Paper # 12

Understanding Frequency Domain Viscoelasticity in Abaqus®

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Abstract

In this paper, the frequency domain viscoelastic model in Abaqus is explored. The input requirement of the model from uniaxial dynamic tests at several frequencies is detailed. The model assumes that the input requirement to Abaqus is independent of the pre-strain in the data. This assumption is examined for unfilled silicone rubber by looking at uniaxial dynamic test results at several pre-strain levels. We emphasize, however, that this assumption does not preclude a dependence of loss and storage moduli of the material on the level of pre-strain. In Abaqus, this dependence is achieved by combining the viscoelastic model with a hyperelastic model. Another common assumption, that the dynamic response of unfilled polymers is independent of the level of dynamic strain amplitude, is also looked at in this study. This assumption is challenged based on uniaxial tests performed at different dynamic strain amplitudes. The material model is used to predict component level response in simulations performed at different preload levels for several frequencies. The component used for this study is an automotive grommet. Experimental data for the grommet at different preload levels at several dynamic load amplitudes is compared to the simulation results.

1. Introduction

In this document, the frequency domain viscoelastic model defined with the Abaqus command *VISCOELASTIC, FREQUENCY=TABULAR is studied. In this model, one set of input comprising two frequency-dependent parameters, we will call them R and I, is needed. This material model assumes that the values of R and I are the same for all pre-strain levels. Another assumption, one commonly made for unfilled polymers, is that the response is independent of the strain amplitude in dynamic loading.

This paper will detail the procedure for specifying R and I using uniaxial material data. We will look at the above mentioned assumption in the context of unfilled silicone rubber. A component level analysis on an automotive grommet will be discussed. The results of the analysis will be compared with experimentally measured data to determine validity of the material model.

2. Experimental Data

The following experimental data is available:

Material Data:

1. Relaxation data at different pre-strain levels is available for the following loading modes: uniaxial tension, equibiaxial extension and planar tension. Long-term relaxation data was used to calibrate a hyperelastic material model.
2. Harmonic excitation data at different pre-strain and frequency levels is available. This data contains loss and storage modulus information. Further, at each pre-strain level the harmonic excitation data is available for several dynamic strain amplitudes.

Component Data:

1. Static curves for different load levels are available.
2. Relaxation curves at different preload levels are available.
3. Harmonic excitation data consisting of loss stiffness and storage stiffness at different pre-load levels is available. Again, the harmonic data at each pre-load level is available for several dynamic displacement amplitudes.

The following figures represent the material harmonic excitation data graphically. Figure 1 and Figure 2 show that the loss and storage moduli depend on the pre-strain. Figure 3 and Figure 4 show that the loss and storage moduli are moderately dependent on the dynamic strain amplitude. The variations of data from mean for the outside curves (strain amplitude 0.001 and 0.02) are shown in Figure 5 and Figure 6. The maximum variation is around 13%.

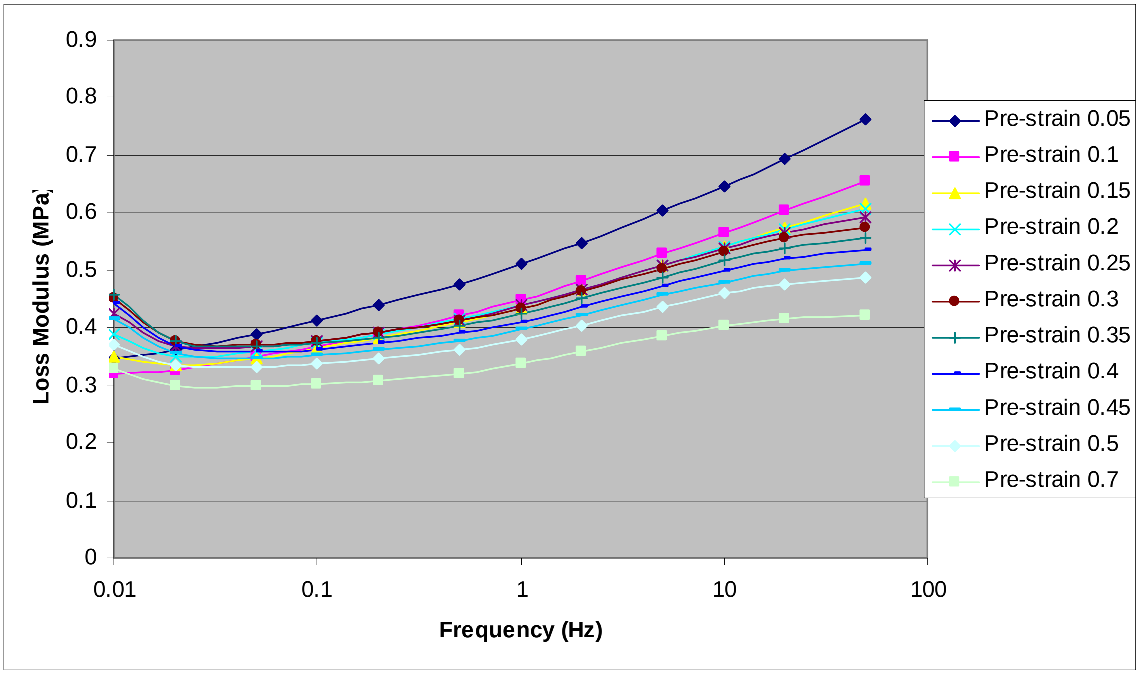

Figure 1. Loss Modulus at 0.02 Dynamic Strain Amplitude as Function of Pre-Strain

