Modeling and validation of static and dynamic seat cushion characteristics

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Automotive seat cushions contribute considerably to static and dynamic comfort of the drivers. Design of a cushion is highly challenging due to its highly nonlinear viscoelastic behavior that is dependent on the seated body mass, and magnitude and rate of the vibration excitation. In this study, a dynamic seat cushion model is developed in the LS DYNA platform to determine its static and dynamic properties. The material model *MAT_FU_CHANG_FOAM_DAMAGE_DECAY (083_1) was used, which showed capability to predict nonlinear dynamic cushion behavior under different preloads, and excitation frequencies and amplitudes. This material model, available in the LS DYNA library, permitted evaluations of the nonlinear rate-dependent viscoelastic behavior of the cushion. The effectiveness of the model in predicting static and dynamic responses is demonstrated by comparing the simulation results with the laboratory-measured data in terms of force-deflection characteristics. The comparisons revealed reasonably good agreements between the simulation and measured responses. Contact pressure distribution on the seat cushion was further obtained, which also showed good qualitative agreement with the reported measured data.

1 Introduction

Foam materials, owing to their good energy absorption and restoring properties, are widely used in automotive seats for enhanced comfort perception of the seated driver. Moreover, polyurethane foams (PUF) are lightweight materials, which possess rate-dependent and moldable characteristics. Dynamic comfort performance of a seat is of greater importance in heavy road and off-road vehicles, which exhibit high magnitudes of low frequency whole-body vibration (WBV) arising from interactions of the tires with the rough terrains [10]. The static and dynamic comfort performance of a seat cushion is generally evaluated in a subjective manner, and is dependents on the seated body weight, and viscoelastic properties of the PUF [4, 6]. Design of a seat, however, continues to be challenging task due to highly nonlinear, and seated mass- and rate-dependent properties of the PUF. A number of finite element (FE) and constitutive material models have been developed for predicting static behavior of the seat cushion, while the dynamic response characteristics have been attempted in fewer studies [13-14]. A number of studies have experimentally characterized dynamic properties of PUF seats, which have provided essential knowledge on the rate- and preload-dependent behavior [2, 11]. These have also contributed to developments in material models, although their implementations have shown limited success thus far [3, 14]. This may in-part be due to consideration of the static force-deflection behavior in defining the material models, leading to notable deviations under cyclic loading [1]. The vast majority of the studies have employed *MAT_LOW_DENSITY_FOAM (057) material model to define nonlinear PUF properties on the basis of measured stress-strain data acquired under static loads. Such a material model, however, cannot accurately predict the PUF response during reloading and thereby the rate effect, when the cushion is subjected to cyclic loads. However, in general, foam materials have shown special characteristics such as high compressibility, strain- rate dependency and, low Poisson’s ratio. Constitutive material models were developed by many researchers to include all the cushion characteristics in a single material model. Few studies suggested empirical constitutive model valid only for uniaxial compression and were valid only under static loading condition [9,12]. These developed models, were not suitable for application, were rate dependent behavior is prominent. Further, Sherwood and Frost [7] proposed a strain rate dependent model which showed its compatibility during uniaxial compression, but was unable to show hysteretic behavior under unloading. Storakers [1] also developed a strain rate dependent model which showed its ability to produce hysteretic effect which was observed during loading and unloading of foam. Although, model showed strain rate dependency and hysteretic effect during loading and unloading, it failed to show cyclic characteristics of foam material. This model was further modified by Fu Chang, to adopt the cyclic characteristics of the foam. This study is aimed at development of a seat cushion for predicting the effects of both the preload and rate on the dynamic properties of the cushion by identifying an appropriate rate dependent material model from those available in the LS DYNA material library.

2 Experimental setup

An experiment was designed to identify static as well dynamic force-deflection characteristics of a seat cushion used in off-road vehicles' suspension seats. The static properties were identified under quasi-static loading applied at a very low frequency of 0.088 Hz, while the dynamic characteristics were obtained under different preloads, and deflection amplitudes and frequencies. The seat cushion was mounted on a electro-hydraulic vibration exciter and the load was applied by a 200mm diameter indenter attached to fixed inertial beam via a load cell, as shown pictorially and schematically in Figs. 1(a) and 1(b). The static-force deflection data was acquired under a 16 mm amplitude harmonic excitation at a very low frequency of 0.088 Hz. Dynamic force-deflection data were acquired under two different preloads (41 and 56 kg) representing seated body masses of about 404 and 551N. The seat cushion under each preload was subjected to harmonic excitations of two different amplitudes (6.35 and 12.5 mm) at frequencies of 0.5, 1, 2, 4 and 6 Hz
in order to characterize the effect of deflection and rate on the force-deflection responses during cyclic loading.

