3. Liang, Y. A new method for multivariable nonlinear coupling relations analysis in complex electromechanical system / Y. Liang, Z. Gao, J. Gao // Ap-plied Soft Computing. – 2020. – Vol. 94. – Art. 106457. – DOI 10.1016/j.asoc.2020.106457
4. Ratner, S. Developing a strategy of environmental management for elec-tric generating companies using DEA-methodology / S. Ratner, P. Ratner // Ad-vances in Systems Science and Applications. – 2017. – Vol. 17 (4). – P. 78–92. – DOI 10.25728/assa.2017.17.4.521
5. Kassner, M. Fatigue strength analysis of a welded railway vehicle structure by different methods / M. Kassner // International Journal of Fatigue. – 2012. – Vol. 34, is. 1. – P. 103–111.
6. Finite element analysis (FEA) of stress distribution in platform-switched short dental implants / K. N. Gosai, V. D. Tripathi, S. Yadav [et al.] // Bioinformation. – 2024. – Mar. 31. – Vol. 20 (3). – P. 248–251. – DOI 10.6026/973206300200248
7. Barbero, E. J. Finite element analysis of composite materials using Abaqus / E. J. Barbero. – Boca Raton : CRC press, 2023. – 456 p.
8. Kanavalau, Y. Evaluation techniques for residual in-use utility of the railway car hopper-batcher bearing structure with a long-term service / Y. Kanavalau, A. Putsiata // Procedia Engineering. – 2016. – Vol. 134. – P. 57–63. – DOI 10.1016/j.proeng.2016.01.039
9. Афанаськов, П. М. Несущая способность кузова вагона-самосвала для перевозки сыпучих грузов после длительной эксплуатации / П. М. Афанаськов // Современные технологии. Системный анализ. Моделирование. – 2020. – № 4 (68). – С. 202–210.

UDC 539.3

SIMULATION OF PLATE BENDING VIBRATION PROBLEMS BY THE MESHLESS BACKWARD SUBSTITUTION METHOD

J. Lin, Y. T. Xu

Key Laboratory of Coastal Disaster and Defence (Ministry of Education), Hohai University, Nanjing, China

College of Mechanics and Engineering Science, Hohai University, Nanjing, China

J. Lun

Materials and Structural Engineering Department, Nanjing Hydraulic Research Institute, China

S. Y. Reutskiy

A. Pidhornyi Institute of Mechanical Engineering Problems, National Academy of Sciences of Ukraine, Kharkiv

In this work the meshless backward substitution method is proposed for the first time to solve the fourth-order plate bending vibration problems. The numerical solution consists of approximation from the boundary conditions and the revised basis functions which satisfying the homogeneous conditions with weighted parameters which are obtained from the governing equations by the collocation method. Then the key issues are the organization of initial approximation and the revised basis function derived from the traditional basis functions. To demonstrate the accuracy and validity of the proposed method, several numerical examples are conducted and compared with popular methods in literature. The obtained results from numerical experiments confirm the potential of the proposed method in terms of both accuracy and efficiency.

Keywords: meshless method, plate bending vibration, radial basis function, backward substitution method.

МОДЕЛИРОВАНИЕ ЗАДАЧ КОЛЕБАНИЙ ИЗГИБА ПЛАСТИНЫ МЕТОДОМ БЕССЕТОЧНОЙ ОБРАТНОЙ ПОДСТАНОВКИ

J. Lin, Y. T. Xu

Ключевая лаборатория прибрежных катастроф и обороны (Министерство образования), Университет Хохай, Нанкин, Китайская Народная Республика

Колледж механики и инженерных наук, Хохайский университет, Нанкин, Китайская Народная Республика

J. Lun

Отделение материаловедения и конструкционной инженерии, Нанкинский гидравлический научно-исследовательский институт, Китайская Народная Республика

С. Ю. Реутский

Институт проблем машиностроения имени А. П. Подгорного НАН Украины, г. Харьков

Отмечено, что впервые предложен метод обратной бессеточной подстановки для решения задач колебаний изгиба пластины четвертого порядка. Численное решение состоит из аппроксимации с учетом граничных условий и пересмотренных базисных функций, которые удовлетворяют однородным условиям с весовыми параметрами, выведенными из управляющих уравнений методом коллокации. Ключевыми вопросами являются организация начального приближения и пересмотренная базисная функция, полученная из традиционных базисных функций. Для демонстрации точности и обоснованности предлагаемого метода приведено несколько численных примеров и проведено сравнение с популярными методами в литературе. Представленные результаты численных экспериментов подтверждают потенциал предлагаемого метода с точки зрения как точности, так и эффективности.

Ключевые слова: бессеточный метод, изгибные колебания пластины, радиальная базисная функция, метод обратной подстановки.

Introduction. Plate structures, serving as fundamental components in various engineering fields such as aerospace, marine engineering, civil construction, and industrial sectors, play a pivotal role and find numerous applications. As for the solution to these problems, conventional and popular methodologies come to the forefront, such as the finite element method, finite difference method, boundary element method, finite volume method. Recent decades have witnessed remarkable developments in meshless or meshfree methods such as smooth particle dynamics, method of particular solutions, and methods based on radial basis functions. The utilization of radial basis functions was introduced by Kansa for the solutions of partial differential equations. Reutskiy introduced a new method called the backward substitution method (BSM) for addressing multi-node problems. The conventional approach of the BSM approach involves transforming the original problem into Laplace equations and then applying the meshless method of fundamental solutions to solve the corresponding equations. However, there is a critical limitation in this approach, especially when dealing with real-application problems in anisotropic and inhomogeneous media. To overcome this limitation and extend the application of traditional BSM, an improved version has been proposed. The solution process begins with an initial approximation from boundary conditions which serves as the foundation for deriving the primary solution. The final approximation is obtained by combining the elementary approximation, the traditional basis function, and their associated correction functions.