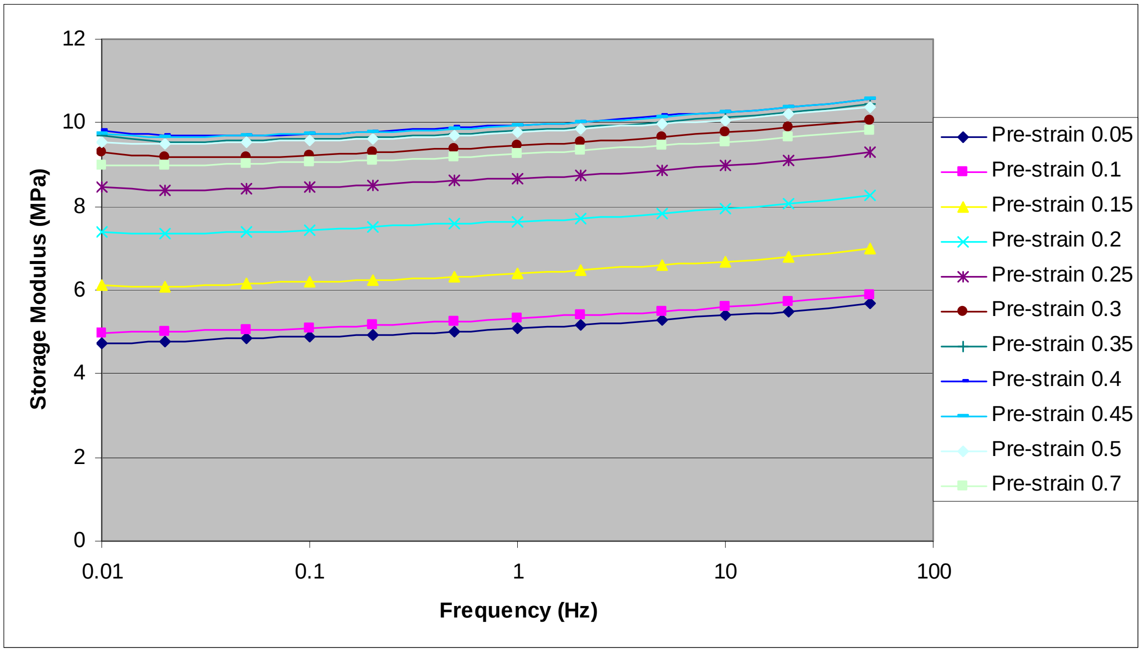

Figure 2. Storage Modulus at 0.02 Dynamic Strain Amplitude as Function of Pre-Strain

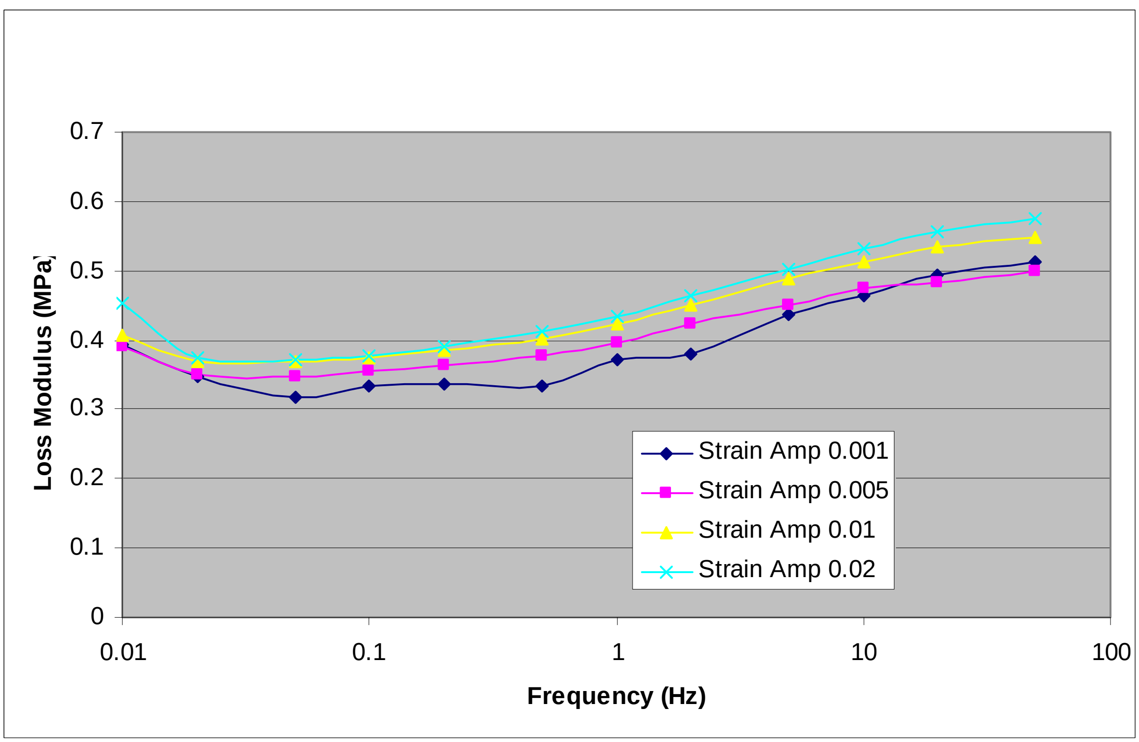

Figure 3. Loss Modulus at 0.3 Pre-strain as a Function of Dynamic Strain Amplitude

