Driving Through Flooded Road

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SPH interaction with deformable Bodies

Driving through flooded roads is always a challenge. Hydrostatic as well as hydrodynamic pressure can cause serious damage to the vehicle. Damage can adversely affect the performance of the vehicle in many ways. For example, high stress and strain can cause part failure, water ingestion into electrical components can lead to instant shutdown of the electrical system, corrosion, due to interaction with water can affect the performance and cosmetics of the vehicle. All of these can be costly fixes that are extremely dissatisfactory to our customers.

General Motors has been designing and building state-of-the-art vehicles for more than a century. Safety, structural durability, part integrity, and performance are key features of every vehicle that General Motors produces. General Motors constantly invests in new technology and methods to improve quality, performance, and customer satisfaction.

Smooth Particle Hydrodynamics (SPH) was developed in the late 70s. This mathematical advancement was transformed in the form of application in the recent past. The application has now been widely accepted by the CAE analysis community to study Fluid-structure-interface, water path analysis, and other hydrodynamic behavior, related to water and oil. General Motors has worked with LS-DYNA® to improve performance issues of its vehicles in many areas of interests such as occupant safety, crash worthiness, structural durability and most recently, on water intrusion issues using SPH.

This study involved structural durability analysis of a vehicle when driven on a flooded road. SPH particles were created to mimic the flooded road. A non-linear transient (crash) model was selected for the analysis. A node-to-surface contact was established between the SPH particles and vehicle. The vehicle was given an initial velocity of 30 km/hour, and the wheels were let to spin with the calculated rotational velocity. The LS-DYNA simulation was run for 400 milliseconds and plastic strain outputs were measured. A physical test was scheduled. Strain gauges and strain rosettes were affixed at the areas where computer simulation results were measured and recorded. The physical test was then performed at the General Motors Milford Proving grounds. Analysis results were then compared with the physical test results.

In conclusion, a good correlation was observed between CAE (SPH analysis) and test results. SPH analysis is computationally very intense. Therefore, steps are being discussed to shorten the total computational time.

Introduction

Hydrodynamic pressure can cause serious damage to a mechanical system [1][2]. Whether it is a ship design, bridge design, home appliances or designing a car, hydrodynamics is one of the key factors in the design process. Driving into water on flooded roads can lead to trouble in many ways. The vehicle can lose control in a rapid and get swept away, volume of water can get into the engine compartment and electrical system and stall the vehicle. Long term issues that arise from water include rusting thereby, causing corrosion [3][4]. The performance of the vehicle is adversely affected by water ingestion and hydrodynamics. Front end outer parts of a vehicle, such as fascia, splash shield, underbody bellypan etc. can break and fall off due to the hydrodynamic pressure. The hydrodynamic pressure can reach a critical extraction point of the snap-fit clips and detach the part from the assembly. Since front end outer parts are made of plastic it is utmost important to ensure their structural integrity to the vehicle.

Smooth Particle Hydrodynamics (SPH) was first introduced in 1977 by Lucy, Gingold & Monaghan to simulate non-axisymmetric phenomena [5][6]. It is a mesh free method, based on Langangian fluid flow as opposed to the conventional Eulerian grid-based technique [7]. SPH method, over the years, have seen wide usage in solving solid mechanics and fluid dynamics [8].

As per the surveyed literature, most of the SPH related work has been done with fluid interacting with the rigid body to study the fluid flow path and the dynamics. The interaction of fluid with the deformable body has been ignored so far. This study would show that SPH method can be applied to predict the strain of a deformable body.

Objective

Based on the issues that a vehicle faces when driven in a flooded road, a water trough test needed to be performed to mimic the flooded condition. The trough was filled with water up to 300 mm. The vehicle was driven in the trough as shown in the Figure 1 below.

Figure 1

The main objective of this paper is to identify the maximum strain in the front end vehicle parts, particularly in the attachment areas and then correlate with virtual simulation.

CAE Methodology

A non-linear, full vehicle LS-DYNA model was chosen for the virtual simulation. A rectangular tank of lenth 5 m x width 2.5 m x depth 0.3 m was contructed. SPH particles, depicting water, were filled in the tank mimicking the flooded road as shown in Figure 2. A total of roughly 3.8 million of SPH particles were created. Each particle was measured to be of size 5.8 mm diameter and the mass of each particle was measured 0.102 gram (considering spherical shape of water droplet). The tank with SPH particles was then placed in front of the mode as shown in Figure 3. A node set was created for the entire SPH particles and a part set was created with the front end parts of the vehicle. The entire vehicle was given a velocity of 30 km/h. Based on the linear velocity and wheel size, rotational velocity was calculated and then assigned to the four wheels. The LS-DYNA simulation was run for 400 milliseconds. The strain and stress results were viewed and measured at the front fascia and the attachment tabs.

