PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Renaissance of the Structural Intensity Analysis

Heow Pueh LEE[1]; Kian Meng LIM[2]

[1,2] National University of Singapore, Singapore

ABSTRACT

Structural intensity represents the flow of energy within a structure, subjected to external excitations. The interest in structural intensity comes from its practical applications such as damage detection, structure-borne noise control and structure optimization. By visualizing the flow of power, it is possible to identify the transmission paths and sources/sinks of mechanical energy within structure. It is a powerful tool for monitoring the structure behavior under different loading conditions which would result in altering energy flow path by using dissipative elements or mechanical modifications. We have extended the applications to not only structural mechanics, but also impact mechanics, fracture mechanics, rotating disk, thermal induced vibration as well as biomechanics. In recent years, Acoustic Black Hole (ABH) is developed for the flexural waves in the beam plate structures. It attracts lots of attentions in focusing wave energy and reducing vibration-acoustic level. It also enhances the efficiency of the passive damping systems, reducing the weight of the damping layers. In this paper, we will first present an overview of the various applications of structural intensity as well as our more recent work on the use of structural intensity for guiding the design of ABH.

Keywords: Structural Intensity, Energy Flow, Acoustic black hole.

1. INTRODUCTION

Structural intensity is a vector quantity representing the power flow per unit cross-sectional area in an elastic medium [1-5]. Analysis of structural intensity in a complex structure could provide essential information about the locations of vibration sources and dominant energy transmission path [6-10]. Reported studies of structural intensity were for various applications ranging from identification of structural defects, vibration reduction, and design optimization [1-17]. There are both reported experimental and numerical studies. Numerical simulations such as the Finite Element Method could be used to generate the flow path of Structural Intensity. The earlier reported works were all related to the vibration of plates and other structures in the general area of structural mechanics. We have over the years extended the applications to not only structural mechanics, but also impact mechanics, fracture mechanics, rotating disk, thermal induced vibration as well as biomechanics. The formulation of Structural Intensity can be found in many papers and will not be presented here. Instead, the various examples of applications will be highlighted in this paper.

2. EXAMPLES OF STRUCTURAL INTENSITY APPLICATIONS

2.1 A Plate with a Damper Excited by a Point Force

Figure 1 shows the classical example of the structural intensity flow path from the point of excitation which is the energy source to a damper, which is the energy sink. The flow of the Structural Intensity can be presented in both the vector plot and the streamline plot. The analysis can be easily extended to a plate with multiple excitation point sources and multiple energy sinks in terms of multiple dampers. A potential application is the diversion of energy away from a crack tip or quiescence area by placing dampers at suitable locations.

[1] mpeleehp@nus.edu.sg [2] mpelimkm@nus.edu.sg

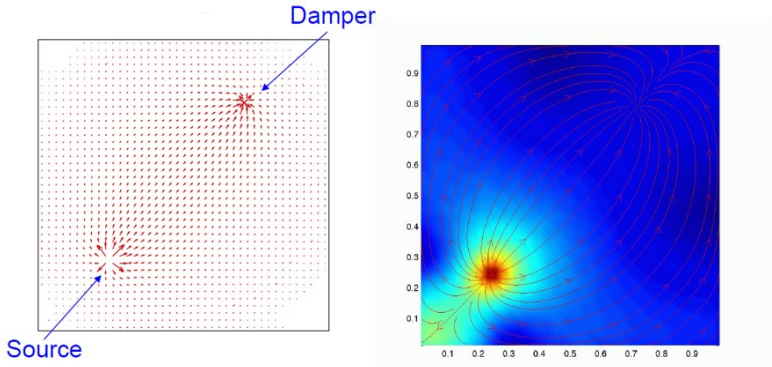

Figure 1 – The Structural Intensity of a plate with a damper subject to a point force excitation.

2.2 Vibration of a Box Structure

Figure 2 shows the structural intensity of a box structure with the external distributed exciting forces at the bottom of the structure. The structural intensity vector and the streamline distribution are also shown in the figure. The box structure could be the cabin of a vehicle or a container.

