

Prediction of Aluminum Wheel Distortion under Pothole Impact

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Abstract: *In the vehicle design, the interaction between road and vehicle is the main criteria in order to meet the durability, NVH (Noise Vibration and Harshness) & handling performance. Potholes in the road can cause damage to the wheel, suspension and chassis components. Pothole size and vehicle speed were the main factors for the damage. The larger pothole can cause severe damage or alignment issues. Based on the severity of the impact, damage will happen to the wheel rim and there will be a reduction in the air pressure inside the tire. In long-term, it will damage the suspension or steering components and it can also lead to premature tire wear and poor handling of the vehicle. Prediction of pothole effect in the vehicle will be useful for redesigning the components at the design stage itself to avoid the damage. To predict the pothole event, several methods and virtual tools were available. The nonlinear dynamic behavior of the vehicle during pothole impact will be captured accurately using Abaqus FE solver. The tire model and the material play a vital role by absorbing energy during the impact. The effect of vehicle speed during pothole impact was also studied. The CAE model of tire was validated with some physical test results and it was used in the vehicle pothole impact simulation. This paper explains more about the modeling of tire, suspension, vehicle, simulation methodology and the correlation of CAE results against the test values. This pothole impact simulation method gives an indication to make the design changes also.*

Keywords: *Pothole, Wheels, Tire, Tire Stiffness, Impact, Distortion, Explicit, Implicit*

1. Introduction

In recent years the Computer Aided Engineering (CAE) has played significant role in the vehicle design and prototyping. Various CAE methods are being used for the entire vehicle development process and in the vehicle durability analysis, NVH analysis, crash/safety analysis, etc. The vehicle interaction with virtual road has been the area of interest in automotive field for a long time. Knowing wheel loads and accelerations will aid the vehicle design process for the durability and NVH performance. Of late, using the virtual simulation methods, the loads and the accelerations can be predicted in the early design stages, which provide the opportunity to optimize and fine tune designs more accurately.

There are mainly two approaches currently being used in the industry. The first using Multi Body Dynamic (MBD) analysis technique with mathematical representation of tire and second is using the Finite Element (FE) solvers with physical representation of tire. Both of these techniques have their own advantages and limitations. The MBD technique is very efficient but they require extensive testing of tires to calibrate tire model, whereas tire calibration is relatively simpler in FE based technique but they were computationally quite expensive. By using FE models, it is also possible to evaluate the stress and deformation levels in the suspension components. With the increased use of low-profile tires, it is increasingly common for the appearance of problems in suspension components due to pothole impacts. In this paper, the pothole test was simulated using FE method, Abaqus implicit and explicit as solvers. The tire model calibration is critical in this simulation. This paper explains the FE representation of the tire model and its calibration. Then the representation of the aluminum wheel, vehicle model, pothole simulation process and the prediction of wheel distortion towards the test results were discussed.

2. Wheel Pothole Impact Test

The potholes have become more frequent as road infrastructures age. Some mechanical failures in vehicle are a direct result of potholes driving maintenance and repair cost. The pothole test represents scenario in which the

vehicle is travelling either on or off-road at various speed when a tire engages a pothole or ditch. During the pothole impact, the tire loses contact with the ground; the suspension spring will force the unsprung mass downward at acceleration much greater than the one gravity (g), which adds the gravitational acceleration acting on the center gravity of the sprung-unsprung mass systems. As the tire drops in the pothole, the vehicle is no longer in level, and the weight begins to shift more severely over the tire “(Billal,2015)”. As the tire hits the edge of the pothole at high speed, a huge concentrated reaction force strikes the tire directly, which results on a severe event with high accelerations, that may exceeds 100 g 's of shock load “(Triche,2005)”. This force will critically deform the tire, sometimes leading to rupture tire carcass cord reinforcement, or even plastic deformations of the wheel. If the wheel deformation is more, then it will lead to reduce the air pressure in tires. The pothole load is one of the critical parameter for the wheel design. The wheel deformation should be very minimal so that the tire air pressure should not reduce and there should not be any visual abnormality in and on the wheel. The vehicle was tested for 30kph, 40kph and 50kph speed over the pothole. Figure 1 shows the pothole in proving ground and its critical dimensions.

