Bushing connector application in Suspension modeling

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Abstract: The Suspension Assembly modeling in utility vehicles is a challenge in terms of representing various bushings used for joints and in general there are multiple bushings in any suspension assemblies. These bushings have typically hyper elastic material bonded between metal sleeves and thus nonlinear in behavior. Also, the joint is very likely coupled with bolt joint which causes additional complexity in capturing the local behavior of the joint. The connector elements available in Abaqus/Standard enables us to capture the appropriate Bushing stiffness in all three axes and the simplified bolt model can accurately capture the local coupled stiffness of the Bushing and Bolt joint. A simplified suspension assembly for upper control arm was analyzed, tested and correlated for load-deflection data. This documentation reveals the effective utilization of Bushing connector and accurate representation of coupled Bushing and Bolt joint in a suspension assembly.

Keywords: Bushing connector, Suspension assembly analysis, Coupled Bushing and Bolt joint analysis, Hyper-elastic Deflection analysis, Connectors, Suspension assembly deflections

1. Introduction

The Suspension assembly in off road utility vehicles is somewhat similar to automotive type construction and has a multitude of bushings that are intended to give varied rotation stiffness at higher loads. A typical construction includes upper and lower control arms with shock mounted on the upper or lower control arm. Bushings are located at the frame mounting points and as well at the wheel upright that connects the upper and lower control arms.

1.1 Typical Suspension assembly components

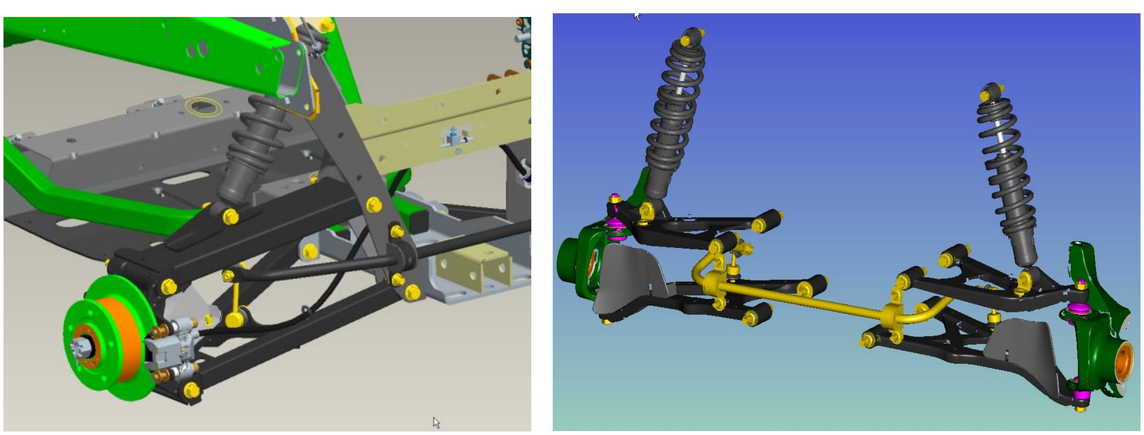


Figure1: Suspension assemblies in Off-road Utility Vehicles

The shown suspensions have vehicle speed ranging from 25Mph to 55Mph. The loads are significant and critical ones are vertical, fore aft, lateral moment and steer moment. At peak, the load passes through any of the weakest links and is likely dependent on the bushing stiffness at individual locations.

2. Bushing construction and Measured Stiffness

Typically, the bushings are a two part construction in that the two metal sleeves sandwich the thermo set rubber or thermoplastic elastomeric (urethane like) material. Thus, with hyper elastic material in between the metal sleeves, the stiffness in different axes for varied loading shows highly non-linear behavior. Below, the data shows that different material has different stiffness for various directions.

Figure2: Picture of the Bushings

The bushings can be clamped in metal brackets on frames and puts the hyper elastic material severely strained in the assembly. Manufactures of these Bushings have stiffness data available for various direction loadings. The data shows a non-linear response for higher loadings, so complete data is required for bushing characterization. The stiffness in each axes shows a non-linear response and the various shapes and material can offer distinctive stiffness in each of these axes. The measured stiffness properties are preferred over virtual estimated ones if the bushings are already available. FE Estimation of bushing stiffness is likely to be quite extensive and time consuming. Below figures3-6 shows various measured properties of bushings.

