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A meshfree model without shear-locking for free vibration analysis of first-order shear deformable plates

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This paper is dedicated to Prof. Dr.-Ing. Peter Wriggers on the occasion of his 60th birthday.

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ABSTRACT

Difficulty in imposing essential boundary conditions in the standard element-free Galerkin method (EFG) is due to the lack of Kronecker's delta function property of shape functions generated by moving least square approximation (MLS). In this paper, we further apply a meshfree model based on the moving Kriging interpolation method (MK) to free vibration analysis of first-order shear deformable plates. The deflection and two rotation field variables of plate are approximated by the MK method, which is employed to construct the shape functions having the delta function property. With this approach, the drawback in enforcement of the boundary conditions caused by the MLS is now avoided. The present formulation is based on the first-order shear deformation plate theory (FSDT) associated with an effective elimination of the shear-locking phenomenon completely, and hence the approach is applicable to both moderately thick and thin plates. Numerical examples considering various aspect ratios and different boundaries are examined and solutions on natural frequencies obtained by the present method are then compared with existing reference solutions, and very good agreements are observed.

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1. Introduction

Plate structures have been intensively used in a variety of engineering disciplines involving civil engineering, automobiles, aerospace, construction sectors, marine, naval, etc., but a thorough understanding of their vibration characteristics is of great importance to engineers and designers making sure reliability in design procedure. The great majority of solutions existing for the flexural vibration of plates at the beginning are based on the classical Kirchhoff assumption [1] which neglects the transverse shear deformation of the plates during the process, and the rotary inertia terms are also ignored. The absence of those characteristics firmly leads to the overestimation of the plate frequencies and significant errors are increased when the thickness-span ratio is increased. A substantial development of plate theory, taking into account the effect of such transverse shear deformation and rotary inertia, was proposed by Reissner [2,3] for the first-order shear deformable theory (FSDT). Mindlin [4–6] later presented a variational approach deriving the governing plate equation for free vibration of the FSDT incorporated the rotary inertia effect. Obtaining analytical solutions for free vibration problems of Reissner–Mindlin plates is more difficult due to more governing equations and kinetic parameters involved [7–14]; thus, approximate solutions with a high level of accuracy using numerical computational approaches are indispensable.

Many numerical methods have been introduced and successfully applied to free vibration analysis of Reissner–Mindlin plates such as Rayleigh method [15], Rayleigh–Ritz methods [16–20], *pb-2* Rayleigh–Ritz methods [21,22], spline strip method (SSM) [23], finite strip method (FSM) [24,25], spline finite strip method (SFSM) [26–28], boundary element method (BEM) [29], generalized differential quadrature method (GDQ) [30,31], discrete singular convolution (DSC) method [32–37], DSC-Ritz method [38], finite element method (FEM) [39–42], etc.

Although these numerical methods have been demonstrated accurately and efficiently in solving such plate vibration problems, their disadvantages are always present for each approach and they still have some limitations in engineering applications. As stated in [36], the structural computations are generally accomplished by employing either global or local methods. The global approach such as Rayleigh, Rayleigh–Ritz, GDQ is highly accurate but often cumbersome in treatment of general boundary conditions and complex geometries, and in contrast, the SSM, FSM, SFSM, etc., standing for the local ones, which are easy

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