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Analysis fluid sloshing when road tanker experience sudden breaking - A computational approach

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ABSTRACT

Sloshing can occur as an outcome of a disturbance to a partly filled fluid road tanker. As an effect, the vibrant behavior of fluid is observed when subjected to sudden breaking of a roadway tanker, because it significantly affects the stability leading to rollover of the tank structure. So, to avoid the in-stability and rollover condition. The baffle is used as suppression media to suppress the vibrant behavior of fluid. This research work is carried out with aid of computational approach using ALE technique. The ALE approach is tested with different configuration of tanks mainly clean bore tank, single baffle tank, two baffle tank and three baffle tanks with 50%,60% and 80% filling ratio respectively. The outcome of this research paper to examine several factors for preventing accidents of road tanker when experience sudden breaking condition.

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1. INTRODUCTION

Sloshing is defined as “The periodic motion of the fluid's free surface in a partially filled tank or container subjected to disturbances” [1]. In general, sloshing is classified into three types such as longitudinal sloshing, transverse sloshing, and rotational sloshing. Fluid sloshing can cause a variety of engineering issues, such as instability and rollover ability. Sloshing phenomena is a nonlinear and uncontrollable behavior which exerts a dynamic load on a container, as a result of which a container may be damaged, or fluid splashed. The study of the sloshing phenomenon is extremely important for fluid transport safety. The free surface fluid can experience a variety of motions depending on the disturbance and shape of the container geometry, such as planar, non-planar, rotational, and symmetric, asymmetric, disintegration, quasi-periodic, and chaotic, among others. The research study discovered that sloshing involves the estimation of moments, forces, hydrodynamic pressure distribution, and natural frequencies of the fluid's free surfaces. These parameters have a direct impact on the dynamic stability and performance of moving containers [2]. Jean Ma and Muhammad Usman [5] demonstrated the sloshing phenomenon in a partly filled container when the container abruptly starts or stops. Sloshing is undesirable due to the vibrant impact force on the tank walls structure and, as a result, the difficulty of low fuel management. Today's solution for preventing sloshing is to incorporate baffles inside the tank.

The presence of baffles dissipates the energy generated by fluid motions. To meet the required performance specifications in service, the design of baffles is an important step in the planning of a fuel tank. Moving mesh algorithm was proposed by N. Aquelet et al [8]. This new ALE feature allows mesh movement while

preventing the mesh has been distorted. The proposed technique is extremely useful for moving containers that are subject to external disturbances. Conducted fluid-structure interaction (FSI) was investigated in the laboratory using a scaled tank subject to external harmonic excitations and studied using a coupled fluid-vehicle model of a partially filled container subjected to braking maneuver by Guorong Yan and Subhash Rakheja [5]. Because sloshing is nonlinear in nature, the experimental study demonstrates its complex behavior. The dominant peak in a slosh force spectrum may occur close to the frequency of external excitations. The longitudinal dynamic fluid slosh influences the vehicle deceleration response. According to Xue-lian Zheng and Xian-sheng Li [3], the conventional baffle with a 5-degree oblique angle is the best at reducing liquid sloshing, and the sloshing force on this baffle is the smallest. The circular baffle, which has a central manhole and eighteen small holes around it, this found to be the most effective design so as to suppress sloshing effect. The reverse staggered configuration baffle with a 25^0 angle has the best anti-sloshing effect; though, the force on this baffle is the greatest. Lastly, the staggered baffle is the best at reducing liquid sloshing. The larger the ant sloshing area, the better the ant sloshing effect of the baffle.
Furthermore, the distance between adjacent baffles can have a significant impact on the development of liquid sloshing; thus, a smaller distance is more effective. To prevent sloshing in moving containers subjected to sudden acceleration or deceleration. The tanker is subjected to various filling ratio tests. With different baffle shape the main objective of this project is to study both these approaches, alternative baffle configuration then determining the best optimal solution for reducing fluid sloshing in terms of the safety of transportation truck.

