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Free vibration analysis of partially perforated circular plates

Kyeong-Hoon Jeong[a]* and Myung-Jo Jhung[b]†

[a]Korea Atomic Energy Research Institute, 111 Daedeok-daero 989 beongil, Yuseong, Daejeon 34057, Republic of Korea.
[b]Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong, Daejeon 34142, Republic of Korea

Abstract

This paper presents free vibration analysis of partially perforated circular plates with a triangular hole pattern and clamped boundary condition. To reflect the effect of circular holes on natural frequencies of the perforated plate, the effective material properties based on the finite element analysis are introduced. The circular plates are divided into the solid annular and perforated central regions to estimate the theoretical natural frequencies of perforated circular plates using the Rayleigh–Ritz method based on minimizing the Rayleigh quotient of the ratio between the maximum potential energy and the total kinetic energy. In the theoretical calculation, the reduction of mass and stiffness in the perforated plate region are considered as a function of the ligament efficiency. The proposed theoretical method is verified by observing a good agreement with finite element analysis results based on the full and equivalent finite element models.

Keywords: Perforated circular plate; modal analysis; natural frequency; Rayleigh-Riz method; effective modulus of elasticity

1. Introduction

The perforated structures are widely used in nuclear power plants to support components, and the reactor coolant flows through the perforated plates. Before the seismic analysis, finite element modal analyses of the reactor

* Corresponding author. Tel.: +82-42-868-8792.
E-mail address: khjeong@kaeri.re.kr

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internals are performed with an appropriate equivalent lumped-mass stick model. It is necessary to idealize a mathematical model consisting of lumped masses connected by elastic massless members to reduce computation time and to save storage memory. As the perforated structures in the reactor internals require a lot of elements for finite element modal analysis, the finite element model for the perforated structures cannot be constructed as they are. Application of equivalent properties of the perforated structures for the finite element analysis can be an effective analysis method. Recently, many investigators have developed approximate solutions to predict the changes in the natural frequencies of rectangular plates with a group of identical circular holes [1~9]. The most effective way, adopted by most authors, is to estimate effective material properties regarding as an equivalent homogeneous plate. In this way, the effective properties such as effective modulus of elasticity and effective Poisson's ratio can be used simply in standard procedures to design the perforated plates. As several partially perforated structures have been used in the reactor internals, the analytical method for modal analysis of partially perforated circular plates with the effective material properties is suggested for a simple and efficient calculation instead of a complicated finite element analysis via full modeling of perforated plates. The approximate method is verified by the finite element analysis. The effective elastic modulus of the perforated material (E^*), and effective mass density (ρ^*) will be used in the theoretical formulation, but the Poisson's ratio (μ) is assumed to be constant regardless of the ligament efficiency.

2. Estimation of effective material properties

In the previous studies [3, 4], the effective material properties were suggested for the clamped square plate as a function of the ligament efficiency, $\eta\,(=(p-d)/p)$. The effective modulus of elasticity for the perforated square plates is used in estimation of the natural frequencies of the partially perforated circular plate. The effective modulus of elasticity of the perforated square plate was obtained using the inverse method for the triangular penetration pattern. It was known that the effective modulus of elasticity in the perforated square plate with the clamped edge does not depend upon the mode number, but they can be given as a function of the ligament efficiency. The effective modulus of elasticity is approximated by polynomials using the curve fitting in References [7, 8].

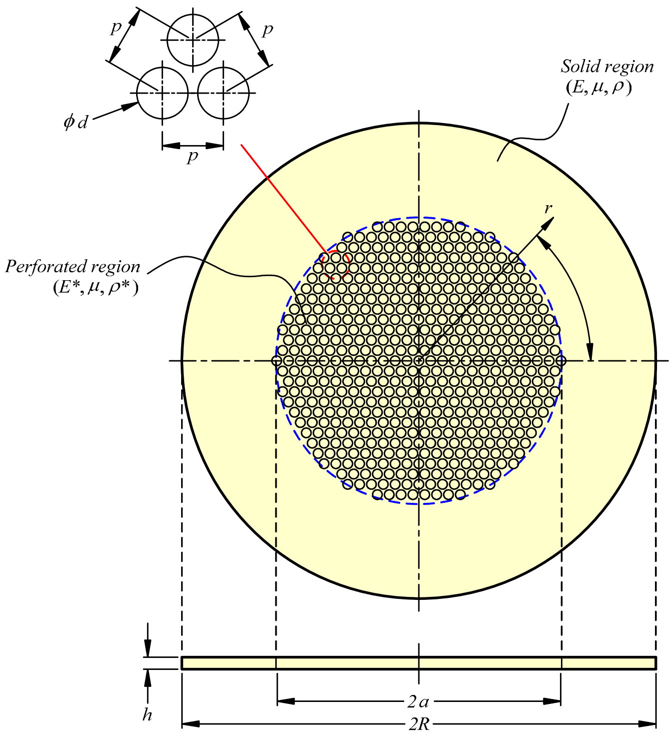

Fig. 1. Analysis model of a circular plate with a central perforation.