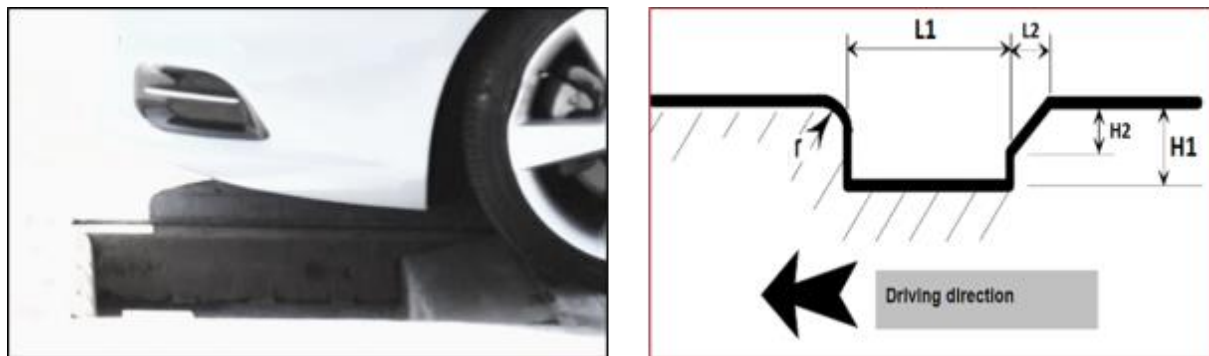


Figure 1. Pothole Diagram (Critical Dimensions)

2.1 Vehicle and Tire Modeling

The FE model for the virtual pothole impact simulation includes the wheel and tire model, front and rear suspension model, BIW and the road profile.

2.1.1 Tire Modeling and Validation

Tire is the highly non-linear component in the suspension system and it plays a vital role as a medium to transfer the load from the road to the vehicle. Figure 2 shows the different components of the tire and finite element model of the tire. The finite element model was constructed using hexahedral and surface elements. The hexahedral elements represent the tread, side wall, the bead wire and liner. The surface elements used to represent the body plies and steel belts. The reinforced textile cords in the body plies and the metallic cords in steel belts were simulated by using the Abaqus rebar layer which was defined as surface elements. The number of cords, size and angle was defined in the rebar layer. The surface element was embedded inside the solid elements.

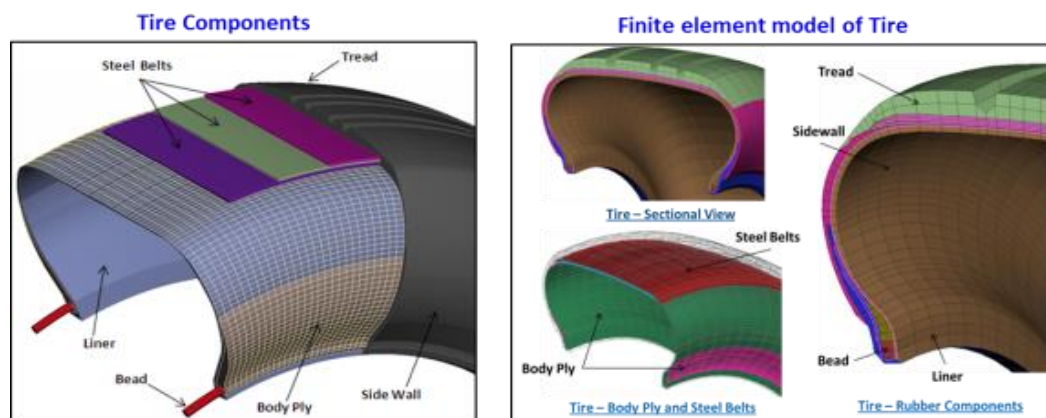


Figure 2. Tire components and Finite Element Model representation

The tire FE model was validated by comparing the vertical stiffness from the test. In testing, a vertical load (which is equivalent to the self-weight of vehicle) was applied, and the vertical deflection at the wheel center was measured at the specific interval of the loading. Figure 3 shows the tire deformation and stiffness curve comparison between the CAE and the physical test results. The CAE stiffness is also close to the experimental results.

