

A Fatigue Life Estimation Technique for Body Mount Joints

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ABSTRACT

A body mount joint is a typical clamped joint that is under severe loading conditions, due to its structural function services as a gateway of load path between body and frame of an automotive vehicle. Stresses/strains on durability concerned components at the joint cannot be captured accurately by using the pseudo stress analysis approach because of the complexity of stress state generated by the pre-stress from clamp load, contacts between the components and nonlinear material properties. In this paper, development of a technique for fatigue life estimation of the joint is described in detail. The technique includes: 1) a finite element analysis (FEA) of local joint model with contacts, clamp load setup and mesh of continuum elements, 2) modeling of nonlinear material properties under cyclic loading, 3) generation of equivalent constant reversed cyclic load along a dominant vector calculated from tri-axial load time histories, and 4) special considerations in stress/strain analyses and fatigue life estimations. A whole cab model which is used to assist processes of the local joint model and bench tests with same configuration and setup as that of the FEA local joint model also are introduced. It is concluded that this technique can estimate fatigue crack mode so that the parameter study to improve design of the joint can be carried out with appropriate accuracy and high efficiency in terms of analysis time.

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INTRODUCTION

In most automotive vehicles, body loads are designed to be transferred through body mounts, therefore special attention is given to underbody structures at the body mount locations to ensure enough there is strength and durability under all the required load conditions. The underbody structure and body mount are normally bolted together, and load transfer between them is due to contacts and frictions. Consequently, detail analyses of the entire joint, called body mount joint, is essential in a vehicle design development.

The body mount joint described in this paper consists of an underbody structure assembly and a body mount assembly. It is a typical body-to-frame joint in a "body on frame" vehicle, such as a pickup truck. The underbody structure assembly is made up of a piece of cross member, reinforcement and a tapping plate with welded nut. The body mount assembly is made up of an upper mount/shear mount and a lower mount/hydromount which provides more damping to the joint. Both the upper mount and lower mount are bolted to a frame bracket, [Fig. 1](#).

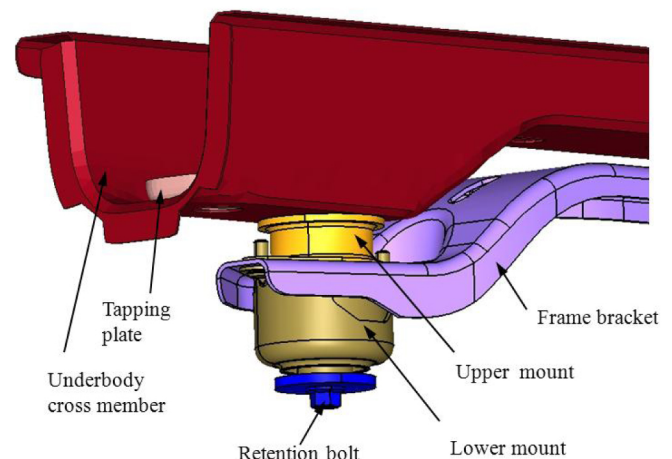


Figure 1. A body mount joint

This joint is one kind of clamped joint [1]. The underbody structure assembly and the body mount assembly are held together by a retention bolt with clamp load. Operation loads at the joint are mainly transferred by contact/bearing between adjacent parts and friction that are proportional to the clamp load. The bolt hole areas of cross member, reinforcement and top-plate of the upper mount are major durability concerns because of the complex distributed and high value stresses/strains generated by both the clamp load and operation loads. The stresses from clamp load perform as mean stresses for fatigue life of the joint. Consequently, nonlinear FEA is essential to capture the stresses/strains more accurately for fatigue life estimations.

Nonlinear FEA is time consuming and economically not practical to run the analysis through full measured load time histories/data series that easily contain about a million data per channel. A simplified loading process is desired to represent major features of the loads and save analysis time.

This paper describes a developed technique for fatigue life estimation of the body mount joint. The technique includes 1) a detailed FEA local joint model with continuum element mesh and all nonlinear setup; 2) material modeling with reflection of cyclic loading stress and plastic strain relation; 3) generation of equivalent constant reversed cycle load based on the full tri-axial measured load time histories and with consideration of weight coefficients of loading directions to stresses near the fatigue concerned areas of the joint; and 4) function selections and considerations in stress/strain analyses and fatigue life estimations. Correlations between FEA and bench test results of the joint are also illustrated. Since the whole cab model is required to assist the processes of the local joint model, the cab model and the necessary analysis procedures also are introduced in the following session.

