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An orthogonal self-stress matrix for efficient analysis of cyclically symmetric space truss structures via force method

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ABSTRACT

The analysis of structures is normally carried out through displacement method while the force method is considered as an alternative approach for this purpose and used on occasion. The generation of compatibility conditions (the transpose of self-stress matrix) is one of the major and complicated parts of any structural analysis using force method. In this paper, an efficient method is proposed for producing orthogonal self-stress matrix related to space truss structures with cyclic symmetry. This is actually performed by eigen-decomposition of a special matrix having the same null basis as in equilibrium matrix. Then, the advantages of the obtained compatibility conditions are demonstrated with respect to different formulations such as standard force method, eigen force method and integrated force method. Finally, the efficiency of the presented method is comprehensively compared with three well-known numerical methods and tested on a set of practical examples. The results indicate clearly the significant superiority of the proposed approach in terms of both computational time and the accuracy of the results.

1. Introduction

The matrix analysis of structures is usually performed through two counterpart approaches known as displacement method (stiffness method) and force method (flexibility method). The displacement method has significantly progressed since the emergence of digital computer systems and since then, it has been successfully extended to support static, dynamic and nonlinear analysis of structures. These considerable progresses are due to the generality and simplicity of the computer implementation of this method. In spite of the long history of the force method, there are difficulties involved in the generalization and programming of this method, reducing its appeal as a viable option. One of the major parts of any structural analysis using force method is the generation of the self-stress matrix (transpose of compatibility matrix). In other words, the force method can be classified as topological, algebraic and mixed algebraic-combinatorial force methods according to the approaches used for the generation of this matrix.

Topological methods were pioneered by Henderson (1960), Maunder (1971), Henderson and Maunder (1969) for rigid-jointed skeletal structures using manual selection of the cycle bases of their graph models. Methods suitable for computer programming were also presented by Kaveh (1974, 1976). However, pure graph theoretical methods are not effective for truss-type space structures since the recognition of the rigidity is still a challenge in this area. Algebraic methods were developed by Denke (1962), Robinson (1973), Topçu (1979), Kaneko et al. (1982), Pellegrino (1993), Soyer and Topçu (2001) and mixed methods were introduced by Gilbert and Heath (1987), Coleman and Pothen (1987), Pothen (1989). In addition, for different finite element models, mixed algebraic-graph theoretical methods were developed by Kaveh and Koohestani (2008a,b, 2009a). A new and general formulation of the force method, namely Integrated Force Method (IFM), was introduced by Patnaik (1973). IFM itself also needs compatibility matrix (Patnaik and Joseph, 1986). This method is the true force method which was successfully extended to dynamic and nonlinear analysis of structural models by Patnaik and Yadagiri (1982), Krishnam Raju and Nagabhushanam (2000) respectively.

There are a considerable number of special structures which can be created by rotational repetition of a substructure about an axis. These structures which have a special property called cyclic symmetry have generated significant interest in the field of structural mechanics. Different formulations for the static, dynamic and nonlinear analysis of these structures have been presented by a significant number of researchers. Among them, it can typically be referred to Hussey (1967), Thomas (1979), Williams (1986). However, there are only a few studies about the advantages of cyclic symmetry in the structural analysis using force method. Zloković (1989), Zingoni et al. (1995) have studied symmetry properties in the force method formulation by using fully symmetric cuts and the group representation theory respectively. Also, Kangwai and Guest (2000) shown that how equilibrium and compatibility matrices can be block diagonalized through symmetry-adapted coordinate system as well as symmetry groups.

In this paper, an efficient and robust method is proposed for the structural analysis of space truss structures through force method.

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