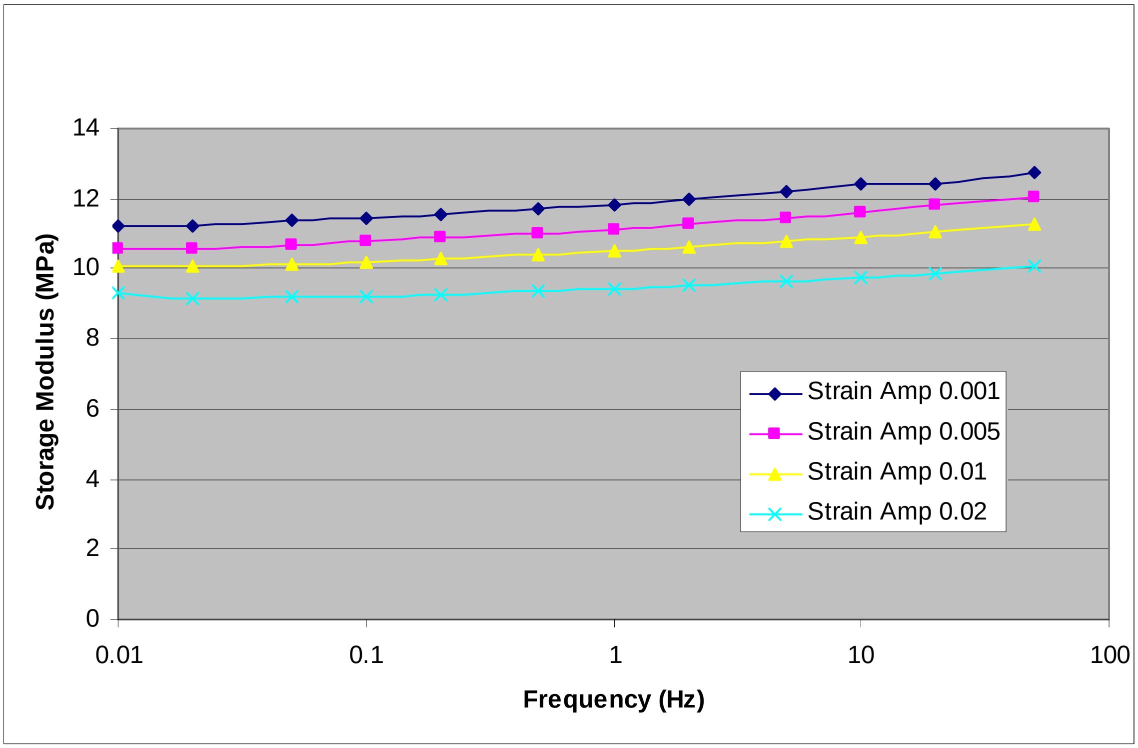

Figure 4. Storage Modulus at 0.3 Pre-strain as Function of Dynamic Strain Amplitude

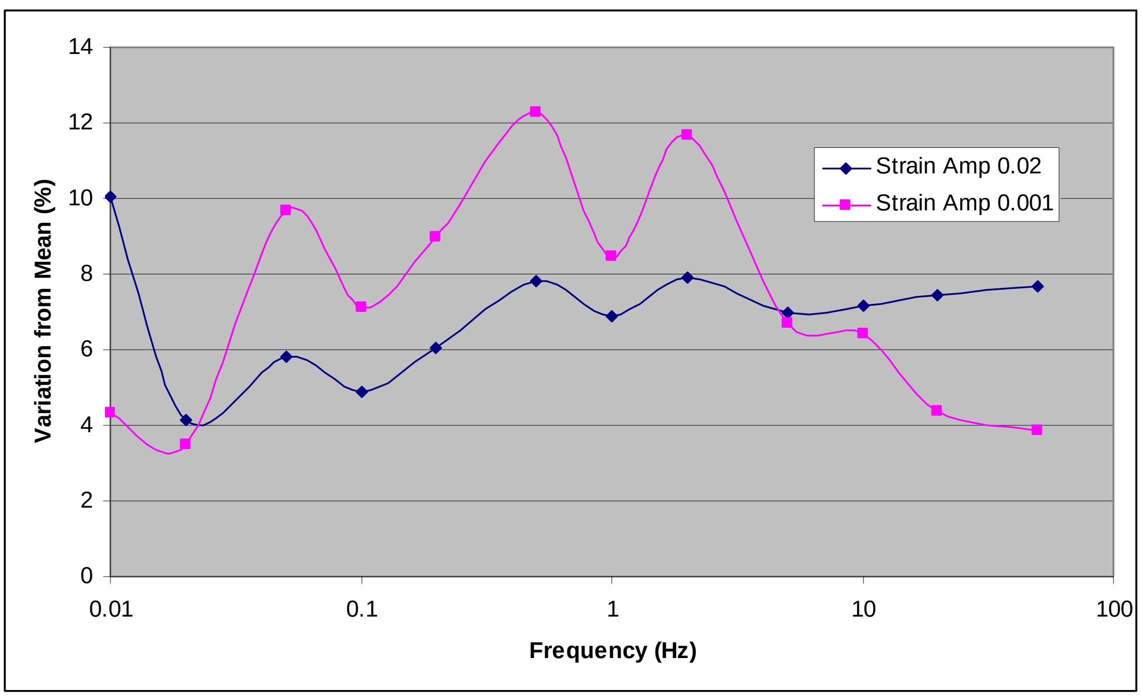

Figure 5. Variation from Mean of Loss Modulus at
Dynamic Strain Amplitudes 0.001 and 0.02