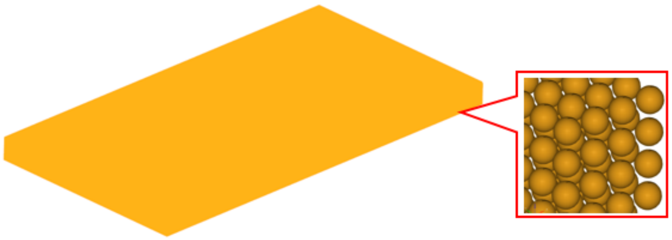


Figure 2

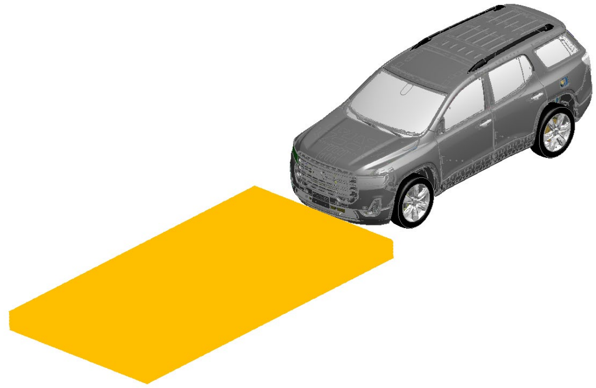


Figure3

Test Setup

The physical test was conducted at the GM Milford Proving ground in Milford, Michigan. Based on the initial CAE simulation result, strain gauges and rosettes were affixed on the front fascia, attachment tabs and other high strain concentration areas as shown in Figure 4. The trough was filled with water; the depth of the water was maintained at 300 mm with the help of gauge-monitor as shown in Figure 5. The test was run and data was collected. The data was then converted into microstrain.

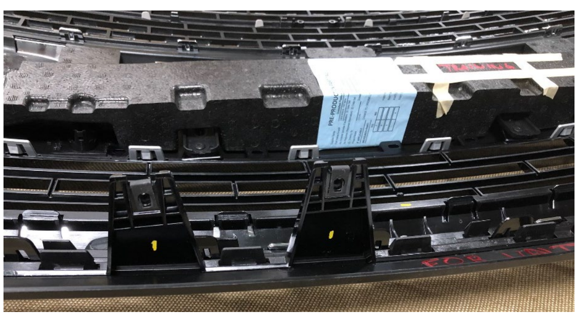


Figure 4

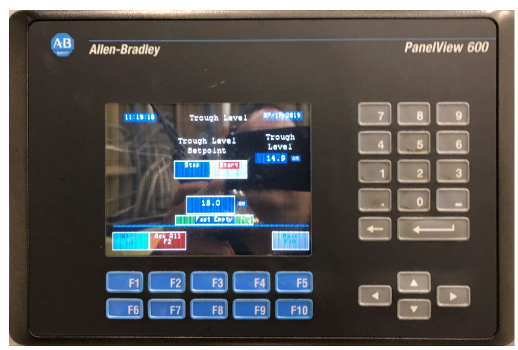


Figure 5

Result

The converted result was then plotted against the CAE simulation as shown in the Figure 6 and Figure 7. The CAE simulation was run for 400 milliseconds, but the results were plotted for only 50 milliseconds as the strain remains almost constants after 50 milliseconds.

Figure 6 (test)

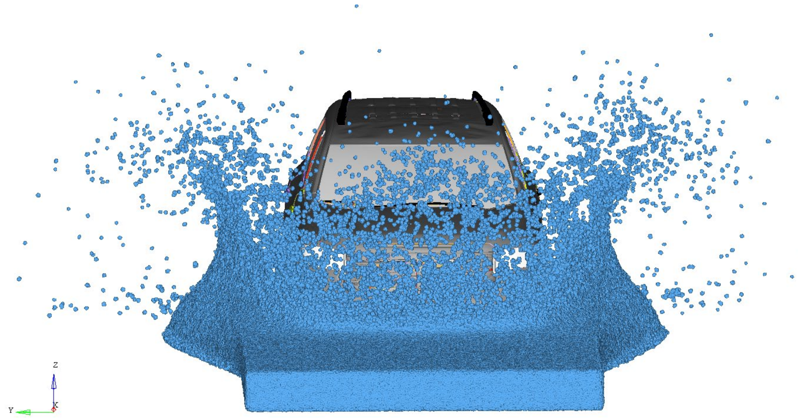
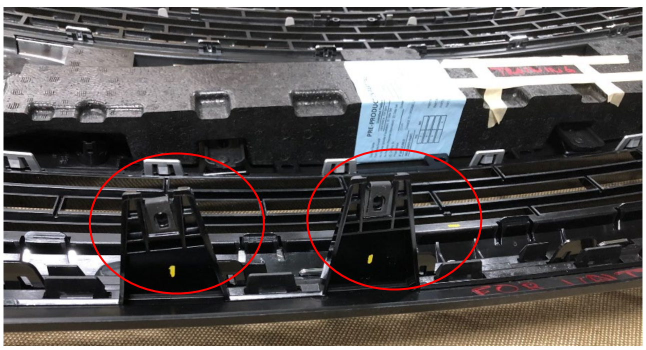