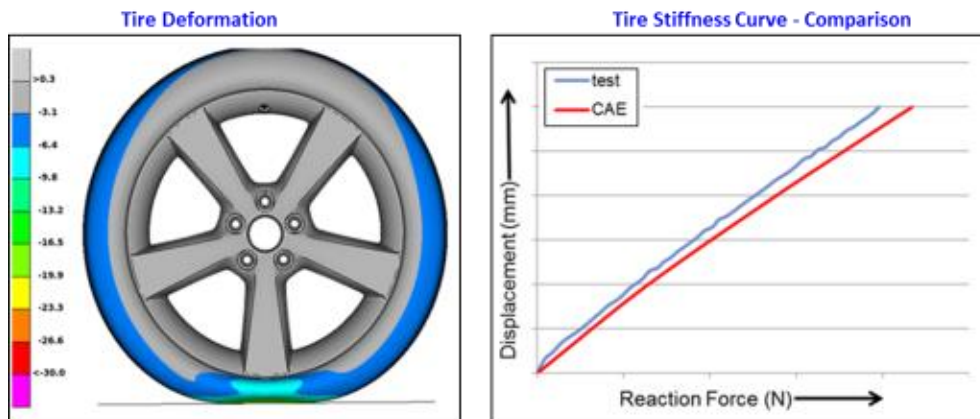


Figure 3. Tire stiffness comparison – Physical Vs FE Tire model

2.1.2 Suspension and Vehicle Modeling

The Body-in-White (BIW) was created using the rigid elements for the representation. The mass element was used to represent the BIW weight and inertia. The front and rear suspension assembly was created using the combination of the solid, shell, beam and connector elements. The coil spring was modelled using the axial connector element with non-linear stiffness and pre-tension was assigned. The damper was modelled slot connector element with the nonlinear damping properties. All bushings were modelled using the Cartesian-Cardan connector element and provided with the nonlinear stiffness for all six degrees of freedom. The wheel was modelled using the tetra element of 6mm element size. Figure 4 shows the FE model of wheel and Tire. Figure 5 shows the FE model representation of front and rear suspension assembly. Figure 6 shows the FE model setup of vehicle pothole impact analysis.