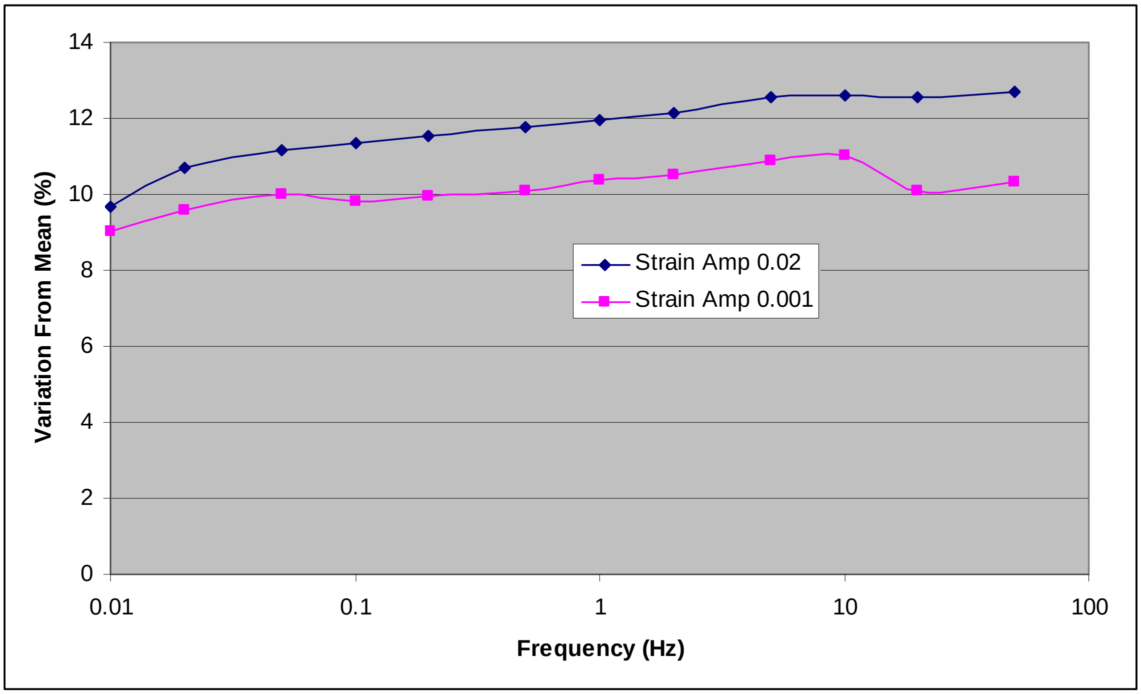

Figure 6. Variation from Mean of Storage Modulus at Strain Amplitudes 0.001 and 0.02

3. Abaqus Material Model and Component Analysis

In the Abaqus preload-independent viscoelastic model, a set of parameters, we call them R and I, are required. These are not entered as functions of pre-strain; hence, the assumption is that these parameters will be independent of pre-strain levels. Since the grommet considered is made of unfilled silicone rubber, the applicability of the assumption can be studied.

Abaqus requires the input of the following entities to describe viscoelastic behavior:
$R = \frac{G_L}{G_\infty}$ and $I = 1 - \frac{G_S}{G_\infty}$, where G_L is the shear loss modulus, G_S is the shear storage modulus and G_∞ is the long term shear modulus. In this study we have experimental data for the uniaxial loss and storage moduli. The following formulae provide the input to Abaqus for a uniaxial test:
$R = \frac{E_L \lambda}{M}$ and $I = \frac{M - T - E_S \lambda}{M}$ where:

E_L and E_S are the apparent uniaxial loss and storage moduli, λ is the uniaxial stretch upon which the harmonic load is superimposed, $M = \frac{d(\lambda T)}{d\lambda}$, and T is the nominal uniaxial stress at the stretch λ.

The long-term relaxation data is used to calibrate a hyperelastic model. The following figures show the experimental response versus a curve fit of the Yeoh model.

