Effect of Dynamic Loading Events on Fuel Tank Sloshing for Two Wheelers

Tanmay Santra , Mihir Bhamhri & Vikas Kumar Agarwal

MAHINDRA 2 WHEELERS LTD

Abstract: Fuel sloshing occurs in vehicle when it accelerates or decelerates. It generates high kinetic energy with unpleasant noise. This fuel sloshing leads to vehicle imbalance. This vehicle instability may occur when the fuel to weight ratio is high. In automobiles, the fuel sloshing generates unpleasant noise which is not expected from the present ones. So, this work presents the capability development and the subsequent use of it to study the stress at the fuel tank mounting brackets, to study the minimum amount of fuel required to have a uninterrupted fuel supply to the carburetor when the vehicles negotiates a bump or pot hole, effect of baffles inside the fuel tank and to study the noise generated because of sloshing.

Sloshing is a phenomenon of fluid- structure interaction. It occurs due to agitation of fluid in fractionally filled container. A case study of a fuel tank partially filled with Petrol was simulated in this paper using Coupled Euler-Lagrangian model. Simulations shows the amplitude of sloshing in tank. The fuel tank used doesn't have baffles. The tank was set into motion by giving a displacement on the vertical direction. The dynamic displacement were generated using MBD software. The load cases considered for the sloshing are vehicle countering a bump, pot-holes and pave track to study the effect of the sloshing.

In this simulation of the fluid in tank is studied using ALE method. Arbitrary Lagrangian-Eulerian finite element methods. In this paper we use the ALE technique to solve fuel slosh problem. The goal of sloshing simulation is to first study the sloshing pattern and then improve the tank design to reduce stresses on the structure. Fuel slosh is an important design consideration not only for the fuel tank, but also for the structure supporting the fuel tank. Fuel slosh can be generated by many ways: abrupt changes in acceleration (braking), as well as abrupt changes in direction (highway exit-ramp). Repetitive motion can also be involved if a sloshing resonance is generated. These sloshing events can in turn affect the overall performance of the parent structure. A finite element analysis method has been developed to analyze this complex event. A new ALE formulation for the fluid mesh can be used to keep the fluid mesh integrity during the motion of the tank. This paper explains the analysis capabilities on a technical level.

1. Introduction

The Eulerian analysis capability in Abaqus/Explicit allows effective modeling of applications involving extreme deformation, including fluid flow. In Coupled Eulerian-Lagrangian (CEL), the Eulerian capability can be coupled with traditional Lagrangian capabilities to model interactions between highly deformable materials and relatively stiff bodies, such as in fluid-structure interactions.

2. CEL Solution Definition

An explicit dynamic step in the finite element method is employed in CEL. The governing equations consist of the conservation laws of mass, momentum and energy and the constitutive equations. The governing equations are integrated in time under the Eulerian coordinates.

An Eulerian material can be modeled as viscous compressible Newtonian fluid:

$$\sigma = -p1 + 2\eta e$$

Where, σ is the Cauchy stress tensor, p is the pressure, η is the shear viscosity and e is the strain rate. Fluid-Structure Coupling is achieved by using the Abaqus/Explicit general contact definition.

3. Modeling

3.1 Modeling the Eulerian Domain

The Eulerian mesh is shown in Figure 1. The materials representing the fuel can flow during the analysis, and the mesh does not need to conform to the topology of the materials in fact, a simple rectangular grid typically provides the best results.

In a traditional Eulerian analysis, material flows through an Eulerian mesh that is fixed in space. Since it is stationary, the Eulerian mesh must be large enough to enclose the entire trajectory of interest, for example, the Lagrangian domain. In the case when the Lagrangian domain moves with a displacement generated by MBD.

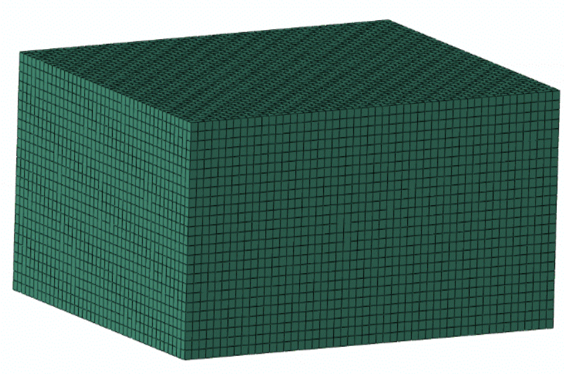


Figure.1 Eulerian Field

The Eulerian material which represents the gasoline inside the fuel tank is modeled as a viscous Newtonian fluid. The density of the fluid is 9.85 × 102 kg/m3, the coefficient of viscosity is 1.02E-006 (kg/m*s), and the sound wave speed is 1.147× 103 m/s"(Fan Li1, Peiran Ding2 and Steve Sibal)".

