Available online at www.sciencedirect.com
ScienceDirect
International Journal of Solids and Structures 44 (2007) 1038–1059
INTERNATIONAL JOURNAL OF SOLIDS and STRUCTURES
www.elsevier.com/locate/ijsolstr

Analysis of shear deformable plates with combined geometric and material nonlinearities by boundary element method

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Received 3 January 2006; received in revised form 3 April 2006
Available online 13 June 2006

Abstract

In this paper a boundary element formulation for analysis of shear deformable plates with combined geometric and material nonlinearities by boundary element method is presented. The dual reciprocity method is used in dealing with the geometric nonlinearity and domain discretization is implemented in dealing with material nonlinearity. The material is assumed to undergo large deflection with small strains. The von Mises criteria is used to evaluate the plastic zone and an elastic perfectly plastic material behaviour is assumed. An initial stress formulation is used to formulate the boundary integral equations. A total incremental method is applied to solve the nonlinear boundary integral equations. Numerical examples are presented to demonstrate the validity and the accuracy of the proposed method.

Keywords: Large deflection; Geometrical nonlinearity; Material nonlinearity; Plasticity; Dual reciprocity method

1. Introduction

The numerical analysis of plate type structures by mean of finite element method accounting from geometrical and material nonlinearity has been developed significantly during the last two decades. The boundary element method after the FEM is the second most utilized computational tool available in solid mechanics. With increasing reliance on numerical method in place of experimental measurements, it is therefore essential to develop alternative solution methods to FEM for the sake of validation.

The range of applications for boundary element method (BEM) in solid mechanics is getting broader (Aliabadi, 2002). Recent developments have extended the application of the method to nonlinear problems in plate bending analysis such as geometric nonlinearity, material nonlinearity and combined geometric and material nonlinearities. In the formulation of the integral equation the nonlinear problems can normally be included in

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0020-7683/$ - see front matter
doi:10.1016/j.ijsolstr.2006.06.004

a domain integral, therefore two kinds of integrals appear in nonlinear problems, i.e., boundary integral and domain integral. There are two main techniques for the evaluation of the domain integrals appearing in the integral equation. The first one is a domain discretization method in which the domain is discretized into internal cells, so that the advantage of BEM, that is, a possibility of reduced dimensionality of the problem, disappears. The second one is transformation the domain integral into equivalent boundary integrals so the domain discretization is not required and the computational efficiency of BEM is maintained.

Domain discretization for dealing with domain integral of plate bending analysis in BEM has been reported by many researchers. Lei et al. (1990) formulated an integral equation for geometrically nonlinear behaviour for Reissner plate. To evaluate the domain integral appearing in the formulation, Lei et al. (1990) discretized the domain into constant triangular cells. A similar work has been reported by Purbolaksono and Aliabadi (2005), however they implemented constant rectangular cells instead of constant triangular cells. Their work (Purbolaksono and Aliabadi, 2005) was focused on studying four methods of solution for the nonlinear problem which included total increment method, cumulative load incremental method, Euler method and nonlinear system method. Purbolaksono and Aliabadi (2005) found the most efficient approach is the total increment method proposed by Wen et al. (2005). Baiz and Aliabadi (2005) made an improvement in evaluating the effect of geometric nonlinearity on the plate bending analysis by implementing 9-node quadrilateral cell and introducing free term factor in the integral equation.

Karam and Telles (1998) and later Ribeiro and Venturini (1998) used the domain discretization in dealing with nonlinear due to material nonlinearity. Supriyono and Aliabadi (2006) were the first to formulate a BEM for combined geometric and material nonlinearities for shear deformable plates. In dealing with the domain integrals appearing in the formulation, Supriyono and Aliabadi (2006) discretized the domain into cells using 9-node quadrilateral cell. To solve the nonlinear system of equation the total incremental method as proposed by Wen et al. (2005) was used. The formulation developed (Supriyono and Aliabadi, 2006) allows for large deflection and small strain and elastic perfectly plastic material behaviour.

The dual reciprocity method (DRM) which transform domain integral into equivalent boundary integral was introduced by Brebbia and Nardini (1983), for analyzing 2D elastodynamic problem. In plate bending analysis the application of the transformation method of domain integral into equivalent boundary integral can be traced through the works by Kamiya and Sawaki (1988), Silva and Venturini, 1985, Sawaki et al. (1990), Wen et al. (2005). Kamiya and Sawaki (1988) analysed the bending problem of plate on Wrinkler-type elastic foundation as a novel extension of the dual reciprocity method (DRM) to the problems concerning the fourth order differential equation. Silva and Venturini (1985) applied DRM to a similar problem taking into consideration the nonlinear effect of elastic foundation. Sawaki et al. (1990) analysed nonlinear bending of thin plate based on the Berger equation. The domain integral which appears in the formulation was transformed to the boundary using DRM and treated through a successive iteration scheme.

Wen et al. (2005) formulated the large deflection effect on the Reissner plate based on the general nonlinear differential equations for large deflection. The nonlinear terms were treated as body forces and determinated by approximation function. The domain integral was transformed to the boundary using DRM. Another contribution of application of DRM in large deflection plate analysis can be found in the work by Wang et al. (1950).

In this paper the boundary integral equation for shear deformable plate with combined geometric and material nonlinearities is presented. The two techniques for evaluating domain integral are employed. The dual reciprocity method is used to evaluate the domain integral due to large deflection effect and domain discretization technique is implemented in dealing with the nonlinear term due to plasticity. The nonlinear terms due to large deflection were determinated by utilizing radial basis function and approximating the derivatives. The formulation is based on an assumption that the material experiences large deflection and small strain (Stricklin et al., 1972) and in the numerical implementation elastic perfectly plastic material is used. In order to solve the nonlinear system of equation the total incremental method is implemented as proposed by Wen et al. (2005).

2. Governing equations

In order to define a general formulation for combined geometrical and material nonlinearities of plate bending, it is considered that plastic strains are only due to bending and membrane, hence total strain rates can be defined as