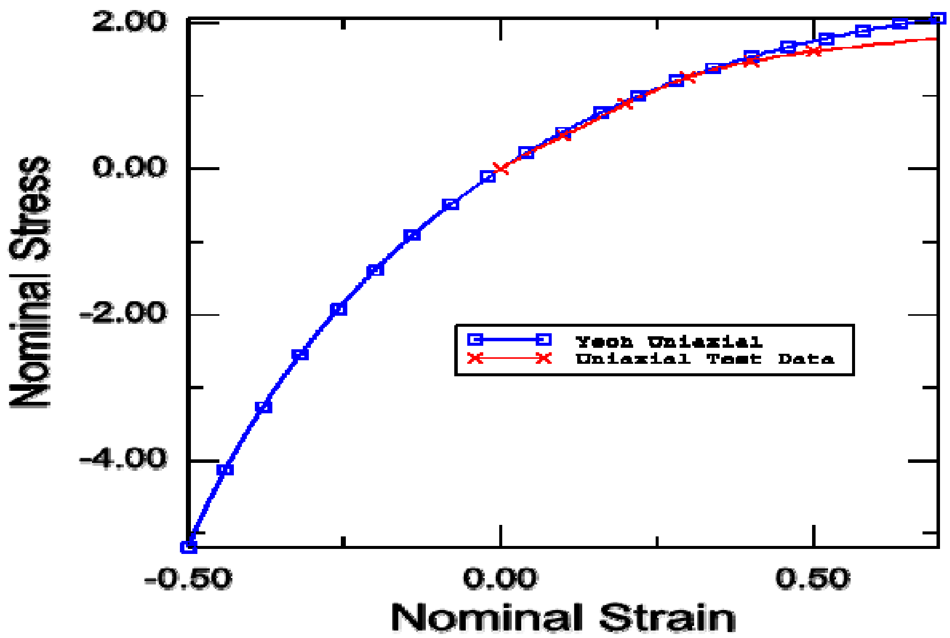

Figure 7. Uniaxial Response

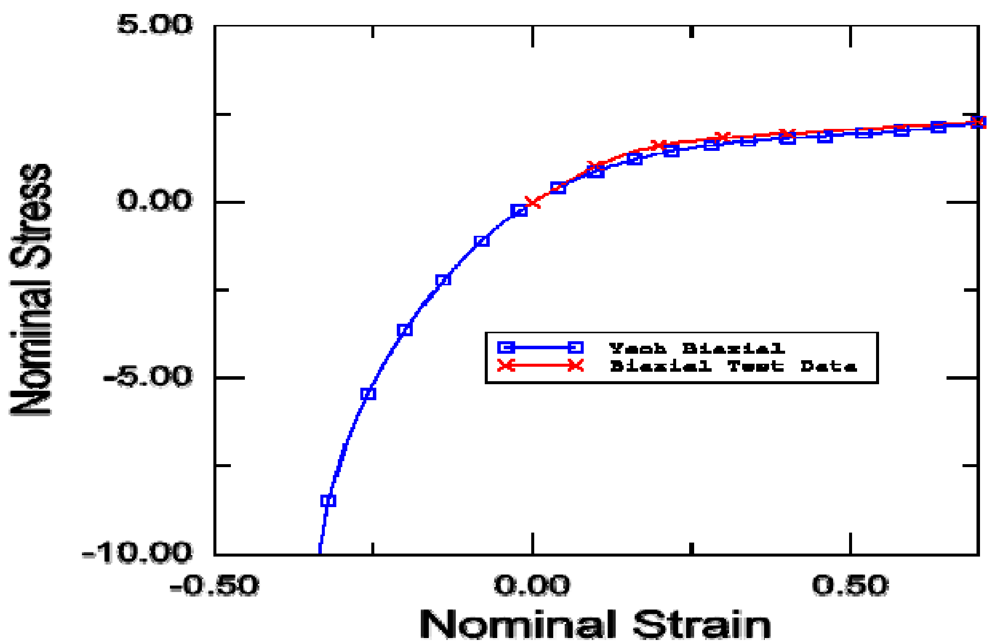

Figure 8. Biaxial Response

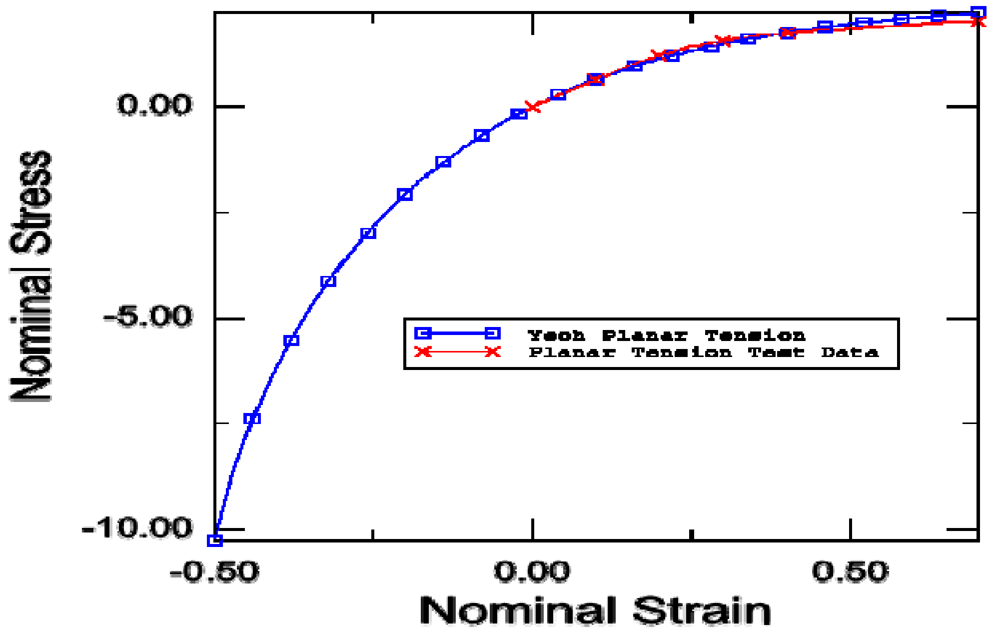

Figure 9. Planar Tension Response

Next, for the grommet material the input quantities $R = \dfrac{E_L \lambda}{M}$ and $I = \dfrac{M - T - E_S \lambda}{M}$, are calculated. The equations for R and I include a pre-strain effect through the quantities λ, *T* and *M*. However, this pre-strain effect does not correspond to the pre-strain effect on the storage and loss modulus in the data as shown in Figure 1 and Figure 2.
In Figure 10 and Figure 11, R and I as computed from test data are shown to be functions of pre-strain level, which poses a problem in using the viscoelastic model in Abaqus, since the model assumes they are not.

