

## Recent Advances on Tanker Vehicle Stability

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In recent years significant attention has been devoted to enhancement of heavy vehicle stability and handling performance of road vehicles. Among various aspects of such studies, tanker truck roll stability is a major concern as they are 5 times more prone to roll over in comparison to other road vehicles. The poor rollover limits of tank trucks are attributed to high center of mass design of the high volume tanks coupled with the dynamic load shift within a partly filled tank under directional maneuvers. Furthermore, tank trucks carry 80% of hazardous materials on the roads, mostly in the tractor-semi trailer combinations, thus also poses significant risk to the environment. Concave Research Centre of Concordia University recently undertook projects towards attainment of improved roll and directional stability limits of tank trucks through studies on their various design and operating factors, and to derive optimal tank design concept.

During a maneuver, fluid slosh within the tank may introduce considerable load shift in the roll and pitch planes resulting in significant reduction in the lateral and longitudinal stability limits. The most common circular cross-section tanks provide high mass center but less lateral load shift, while the modified oval construction yields lower mass center but larger lateral load shift. An optimal tank cross-section has been developed through multi-parameter constrained optimization to build upon the merits of the circular as well as modified oval tanks. The optimal tank cross-section comprised a wider bottom to achieve lower center of mass of the tank and a narrower top to reduce the magnitude of fluid slosh that result from dynamic interaction between partial fill condition and vehicle dynamics. Although baffles are known to offer definite resistance to sloshing of cargo under braking maneuvers, they do not resist the lateral slosh of the fluid cargo, which produces the primary overturning moment. Tanks on the other hand are often designed without baffles to facilitate cleaning between transportation of different cargo. Design of baffles thus also present a scope for improvement of tanker stability limits.

The study and results presented deal with an in-depth investigation of tanker vehicle roll stability due to partially filled liquid cargo and optimal design of tank shape. The stability analysis of such vehicles involves integration of complex fluid slosh analysis and the resulting forces and moments with the directional dynamics models of the vehicle. Furthermore this study examines the role of baffles and baffles design on the

fluid slosh behavior under dynamic environment. An extensive experimental and analytical research using circular as well as optimized cross-section with and without baffles is undertaken for this investigation. For the experimental investigation, a tank slosh simulator was realized using a custom designed horizontal slip table. Instruments were used to measure forces at tanker supports as well as displacements and accelerations of the table. The force signals were manipulated to derive slosh forces along the lateral, longitudinal and vertical directions as well as roll, yaw and pitch moments. Experiments were also performed with single- and multiple-orifice baffles in conjunction with the optimal cross-section tank. A comprehensive test matrix was designed to measure slosh forces and moments caused by various fill levels within tanks with different baffles, while subjected to different excitations. Harmonic excitations of varying frequencies and magnitudes were further applied to study the frequency response behaviour and natural frequencies of partly-filled tanks. The data acquired from the experiments were inertia corrected and analyzed to determine the nature of slosh forces and moments, and slosh frequencies under different fill volumes and excitations. These data were subsequently used for validation of the analytical dynamic slosh models.

In the final phase of the study, a nonlinear three-dimensional model is developed for analysis of fluid slosh. The model was developed for both tanks and three configurations involving un-baffled and baffled tanks in order to characterize the nature of dynamic slosh forces and moments under different excitations and to study the role of baffles. The nonlinear models were developed for both the scaled test tanks and full-size highway tanks. The models were solved under lateral, longitudinal and simultaneous lateral and longitudinal acceleration fields, using the FLUENT software. The pressure distributions at the submerged tank wall in the three-dimensional domain were analyzed to derive the resulting lateral and longitudinal forces, and roll, yaw and pitch moments imposed on the structure of the tank with and without baffles. The influences of magnitudes of acceleration and fill condition on the transient and steady-state forces and moments were further investigated for the cleanbore as well as baffled tank. The results obtained for the optimal cross-section test tank under various excitations and fill volumes were compared with the measured data to demonstrate the validity of the models.

The results in general suggest the amplification ratios of the resulting forces and moments could approach as high as 2. The results clearly show that the presence of baffles helps to suppress the peak as well as mean slosh forces and moments significantly. The results further show that lateral or longitudinal excitations in the vicinity of fundamental slosh frequency results in whirling of free surface and considerable magnitude of forces in the direction other than the excitation axis, suggesting strong coupling between longitudinal and lateral slosh. The simulations performed with the optimal tank clearly revealed that the optimal geometry yields not only lower mass center but also considerably lower load shift when compared with the conventional tanks for the 30% to 70% fill volume range under different magnitudes of lateral accelerations.