence of liquid sloshing on transport safety coupled with the factors of people, vehicles, roads and environment, three-class evaluation index system of transport safety was established and the weight of the index was determined by the analytic hierarchy process (AHP).

b) The vehicle dynamic model was constructed by the software of Trucksim, and the influences of liquid sloshing on vehicle handling stability were analyzed. The simulation results show that forces and moments generated by the liquid sloshing significantly reduce the vehicle stability.

c) The research method provided reference for practice and decision-making in road transport of dangerous goods safety evaluation.

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