The commercial software NASTRAN is used for pseudo stress analyses of the whole cab model. Abaqus is used for nonlinear stress/strain analyses of the local joint model. And nCode Design Life is used for fatigue life estimations of both the whole cab model and the local joint model.

THE WHOLE CAB MODEL AND ANALYSES

Initially, the whole cab model is generated for fatigue life estimations of the entire cab using pseudo stress approach [2]. First, linear stress analyses under unit loads using inertia relief technique is carried out. Then, fatigue life calculations are done using linear superposition for full time history/series of loads with elastic-plastic corrections. The FEA model includes all the body-in-white structure components, exterior components and all other parts attached on the cab such as battery tray, Fig. 2a. The body-in-white structure components are meshed by using shell elements and connected by bar elements for spot welds, rigid elements for bolts and seam welds, and solid elements for adhesives. The plastic exterior parts are modeled in the same way as the structure

components are modeled. The plastic trays are modeled by using tetra elements, and the attached masses and payloads are modeled by using concentrated mass elements. Doors are modeled by using super elements. Rubber bumpers are modeled by using spring elements.

Stresses/strains at the body mount joint locations cannot be accurately obtained because of limitations of the linear approach. However, special modeling efforts have been taken for the underbody joint: instead of rigid connection on the whole footprint covered by the top plate of the upper mount, equivalent deformable “washers” that are 1.5 times thicker than the connected panels are used, Fig. 2b. This simplified “washer” model is from the concept published in author's previous study [3]. The “washer” size is determined by the contact area of the top plate from clamping simulation result of the local joint model which is described in the following sections. The offset of loading point is same as what is used in the local joint model.

In this paper, the whole cab model is used 1) to determine the weight coefficients of the tri-axial force time histories based on the tri-axial unit load stress results around the joint; 2) to establish the cycle repeats of the equivalent constant reversed cyclic load for the local joint model; and 3) to assist fatigue life calibrations of the joint model.

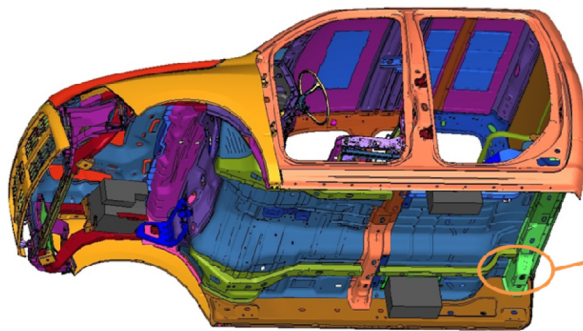
THE LOCAL JOINT MODEL

The local joint model contains the cross member, reinforcement, tapping plate, upper mount, bolt, sleeve and washer plate, Fig. 3. The detailed model of the lower mount is ignored because of its complicated configuration and less effect to the results of the concerned locations.

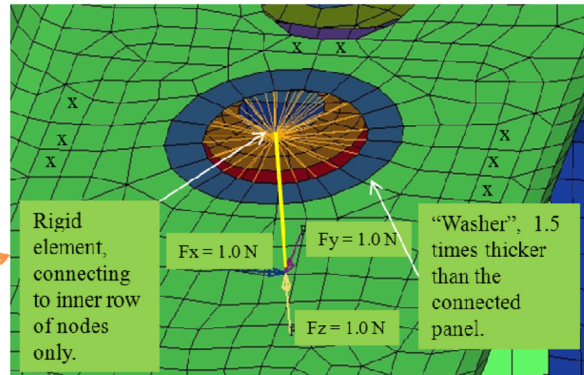
The entire local joint model is meshed by using hexahedral dominated continuum elements so that stress state in the three dimensions can be captured more accurately [4]. At critical locations with low fatigue life, membrane elements are used as skins to capture high stresses/strains on surfaces of the continuum elements. Spot welds are modeled by using bar elements.

Contacts at all the interactive locations are simulated. Nonlinear material properties and nonlinear geometries are used. Clamp load in the bolt is simulated by PRE-TENSION SECTION function in Abaqus. The rubber in the upper mount is modeled as Hyperelastic material with Order 1 Polynomial model.