2.1 Radial stiffness

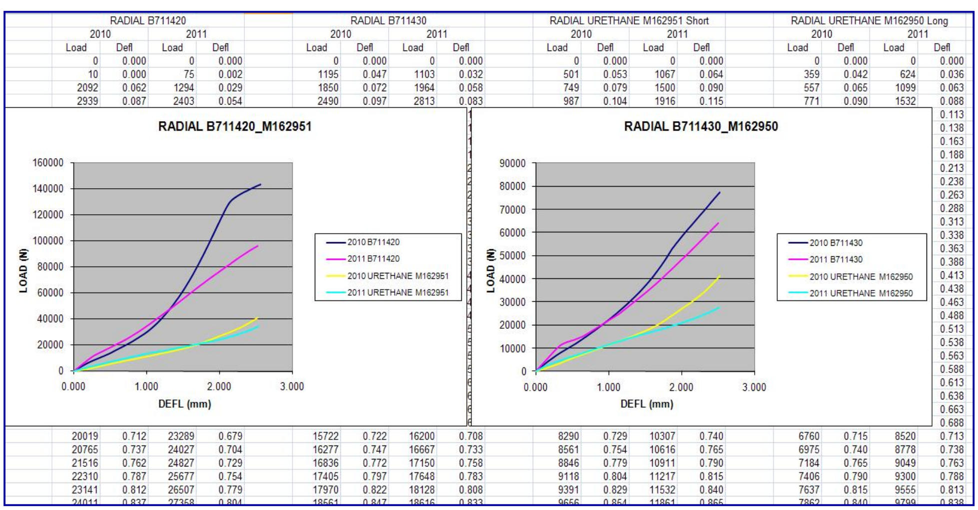


Figure3: Radial Stiffness of Bushings

2.2 Axial Stiffness

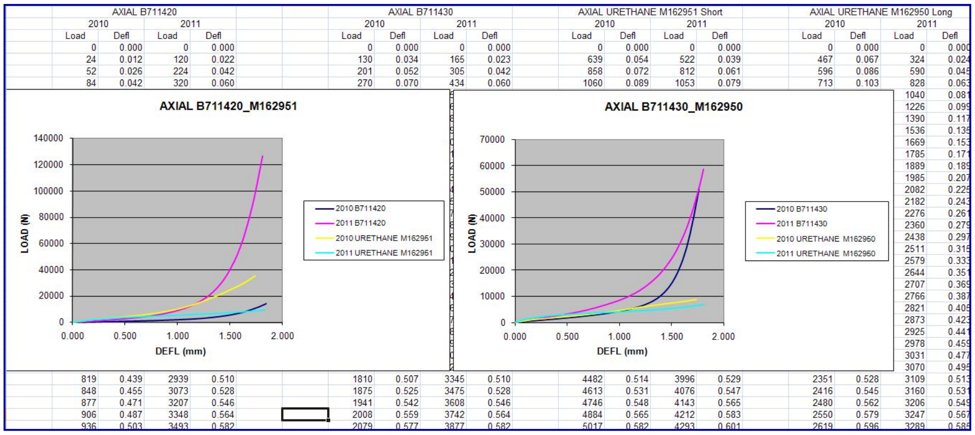


Figure4: Axial Stiffness of Bushings

2.3 Torsion stiffness

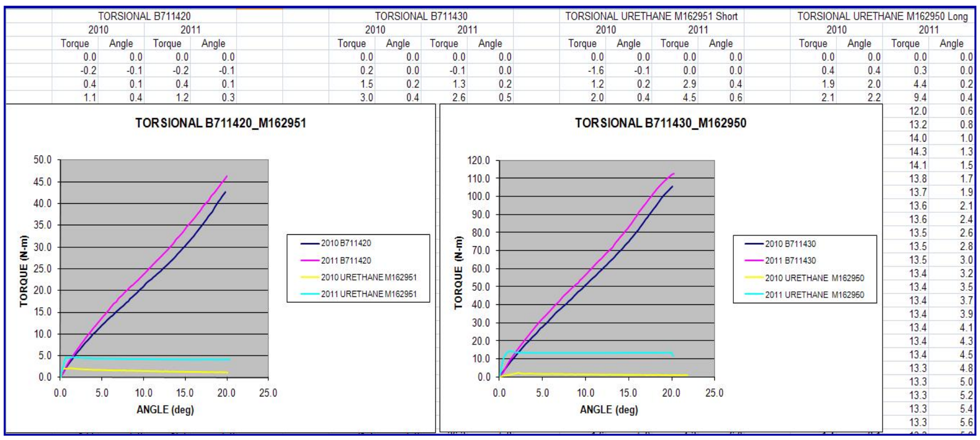


Figure5: Torsion Stiffness of Bushings

2.4 Conical Stiffness

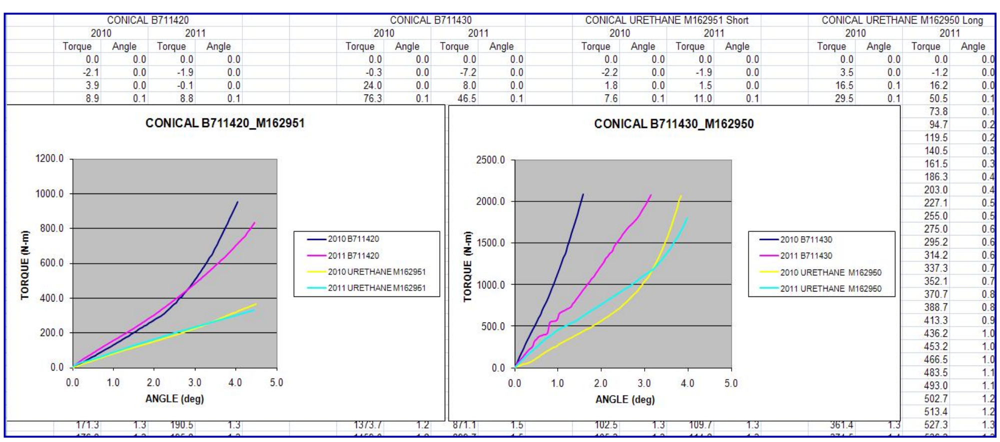


Figure6: Conical Stiffness of Bushings

3. Simplified Modeling of a Bushing connector

The simplified bushing modeling as illustrated in section 4.1.11of the Abaqus example problem (three point linkage analysis), shows that the Solid modeling of these bushings can be fairly represented by a bushing connector with stiffness data keyed in all directions. The modeling of bushing as a connector, a solid or a sub model has shown similar Force vs. Deflection results. Furthermore, bushing connector version is the fastest and simplest to model.

