Engineering Structures 33 (2011) 3620–3627

Contents lists available at SciVerse ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Configuration optimization of clamping members of frame-supported membrane structures

M. Ohsaki [a,*], T. Nakajima [b], J. Fujiwara [c], F. Takeda [c]

[a] Department of Architecture, Hiroshima University, Japan

[b] Department of Architecture and Architectural Engineering, Kyoto University, Japan

[c] Technical Research Center, Taiyo Kogyo Corporation, Japan

ARTICLE INFO

Article history:
Received 3 June 2010
Received in revised form
23 July 2011
Accepted 25 July 2011
Available online 25 August 2011

Keywords:
Membrane structure
Clamping member
Configuration optimization
Stress constraints

ABSTRACT

A method is presented for configuration optimization of frames that have specified properties on nodal displacements, stresses, and reaction forces against static loads. The conventional ground structure approach is first used for topology optimization. A feasible solution with a small number of members satisfying all the design requirements except the stress constraints is obtained by assigning artificially small upper-bound displacement, or by penalizing the stiffness of a thin member. This way, the well-known difficulty in topology optimization under stress constraints is successfully avoided. The nodal locations and cross-sectional areas of the feasible solution are next optimized to obtain an approximate optimal configuration under stress constraints. The proposed method is applied to the design of self-fastening clamping members for membrane structures modeled using frame elements. An optimization result is also presented for a clamping member that adjusts deformation of membrane by applying a clamping force with a vertically attached bolt.

1. Introduction

Shape and topology optimization of continuum structures is a rather matured field of research [1–3], and there are many applications in various fields of engineering including civil and architectural engineering [4–6]. The first author presented a method of optimizing shapes of beam flanges for maximizing the plastic energy dissipation under static deformation [7,8]. This way, it is possible to optimize performances of mass-produced parts of building structures. However, topology optimization of continuum under stress constraints is still difficult, because of the design dependency of the optimization problem [9].

There is also a great deal of research on simultaneous optimization of shape and topology, which is called *configuration optimization*, of trusses and frames [10–13]. Optimal topologies of trusses under constraints on global properties such as compliance and displacements can be easily obtained using the standard ground structure approach, where unnecessary members are removed through optimization from a highly-connected ground structure. However, even for trusses, there still exist several difficulties in problems under stress constraints [14–16], which are categorized as local constraints [17] that lead to the existence of many thin members or elements; i.e., the number of members cannot be reduced effectively by simple application of the ground structure approach. In the most widely used SIMP (*solid isotropic microstructure with penalty* or *solid isotropic material with penalization*) approach [18,1] to topology optimization of continua, an intermediate value of material density is penalized by assigning artificially small stiffness. Kim et al. [19] penalized the stiffnesses of the joints to obtain simple optimal topologies of frames. Takezawa et al. [20] formulated a frame optimization problem using a penalization parameter; however, they did not penalize the stiffness in the numerical examples. Therefore, to the authors' knowledge, there is no study on direct application of SIMP approach to topology optimization of frames.

Membrane structures are widely used for stadiums and arenas covering large space with lightweight membrane materials [21,22]. Membrane structures are generally connected to the boundary frames with clamping members as illustrated in Fig. 1. Since such devices are mass-products and have a large portion of the total weight of the membrane structure, the total production cost can be reduced by optimizing the cross-sectional shapes of members. Furthermore, when external loads such as wind loads are applied to the membrane, its tensile force increases and the membrane sheet may detach from the clamping member prior to the fracture of the membrane material. Therefore, the load resistance capacity of the membrane structure can be improved by optimizing the clamping members so that the clamping force increases as a result of increase of the tensile force of the membrane.

* Correspondence to: 1-4-1, Kagamiyama, Higashi-Hiroshima 739-8527, Department of Architecture, Hiroshima University, Japan.
E-mail address: ohsaki@hiroshima-u.ac.jp (M. Ohsaki).

0141-0296/$ – see front matter
doi:10.1016/j.engstruct.2011.07.026