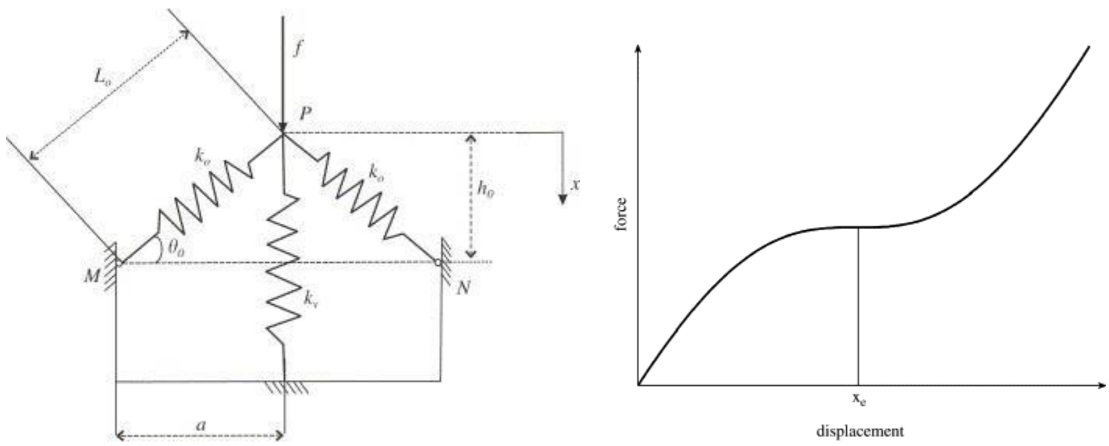
Summary of Research

Background

A sacrificial structure which serves as a line of protection for the main isolated structure, should play two roles as an energy absorber and a load threshold, which prevents the propagation of excessive energy or force in main structure (Wadee, Phillips & Bekele, 2020). A structural model which satisfies those two requirements, along with its typical load-displacement response, is presented in **Figure 1 (a)** and **(b)** (Carrella, Brennan & Waters, 2006, p.679).



(a) Structural model (b) Typical load-displacement response

Figure 1 Structural model and load-displacement response of isolator (Carrella, Brennan &Waters, 2006: p.679)

The quasi-zero stiffness range in **Figure 1.1 (b)** acts as a load threshold because within this range the increase in displacement will result in no increase in load transferred from sacrificial structure to main structure. Elongating this quasi-zero stiffness range is of prior interest by researchers as the zero-stiffness nature is perfectly efficient for energy absorption.

The name of "sacrificial" implies a bad ending for the structure after it fulfills its function of structural isolation. This research aims at making the structure used for structural isolation less "sacrificial" by introducing a recoverable feature, so that the structure may be able to function for multiple times. This recoverable feature comes from the introduction of sequential buckling of lattice layers by deliberate utilization of snap-through instability at unit cell level. The illustration of snap-through and sequential buckling behaviour are shown in

Figure 2 and Figure 3.

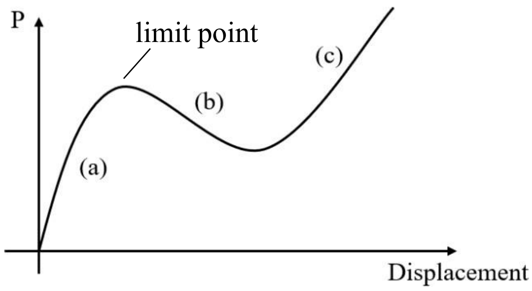


Figure 2 Illustration of snap-throughbehaviour

Figure 3 Illustration of sequential buckling behaviour

From **Figure 2 and Figure 3**, one can think of sequential buckling as a series of snap buckling, which gives an idea that if the layers of a lattice experience snap buckling in a sequential manner and meanwhile the limit point of each layer is maintained at a practically same level, then an approximate quasi-zero stiffness range could be obtained, as illustrated in **Figure 4**. In this way, elongating the quasi-zero stiffness range of equilibrium path becomes simple as the number of lattice layers dictate the length of this range. Also, if the snap buckling of each layer is pure elastic, then an ideal recoverable structure with 100% of recoverability can be obtained. While it is not always practical to have pure elastic buckling and when plasticity occurs in the structure, the percentage of recovery could be investigated and designed to fulfil service requirements.