Figure 6 (SPH analysis)



Tab3 Tab2

Figure 7 (test setup)

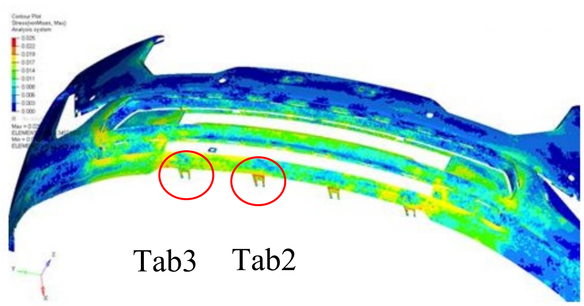


Figure 7 (CAE simulation)

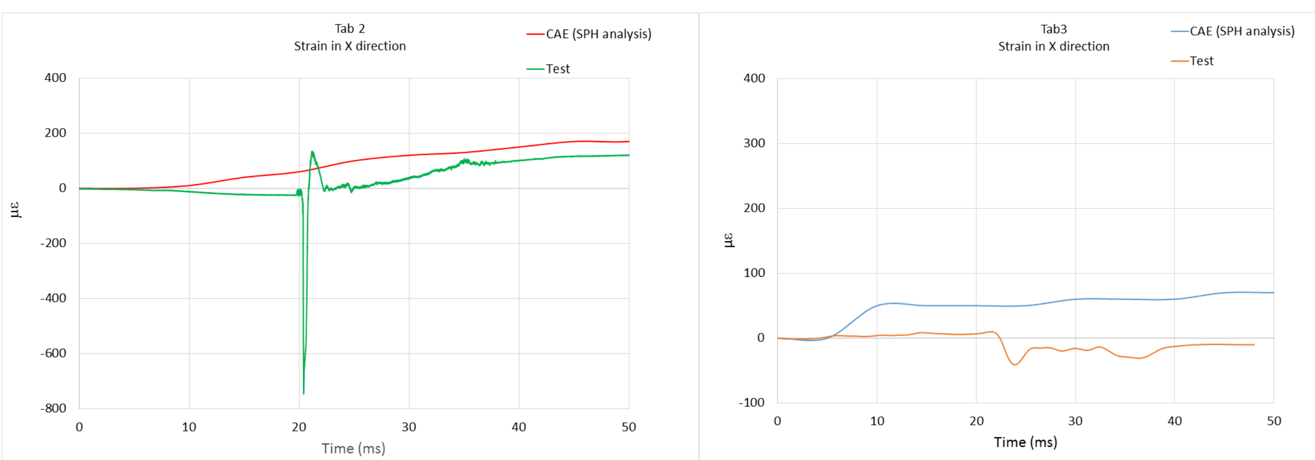


Figure 8 (Test vs SPH analysis)

Conclusion

It was obsereved that the strain results from CAE simulation were correlated well with the test results. It was also observed that with time, the strain at the measured locations (tabs) remain constant throughout the test and CAE simulation.
It was also noted that computational time is inversely proportional to the size of the particle and number of particles.

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References

[1] Effect of Hydrodynamic Thrust Bearings on Lateral Shaft Vibrations
https://doi.org/10.1115/1.2920697 N. Mittwollen, T. Hegel J. Glienicke *J. Tribol*. Oct 1991, 113(4): 811-817
[2] EFFECT OF ASYMMETRIC HYDRODYNAMIC IMPACT ON THE DYNAMIC RESPONSE OF A PLATE STRUCTURE
Jianbo Hua*, Jeun-Len Wu** and Wei-Hui Wang**
https://jmst.ntou.edu.tw/marine/8-2/71-77.pdf
Journal of Marine Science and Technology, Vol. 8, No. 2, pp. 71-77 (2000)
[3] Wang S, Q., Wei, M., X., Wang, F. Transition of Mild Wear to Severe Wear in Oxidative Wear. 2008;32
[4] Quinn TFJ. Review of Oxidational Wear. Part I: The Origins of Oxidational Wear. 1983;16.
[5] J.J Monaghan. Smooth Particle Hydrodynamics. Annual Reviews, Astro.Astrophys. 1992.30:543-74
[6] M. Muller, D. Charypar, and M. Gross ¨ . Particle-based fluid simulation for interactive applications, in Proceedings of Eurographics/SIGGRAPH Symposium on Computer Animation
[7] M. Pastor, T. Blanc, B. Haddad, S. Petrone, M. Sanchez Morales, V. Drempetic, D. Issler, G. Costa, L. Cascini, G. Sorbino, S. Cuomo. https://doi.org/10.1007/s10346-014-0484-y
Application of a SPH depth-integrated model to landslide run-out analysis
[8] Changadevkumar Desai, Sushilkumar Vishwakarma, Pavol Vasko Washing Machine Outlet Hose Analysis in Full Water Condition
https://doi.org/10.1007/978-981-13-8468-4_7