Developing sufficiently accurate reduced-order models using an efficient error assessment method

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Abstract. Before utilizing a reduced-order model (ROM) of a complex finite element model, the ROM's accuracy should be checked and, if the accuracy is not satisfactory, the ROM must be developed further. This work proposes an efficient error assessment approach to evaluate the ROM's accuracy, which does not require additional data points from the finite element model. Furthermore, a strategy of updating the load cases to aid improvement in accuracy is highlighted. Finally, a 7^{th}-order ROM's construction procedure is used as an example to illustrate the proposed method.

Introduction

The ICE method can generate the ROM of the finite element (FE) model with geometric nonlinearity by capturing the FE model's static force relationship accurately. This method uses a series of static load cases, F_{r0}, and the corresponding static modal displacement, r_0, to estimate the ROM's parameters via the fitting procedures, and the ROM's accuracy is strongly dependent on the fitting results[1]. Generally, the fitting results can be evaluated by comparing the nonlinear stiffness force between the ROM and the FE model, but the later requires the calculation of additional data points in the FE software. The purpose of this study is to propose an approximate error formula to evaluate the ROM's accuracy efficiently without additional FE executions and then use this error formula to guide where additional data points are needed to improve the accuracy. Specifically, we propose comparing the ROM's accuracy with a higher-order (in terms of power of polynomial used) ROM which might be viewed as an approximation to the full order FE code[2]. In this approach, the approximate error for evaluating the n^{th}-order ROM's accuracy can be written as,

$$\hat{\varepsilon}_n(r) = \frac{\|f_n(r) - f_{n+2}(r)\|}{\max\|f_{n+2}(r)\|} \tag{1}$$

where the r is the modal displacement in the ROM, the $f_n(r)$ and $f_{n+2}(r)$ are the stiffness forces in the n^{th} and $(n+2)^{\mathrm{th}}$-order ROM, respectively. The Eq.(1) is computationally efficient, as it does not require extra static FE analysis. This error formula can then also be used to govern where an additional data point is needed should the ROM's accuracy be insufficient.

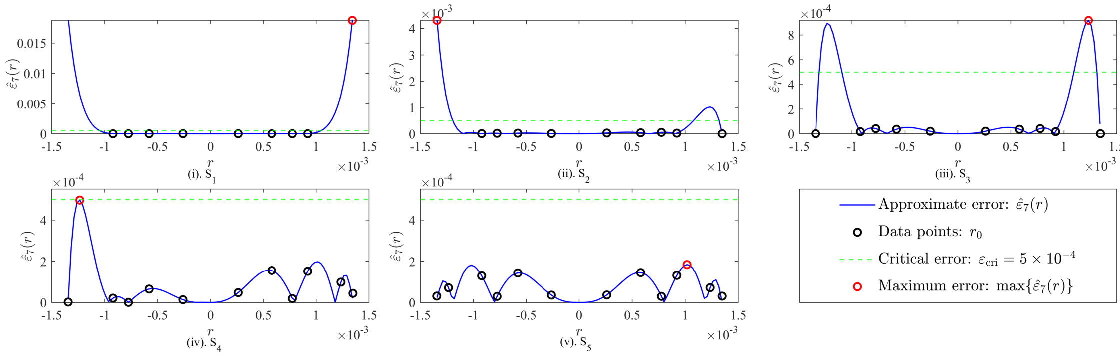

Figure 1: The ROM's construction and evaluation

Results and discussion

Figure 1 depicts a 7^{th}-order ROM's construction procedures. As the initial load distribution S_1 is given, the next load cases can be determined from the Eq.(1). Specifically, the point related to the maximum error, $\max\{\hat{\varepsilon}_n(r)\}$, under the S_i will be extracted and the next load case will be calculated by substituting the coordinate of this point into ROM's nonlinear stiffness force. Then, the load distribution will be updated to S_{i+1} by adding this new load case in S_i, and ROM will be constructed and evaluated again based on the S_{i+1} until the $\max\{\hat{\varepsilon}_n(r)\}$ smaller than $\varepsilon_{\mathrm{cri}}$. Meanwhile, it can be observed that every new load case can decrease the fitting error continuously, which indicates the new load case provided by the proposed method is reasonable. From the results, it suggests that the approximate error formula can not only evaluate the fitting error efficiently but can efficiently guide the load case selection, which can keep the total times of static analysis small.

References

[1] Park K., Allen M.S. (2021) Quasi-static modal analysis for reduced order modeling of geometrically nonlinear structures. *J. Sound Vib.* **502**:116076.

[2] Nicolaidou E., Melanthuru V.R., Hill T.L., Neild S.A. (2020) Accounting for quasi-static coupling in nonlinear dynamic reduced-order models. *J. Comput. Nonlinear Dynam.* **15**(7):071002.