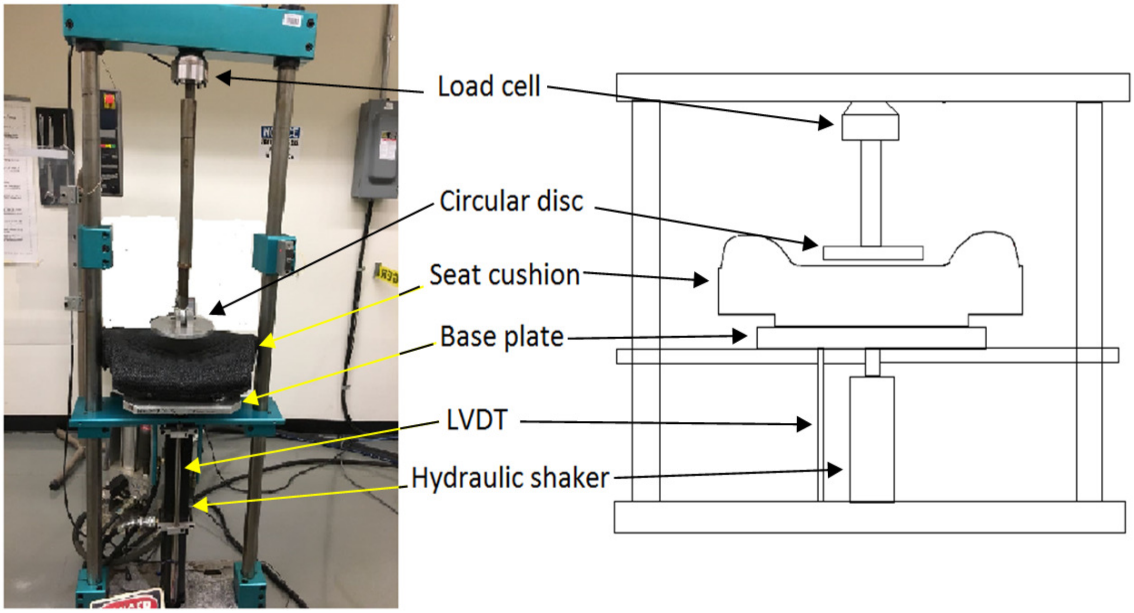


Fig. 1: (a) Pictorial and (b) schematic illustrations of the experimental setup.

3 Modeling and simulation

Simulation model of the seat cushion was formulated in the LS DYNA platform to obtain its viscoelastic properties as functions of the seat load, and magnitude and rate of deformation. The model is formulated so as to mimic the experimental setup. The geometry of the seat cushion was initially defined to formulate a solid model of the seat including the side wings. The FE model of the cushion supported on the rigid base plate together with the circular indenter was subsequently formulated, as shown in Fig. 2. Tetrahedron elements, limited to 10 mm, were used for the PUF seat cushion, while the base plate and indenter were modeled using quadratic elements. The base plate was constrained in all the directions, while the loading on the top surface was applied via the 200mm diameter indenter disk. Contacts between the cushion base and rigid base plate, and between the cushion and the indenter were implemented using 'AUTOMATIC SURFACE TO SURFACE' contact elements available in LS DYNA. Material model *MAT_FU_CHANG_FOAM_DAMAGE_DECAY (083_1) was selected for the cushion material. This model is considered suitable for predicting rate dependent behaviour of PUF and allows the user to input experimental stress-strain data for identifying the model constants. The material model considers the loading curve depending on the strain rate developed during compression, while the curve corresponding to lowest strain rate is used during unloading. This material model utilizes one dimentional material law due to the assumption of zero Poission's ratio and is based on unified constitutive equations for foam materials reported by Fu Chang [5].