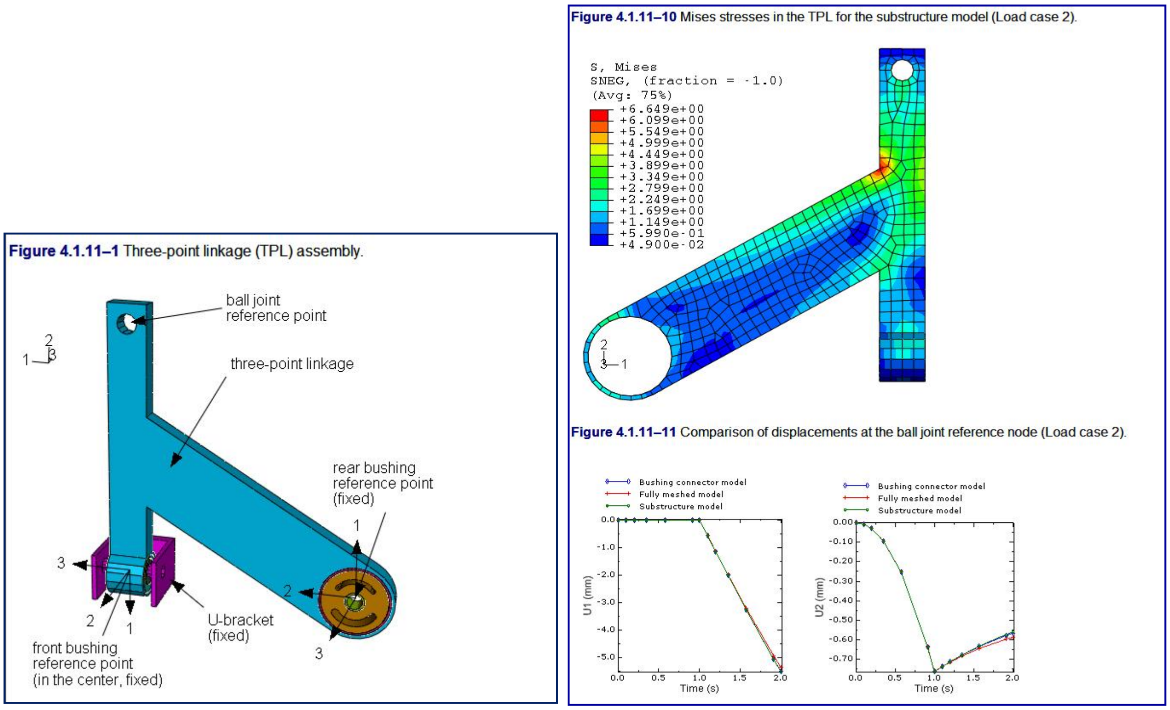


Figure7. Abaqus example for modeling Bushing connector

In the above example the bushing stiffness (nonlinear constitutive behavior) was estimated with the help of static analysis. In the presented simplified suspension modeling, the bushing stiffness is a measured one. The example also shows the effect of clamping the bushing with a bolt joint. This illustration is vital for applying the bushing connector element in suspension assembly related analysis.

4. Simplified Suspension Assembly FE Modeling/Test Set-up

In a simple setup to represent the suspension assembly, the upper control arm and a rigid shock was assembled with two bushings and clamped down with a bolt joint. The deflection measured at the load actuator.

Figure8: Test Set-up of simplified suspension assembly

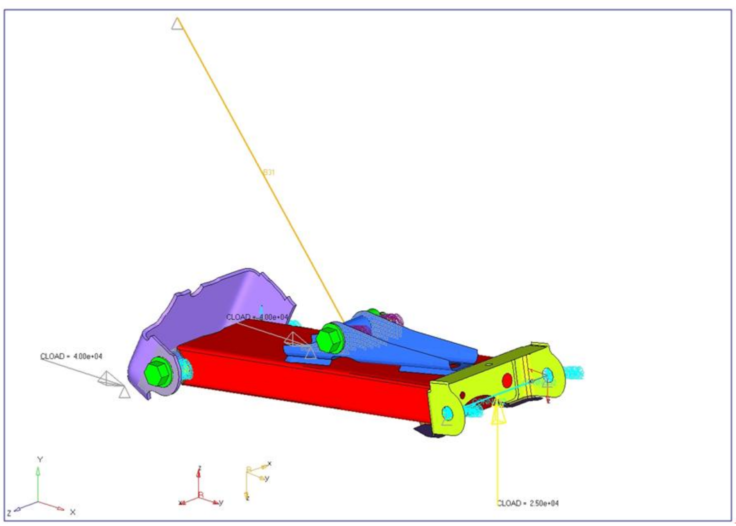


Figure9: FE modeling of the Simplified suspension assembly

The M12 bolt was torqued to 128N-mt and the FE model as shown above has bolt pretension modeled. The bolt was modeled with simple beam element and has gap element defined. The bushing connector was defined for the bushing connections with non-elastic stiffness in all three axes. Also, the bolt was modeled as solid to understand the gap element sensitivity (refer figure12).

