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Towards a Rapid and Cost-Effective Estimation of Fluid-Structure Interaction in Blast-Loaded Plates

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The numerical modelling of structures subjected to blast loads presents significant challenges, primarily due to fluid-structure interaction (FSI) effects. When a blast wave impacts a structure, it induces a sudden pressure increase followed by a gradual decay. The structural response, in turn, modifies the applied blast load, creating a mutual interaction that increases the computational cost of numerical simulations, which must account for coupled fluid-structure effects. To simplify this complexity, uncoupled approaches are often used in air-blast analysis, where the structural response is assumed not to influence the blast load. However, in scenarios where FSI effects are pronounced, these uncoupled models can lead to significant inaccuracies, particularly in overestimating the structural response.

This work introduces a practical method for estimating the error associated with using an uncoupled approach instead of a coupled one. Specifically, the study focuses on blast-loaded plates with clamped boundaries, a structural configuration where FSI effects are very relevant. The proposed method provides a dimensionless number that quantifies the difference in deflection predicted by the two modelling approaches.

The key advantage of this approach is that the dimensionless number can be obtained from a single uncoupled simulation, making it a computationally inexpensive tool for engineers to assess whether a more advanced and costly coupled analysis is necessary. The dimensionless parameter is derived analytically by modelling the plate's centre as a free-standing plate. The formulation remains valid for plates experiencing large inelastic deformations, up until the plastic hinge at the boundary propagates toward the centre. The validity of the proposed method was tested against experimental case studies, where both coupled and uncoupled simulations were performed to determine the actual deflection difference. The results confirm that the proposed dimensionless number effectively captures FSI trends and provides a reliable estimate of its impact on structural response. In summary, this work presents a computationally efficient approach for estimating the influence of FSI effects in blast-loaded structures. The derived metric enables mechanical engineers and analysts to make informed decisions about the necessity of coupled simulations, offering a practical and accessible tool for early-stage structural assessment.

Keywords: fluid-structure interaction, blast loading, blast-loaded plates, numerical simulations.

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