An Eulerian section assignment defines the materials that may be present in the mesh over the course of the analysis, and an initial condition determines the domain of material which is present in each element at the beginning of the analysis, since few elements on the boundary would be partially filled with a fluid material. The initial condition effectively determines the initial topology of the materials in the model. Figure 2 shows the initial condition of the fuel inside the fuel tank. The tank illustrated is for a typical 2 Wheelers application without any baffle plate.

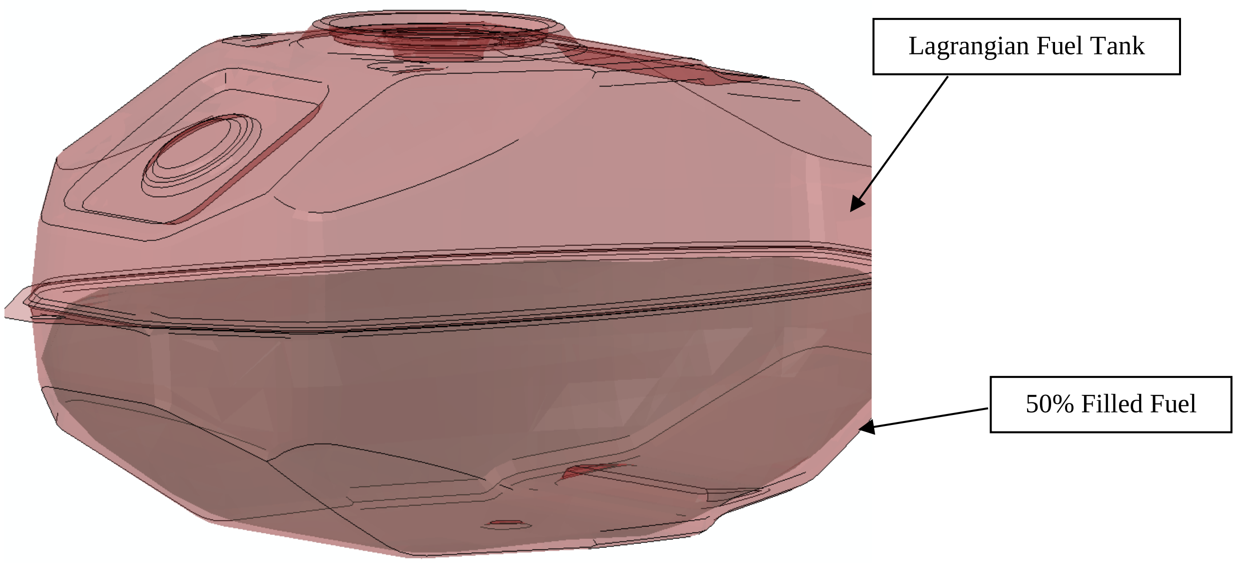


Figure 2. Eulerian material Initialization

3.2 MBD Load Generation

Vehicle model is assembled by collecting the geometry of various components with proper mass and inertia property using the MBD simulation tool Adams. The smaller components cluster with no relative motion among them are taken in the form of lumped masses. The various components are assembled using appropriate joints. Spring-Damper and bushing stiffness and damping coefficients are assigned as per the design or testing data. The bump road used for the simulation consists of 2 kinds – Bump Road and Pothole Road. The shape of the bump is taken same as the bump cam of the Bump Roller Test Rig and the pothole is taken as reverse of bump.

The road is modelled as FEA mesh model and saved in the Road Data File (RDF) format to be used by Adams model. This works in conjunction with the front and rear tire generated according to the tire data collected from the testing or tire manufacturer standard data. The vehicle is then run at a uniform straight line speed of 10 kmph on the road imported. Measurements of the displacements of the Fuel Tank front mounting location in the X, Y & Z directions against time are exported. This displacement data is further required for solving the Fuel Tank Sloshing problem.