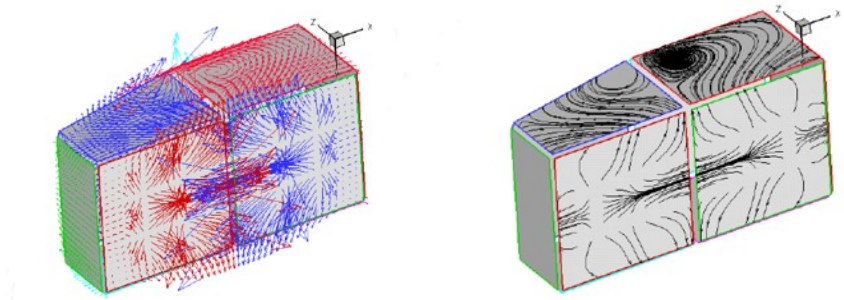

Figure 2 – The Structural Intensity of a box structure subjected to base excitation.

2.3 A Human Head subject to Impact Loading

Head injury is traditionally analyzed in terms of stress wave propagation. Figure 3 shows the structural intensity flow pattern of a human head model subject to an impact loading at the forehead as well as the back of the head. We can see the energy flow towards the spines.

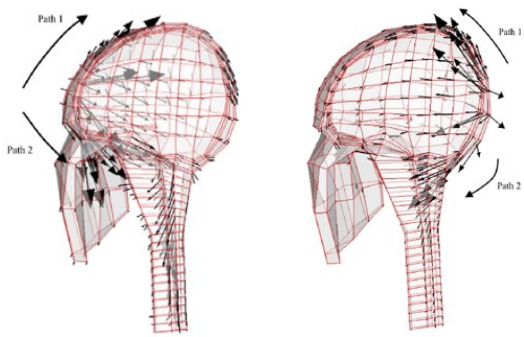

Figure 3 – The Structural Intensity of a human head model subject to frontal and rear impact.

2.4 A Beam with Acoustic Black Hole

Figure 4 shows the structural intensity of a beam with acoustic black hole. More details can be found in the authors' earlier work [11]. We can observe the band of in-plane pointing SI vectors at different regions along the beam. Higher SI values can also be seen on the top and bottom edges of the ribs connecting the beam to the wedge region. Some of the structural intensity vectors at the ribs are pointing out-of-plane instead of in-plane, signifying that the energy/power flow at these regions are actually not along the beam axis.

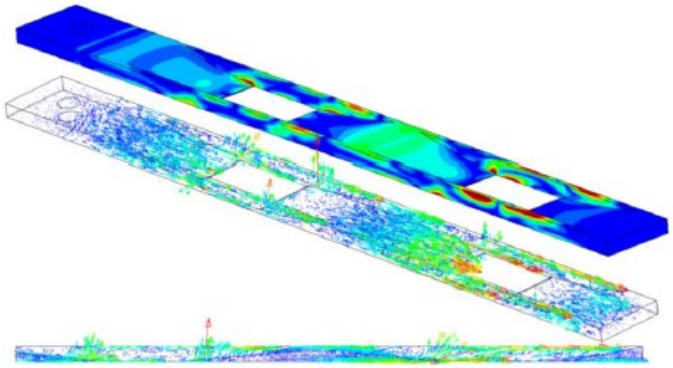

Figure 4 – The Structural Intensity of a beam with Acoustic Black holes.

2.5 A High Heel Shoe with Reinforcement Bars

The Structural Intensity analysis can also be used for shoe design such as the diversion of energy from the point of impact. Figure 5 shows the Structural Intensity of the base of a high heal shoe with two reinforcement bars to divert the energy from the point of impact at the heel to the front of the shoe. Other potential designs such as reinforcement base plate has also been investigated.

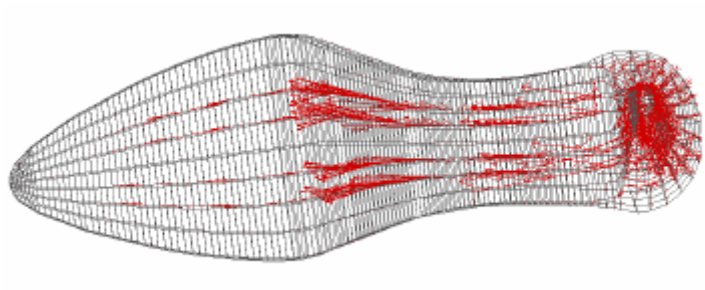

Figure 5 – The Structural Intensity of a high heel shoe with two reinforcement bars.

The drastic differences between the structural intensity of a flat shoe and a high heel shoe is shown in Figure 6. We can see the severe stress concentrations in the calcaneus for high heel shoe.