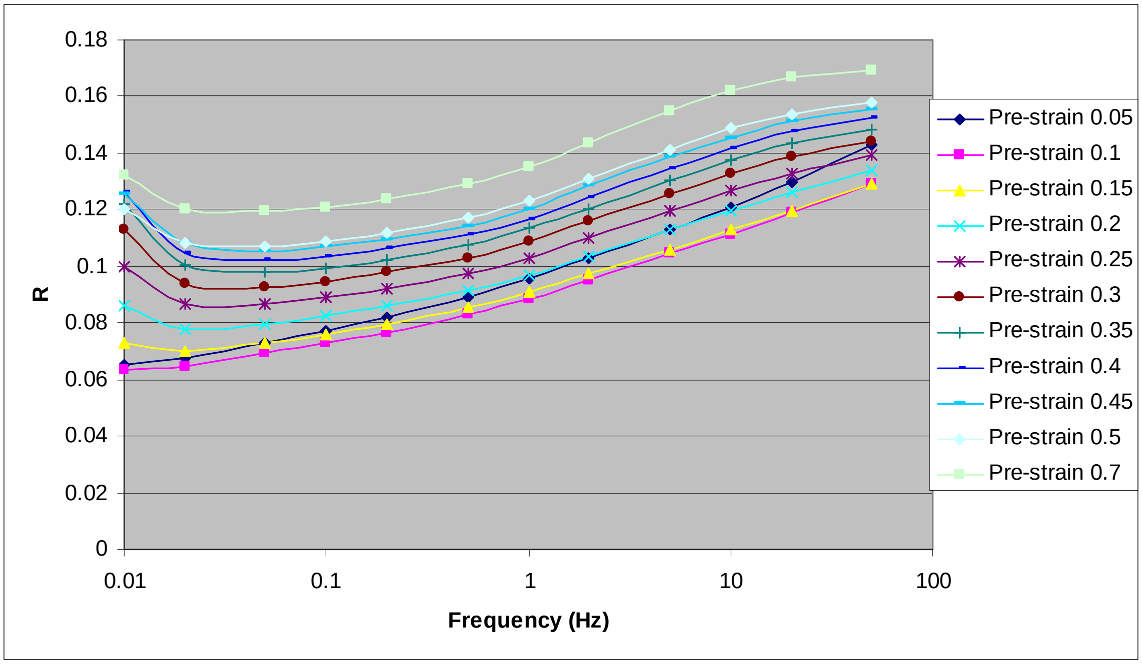

Figure 10. Variation of R with Pre-strain for Dynamic Strain Amplitude 0.02

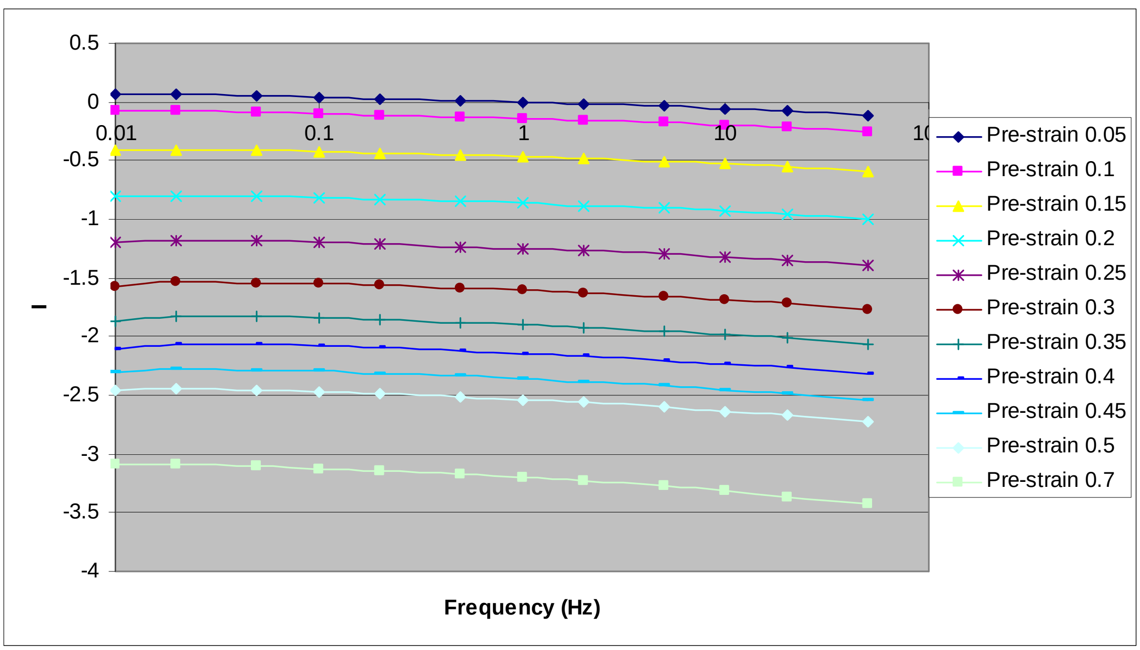

Figure 11. Variation of I with Pre-strain for Dynamic Strain Amplitude 0.02

Based on these results, we can say clearly that one set of R and I for all pre-strain levels does not exist. For a structural analysis, some approximation to R and I has to be performed.

Two approximations for R and I are done for a component level analysis. In the first case, R and I are averaged across all pre-strain levels and an averaged value is entered in

Abaqus. Thus, in this case one material property is used for all pre-load levels. In the second case, values of R and I corresponding to some typical level of the first strain invariant I_1, in the component is taken. This typical value is determined based on prior static loading of the component to the desired pre-load level. The component data was available for two pre-load levels; compressions of 1mm and 2mm. For 1mm, R and I corresponding to a pre-strain of 0.1 is taken. For 2mm, R and I corresponding to a pre-strain of 0.3 is taken. Thus, in this case, different material properties are used for different pre-load levels. For all cases, the material data for dynamic strain amplitude 0.02 is taken.

Figure 12 shows the component assembly. The finite-element simulation of the component test is axisymmetric. In the calculation, the component is compressed between rigid surfaces.

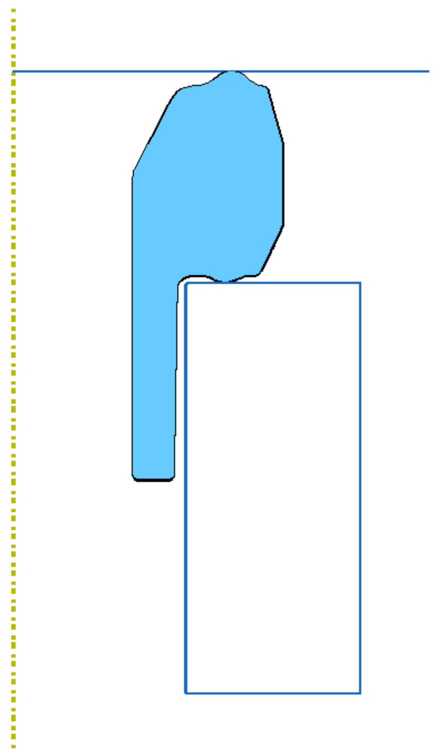

Figure 12. Grommet assembly

Figure 13 and Figure 14 show the component experimental response versus the response predicted by Abaqus for two pre-load levels, 1mm and 2mm. The component response is for a dynamic load amplitude of 0.01 mm. Based on these figures, the viscoelastic model does not appear to model the component response for storage stiffness very well. The response when R and I are based on a typical pre-strain level is better than that for averaged R and I. However, as mentioned before, if we use different R and I for different pre-load levels, we are using different material models, which is not desirable.