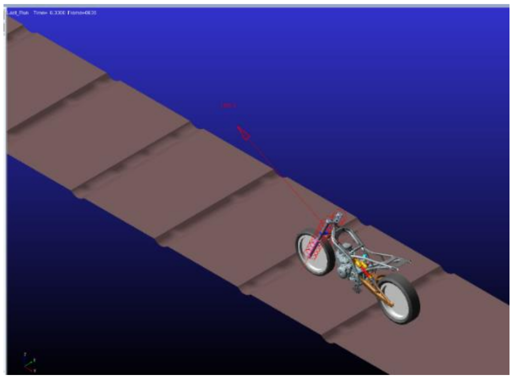
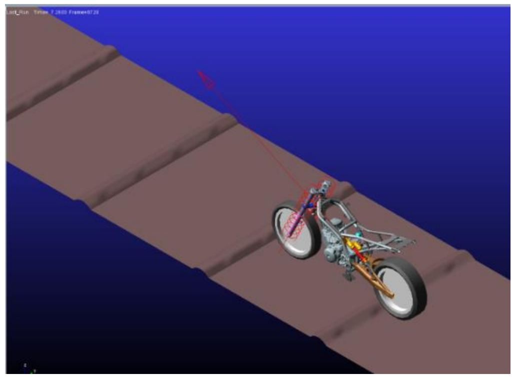
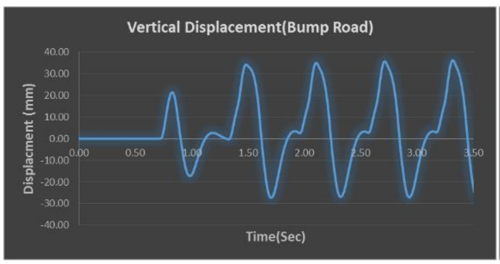
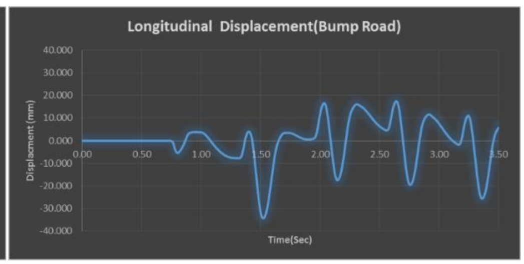
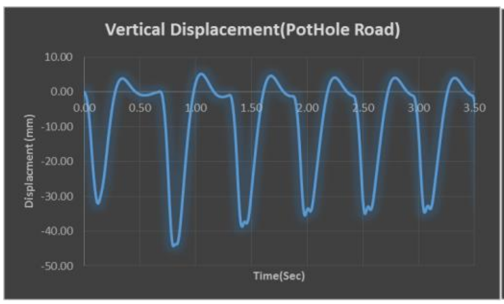



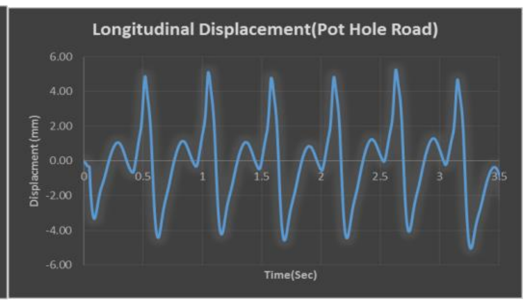
Figure.3 Pot Hole Road Model Bump Road Model

The variation of the displacement of the front mounting location of the fuel tank when it encounters a bump and the pot holes are shown in the graphs below.









3.3 Modeling the Lagrangian Domain

The tank and frame structure is modeled using traditional nonlinear Lagrangian elements (shell, connector, etc.), as seen in Figure 3. This example consists of a fuel tank, tank brackets, and frame. The total number of Lagrangian elements is 7754 linear quadrilateral elements of type S4 and 306 linear triangular elements of type S3. The Eulerian mesh represents the fuel fluid domain with 54600 linear hexahedral elements of type EC3D8R. The simulation was carried with 12 CPUs. The C3D10 is converted to C3D10M from the mesh module since the general C3D10 is not supported in the Abaqus Explicit.