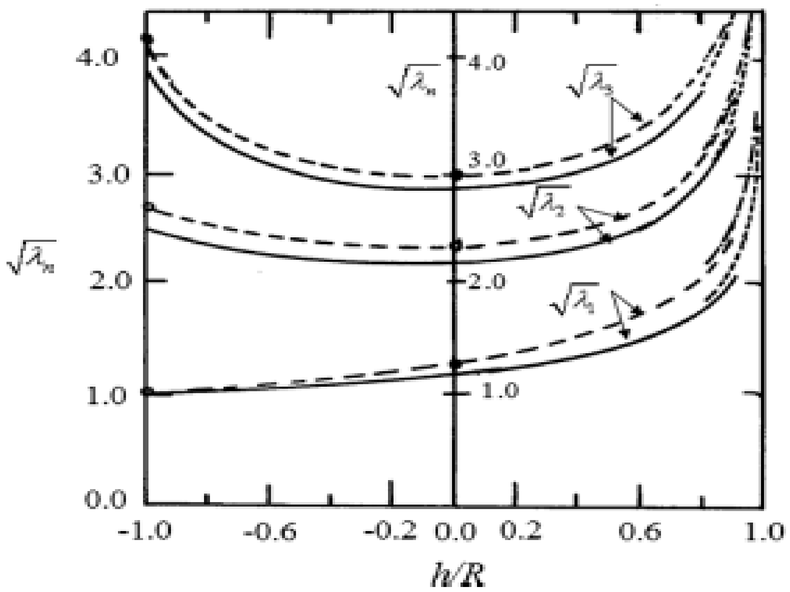


Figure 1. Effect of h/R with slosh effect

2. MATHAMTICAL MODELING

In dynamic situation, the road tanker always experiencing disturbed forces due to irregular surface contours of the road and may be because of sudden acceleration or deceleration. As a result, container may subjected to accidents causing fluid to spill out of the parent structure It is necessary to analyze the sloshing phenomenon since it is one of the prominent aspects for reducing its detrimental effects over the structure of tanker. Any attempt to reduce sloshing phenomena would further help to optimize the design in terms of economy and reducing the bare weight of the tanker. As such, any development made to the design of the tanker would directly benefits to the society such as...

1. Reduced transportation time possible due to the enhanced speed limit.
2. Reduced indirect cost incurred due to accidents.
3. Compliance to safety and environment standards (for spillage of hazardous contents over the roads due to potential accidents)

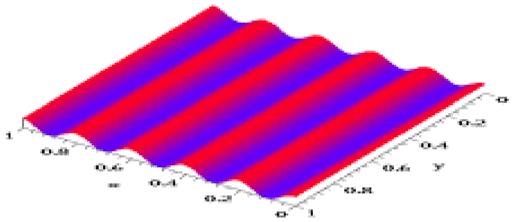


Figure 2: 1D Wave formulation

$$\frac{1}{c^2}\frac{\partial^2 u}{\partial t^2} = \frac{\partial^2 u}{\partial x^2} \qquad [1]$$

Where, c represent the propagation velocity of the wave.

The magnitudes of forces within the steady and transient state are derived from the pressure distribution over the wetted boundaries of the baffled likewise because of the clean bore tanks. The resultant slosh force is evaluated by integration over the wetted area of the wall cell, such that

Fx = ∑PcAcI

FY = ∑PcAcI

Fz = ∑PcAcI

Where, Fx, Fy, Fz are the resultant slosh forces acting on the tank wall along the fixed x, y and z axes due to pressure Pc acting on cell "c" with area vector Ac.