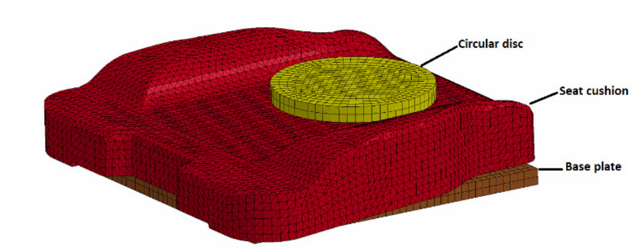


Fig. 2: Seat cushion assembly in LS DYNA platform

Model Simulations were performed in two sequential stages. In the first stage, the material model was identified using the measured static force-deflection data and verified by comparing the model response with the measured data. The measured data acquired during quasi-static loading and unloading of the cushion foam were used in order to tune the material model corresponding to the loading and unloading. The material model was tuned through repeated simulations and verified by comparing the simulation results with the measured data. Table 1 summarizes the material data used for base plate, circular indenter and cushion. In the second stage, the material model was further tuned for predicting dynamic characteristics of the cushion subject to harmonic excitations. The cushion was initially preloaded by introducing a predetermined displacement of indenter disc to achieve desired preload. The magnitudes of the displacement were estimated from the mean static force-deflection data as 26 and 30.5mm (Fig. 3(a)), respectively, for realizing desired preloads of 404N and 551N. Fig. 3(b) illustrates the deformed cushion model subject to predefined preload of 404N. The indenter disc was subsequently subjected to a harmonic deflection to determine dynamic properties of the cushion as function of the deflection amplitude and the frequency. The simulation results were obtained for two different amplitudes (6.35 and 12.7mm) and five different frequencies (0.5, 1, 2, 4, 6 Hz).

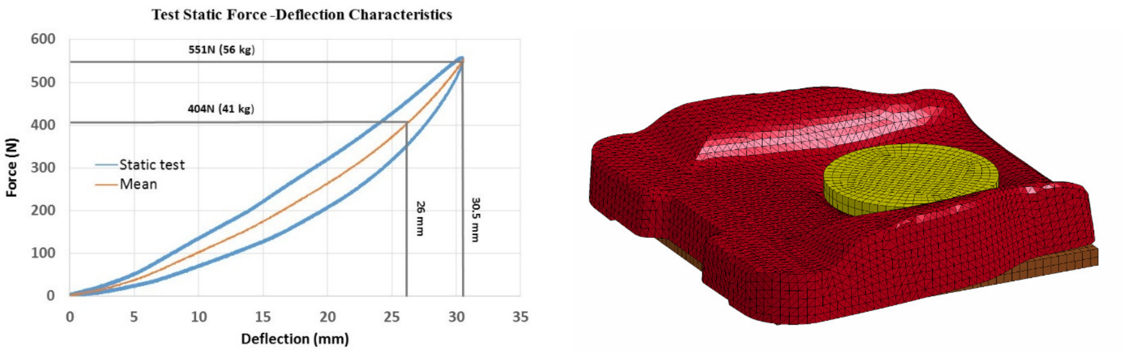


Fig. 3: (a) Measured static force-deflection characteristics of the seat cushion; (b) cushion model deformation under 404N preload.

Table 1: Material properties used for developing the model

	Density, ρ (kg/m^3)	*Youngs modulus, E (MPa)*	*ELFORM*
Rectangular plate and circular disc	*7580*	*210E3*	*2*
Cushion	*58*	*0.2-0.5*	*10*

4 Results and discussion

The quasi-static force-deflection response of the cushion obtained from the model is compared with the measured data in Fig. 4. The good agreement between the simulation and measured results during loading as well as unloading suggest validity of the material model used in the study. Similar degree of agreement was also observed between the steady-state simulation results and the measured data under dynamic excitations in the ranges considered for both the preloads. As examples, Fig. 5 illustrates comparisons of dynamic force-deflection responses of the model with the measured data considering 404 N preload, and 6.35 mm deflection at 0.5 and 1.0 Hz. The comparisons show very good agreements between the simulation model and the measured data for the loading as well as unloading portions of the cyclic loading. The comparisons suggest validity of the material model identified from the loading and unloading stress-strain data.

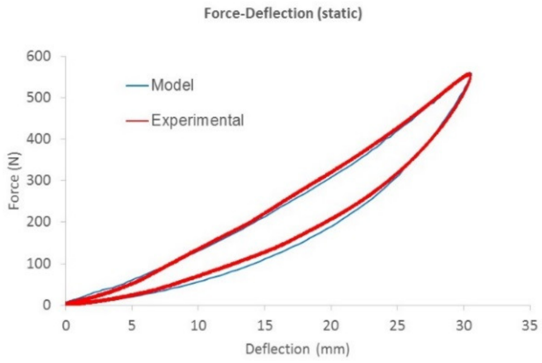


Fig 4. Comparison of force-deflection response of the simulation model with the measured data under static loading and unloading.