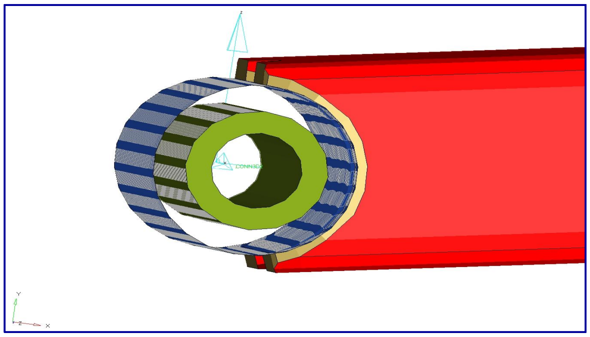


Figure10: FE modeling of the Bushing connector

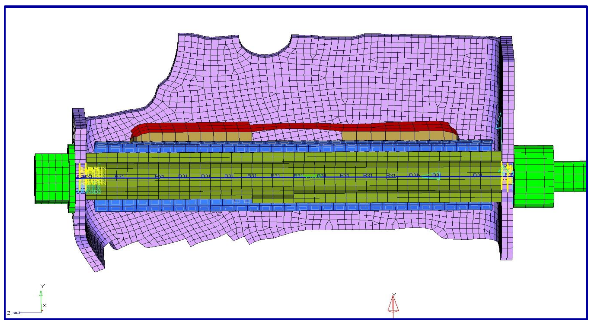


Figure11: FE modeling cross section of the Bolt joint with Beam element

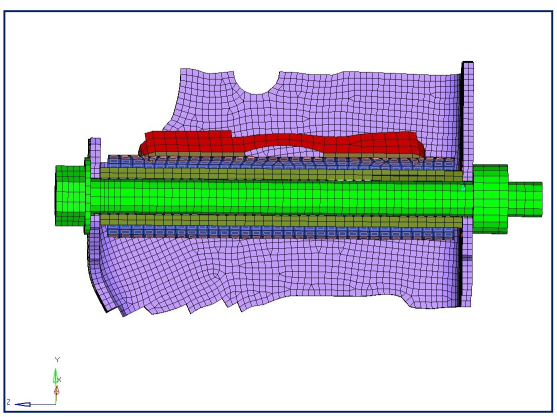


Figure12: FE modeling cross section of the Bolt joint with Solid elements

The Bushing connector element is quite simple in that two surfaces that sandwich the hyper elastic material are defined and coupling constraint defined to tie the two surfaces through each node of the two-node bushing connector element. Additionally, the bolt joint may be defined with beam element (refer figure 11) in conjunction with gap elements or as a solid element (refer figure 12). The pretension is always a preceding step. The bushing connector element has a local co-ordinate for orientation and thus corresponding stiffness assigned. This method of modeling is quite simple considering the solid modeling of the bushing as used in one of the past Simulia presentations (SCC2010) on Modeling and Analysis Techniques for Suspension Rubber Bushings by Satoshi Ito et.al.

5. Simplified Suspension Assembly FE vs. TEST data, Correlation efforts

5.1 Vertical Load Setup

The upper control arm deflection due to vertical load at the load actuator point was measured and correlated to the FE estimated deflection.

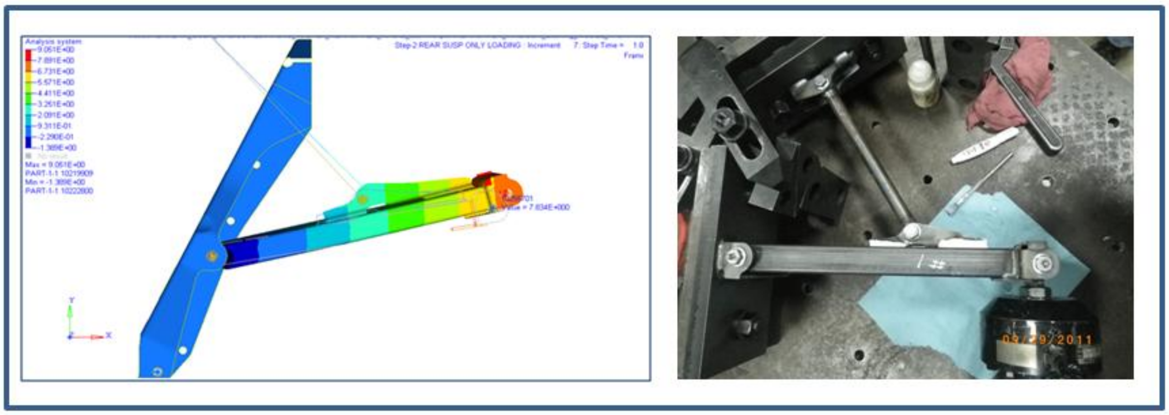
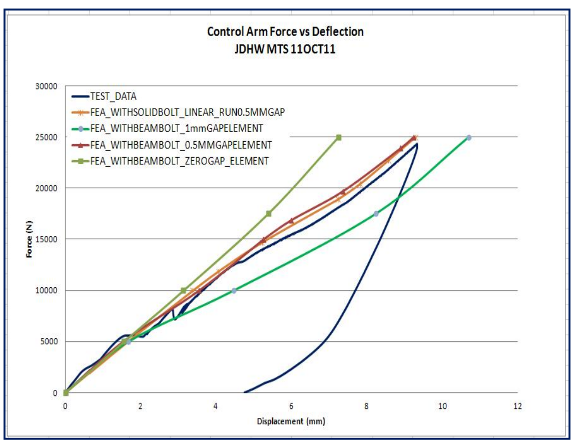


