Study on rollover risk of the tanker with different liquid filling coefficient in emergency turn

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Abstract. 3D simulation model of petroleum sloshing in off-road tanker based on the VOF method, moving coordinate system and the actual size of the internal petroleum and tank structure is established in this paper. The mathematical model of the petroleum sloshing in tank is established, lateral rollover torque of petroleum sloshing in emergency turning is researched, the effects of the cross section shape and baffle area in tank on the dynamic characteristics of petroleum sloshing is studied.

1. Introduction
Driving state of off-road tanker will change in an emergency turn, it will cause sloshing of liquid in tank, impact the tank wall, cause the shift of the center of gravity of the liquid at the same time, changes the center of mass of the tanker, resulting in the axle load distribution uneven, easily occurred rollover accident. Therefore off-road tanker in motion exists security risks, the rollover easily cause explosion and leakage of petroleum[1-2]. 3D simulation model of petroleum sloshing in off-road tanker based on the VOF method, moving coordinate system and the actual size of the internal petroleum and tank structure is established in this paper[3-4]. The mathematical model of the petroleum sloshing in tank is established, lateral rollover torque of petroleum sloshing in emergency turning is researched, the effects of the cross section shape and baffle area in tank on the dynamic characteristics of petroleum sloshing is studied[5-6].

2. A numerical calculation model of the petroleum sloshing in the tank
(1)The basic equations of fluid motion

3D-model and coordinate system of off-road tanker is shown in figure 1, \(x_0, y_0, z_0\) is the coordinate system fixed in the earth coordinate system, \(x, y, z\) is the moving coordinate system built in the center of the tank[4].
The petroleum in the tank can be considered to be incompressible viscous fluid, its density is constant, the heat transfer is not considered, the equation of motion is built with the movement of the coordinate system in the tank[4].

\[ \vec{v}_a = \vec{v} + \vec{v}_c \]  \hspace{1cm} (1)

where \( \vec{v} \) is the velocity vector in motion coordinates, \( \vec{v}_c \) is the motion coordinate velocity vector relative to the stationary coordinate system, it can be expressed as:

\[ \vec{v}_c = \vec{v}_i + \vec{\omega} \times \vec{r} \]  \hspace{1cm} (2)

where \( \vec{v}_i \) is the translational velocity vector in the moving coordinates; \( \vec{\omega} \) is rotating angular velocity vector in moving coordinate system; \( \vec{r} \) is the vector from the origin of the moving coordinate system to micro liquid Group K, the motion control equation in the moving coordinates is shown as:

continuity equation \[ \nabla \cdot \vec{v} = 0 \]  \hspace{1cm} (3)

momentum equation \[ \rho \frac{d\vec{v}}{dt} = \rho \vec{F}_g + \rho \vec{f}_a - \nabla p + \mu \Delta \vec{v} \]  \hspace{1cm} (4)

fluid volume fraction transport equation \[ \frac{dF}{dt} = 0 \]  \hspace{1cm} (5)

where \( \vec{f}_a \) is the inertial force of unit mass introduced for non inertial coordinate system in the moving coordinate system.

\[ \vec{f}_a = -(2\vec{\omega} \times \vec{v} + \vec{\omega} \times \vec{\omega} \times \vec{r} + \vec{\alpha} \times \vec{r} + \vec{\alpha}) \]  \hspace{1cm} (6)

where \( \vec{\alpha} \) is translational acceleration for the moving coordinate system relative to the stationary coordinate system; \( \vec{\alpha} \) is the rotational acceleration for moving coordinate system relative to the stationary coordinate system.

(2) The boundary conditions of the fluid motion

The petroleum in the tank is a viscous fluid, so the non slip boundary condition is applied on the solid wall between liquid and solid:

\[ \vec{v} = \vec{v}_b \]  \hspace{1cm} (7)

where \( \vec{v}_b \) is velocity of the tank relative to the origin of coordinates in a moving coordinate system, if the deformation of the tank wall, \( \vec{v}_b = 0 \).
The surface stress conditions:

\[
\frac{\partial v_n}{\partial \tau} + \frac{\partial v_t}{\partial n} = 0 \tag{8}
\]

\[
p - 2\mu \frac{\partial v_n}{\partial n} = p_0 \tag{9}
\]

where \( p_0 \) is the atmospheric pressure is perpendicular to the surface of the liquid, \( v_n \) is the normal velocity perpendicular to the surface of the liquid, \( v_t \) is the tangential velocity.

3. Simulation study on the influence of oil sloshing on rollover stability when turning

One common off-road tanker containing 7000L petroleum is simulated in this paper, the tank is made of tanker body, manhole, lateral and vertical baffle etc. the structure is shown as Figure 2, the thickness of the tank header is 5mm, the thickness of the tank body and the baffle is 4mm, the material is Q345, the internal petroleum is No. 0 diesel, the surface tension coefficient is 0.0263257N/m, operating parameters with a great influence on the petroleum sloshing in the tank are braking deceleration, braking initial velocity and liquid filling coefficient[7-8].

![Figure 2. The structure of 7000L tank.](image)

The mesh of tank body is shown as Figure 3, generating 341957 units and 680801 nodes, the mesh of petroleum in the tank generates 682107 units and 177947 nodes[9].

![Figure 3. The mesh of tank body.](image)

4. Lateral Stability Analysis on emergency turning

Rollover torque of the tanker with 50% liquid filling coefficient is 37621N.m, rollover torque of the tanker with 60% liquid filling coefficient is 36929 N.m, rollover torque of the tanker with 70% liquid filling coefficient is 39713N.m, rollover torque of the tanker with 80% liquid filling coefficient is 45487N.m, rollover torque of the tanker with 94% liquid filling coefficient is 36270N.m, rollover risk of the tanker with 80% liquid filling coefficient is the highest, rollover
risk of the tanker with 70% liquid filling coefficient is the higher, rollover risk of the tanker with
94% liquid filling coefficient is small, of maximum roll torque of the tanker with every kind of
filling coefficient generate in the earlier emergency turn, and then decrease gradually, as shown
in Figure 4, the maximum stress appears in the 80% filling coefficient, the maximum stress of
each kind filling coefficient appear in earlier emergency turn, as shown in Figure 5.

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