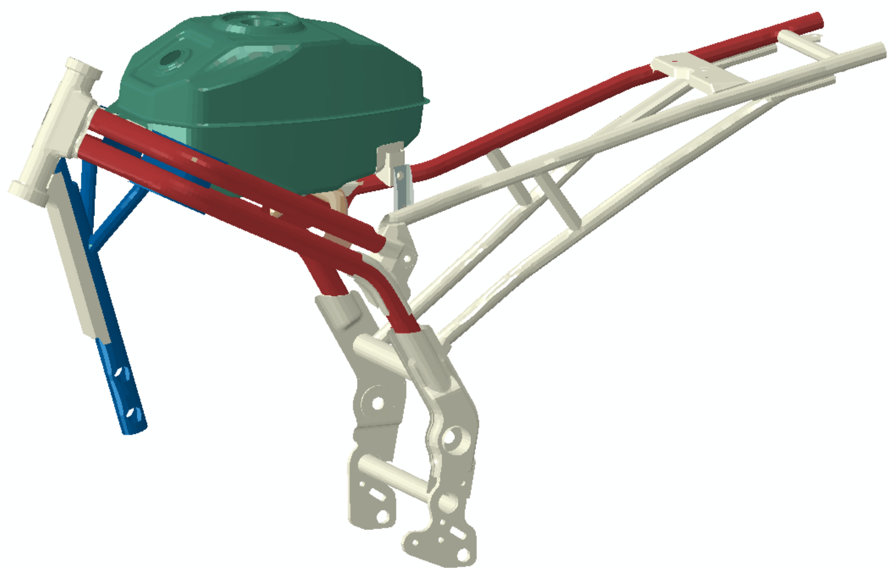


Figure 4. Fuel Tank Assembled Condition

3.4 Domain Modeling Eulerian-Lagrangian Contact

The unique feature of the CEL capability is contact definition between the Eulerian material and Lagrangian mesh using the general contact capability of Abaqus/Explicit. While general contact capability allows the very powerful all-inclusive general contact definition, it is often prudent to eliminate unnecessary contact surfaces from the CEL analysis to improve the efficiency. The Eulerian-Lagrangian contact formulation is based on an enhanced immersed boundary method. In this method, the Lagrangian structure occupies void regions inside the Eulerian mesh. The contact algorithm automatically computes and tracks the interface between the Lagrangian structure and the Eulerian materials. A great benefit of this method is that there is no need to generate a conforming mesh for the Eulerian domain. A friction property is introduced into a mechanical surface interaction model governing the interaction of the contact surfaces. A friction coefficient of 0.1 is used in the simulation.

3.5 Fuel Initialization Step

The Eulerian mesh and the Eulerian-Lagrangian contact are added to the FE model of the fuel tank from the previous step. To initialize gasoline in the assembled fuel tank, the Volume Fraction tool in Abaqus/CAE is used (as shown in Figure 5). The Body highlighted in pink color is the fuel which is the reference instance and the volume is extracted from the surrounding Eulerian surrounding." (Fan Li1, Peiran Ding2 and Steve Sibal)".

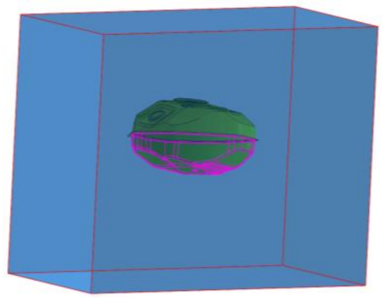


Figure 5. Volume Fraction Tool

3.6 Fuel Sloshing Simulation Step

The deformed tank mesh and its associated material state from the Abaqus/Standard assembly step are transferred into Abaqus/Explicit. In the meantime, the fuel inside the tank is included into the model by defining an Eulerian mesh initialized with gasoline. The slosh event simulated for this fuel tank system is 3.5 seconds for the above discussed load-cases. The Eulerian mesh motion feature (*Eulerian Mesh Motion) is engaged to allow the Eulerian mesh to move in space to enclose the fuel tank

4. Results

This study demonstrated that with the Abaqus CEL function, the FSI simulation method has been used for an integrated fuel tank system slosh simulation. The detailed gasoline flow patterns are shown in Figure 8 and Figure 9, respectively.