Figure13: FE results of Vertical Deflection of the Upper Arm



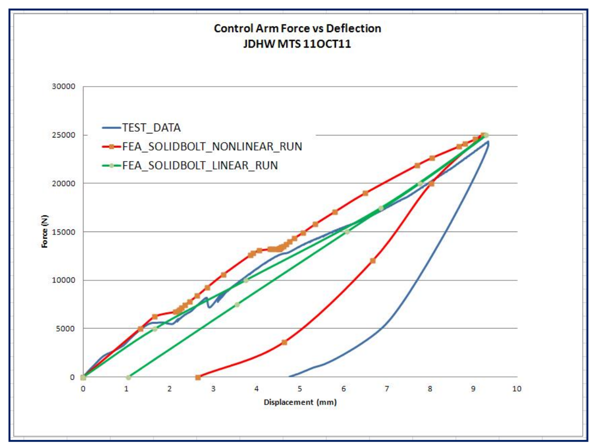


Figure14: Force vs. Deflection for Vertical up Load

Figure15: Force vs. Deflection, LINEAR & NONLINEAR RESULTS

As shown in the Force Deflection results (Figure 13) for a simplified version of beam element bolt model coupled with bushing connector, the measured data can be matched with detailed bolt joint connection. The bolt joint stiffness is significant at the increased load of beyond 10kN. A higher gap of more than 0.5mm between the bushing and bolt or bolt shank and mounting bracket hole shows lower stiffness and deviates from the test data. The 0.5mm gap shows better correlation, while the less than 0.5mm gap shows a stiffer curve in FE results. Also, as shown in Figure 14, the linear and non linear results of solid bolt model, shows significant infection point correlation due to bolt slip and varied contact path stiffness. Some deviation in the plastic deformation at the mounting bracket is attributing to contact patch of bolt threads to mounting bracket. Also, the unloading stiffness shows some difference which is likely due to rubber bushing relaxation. Overall, the bushing stiffness under vertical load is quite well matching which is evident from elastic deflection region. The vertical loading puts the coupled bushing connector and bolted joint to influence the overall stiffness. While the simplified bushing connector modeling is quite effective the bolt joint representation is much accurate with complete solid modeling.

