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Extended Abstract

An effective topology optimization method for crashworthiness of thin walled structures using the equivalent linear static loads

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Abstract

The equivalent static loads method for nonlinear dynamic response structural optimization may be failed in large deformation crash conditions, due to topology optimization with the equivalent static loads mostly beyond the linear range and causing numerical defects such as high compliance of elements. To overcome the above disadvantage, an advanced structural topology optimization method for crashworthiness considering crash-reduced large deformation and plastic buckling is proposed using newly defined equivalent linear static loads. The equivalent linear static loads can adaptively scale to guarantee that the topology optimization is performed within linear range. At each cycle, the crash simulation is performed and the nonlinear nodal displacement vector at the time step with the maximum strain energy is scaled by an adaptive displacement-scaling factor. The equivalent linear static loads that are generated by multiplying the linear stiffness matrix and the scaled nodal displacement vector will be incorporated into topology optimization, which can guarantee the topology optimization to remain in linear range and further solve the numerical instability problems. The process is repeated until the convergence criteria are satisfied. The effectiveness of the proposed method is evaluated by solving a crashworthiness topology optimization of a crash box considering crash-induced plastic buckling to determine the location and profile of crash triggers. The results show that the proposed method can effectively solve the large deformation crashworthiness topology optimization of thin-walled structures and provides a feasible strategy for crash triggers design in crash box. With the continuous increase of car ownership, energy saving and safety have become main challenges for car development. Vehicle lightweight technology and structural crashworthiness design have become an important technical means to meet these challenges. Due to their light weight, low cost, and the ability to effectively dissipate a large amount of impact kinetic energy during crash, thin-walled structures have been wildly used in the energy absorbing structure of automotive buffer systems to absorb crash energy and improve vehicle safety.1,2 An important feature of these structures is the crashworthiness performance of absorbing energy through plastic deformation under crash conditions.2,3 Besides the crashworthiness, its economy, environmental friendliness, and maintainability are also significant. The material, size, and cross-sectional shape of the structure are the important factors affecting the crashworthiness of the structures.4 The effects of filling materials on the crashworthiness of various foam-filled tubes with different cross-sections are studied, such as circular tubes,5,6 square tubes,7–10 single and bi-tubular polygonal tubes,11 conical tubes,12–14 multi-cell tubes,15 corrugated tubes,16,17 ellipse tubes,18,19 double-hat tubes,20 star polygon tubes,21 and so on. In addition, to reduce the weight while maintaining the mechanical property of the original tube, patterned windows22–24 and circular discontinuities25,26 are introduced to the thin-walled structures. Recently, the effect of holes as crush initiators on the crashworthiness performance of bi-tubular aluminum profiles is analyzed.27 In addition, in the design of thin-walled structures, a series of novel optimization algorithms such as size optimization,28,29 shape optimization,30,31 topology optimization,32,33 multi-objective optimization,18,19 multi-objective reliability-based design optimization,34,35 and multiobjective robust-based design optimization14,36 have been proposed. These methods provide a series of powerful tools to design complex engineering structures to satisfy different design requirements. However, in practice, it is very important and challenging to determine the location and shape of those discontinuities.

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