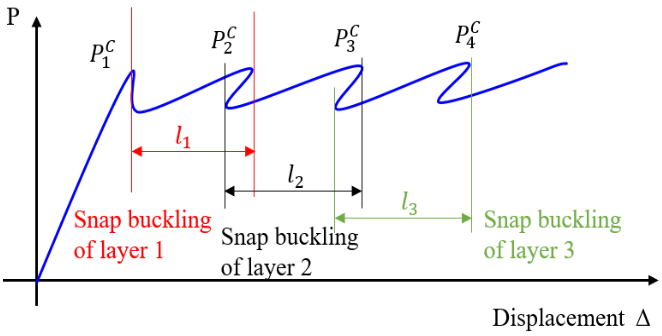


Figure 4 Illustration of the approximate quasi-zero stiffness range

Research Outline

General

This research numerically explores recoverable lattice structures for structural isolation. Material employed in this study is stainless-steel powder for additive manufacturing. Detailed material properties can be referred to previous work by Zhang et al. (2021). Commercial software ABAQUS 2020 is used for numerical modelling.

Unit cell level

At unit cell level, the main aim is to find out suitable geometry and configuration of unit cell which can provide the snap-buckling behaviour as well as a high level of recoverability. Different configurations of two-dimensional unit cell are studied in the second chapter of thesis and a unit cell with its configuration presented in **Figure 5** is proved to be able to provide a snap buckling equilibrium path under quasi-static loading as well as relatively high recoverability. This unit cell is consisted of external beams and internal struts. The quasi-static loading direction and boundary conditions are also shown in **Figure 5**. An illustration of typical equilibrium path of this unit cell with loading and unloading parts is shown in **Figure 6**. The equilibrium path can be conceptually divided into two ranges: the first range is "internal strut dominant" and the second range is "external beam dominant". Detailed explanation of these two ranges is presented in Chapter 2.

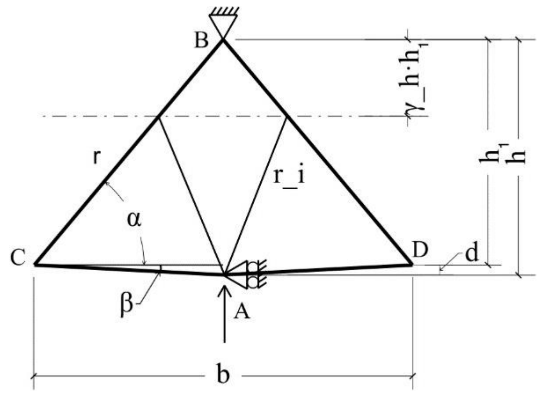


Figure 5 Illustration of the approximate quasi-zero stiffness range

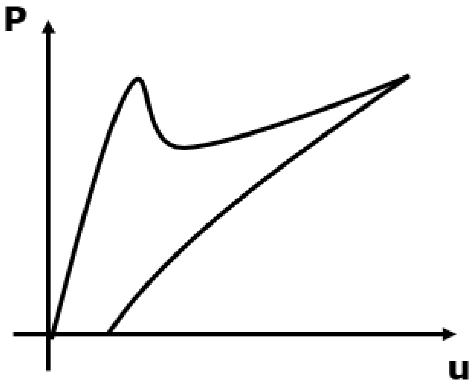


Figure 6 Typical equilibrium path

The parameters shown in **Figure 5** play very important roles in the mechanical behaviour of the unit cell. By altering these parameters one can dictate the shape of equilibrium path of unit cell as well as the level of recoverability. The effect of these parameters is discussed in the end of Chapter 2. With deliberate determination of these parameters, 70%-80% recovery can be achieved. The insight into these parameters gives the flexibility of designing the sacrificial lattice for different designing requirements.