Figure 4. Finite Element Model of Wheel and Tire

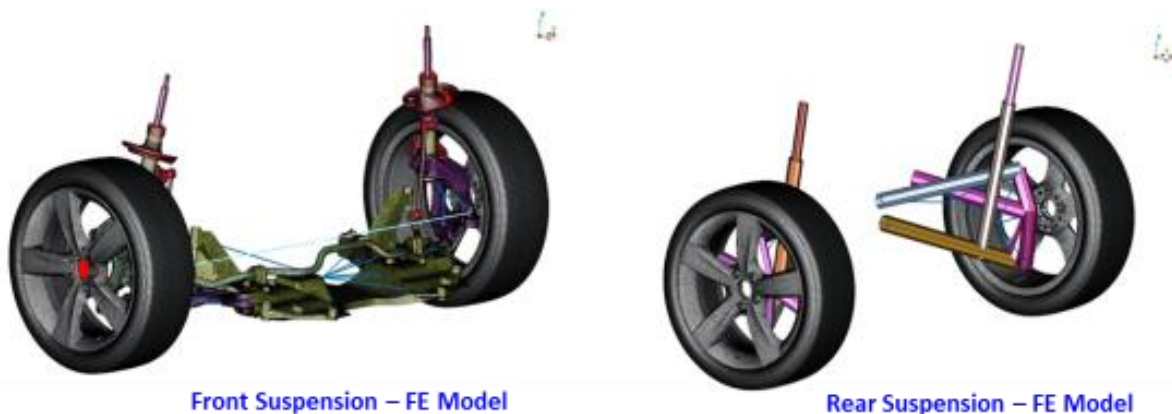


Figure 5. Finite Element Model of Suspension Assembly

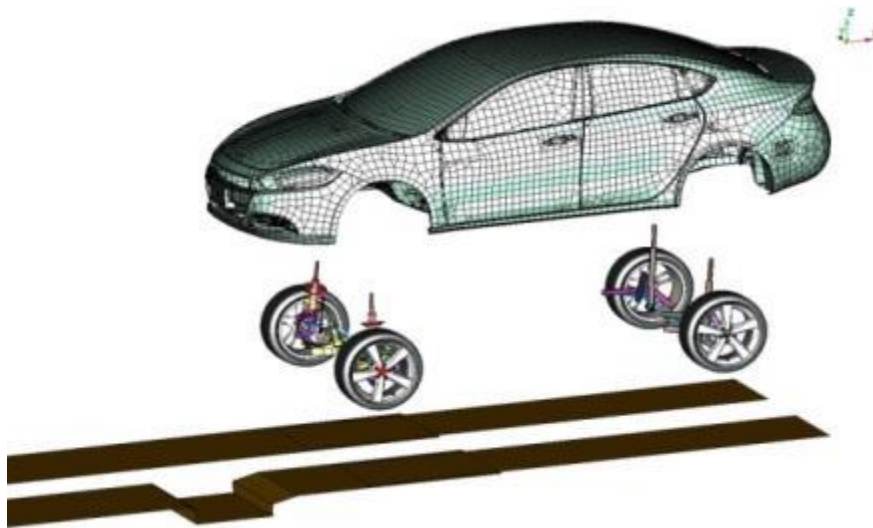


Figure 6. Finite Element Model setup of vehicle pothole impact analysis

2. Pothole Impact Simulation

The simulation of pothole impact is a highly non-linear dynamic event and it was solved by using explicit solver. Before the pothole impact, the tire has to be inflated and tire vertical load (due to vehicle self-weight) applied, both of which are quasi-static in nature. An explicit simulation of tire inflation and tire footprint load would consume more time to be solved. The ideal solution to the problem is to perform the quasi-static analysis using implicit code and use these implicit results as an initial condition for the dynamic analysis which was performed using explicit code. The “IMPORT” capability in Abaqus code is able to import the deformed mesh and the associated material state from the implicit solver to the explicit solver and vice versa, and in the present study this has been chosen to simulate the vehicle pothole test “(Triche,2005)”. The tire inflation and foot print analyses was done using the implicit solver. The tire rolling and the pothole impact were done in the explicit solver

3.1 Implicit Analysis

For the implicit analysis, only the wheel-tire assembly and the road rigid surface were considered as shown in Figure 7. The tire inflation was done by applying the uniform pressure inside the tire and followed by foot print analysis in next step. In footprint analysis, wheel center load was applied and tire will contact the rigid road. Using the *IMPORT capability in Abaqus, the implicit analysis results were transferred to the explicit analysis, for reducing the simulation time and for a better accuracy.

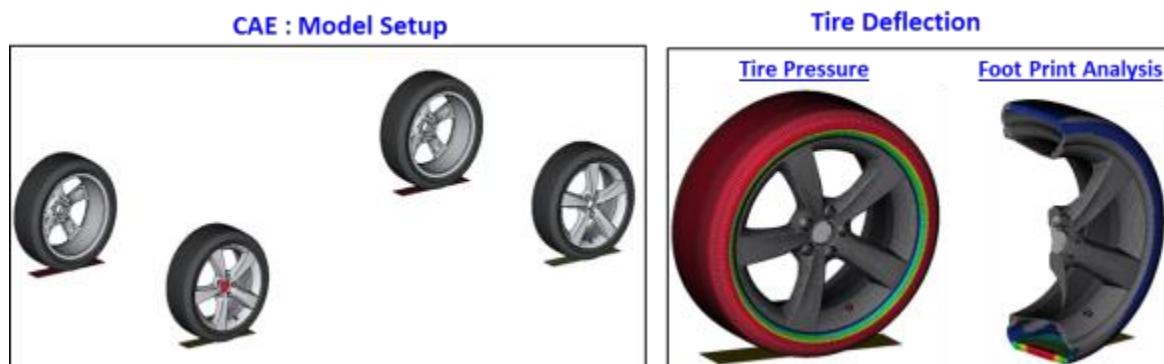


Figure 7. Implicit Analysis - Results

3.2 Explicit Analysis

The tire footprint results from the implicit analysis were imported to the explicit analysis. In explicit, the front and the rear assemblies were modeled using shell and solid elements. The body parts near the suspensions were modeled as shell elements and the remaining body parts were represented as a mass element. Figure 8 shows the vehicle pothole impact event in CAE.