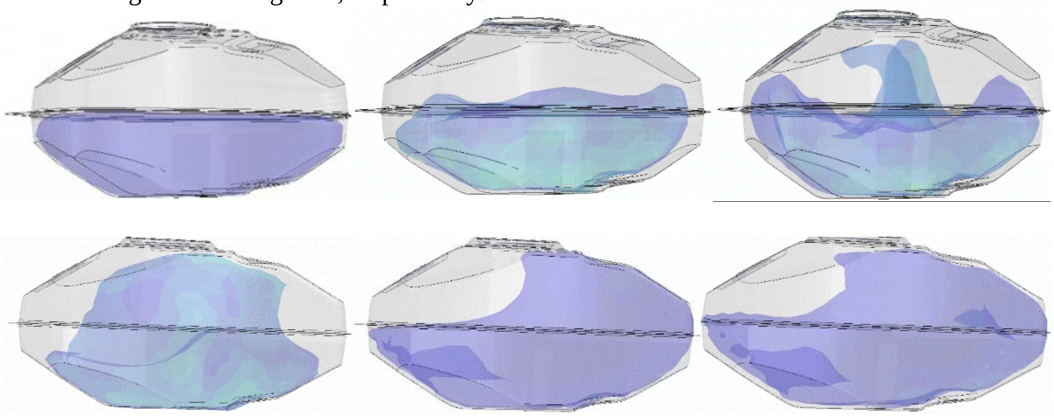


Figure 6 Sloshing Pattern of the Fuel Subjected Bump Road

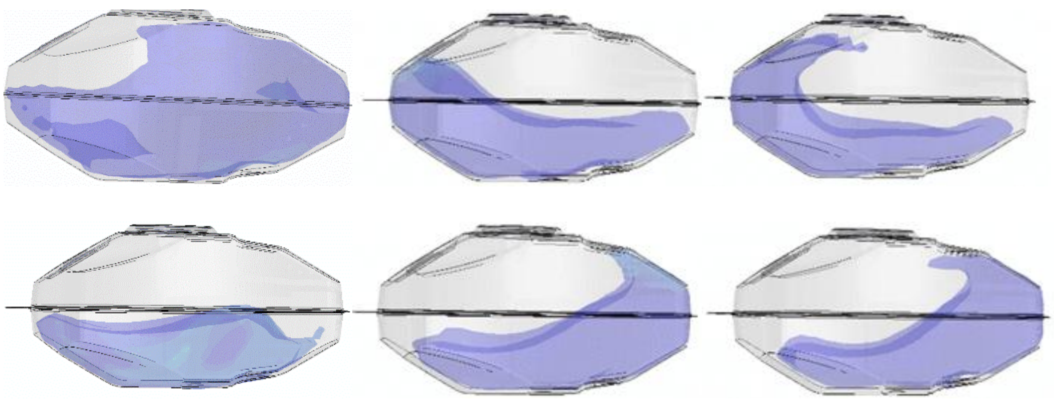


Figure7 Sloshing Pattern of the Fuel Subjected to Pot Hole in the Road

The stress developed due to impact of the fuel on the tank body is probed at four most critical location as shown below in the figure 8.

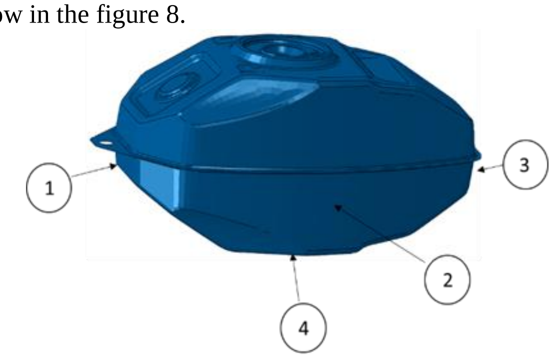


Figure 8 Stress Probe Location

These four location are selected on the basis of intensity of the sloshing on the tank. The following graphs shows the stress histories at the four location.