In this paper, we further extend this method for the first time to solve the fourth-order plate bending vibration problems. We will provide detailed explanations of the boundary conditions approximation and revised basis function tailored to the specific problems under consideration. To validate the accuracy and effectiveness of this approach, several examples in regular and irregular domains have been performed and the results are rigorously compared with existing popular methods in literature.

Problem definition. In general, according to the principles of thin plate theory, the governing equation for plate bending vibration problem under external loading $q(\mathbf{x})$ can be simplified as below:

$$\nabla^4 w(\mathbf{x}) + \lambda w(\mathbf{x}) = p(\mathbf{x}),\ \ \mathrm{x} \in \Omega,$$

with $w(\mathbf{x})$ represents the deflection of the middle surface of the plate, $p(\mathbf{x}) = \dfrac{q(\mathbf{x})}{D}$, and λ represents the types of the plate where

$$\lambda = 0,$$

applies to the Kirchhoff plate, and

$$\lambda = \frac{k_w}{D},$$

applies to the Winkler plate, with k_w representing the foundation stiffness. The plate flexural rigidity *D* are defined as follows:

$$D = \frac{Eh^3}{12(1-\mu^2)},$$

In this study, we consider the following three typical boundary conditions:

Clamped edge:

$$w(x, y) = 0,\ \ \ell_{\theta_n} = 0. \tag{1}$$

Simply supported edge:

$$w(x, y) = 0,\ \ \ell_{M_n} = 0. \tag{2}$$

Free edge:

$$w(x, y) = 0,\ \ \ell_{V_n} = 0. \tag{3}$$

Method for the problem. The numerical solution comprises two components:

$$w(\mathbf{x}) = w_p(\mathbf{x}) + w_\delta(\mathbf{x}),\ \ \mathbf{x} \in \Omega,$$

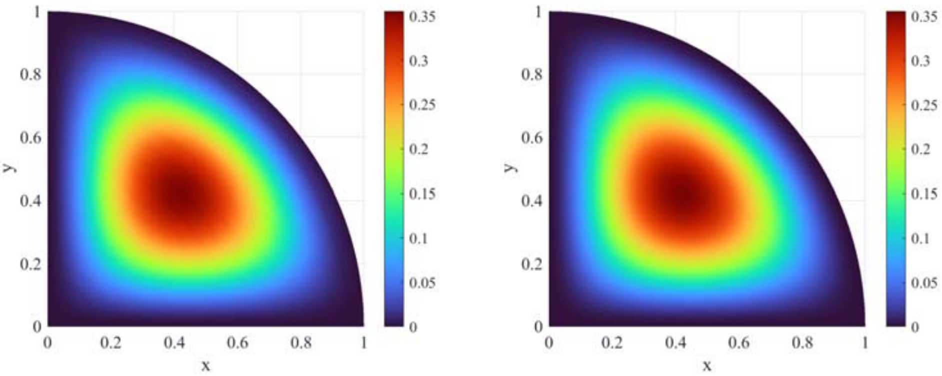
where first part $w_p(\mathbf{x})$ is the boundary approximation, which satisfies the original boundary conditions, and the second part $w_\delta(\mathbf{x})$ is the correction function, which satisfies the governing equation and the homogeneous boundary conditions. These two parts are represented as linear combinations of the basis functions $\theta_l(\mathbf{x})$ and $\Phi_u(\mathbf{x})$, respectively:

$$w_p(\mathbf{x}) = \sum_{l=1}^{L} \alpha_l \theta_l(\mathbf{x}), \mathbf{x} \in \Omega;$$

$$w_\delta(\mathbf{x}) = \sum_{u=1}^{U} \gamma_u \Phi_u(\mathbf{x}), \ \ \mathbf{x} \in \Omega.$$

These functions are approximated by the modified radial basis functions. For more details, please refer to some related papers.

Numerical results. In this case, the aim is to verify the applicability of the proposed numerical method by examining the response of an irregular plate under the influence of a uniform load q_0. The geometry of the plate is a right-angled sector with (0, 0) as the center of the circle and radius 1.



a) *b*)

Fig. 1. The numerical solution by the present method and FEM:
a – Numerical solution; *b* – FEM solution

The obtained results from numerical experiments confirm the potential of the proposed method in terms of both accuracy and efficiency.

УДК 629.4.045:629.4.015

ПРИМЕНЕНИЕ СОВРЕМЕННЫХ ТЕХНОЛОГИЙ ДЛЯ ОЦЕНКИ ДИНАМИЧЕСКИХ ХАРАКТЕРИСТИК СИСТЕМЫ «ДЛИННОМЕРНЫЙ ГРУЗ – СЦЕП ВАГОНОВ»

М. Г. Гегедеш[1, 2], И. А. Ворожун[2], А. В. Ворожун[2]

[1] *Учреждение образования «Гомельский государственный технический университет имени П. О. Сухого», Республика Беларусь*

[2] *Учреждение образования «Белорусский государственный университет транспорта», г. Гомель*

Рассмотрены возможности применения инженерного пакета MSC.Adams для имитации работы системы «длинномерный груз – сцеп вагонов» и анализа движения такой системы в условиях эксплуатации, приближенным к реальным. Выполнено компьютерное моделирование соударения системы «длинномерный груз – сцеп вагонов» при условии закрепления груза с помощью турникетных опор, включающих как подвижные, так и неподвижные эле-