3.3 Result Discussions

During the pothole impact at 40 km/h speed, the tire directly impacts the edge of the pothole. The tire-road contact becomes zero, as it enters the pothole and during the impact a shock load was developed. During the impact, the tire fully compresses and load transfers directly to the wheel rim, generating a huge acceleration in Z direction, over 100 g.

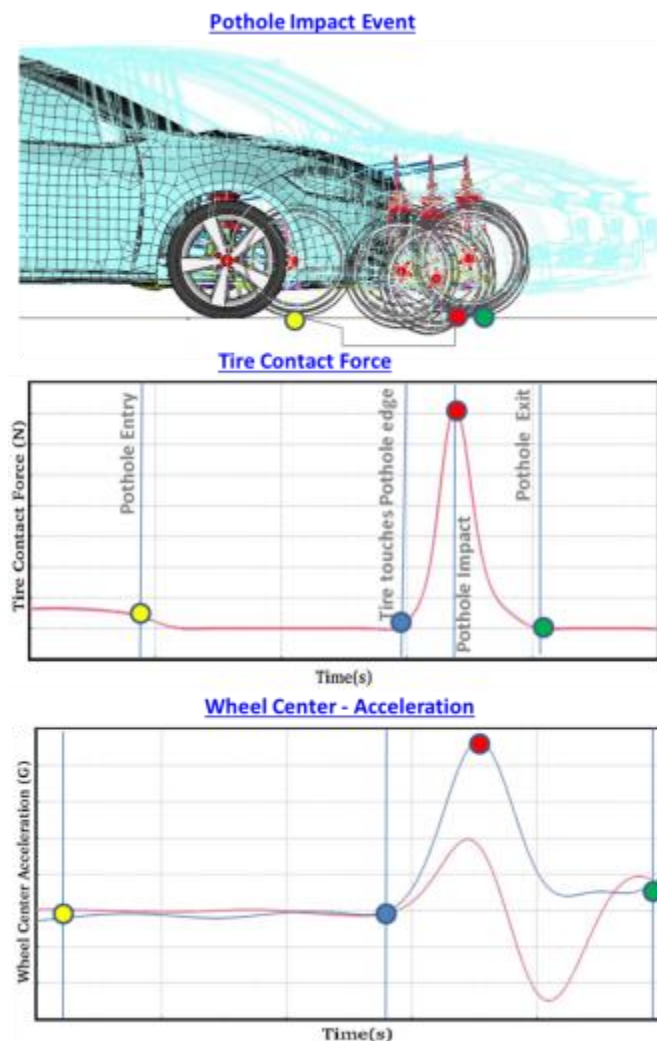


Figure 8. Vehicle pothole impact event in CAE

3.4 Correlation of Force and Accelerations

In previous studies “(Billal,2015)”, the CAE results correlation was done with the force and the acceleration measurement done during the physical impact. During the test, the vehicle was running at 40 km/h speed (with a tire pressure of 32psi) towards the impact on the pothole. The similar pothole impact simulation method and the process were performed and results were compared with the test results. In this study, the wheel was not deformed and only the force and accelerations were compared with test results for the correlation, which gives more authenticity in the methods and process. The force was measured at the ball joint; the acceleration was measured in the wheel center and near shock tower region. Figure 9 shows the ball joint force comparison

between the test and CAE results. Figure 10 shows the wheel center and shock tower acceleration comparison in fore-aft direction between the test and CAE results. Figure 11 shows the comparison of vehicle's vertical acceleration at wheel center and shock tower region for the physical test and CAE results.