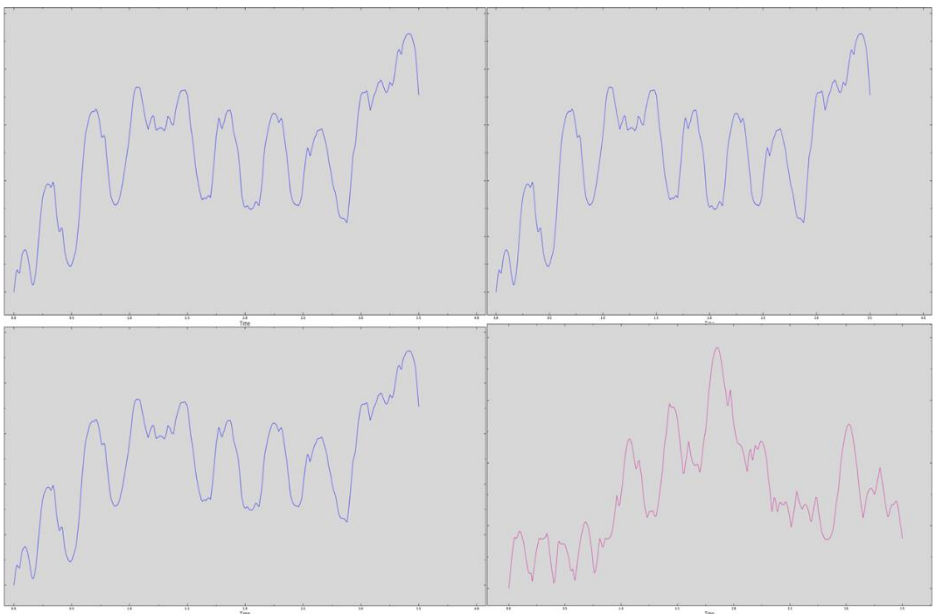


Figure 9 Stress (MPa) V/S Time (Sec) for Bump Road @ location 1, 2, 3 & 4

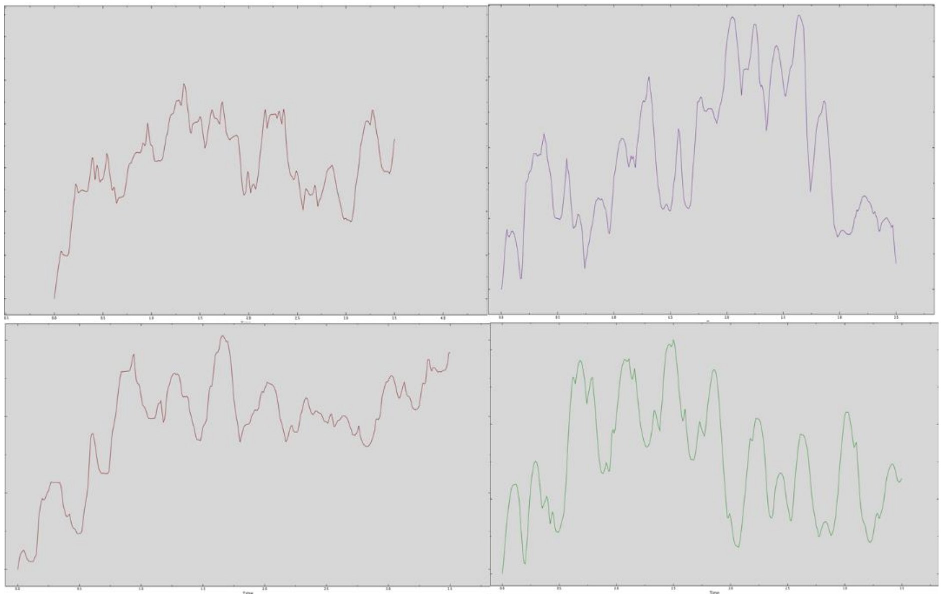


Figure 10 Stress (MPa) V/S Time (Sec) for Pot hole Road @ location 1, 2, 3 & 4

5. Conclusion

The stress developed because of the impact of the fuel on the tank is very less. Abaqus/Standard with the Abaqus/Explicit CEL function can be further used to create a seamless fuel system simulation method. With Abaqus's outstanding performance, it is possible to solve a FSI simulation such as a fuel tank slosh durability. Using Abaqus CEL, it is possible to study not only the fuel slosh flow patterns but also the dynamic stress pattern.

6. References

1. Fan Li[1], Peiran Ding[2] and Steve Sibal " Coupled Fluid / Structure Interaction Simulation Using Abaqus CEL"
2. Won-Joo Roh, Sok-Hyun Cho and Jae In Park "Simulation of Sloshing in Fuel Tanks and Parametric Study on Noise Reduction by Decreasing Impact Pressure" Hyundai-Kia Motor Company.
3. Abaqus User Manual

7. Acknowledgement

The authors would like to thank to Simulia 3DS Technical Support Team member Mr. Shripad Tokekar for his cooperation in the development of technology for predicting the sloshing flow.