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Analysis of clustered tensegrity structures using a modified dynamic relaxation algorithm

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ABSTRACT

Tensegrities are spatial, reticulated and lightweight structures that are increasingly investigated as structural solutions for active and deployable structures. Tensegrity systems are composed only of axially loaded elements and this provides opportunities for actuation and deployment through changing element lengths. In cable-based actuation strategies, the deficiency of having to control too many cable elements can be overcome by connecting several cables. However, clustering active cables significantly changes the mechanics of classical tensegrity structures. Challenges emerge for structural analysis, control and actuation. In this paper, a modified dynamic relaxation (DR) algorithm is presented for static analysis and form-finding. The method is extended to accommodate clustered tensegrity structures. The applicability of the modified DR to this type of structure is demonstrated. Furthermore, the performance of the proposed method is compared with that of a transient stiffness method. Results obtained from two numerical examples show that the values predicted by the DR method are in a good agreement with those generated by the transient stiffness method. Finally it is shown that the DR method scales up to larger structures more efficiently.

1. Introduction

Recent advances in theory and practice of active structural control have modified the general perception of structures. Upon integration of active elements, structures become dynamic objects capable of interacting with their environments. Increasingly, the ability to adapt to performance demands and environmental conditions has become key design criteria for a range of structural and mechanical systems. Among many structural topologies, the tensegrity concept is one of the most promising for actively controlled structures (Adam and Smith, 2008; Masic and Skelton, 2006; Raja and Narayanan, 2007; Smaili and Motro, 2007; Sultan and Skelton, 2003; Wroldsen et al., 2009). Tensegrities are spatial, reticulated and lightweight structures that are composed of struts and cables. Stability is provided by the self-stress state in tensioned and compressed elements (Juan and Mirats Tur, 2008; Mirats Tur and Hernàndez Juan, 2009). The tensegrity concept has applications in fields such as sculpture, architecture, aerospace engineering, civil engineering, marine engineering and biology (Skelton and de Oliveira, 2009). Tensegrity structures have a high strength-to-mass ratio and this leads to strong and lightweight structural designs (Skelton et al., 2001; Wang, 2004; Bel Hadj Ali et al., 2010). Furthermore, tensegrities are flexible and easily controllable using small amounts of energy (de Jager and Skelton, 2005). These features create situations where tensegrity structures are particularly attractive for active and deployable structures.

As a special type of prestressed pin-jointed framework, tensegrity structures are composed of axially loaded elements and this provides opportunities for actuation and deployment through changing element lengths. Length changes can be made to struts and cables through various actuation strategies. Strut-based actuation, employing telescopic members, has already been used in active tensegrity control applications. Fest et al. (2004) experimentally explored shape control of a five-module large-scale active tensegrity structure. The actuation strategy was based on controlling the self-stress state of the structure through small movements of ten telescopic struts. This actuation was also used for self-diagnosis, self-repair and vibration control (Adam and Smith, 2008; Bel Hadj Ali and Smith, 2010). Kanchanasaratool and Williamson (2002) used actuated struts to perform feedback shape control for a simple tensegrity module. Hanaor (1993) studied deployment of a simplex-based tensegrity grid using telescopic struts. Tibert and Pellegrino (2002) numerically and experimentally investigated use of telescopic struts for the deployment of tensegrity reflectors. Generally, strut-based actuation becomes difficult to implement under conditions where internal forces are substantial, and required changes in shape are large. Furthermore, when strut-actuation is used for deployment, the structure may have no stiffness until it is fully deployed.

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