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Structural intensity analysis of stepped thickness rectangular plates utilizing the finite element method

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ABSTRACT

Stepped thickness rectangular plates are found in various engineering branches, and knowledge about their dynamic performance represents an important issue for rational structural design. The structural intensity analysis, assessing magnitude and direction of vibration energy flow provides information on dominant transmission paths, and vibratory energy distribution including sink positions. In this paper, vibration energy flow in stepped thickness rectangular plates is analysed by structural intensity technique employing the finite element method. An outline of structural intensity formulation for a plate element is given, and developed analysis system combining in-house code and commercial FE tools is described. Numerical examples include structural intensity analysis of stepped thickness rectangular plates subjected to harmonic excitation forces with different sets of boundary conditions, where special attention is paid to influence of plate thickness ratio variation on vibration energy flow. Moreover, different structural intensity components of a simply supported stepped thickness plate are separately quantified, to assess their contribution to the total intensity.

1. Introduction

Rectangular plates with stepped thickness have many practical applications in almost all fields of engineering and their vibration properties are extensively investigated by many researchers. Abrupt plate thickness variations can be made for many reasons as for instance; material reduction, stiffness enhancing, designated strengthening, altering of dynamic properties, etc. Ordinary procedure for assessment of dynamic properties of plate structures implies modal analysis, i.e. determination of natural frequencies and mode shapes, which are further compared with excitation frequencies if necessary. Moreover, it is indispensable to check whether the response amplitudes satisfy prescribed criteria sometimes, and therefore forced vibration analysis in frequency or time domain is required [1,2]. For the purpose, there are different analytical, semi-analytical and numerical approaches offered in the relevant literature. However, exact solutions can be obtained only for simply supported plates or plates simply supported along two opposite edges in the direction of stepped thickness change, and therefore usually numerical methods are applied. Although this problem is extensively considered over the past years, due to its complexity the vibration analysis of both stepped thickness rectangular and circular plates still represents an important research topic, which is obvious from very recent references [3–6].

The structural intensity (SI) analysis, which calculates vibration energy flow from vibratory velocity and internal force of the structure, gives information on source power, dominant transmission paths and energy dissipation. As explained in [7] many problems related to structural vibration require some control measures to be taken to reduce the amount of mechanical energy being transported by structural waves, where vibroacoustical isolation of sources generally does not yield a complete solution. It is therefore very useful to determine the dominant paths of power flow through the structure [7]. Hence, the structural intensity analysis provides additional information and deeper physical insight into vibration characteristics of the structure. The structural (vibration) intensity analysis is investigated for a long time, both experimentally and numerically. The usual objective of measuring the vibratory energy propagation is exact determination of vibration source location, identification of energy propagation paths and regions of vibration absorption [8]. In 1970, Noiseux introduced power flow measurement method for beams and plates, based on measured acceleration and wave equation [9]. After that,

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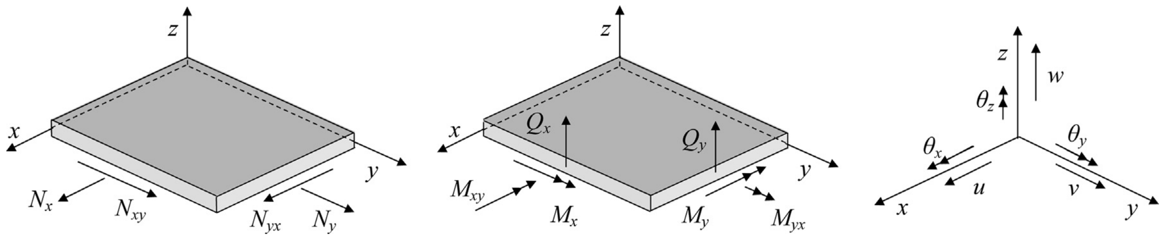

Fig. 1. Forces, moments and displacements for plate element.