From research study it was observed that not only dynamic force, the moment caused by shifting center of gravity point is also changed. The Roll, Pitch, and Yaw moment of origin point i.e. O can be integrating the moment corresponding to each cell over the wetted area:

M = Rc * Fc

Where Fc is the Force vector caused by a cell "c" on the boundary, Rc is the position vector of cell"c" with respect to "O" and M is the moment vector about point "O". The coordinate of this point "O" is (0,-R, 0), where R is the tank radius. In the description of the ALE method [6], the computational domain is defined to combine the advantages of two classical kinematical formulations, the Lagrangian algorithm and the Eulerian algorithm. The mesh nodes on the reference domain could move with an arbitrary velocity appointed according to the material particle velocity. Assume a physical property f described by the ALE algorithm; its absolute derivative should be written as the following expression:

$$\frac{\mathrm{D}f}{\mathrm{D}t} = \left.\frac{\partial f}{\partial t}\right|_{\mathbf{w}} + (\mathbf{u} - \mathbf{w}) \cdot \nabla f = 0$$

Where u and w are the velocities of the material particle and the mesh, respectively,

In the Eulerian algorithm, the mesh velocity is equal to zero, whereas in the Lagrangian algorithm, w=u.

Let us consider; function F (x, y, z, t) =0 represents the position of each material particle on the free surface. Such that DF/Dt =0 at free surface It also signifies that Material particles on free surface is always on computational domain with respect to time, whereas ∇F is vector term normal to the free surface then r=equation can be written as:

$$\frac{Df}{Dr} = \frac{\delta f}{\delta t}|_w + (u-w).\vec{v}.f = 0$$

3. SIMULATION OF MODIFIED BAFFLE TANK

As per ADR & EN Norms for transportation container cargo no tanker is completely filled with 100% filling condition since with this filling condition we can easily suppress the longitudinal behavior, but it has more roll over behavior when tanker taking turn. Generally, a tanker is partial filled with 95 %. It also seen that 40% to 80 % filling ratio also termed as critical region of transportation tanker. The physical model of the current study is shown in Figure 5. The physical model consists of a cylindrical container, which is partially crammed with water as working fluid (ρ=1000 kg/m3, μ = 0.0687 kg/m-s). The scale of the tank is of 6 m length and a couple of 1.5 m diameter. The Water as fluid occupies either 40% or 80% of the whole volume of the space within the cylinder. The remaining a part of the tank is occupied with air. However, in this study we considered only the sloshing because of the acceleration and deceleration of the vehicle. To reduce the sloshing rate three similar circular baffles are introduced within the tank. The distance between adjacent baffles is kept same and, the center of the baffles coincides with the axis of the tank. The main points various dimensions of the physical model are given in to modify the existing tanker, initially, we have to understand the various design consideration of the road tanker as mentioned in Figure 3 [a] and [b].

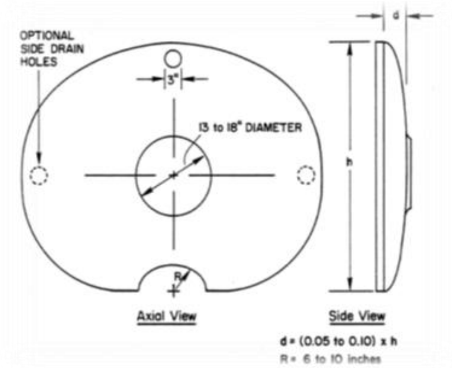


Figure 3[a]: Dish shaped baffle construction

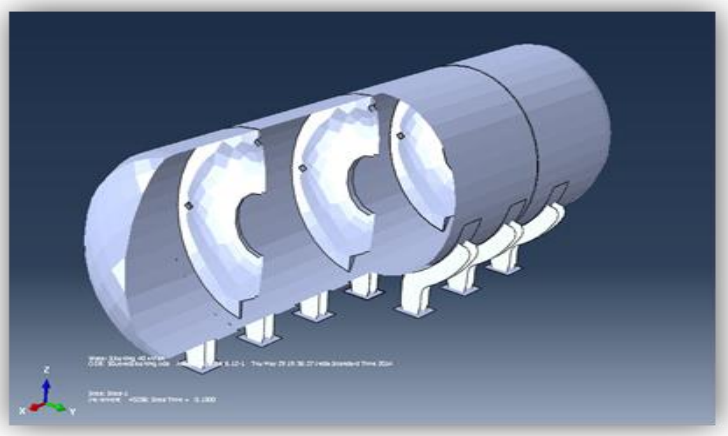


Figure 3[b]: Three-dimensional model of Dish shaped baffle construction

Whenever tanker subjected to sudden deceleration or acceleration there will be the free surface of fluid occurs it will result in to splash of fluid surface inside tanker geometry. This fluid splash exerts an undue force on tank structure which in turn results in instability of the tanker and when tanker taking a turn it results in the rollover ability of the tanker. To reduce the sloshing in tanker modification in Tanker Geometry can be done by…