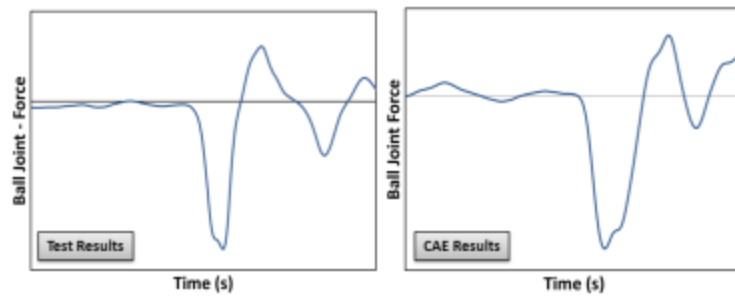


Figure 9. Ball joint - Force comparison: Test Vs CAE

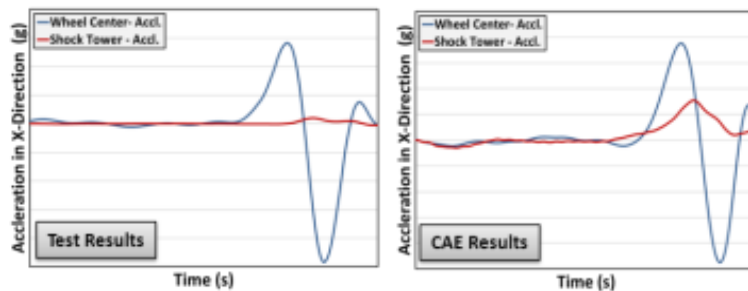


Figure 10. Comparison of fore-aft acceleration: Test Vs CAE

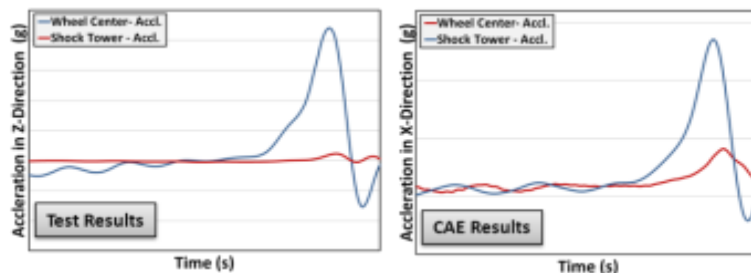


Figure 11. Comparison of Vertical Acceleration: Test Vs CAE

3.5 Prediction of Wheel Deformation

In the current study, pothole impact simulation was performed at various vehicle speeds (30KPH, 40KPH & 50KPH). Figure 12 shows the comparison of force along fore-aft and vertical direction at wheel center for various speeds of vehicle. Figure 13 shows the wheel distortion for various speeds. Figure 14 shows the comparison of plastic strain in wheels for various speeds of vehicle. The amount of plastic strain, distortion, and force at wheel center along fore-aft and vertical direction were less at 30KPH compared to other speeds.