Lattice level

The investigation at unit cell level provides very useful information for the study at lattice level. A three-dimensional numerical model is shown in **Figure 7**. Load condition and theoretical conditions are shown in **Figure 8**. Two ways of specifying geometric parameters of lattice layers are explained in Chapter 3 in order to achieve the sequential buckling behaviour.

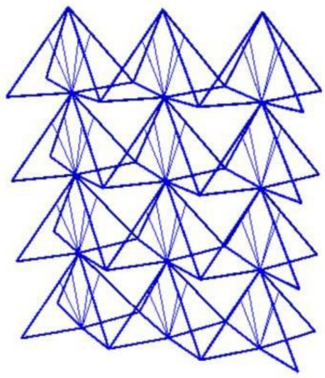


Figure 7 3(columns) × 4(rows) lattice

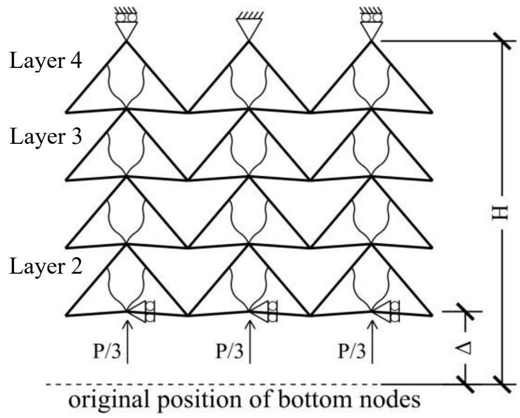
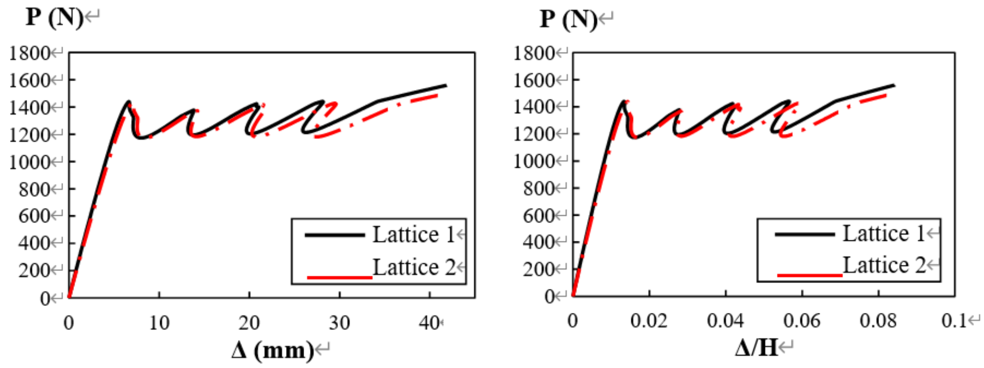


Figure 8 Theoretical load and boundary condition

Two lattices are then studied in this part of research with the two different parameter assigning methods. Details of the two lattices are given in Chapter 3. The load displacement response of the two lattices are presented below. A 70%-80% recovery is predicted for the lattices designed.



(a) P-Displacement curve (b) P-Normalized displacement curve

Figure 9 Load displacement response for lattice 1 and lattice 2

Reference

Carrella, A., Brennan, M. J. & Waters, T. P. (2007) Static analysis of a passive vibration isolator with quasi-zero-stiffness characteristic. *Journal of Sound and Vibration.* 301 (3-5), 678-689.

Wadee, M. A., Phillips, A. T. M. & Bekele, A. (2020) Effects of Disruptive Inclusions in Sandwich Core Lattices to Enhance Energy Absorbency and Structural Isolation Performance. *Frontiers in Materials.* 7.

Zhang, R., Gardner, L., Meng, X., Buchanan, C., Matilainen, V. P., Piili, H., & Salminen, A. (2021). Optimization and compressive testing of additively manufactured stainless steel corrugated shells. *Eurosteel 2021*, Sheffield, UK.