

Optimal Shape Design of Crash-Resistant Parts Using Linear Buckling Analysis

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Automotive structures are required to achieve both high crash safety performance and lightweight design. In vehicle body development, topology optimization has been widely used as a structural design support method for improving stiffness and reducing mass. However, conventional topology optimization often employs compliance minimization, or stiffness maximization, as the objective function. This approach does not always provide effective reinforcement layouts for thin-walled members whose deformation behavior is dominated by buckling.

To address this issue, the present study focuses on the initial buckling behavior of crash-resistant parts. The buckling load obtained by linear buckling analysis was adopted as the objective function for topology optimization. In the proposed method, the load factor calculated from the generalized eigenvalue problem is multiplied by the reference load, and the resulting buckling load is maximized during the optimization process.

The proposed method was first evaluated using a thin-walled square tube model. The model had a side length of 50 mm and a height of 100 mm. A 1180 MPa grade steel sheet with a thickness of 1.0 mm was assumed, and the shell elements of the square tube were defined as the design space. The volume fraction was constrained to 30% or less. For comparison, conventional topology optimization based on compliance minimization was also performed.

In the square tube model, the conventional method retained flat wall regions, whereas the proposed method retained ridge regions considered to contribute to buckling resistance. LS-DYNA compression analysis showed that the maximum load of the part reinforced by the proposed method was 181 kN, while that of the part reinforced by the conventional stiffness-maximization method was 175 kN. These results indicate that using buckling load as the objective function can derive reinforcement layouts suitable for improving compression strength.

The proposed method was then applied to the front side member of the 2012 Toyota Camry finite element model released by the Center for Collision Safety and Analysis. Shell elements were superposed on the original structure and defined as the design space for additional reinforcement parts. The thickness of the design space was 1.2 mm, and the volume fraction was constrained to 10% or less.

For the front side member, the reinforcement shape obtained by the proposed method (Fig. 1(a)) was compared with a manually designed ridge-reinforcement structure (Fig. 1(b)). LS-DYNA compression analysis showed that the maximum load of the part reinforced by the proposed method was 258 kN, while that of the manually reinforced part was 252 kN. Therefore, the proposed method can derive reinforcement locations intended to improve the initial strength associated with buckling behavior.

These results demonstrate that topology optimization using the first-order buckling load obtained from linear buckling analysis is effective for deriving reinforcement shapes for thin-walled crash-resistant parts. Future work will clarify the relationship between post-buckling deformation behavior and crash energy absorption performance and expand the applicability of the proposed method to crash member design.

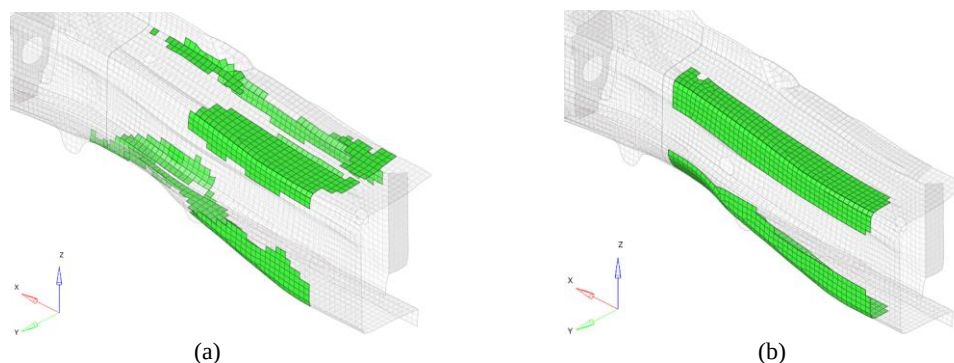


Fig. 1 Reinforcement shapes of the front side member:
(a) optimized shape using the proposed method and (b) manually designed ridge reinforcement.