1. Number of baffles Plates inside the Tanker geometry.
2. Location of baffles Plates inside the Tanker geometry.
3. The shape of baffles Plates inside the Tanker geometry.

To reduce this phenomenon baffles introduced in-tank structure. The Various baffles and they are position in tanker as explained below. Analysis of the tanker is done with partial filling condition of fluid. According to the research study it was found that Sloshing loads found to be more with 50 to 75 % of the filling condition in order to study behavior we have to consider three filling conditions i.e. at 50%, 60% & 80% with clean bore construction and same for with one, two and three baffle conditions. CAE work is initiated with suitable assumptions are as follows.

1. Simulation is turbulent &transient in nature.
2. Deceleration of 0.8gacts along the tank i.e. 40 Kmph

3. Total simulation time is 1.5 Seconds (Since sudden breaking conditions were considered)
4. No heat transfer is considered between environment and fluid containing tank.
5. Working fluid is considered as homogeneous and in equilibrium. During the simulation study, Tank structure and baffle plates are considered as non-deformable body.

Since we are interested to evaluate the suppression phenomena of fluid. Working fluid is considered as Newtonian & incompressible. Fluid containers consist of two working stages such as Air and Water. Run time Parameters: Simulation time = 1.7 seconds; Initial Time step = 1.0e-6. The ALE approach works much similar to the eulerian approach. The main difference is ALE approach follows Mesh Smoothing concept. In the Eulerian formulation the nodes are moved back to their original positions, while in the ALE formulation the positions of the moving nodes are calculated according to the average distance to the neighboring nodes. So to avoid the simulation from divergence the quality of mesh should be good one. The orthogonal quality should be greater than 0.4, skewness should be less than 0.75. The tanker is discretized with 108721 nodes and ALE domain as water as fluid is discretized with 285486 nodes.

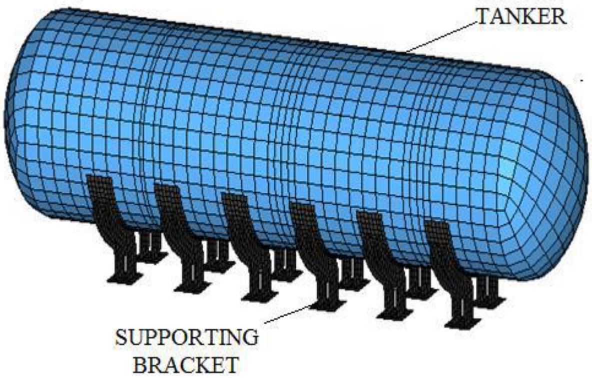


Figure 4: Mesh model structure

Other comparable codes such as MSC/Dytran use a similar calculation scheme. There are two types of ALE elements in MSC-DYTRAN: single material and multi-material. The single material element type can only contain one phase (fluid) at a time, whereas the multi-material element type can contain multiple materials. During the experimental tests, the road tank structure containing partially filled fluid is modeled using CAE software such as CATIA. The behavior of sloshing inside the tanker subjected to external excitation is more accurately assessed by the implementation of various computational software such as MSC Dytran or Abacus. The computational model is imported into Hypermesh software for Meshing, where it is discredited into a small number of elements and loads and boundary conditions are applied to twelve different filling ratios.

