A surrogate approach for stochastic modeling of a crash box under impact loading in the time domain

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Abstract. A time-dependent stochastic modeling of a crash box was performed considering the material property, the impact velocity and the thickness of the crash box as the uncertain parameters. To study such problem, a surrogate model has been developed combining a proper orthogonal decomposition (POD) and a polynomial chaos expansion (PCE) approach. The stochastic response was projected on some POD vectors. The coefficient corresponding to a POD vector is then uncertain and was predicted using a PCE approach. Uncertainty quantification was performed for the impactor displacement, impactor velocity and contact force by the POD-PCE model and leave-one-out (LOO) errors were computed. With the POD approach, it was possible to obtain very good results, whereas the number of PCE coefficients is quite low. It was also possible to achieve a low LOO error for the stochastic responses with very few model evaluations and with low degree polynomial.

Introduction

Crash box is one of the important parts in a car body for providing safety to the passengers during a crash. Therefore, a proper design of a crash box can reduce the chance of the life loss. All the parameters of a crash box should be designed properly and often, the design parameters are uncertain in nature. Therefore, uncertainty quantification (UQ) is one of the possible ways to design the crash box under uncertain parameters. Monte Carlo simulation (MCS) can be used for UQ of such complex problem, however, high computational cost restricts MCS to apply for such problem. To avoid the crude MCS approach, researches have developed surrogate modeling approach which maintains a trade-off between accuracy and efficiency. The surrogate modeling approach includes polynomial chaos expansion (PCE) [1], Kriging [2], support vector machine. As the crash problem is a dynamical system under impact loading, most of the surrogate models needs to be computed at each time-step. To address this issue, a proper orthogonal decomposition (POD) based PCE model [3] is used in this paper.

Results and Discussion

UQ was performed for a crash box (Fig. 1) under impact loading considering three uncertain parameters which are material property, crash box thickness and impact velocity. Three responses were considered for UQ, which are impactor displacement, impactor velocity and contact force. The time domain and the randomness were suitably decoupled using the POD approach and the stochastic responses were represented with very low number of POD vectors. As a result, the number of PCE model evaluations was much less as compared to the conventional PCE model. A quite good leave-one-out (LOO) error (i.e. 1×10^{-3}) was achieved for the impactor displacement and impactor velocity using very low number of model evaluations by the adaptive POD-PCE model. However, it was much difficult to achieve a good LOO error for the contact force because the behavior of the contact force was highly non-smooth as compared to the other responses. Furthermore, the time-dependent statistical moments were predicted only by post-processing the PCE coefficients and POD vectors. The accuracy of the statistical moments predicted by the adaptive POD-PCE model was quite good for all the responses. The standard deviation for the contact force is shown in Fig. 1. Therefore, it was worth to use the adaptive POD-PCE model for the time-dependent crash problem at a reduced computational cost.

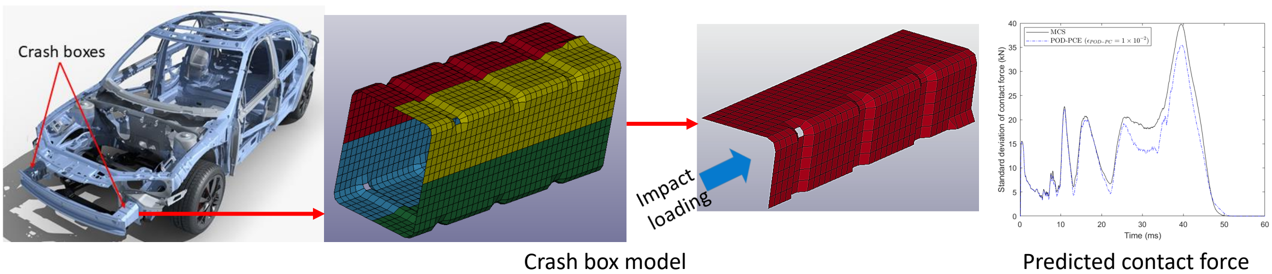

Figure 1: Finite element model of the crash box and predicted contact force standard deviation by the adaptive POD-PCE model

References

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