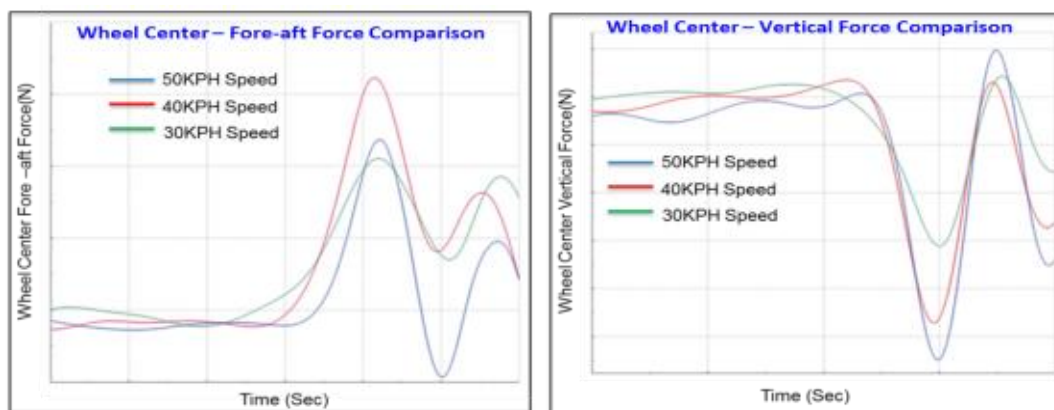


Figure 12. Comparison of Wheel Center Force for different speeds

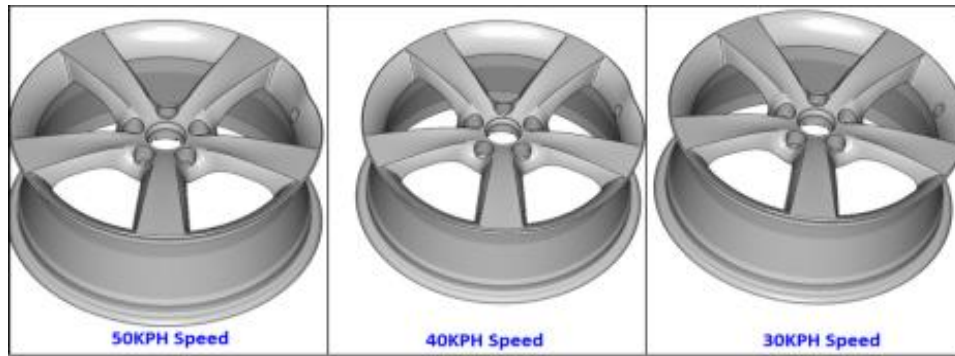


Figure 13. Comparison of Wheel distortion for different speeds

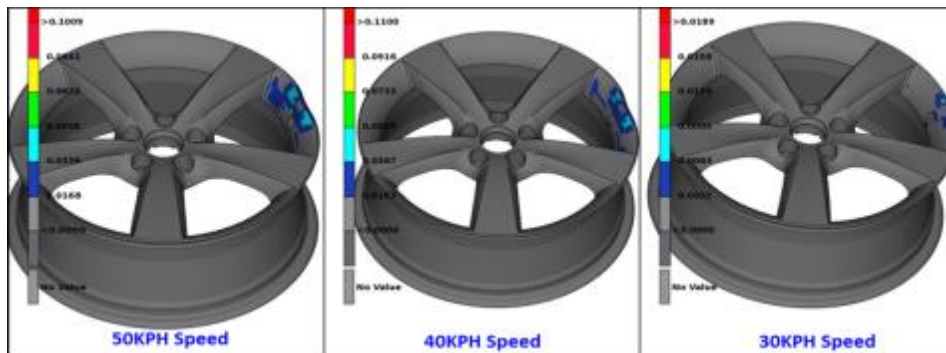


Figure 14. Comparison of plastic strain in Wheels for different speeds

Figure 15 shows the event of wheel distortion between the CAE and pothole test. Figure 16 shows the comparison of distorted location for front wheel between test and CAE for various speeds (40KPH & 50KPH). The distorted location of the wheel in CAE is matches with test results.