4. RESULT AND DISCUSSION

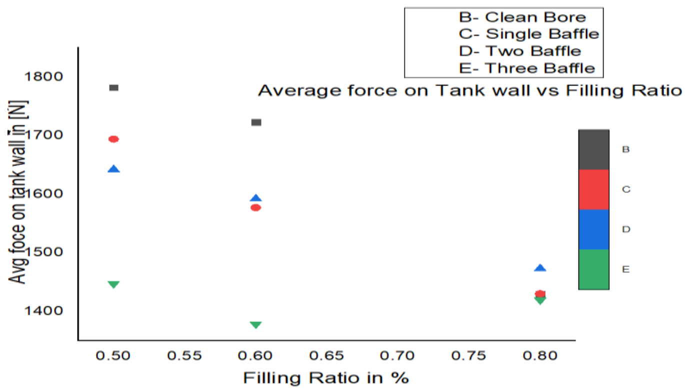


Figure 5: Avg force on tank wall vs Filling ratio

The result shows in Figure 5, when transportation tank is filled with minimum fill condition sloshing force on the tank is high.

This sloshing force is lowered with more fill ratios in transportation tank but it gradually increases the moment forces which results in rollover of the transportation tanker. The amount of stress developed on the modified baffle found to be less compared with the designed stress for the material. The modified baffle is designed such a way that it helps to drain the tanker in minimum time. To validate this analysis the research paper used is “Effects of Transverse Baffle Design on Reducing Liquid Sloshing in Partially Filled Tank Vehicles” by Xue-lian Zheng, Xian-sheng Li, Yuan-yuan et al [20]. In which author has investigated the fluid sloshing when tank subjected to sudden breaking the results were computed by conventional quasi static method and compared with fluent simulation by using same inputs ALE Approach, we found out 1100.42 N. Hence the ALE approach is validated.

Table 1: Simulation approach comparision with Quasi-static Approach

Sr No.	Quasi-Static Method	VoF Simulation Approach	ALE Simulation Approach	% of Deviation
01	1085.36 N	1107.921 N	1100.42 N	7.4%

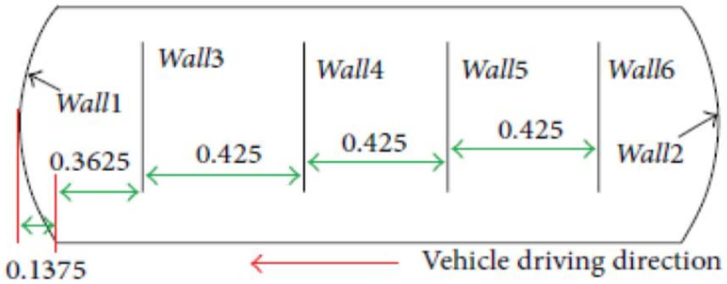


Figure 6: Tank wall configuration of case validity [20]