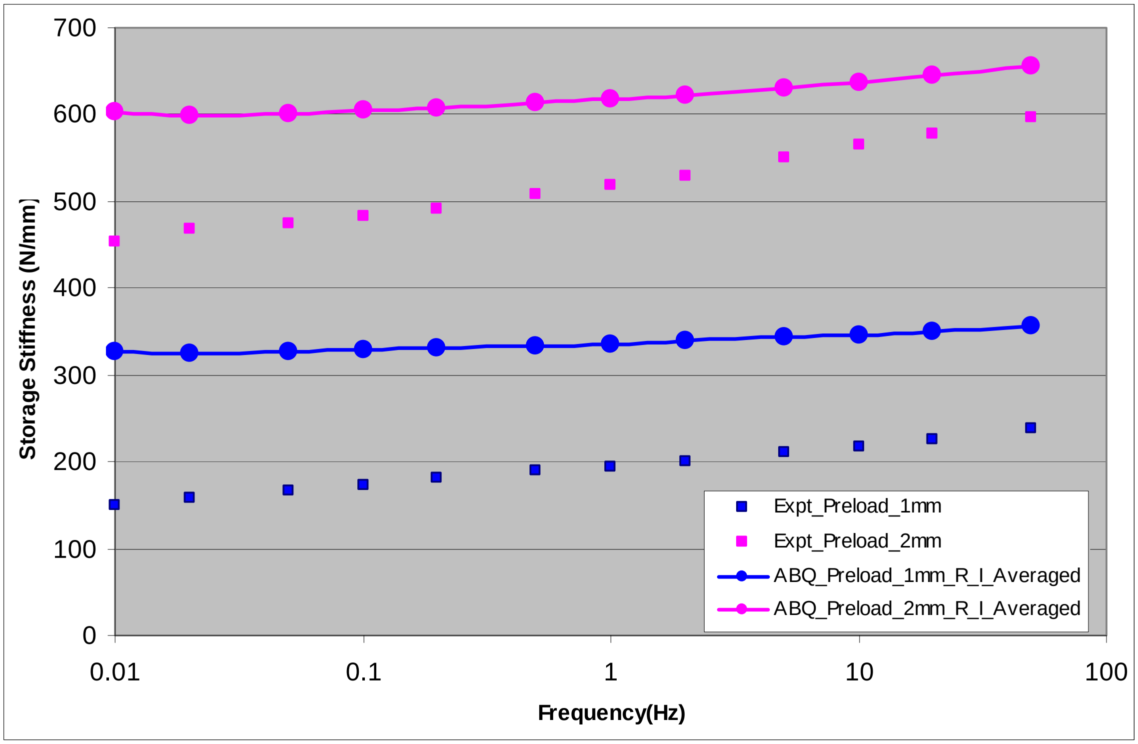

Figure 13. Storage Stiffness of Component for Dynamic Load Amplitude 0.01mm (R and I Averaged Across all Pre-Strain Levels)

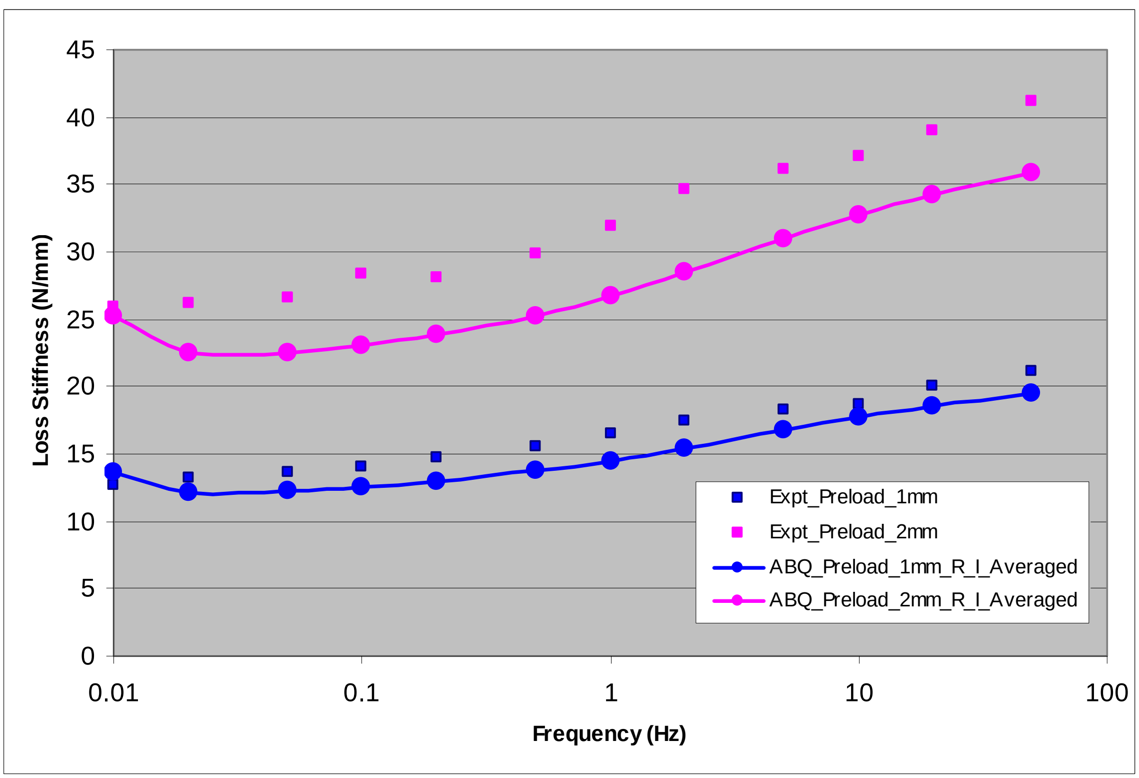

Figure 14. Loss Stiffness of Component for Dynamic Load Amplitude 0.01 mm (R and I Averaged Across all Pre-Strain Levels)