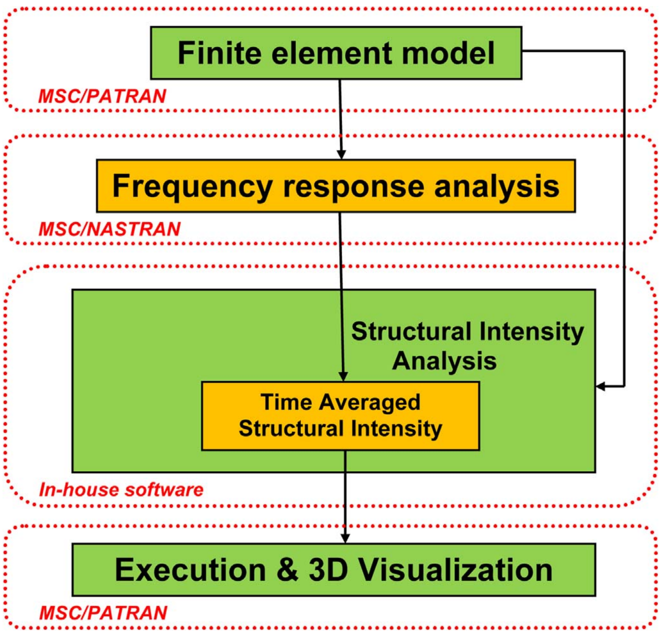

Fig. 2. Flowchart of computational system for structural intensity analysis and visualization.

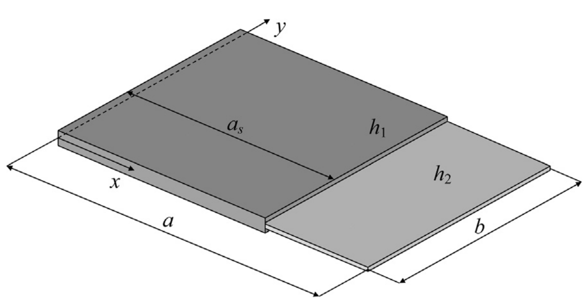

Fig. 3. Rectangular plates with stepped thickness.

Table 1
Thickness of plate for different case.

Case	h_1 (mm)	h_2 (mm)	h_2/h_1
A	20.00	20.00	1.00
B	15.00	25.66	1.71
C	25.66	15.00	0.58
D	10.00	32.63	3.26
E	32.63	10.00	0.31

measurement methods based on vibratory amplitudes in frequency and/or time domain and internal forces numerically estimated by the finite difference method are offered by Pavic [7], Fahy and Pierri [10] and Verheij [11]. In this context it is also worthy to mention frequency response technique introduced by Linjama and Lahti [12], near-field acoustical holography presented by Saijyou and Yoshikawa [13], and scanning laser vibrometer presented by Pascal et al. [14]. Eck and Walsh [15] used electronic speckle pattern interferometry to measure vibrational energy flow in a plate with high energy flow boundary crossing, while Mandal et al. [16] performed experimental investigation of power flow in thin technical orthotropic plates in frequency domain by the two-transducer method, using the cross-spectra of acceleration signals. In the context of numerical models, application of the finite element (FE) method using the normal mode approach to SI analysis of structures is illustrated for a simply supported plate by Gavric and Pavic [17]. The SI pattern of composite plates with opening is studied by Xu et al. [18]. The same group of authors presented very interesting SI application case within the energy transmission study of rotating hard disk systems [19]. The transient dynamic characteristics of plates under low-velocity impacts are analysed by Liu et al. [20]. Structural intensity analysis of thin laminated composite plates subjected to thermally induced vibration is performed by Tran et al. [21], where streamline technique, well-known presentation tool from fluid mechanics, is used to represent the obtained results. Park and Hong [22] utilized SI technique to analyse transverse vibration of Mindlin plates considering the effects of shear distortion and rotary inertia, while Xu et al. applied SI technique to analyse vibration performance of stiffened panels of marine structures [23]. Also, utilizing the FE method, Khun et al. [24] performed SI analysis of plates with multiple discrete and distributed spring-dashpot systems. The energy transmission through a box-type structure built up by plates is considered by Chen et al. [25], while Roozen at al. [26] used measured data of kinematic quantities to compute structural intensity and its irrotational part in plate-like structures. Very recently, Petrone et al. [27] presented numerical and experimental analysis on structural intensity in orthotropic rectangular plates, investigating the effects of constraints, load conditions, damping, thickness and fibers orientation. Finally, it is worthy to mention novel attempt to extend the SI concept to the random domain by introducing a physical quantity denominated random structural intensity (RSI), with application to mechanical systems whose dynamical responses are stochastic due to random excitations [28].

Within the scope of FE application to SI analysis, it is important to mention the use of different calculation systems, involving commercial tools at some assessment level like NASTRAN [29,30], ANSYS [18,19,23,31], or ABAQUS [21,24,32].

In spite of the above described wide range of applications of the structural intensity technique to different structures, to the author's knowledge there are no available references dealing with its application to stepped thickness rectangular plates. Moreover, in all above references, the total structural intensity is considered, which provides only global perspective on the energy transmission.

Motivated by the state-of-the art and in order to shed more light on vibration phenomena inherent to stepped thickness rectangular plates subjected to harmonic excitation force, in this paper their SI analysis utilizing the finite element method is performed. Therefore, expressions for structural intensity of plate