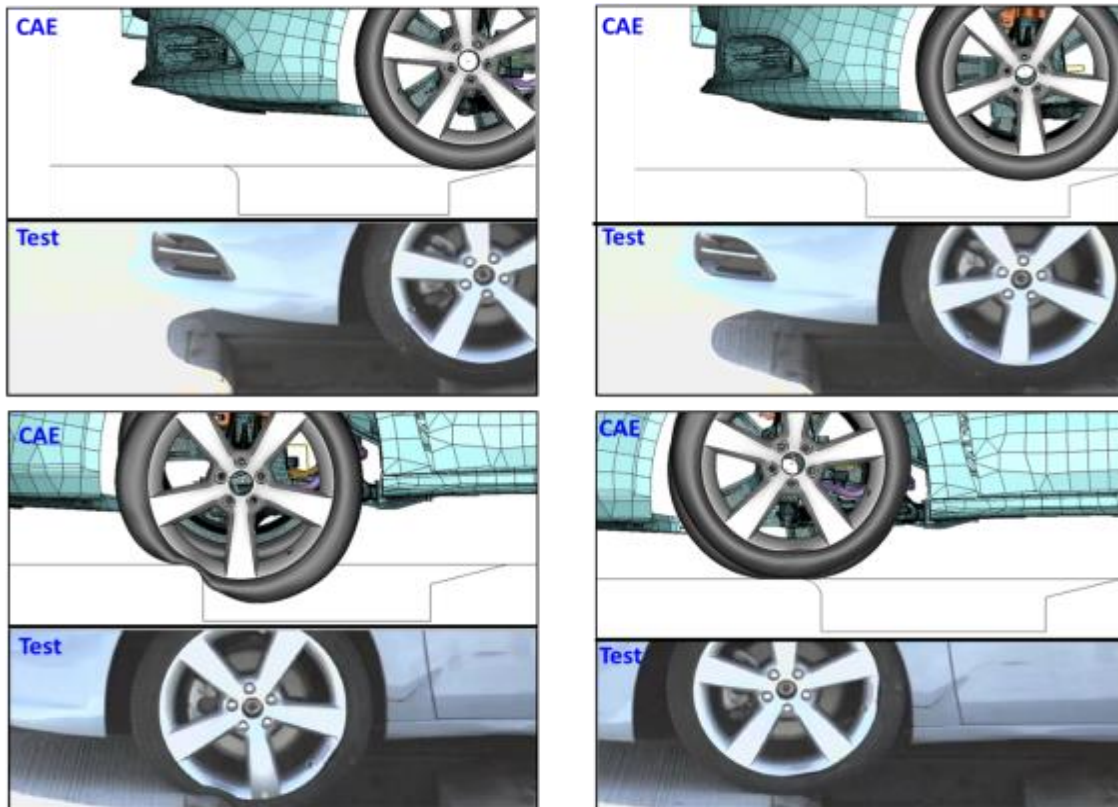


Figure 15. Comparison of Wheel distortion: CAE Vs Test



Figure 16. Comparison of Distorted location in Wheel: Test Vs CAE

3.6 Design Modification

Based on the pothole impact results for the baseline design, design modifications were done in the wheel by adding additional material. Figure 17 shows the comparison between baseline and new wheel design, no visual wheel distortion was found in the new design.

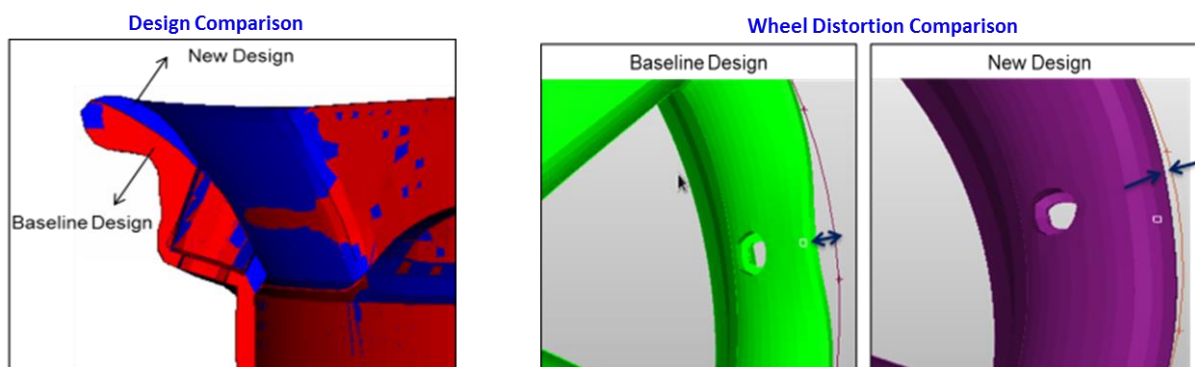


Figure 17. Comparison between Baseline and New design of wheel

3. Conclusions

For the design and validation of wheel and other suspension components, the pothole impact test is a key event. In this paper, a procedure for pothole impact test was presented. This method will be helpful to study the behavior of the vehicle at different operating conditions. Tire modeling is a main part in this simulation and the modeling procedure was explained in a detailed manner which will save the simulation time. The suspension and wheel validation for the misuse events could be done using this simulation process. The pothole impact virtual simulation is useful to extract the forces and acceleration at the wheel center and other joints. By using this method, a good correlation was also achieved between CAE and test results. This pothole impact simulation technique provides an idea to make the design changes to avoid the wheel distortion.

4. References

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