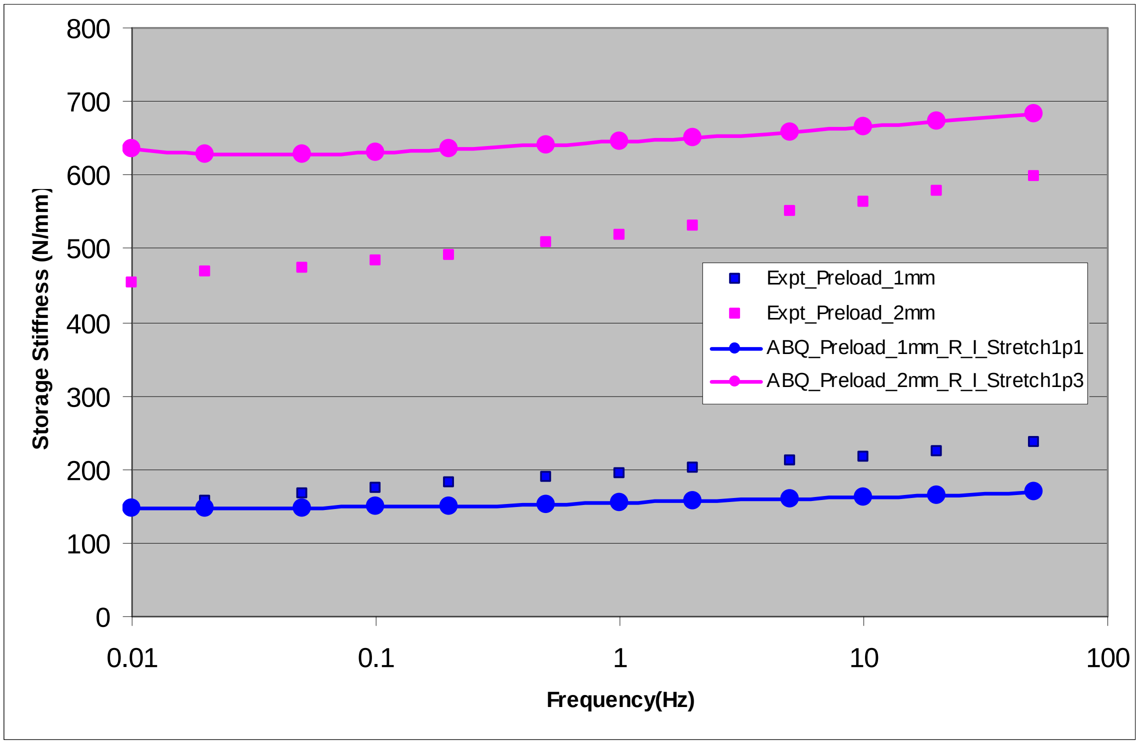

Figure 15. Storage Stiffness of Component for Dynamic Load Amplitude 0.01mm (R and I Based on Typical I_1 Values)

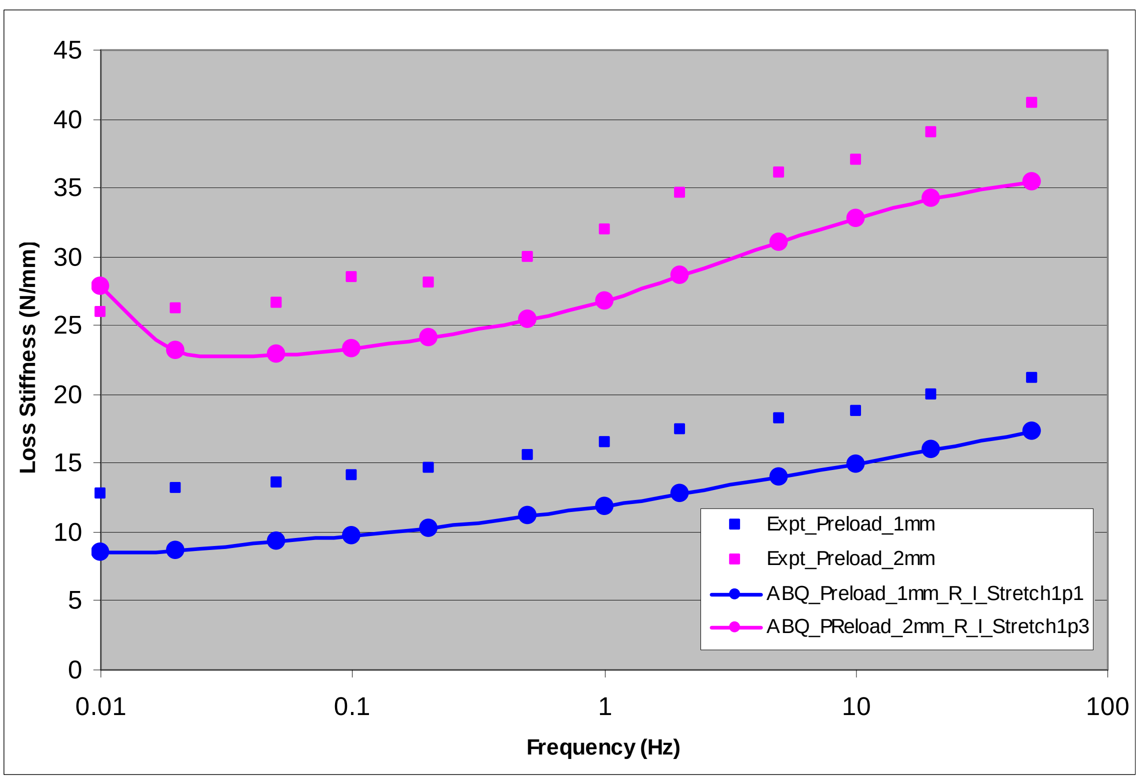

Figure 16. Loss Stiffness of Component for Dynamic Load Amplitude 0.01mm (R and I Based on Typical I_1 Values)

4. Conclusions

Based on the above results the following conclusions are made:

1. The storage and loss moduli have a dependence on the strain amplitude.
2. The input requirement of a constant value for R and I across all pre-strain levels is not consistent with experimental data. Some approximations for these quantities have to be made for a system-level analysis.
3. Better results are obtained if the Abaqus input is based on level of deformation seen in the component. The downside of this is that an additional analysis to determine the level of deformation of the component is needed.