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Free-form Optimization Method for Designing Spatial Frame Structure

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ABSTRACT

Frame structures composed of straight or curved members may be regarded as eco-friendly structures. Although the members are slender, the assembled structure has high load-carrying capacity and can contribute to a lighter weight and resource savings. Such structures are extensively used in various fields of engineering, especially in space, civil and architectural structures. Their lightness and slenderness are apt to result in a lack of stiffness or strength. Therefore, in the design of a frame structure, it is important to optimize its shape in order to satisfy the requirements of various structural characteristics, while achieving a lighter weight. As the design variable to determine the optimum shape of a spatial frame structure, one can consider the in-plane shape variation that move in the longitudinal direction to the member and/or the out-of-plane shape variation that move in the normal direction to the member.

In this paper, we present a new parameter-free shape optimization method for the optimal free-form design of three-dimensional frame structures. It is assumed that a frame structure is based on the Timoshenko's theory and is varied in the out-of-plane direction to the frame. It is also assumed that the prismatic shapes of cross sections are constant with respect to the shape variation. Using the compliance as an index of the stiffness, a stiffness maximization problem subjected to a volume constraint is formulated as a distributed-parameter, or a parameter-free shape optimization problem. The shape sensitivity function and the optimality conditions for this problem are theoretically derived by combining the Lagrange multiplier method, the adjoint variable method and the material derivative method. The material derivative method is applied to the virtual 3D domain of each frame with a specified prismatic cross section. The shape sensitivity function derived is applied to the frame structure as the distributed traction force to vary the shape. The optimum shape variation is obtained as the displacement field in this pseudo-elastic frame analysis, which is called a velocity analysis. The stiffness tensors of the pseudo-elastic frame have roles of both the positive definite tensor which is needed in a gradient method in a Hilbert space and the mesh regularization in a shape updating. The displacements are then added to the

reference shape to update the shape. By repeating the stiffness analysis, the sensitivity analysis, the velocity analysis and the shape updating, the optimum free-form of a frame structure is determined. The optimization system can be easily developed combining with a standard commercial FEM code.

The calculated results will show the effectiveness and practical utility of the proposed parameter-free method to determine the optimal free-form of spatial frame structures. It will also show that the axial-load-carrying structures are obtained by the proposed method.