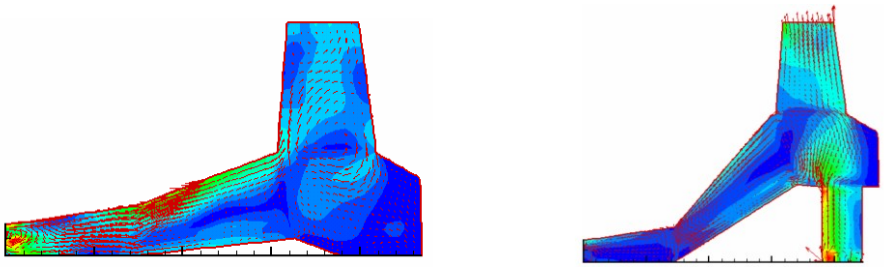

Figure 6 – The Structural Intensity of a flat shoe and a high heel shoe.

3. CONCLUSIONS

The paper has presented a few examples from traditional structural mechanics to biomechanics and also specific examples related to the analysis of shoe designs. There are many other potential applications from ships to airplanes which have not been covered in this short presentation. For example in the field of fracture mechanics, it has been derived theoretically that the normal component of the structural intensity along crack edge equals J-integral. Structural Intensity is the power flux or

vector representation of the J-integral at the crack tip [17].

ACKNOWLEDGEMENTS

This study is supported by the Singapore Maritime Institute (Project ID: SMI-2015-MA-08).

REFERENCES

1. Gavric′ L, Pavic′ G. A finite element method for computation of structural intensity by the normal modeapproach. Journal of sound and vibration. 1993;164 (1): 29–43.
2. Pavic′ G. Measurement of structure borne wave intensity, part i: Formulation of the methods. Journal of Sound and Vibration. 1976;49 (2): 221–230.
3. Pavic′ G. The influence of curvature on structure-borne acoustical power propagation in a cylindrical circular shell. 1986;Paper D:6–6.
4. Gavric′ L. Power-flow analysis using infinite beam elements, Le Journal de Physique IV, 1992;2 (C1):C1–511.
5. Xu X, Lee HP, Wang Y, Lu C. The energy flow analysis in stiffened plates of marine structures. Thin-Walled Structures. 2004;42 (7):979–994.
6. Xu X, Lee HP, Lu C, Guo J. Streamline representation for structural intensity fields. Journal of sound and vibration. 2005;280 (1):449–454.
7. Cies′lik J. Vibration energy flow in rectangular plates. Journal of Theoretical and Applied Mechanics 2004;42(1):195–212.
8. Hambric SA. Power flow and mechanical intensity calculations in structural finite element analysis. Journal of Vibration and Acoustics. 1990;112 (4):542–549.
9. Wong W, Wang X, Cheng L. Modal power flow analysis of a damaged plate. Journal of Sound and Vibration. 2009;320 (1):84–100.
10. Noiseux D. Measurement of power flow in uniform beams and plates. The Journal of the Acoustical Society of America. 1970;47 (1B):238–247.
11. Chong BMP, Tan LB, Lim KM, Lee HP. A review on acoustic black-holes and the experimentaland numerical study of ABH-featured 3d printed beams. International Journal of Applied Mechanics. 2017; 1750078.
12. Li K, Li S, Zhao DY. Investigation on vibration energy flow characteristics in coupled plates by visualizaiton techniques. Journal of Marine Science and Technology. 2010;18 (6):907–914.
13. Rook T, Singh R. Structural intensity calculations for compliant plate–beam structures connected by bearings. Journal of sound and vibration. 1998;211 (3):365–387.
14. Pang ZH, Xiang Z. Nonlinear dynamical analysis of a breathing crack plate based on structural intensity method. DEStech Transactions on Materials Science and Engineering, AMMME, 2016.
15. Tian X, Liu G, Gao Z, Chen P, Mu W. Crack detection in offshore platform structure based onstructural intensity approach. Journal of Sound and Vibration. 2017;389:236–249.
16. Kim KS, Kang YJ, Chin SW, Jung IH, Lee JW. Damping patch placement on outdoor unit of air-conditioner by using structural intensity technique, International Refrigeration and Air Conditioning Conference at Purdue, 2004. p. R092.
17. Wang F, Lee HP, Lu C. Relations between structural intensity and J-integral. Engineering Fracture Mechanics. 2005;72 (8):1197-1202.