5.2 Lateral Load Setup

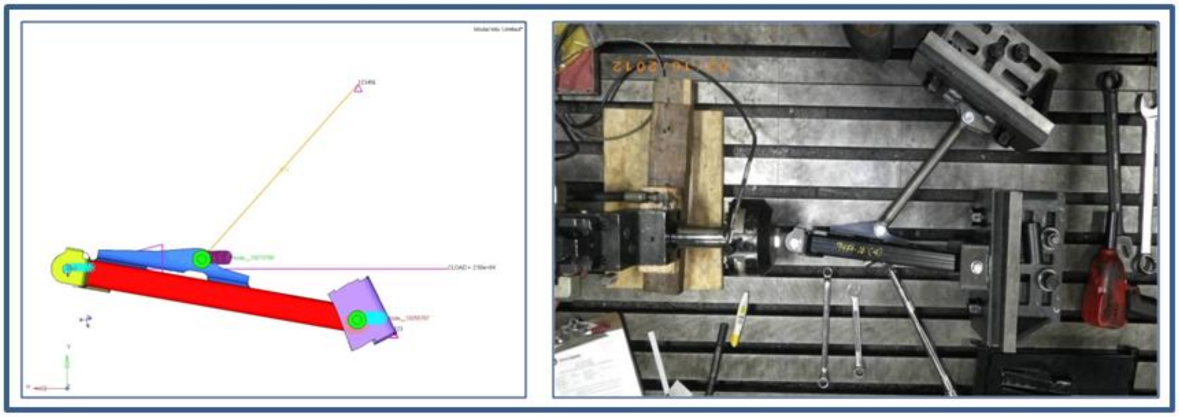


Figure16: Lateral Loading FE model and Test Setup

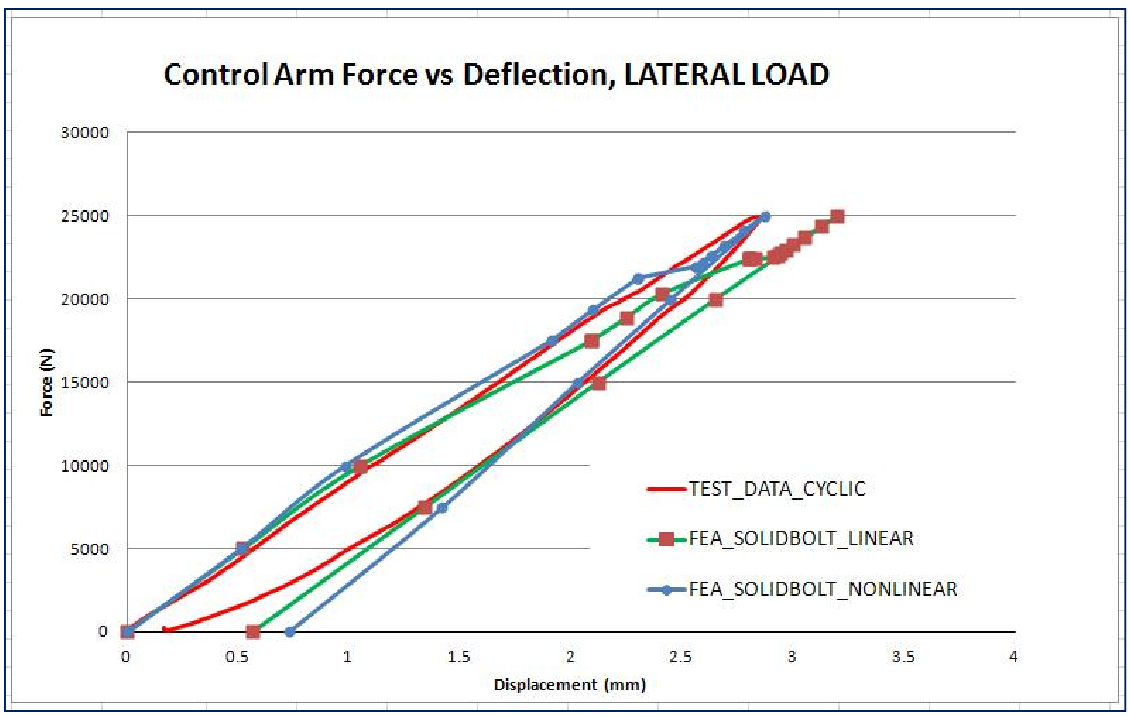


Figure17: Lateral Loading Force vs. Deflection

The lateral load shows a reasonably good correlation with detailed solid modeling of bolt and bushing connector element. The Lateral loading, similar to vertical loading, puts the bushing under radial direction. The unloading curve shows varied stiffness in the end, again likely due to rubber stress relaxation.