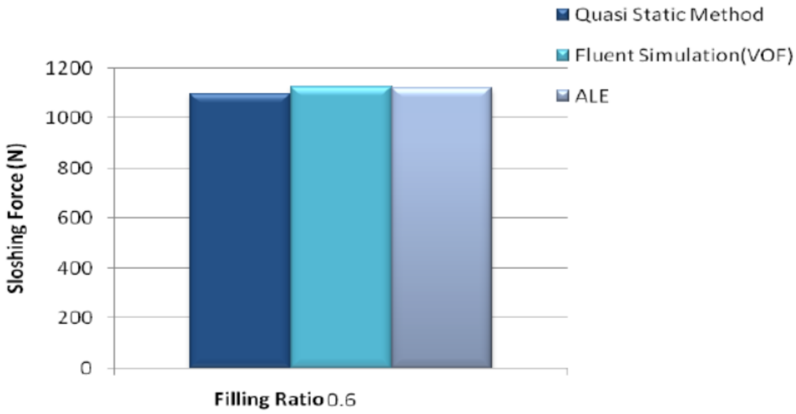
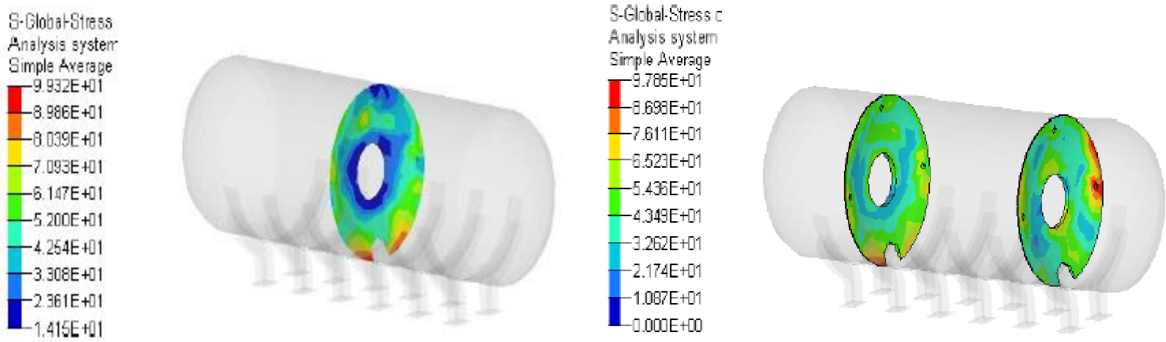
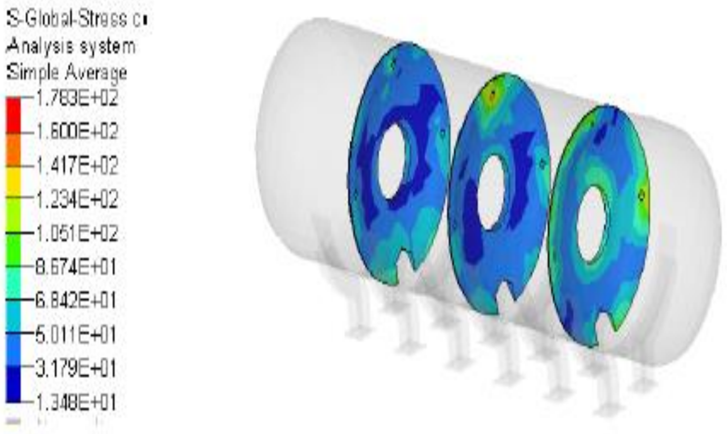


Figure 7: Simulation approach comparision with Quasi-static Approach



[a] Single Baffle Constructin [b] Two Baffle Constructin



[c] Three Baffle Constructin

Figure 08: Average stress acting on baffle construction considering 80% filling ratio

4. CONCLUSION & FUTURE PERSPECTIVE

The transportation road tank always subjected to instability as well as roll over. The rollover accidents are very destructive event as compared with frontal and side crush, a great care should be taken while redesigning or modifying the tank structure. With the help of suitable material and proper location of baffle, a better design is achieved.

1. The dish shaped baffle found more effective than the conventional baffle or straggled baffle configuration.
2. The sloshing force fluctuation is found to be more at lower fill level and high acceleration.
3. Increase in filling level in the tank, it increases the magnitude of the forces and moment due to the large mass of fuel, but the variation of force is less.
4. Transverse baffle with holes reduces slosh forces and moment significantly in the pitch plane which improves braking performance of the vehicle.
5. Transverse baffle and transverse baffle with holes is not capable of reducing roll moment and hence no effect on steering performance
6. To reduce the impact of sloshing forces in tank wall, baffles are provided inside the tank, which can work as a damper and sufficiently reduce the amount of slosh waves.
7. It can be predicted that the larger the fill level of tank, greater the complexity of fluid sloshing.

Scope for future work for efficient performance would be as follows:

1. The Modified baffle further can be analysed for sudden acceleration of the tank for various filling ratios.
2. Various shape and size of modified baffle can be designed in terms of further optimization of the tank.
3. Modified baffle can be analysed for different fluids such as edible oil, castor oil, LPG etc
4. Fluid sloshing can also be analysed by baffle at various positions in transportation tank.
5. Generally roll over threshold for transportation tank is 0.4g with various fill ratios one can also analysed the fluid sloshing for roll over behaviour.

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