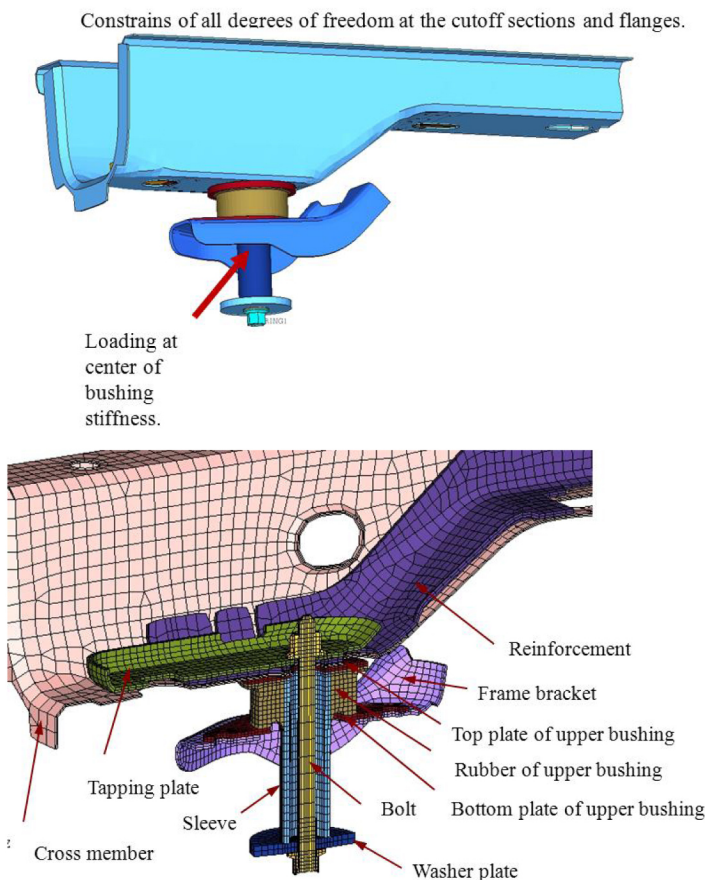
It should be noted that due to instrumentation limitation, in data acquisition only tri-axial force time histories are measured with the load cell mounted between the cross member and the top plate of upper mount. All the tri-axial moments were not available.



(a) the whole cab model



(b) the simplified bolt joint model

Figure 2. The whole cab model and the simplified bolt joint model**Figure 3. FEA model of the body mount joint**

In the local joint model, an equivalent constant reversed load is applied at the stiffness center of the entire mount assembly in the vertical direction. Moment effect can be approximately taken into account. The loading point is decided based on the following considerations:

For description convenience, a cylindrical coordinate system is used in the joint model with its center line along the global vertical, z axis. At the joint, all the forces in the radial

direction will be transferred by means of rubber elements/springs in the whole mount assembly. The upper mount has one rubber element/spring while the lower mount has three elements/springs. Considering the fact that both the upper and lower mounts have unique spring rates in the radial direction, the stiffness center in the radial direction can be calculated by Equation (1):

$$z_r = \frac{\sum_{i=1}^n z_i k_i}{\sum_{i=1}^n k_i} \quad (1)$$

where z_r = offset of stiffness center of the entire mount assembly from bottom surface of the cross member,
 z_i = offset of stiffness center of i -th rubber element/spring from bottom surface of the cross member,
 k_i = stiffness of i -th rubber element/spring in the radial direction, a known parameter as the mount is designed, and
 n = total number of rubber elements/springs in the entire mount assembly.

In the local joint model, $n = 4$ and $z_r = 57$ mm. Thus the loading point of the joint is on center line of the bolt with vertical offset of 57 mm from bottom of the cross member. The force is distributed by a coupling element. The dependent node of the coupling element is the loading point, and the independent nodes are all the nodes on the surface of sleeve underneath the level of the frame bracket and all the nodes on the bottom surface of the frame bracket.

MATERIAL MODELING

In the local joint model, all the durability concerned components are made of mild steel. The following procedure has been developed to define nonlinear material properties for the mild steel:

1. Select a material from the material database associated with nCode DesignLife based on grade and monotonic stress-strain properties: yield strength and tensile strength. This material is used for both stress/strain and fatigue analyses.