5.3 Fore aft Load Setup

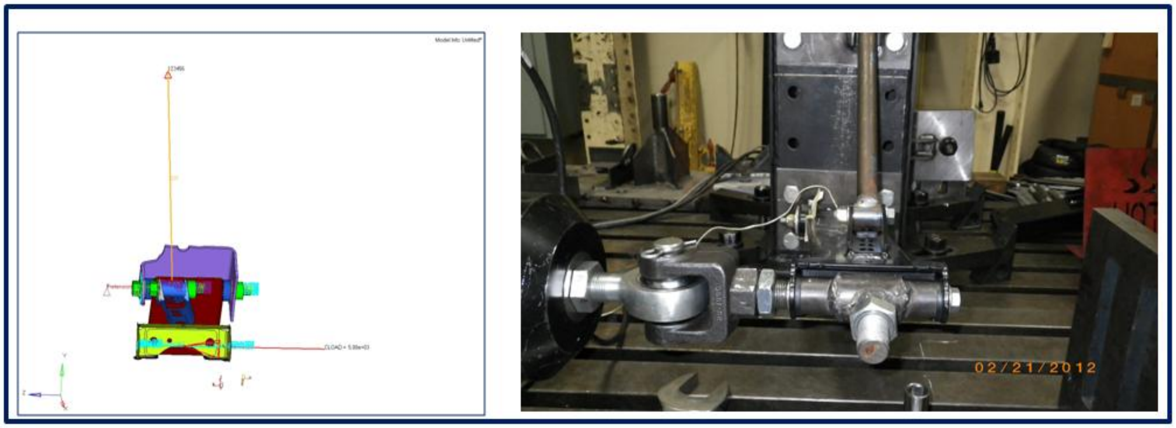


Figure18: Fore-aft Loading FE Model and Test Set up

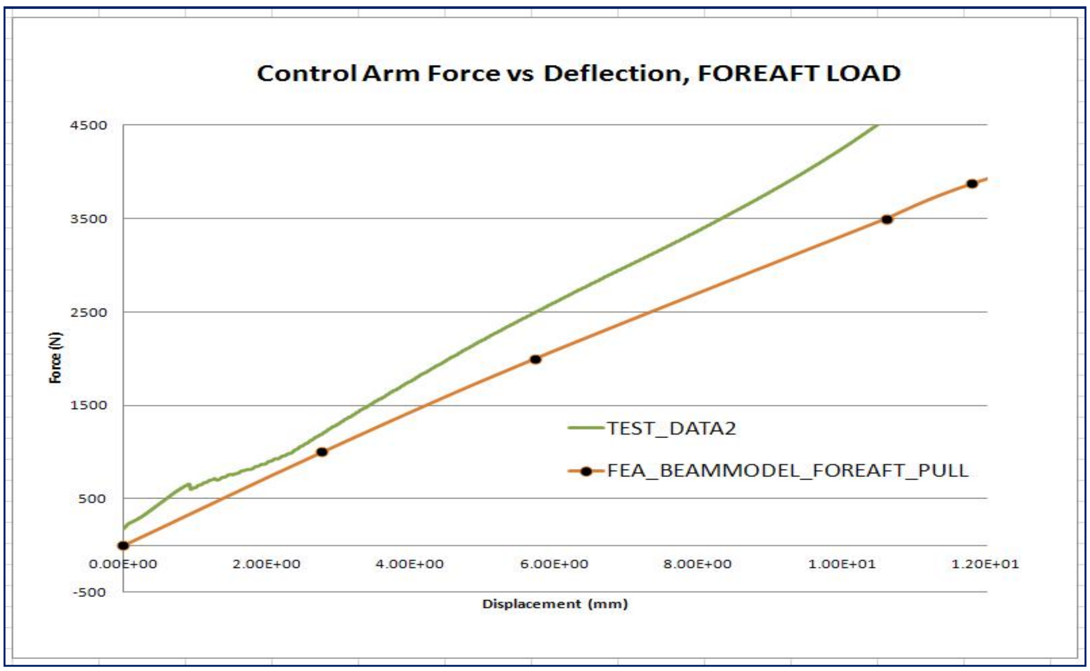


Figure19: Fore-aft Loading Force vs. Deflection

The fore-aft load force vs. deflection shows good correlation, although varied stiffness still can be seen. The fore-aft loading essentially puts the bushing in an axial direction, while the additional path of rigid shock creates more variables to capture. This modeling setup may not be an ideal one for the axial bush stiffness correlation; the data shows promising relative correlation. The stiffness of the bushing has the bolt pretension accounted.

6. Conclusions

The rubber sandwiched between metal bushings used in the suspension assembly of off road Utility vehicles has a high nonlinear stiffness behavior due to hyper elasticity of rubber or hyper-elastic polymers. The measured bushing properties are the simplest way one can represent the bushings accurately in the suspension assembly. The bushing connector can be the simple modeling procedure for the rubber bushings. The bushing connector when coupled with bolt joint offer varied stiffness in the joint and accurate representation of this coupled bolt joint is possible due to a simplified bushing connector element.

The bushing stiffness is coupled with the bolt joint stiffness and need to distinguish the stiffness representation in the FE model. The multitude variables of bolt joint can be analyzed with faster analysis cycles due to simplified bushing representation through bushing connector element. The bolt can be a 3D beam element and it needs to have to a gap variation defined with gap elements. For better accuracy the solid modeling of the bolt is essential, specifically to capture the local plasticity.

The simple upper control arm correlation showed that the bushing stiffness coupled with bolt joint stiffness can be modeled fairly close to the actual force deflection response. It is possible that the bolt joint stiffness is weaker when compared to bushing stiffness for a particular peak load or bushing may be more complaint compare to bolt joint. The bushing compliancy can be well analyzed or designed with complete coupled model and hence better designed suspension assembly.

The solid modeling of the bushing instead of the connector element is time consuming for both solution and modeling. Also, is not practical with many bushings in one corner suspension of a vehicle. The bushing connector has a promising modeling method, specifically if measured properties are available.

The bushing connector modeling and its correlation to a simplified suspension assembly were done using ABAQUS-Standard and solution time was less than an hour.

7. References

1. Mechanical Engineering Design, Shigley and Mischke
2. Fastening Technology and Bolted/Screwed Joint Design – EduPro US Inc, Bengt Blendulf
3. ABAQUS Online Documentation
4. Modeling and Analysis Techniques for Suspension Rubber Bushings – SCC 2010
   - Satoshi Ito*, Taro Koishikura*, and Daichi Suzuki**
   *Toyota Motor Corporation
   **Toyota Technical Development Corporation