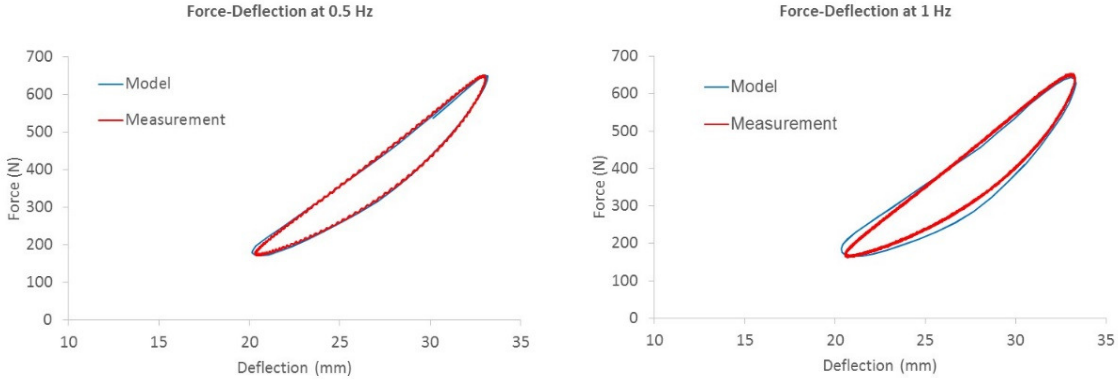
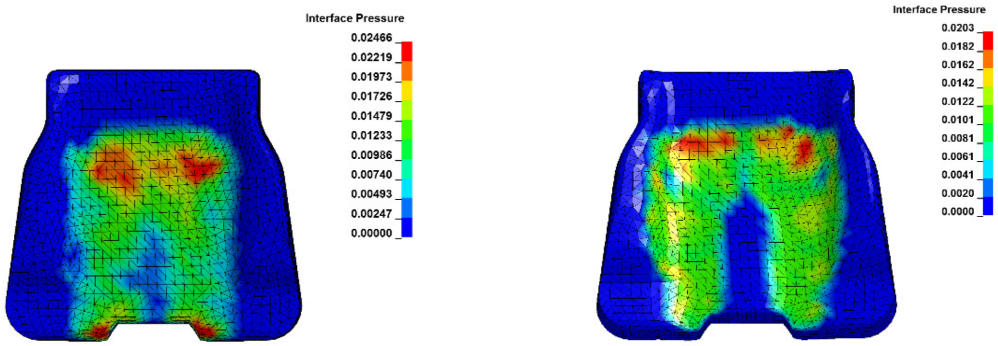


Fig. 5: Comparisons of dynamic force-deflection responses of the simulation model with the measured data under 6.35 mm harmonic deflection at (a) 0.5 Hz; and (b) 1.0 Hz (preload =404 N).

The simulation model was further used to predict contact pressure distribution at the seat. For this purpose, a human buttocks model with 478N load was integrated to the seat cushion model to compare the contact pressure distribution. Figure 6(a) illustrates the contact-pressure distribution obtained under the static load. The results revealed peak pressure concentration in the vicinity of the tuberosities region of the buttock model, which was observed near 20.3 kPa. This peak pressure was in good agreement with that reported in [6]. Figure 6(b) further illustrates the pressure distribution obtained under 6.35mm harmonic deflection of the cushion at a frequency of 1 Hz. The results show pressure under dynamic deflection was observed in the order of 24.7 kPa, which was notably higher than the static contact pressure. This tendency has also been reported in [11]. The results also revealed notable difference in the effective buttocks-seat contact areas obtained under static and dynamic conditions.



(a) Dynamic cushion model (b) Static seat cushion model

Fig. 6 Contact seat pressure distribution on dynamic and static seat cushion model

5 Summary

A dynamic rate-dependent seat cushion model is developed by identifying parameters of the material model available in LS DYNA material library. The simulation results obtained under static and dynamic cushion deflections showed reasonably good agreements with the measured data, for the ranges of preload, excitation amplitude and frequency considered in the study. The validated seat cushion model can provide essential design guidance for realizing cushion designs with desired visco-elastic properties and contact pressure distribution considering variations in the seated body mass, and seat magnitude and frequency of seat excitation. Although, dynamic characteristics of single cushion foam are considered for identifying the material model, the methodology can yield desirable/optimal material properties for realizing enhanced comfort performance of the seat.

6 Literature

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