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Lateral stiffness of polycal wire rope isolators – An experimental study

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Abstract. The PWRI is a type of passive isolation system which is commonly used as shock and vibration isolation system especially applied in lightweight equipment and electronic devices. The PWRI can provide isolation in all direction. It can be flexible in any direction and in all three planes which depends on its stiffness. An experimental study of the lateral stiffness of Polycal Wire Rope Isolators (PWRI) is presented in this paper. It also studied effect of variations in height and width of PWRI on its static stiffnesses. Suitable experimental setup was designed and manufactured to meet the test conditions. The results show that their elastic stiffnesses for lateral loading conditions are highly influenced by their geometric dimensions. It is found that their compressive stiffness reduced by 56% for an increment of 25% in their height to width ratio. Therefore, the stiffness of PWRI can be fine-tuned by controlling their dimensions according to the requirements of the application.

1. Introduction

Vibration and shock can cause damage to the equipment and structure which become major concerned by many industries and seismic countries. Vibration isolators such as wire rope isolators (WRI) can be used as a system to attenuate the vibration and shocks effectively [1, 2]. Wire rope isolator is comprised of few wire ropes which are griped in between two metal mounting plates which can be in spherical or helical shape, which is named polycal wire rope isolator (PWRI) as shown in figure 1. Vibration energy is dissipated due to the frictional rubbing between wire rope strands [1, 3].

Figure 1. Polycal Wire Rope Isolator (PWRI)

Many researchers have carried out an intensive study on the wire rope isolators. There are wide potential applications for WRI such as in aerospace and industrial machinery [4]. Besides, WRI provides vibration isolation in all directions. It can be simplified as a damper with a damping coefficient (C), which dissipates energy and a spring with a stiffness coefficient (K), which represents elasticity of the system. Characteristic of stiffness can be determined through monotonic loading, which involves loading and unloading process in the experiment in this paper. During the loading process, the increase of the load on the isolator will lead the isolator to increase in displacement. However, due to non-linear behaviour of the isolator, the gradient of the load-displacement curve or compression stiffness decrease, with an increase of the displacement. C. Weimin et al. [5] explained the softening phenomenon is due to the certain degree of slip happens between wire rope strands and wire rope undergo a certain degree of twisting. The author then elaborated upon the loading and unloading curve of the ring structure wire rope isolator into the double-linear retarding model as described in the paper in which the stiffness was divided into two values which were early stiffness, K_1 and later stiffness, K_2.

Demetriades et al. [6, 7] performed the study on the stiffness and damping capacity of helical wire rope isolators and suggested that the stiffness properties of the WRI is a function of its geometric dimensions and wire rope material properties. Balaji et al. [8, 9] has developed the analytical models for the stiffness of helical WRI and these models can be used to design the helical WRI. Massa et al. [10] designed a ball transfer unit to improve the vertical stiffness of the WRI. The studies [6, 7, 11, 12] available in the literature are mainly available for helical type WRI however the studies on PWRI are very limited. Hence, in this work, the lateral static stiffness and its influence of height-width ratio is studied experimentally using monotonic loading tests. This study can enhance the understanding of stiffness characteristics of PWRI.

2. Methodology

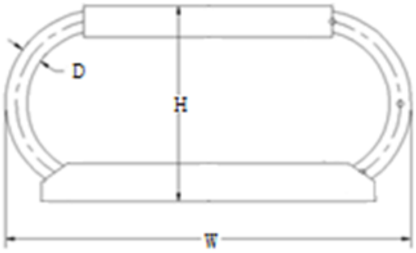
2.1. Equipment

The monotonic loading experiment was carried out in-house using the INSTRON Universal Tensile Testing Machine (UTTM) (figure 2). It is able to provide a maximum load of 100kN to the specimens. The testing machine sent the data to the Bluehill software and was then processed and displayed as a graph. The raw data was saved in the form of a graph in a PDF format as well as in an excel file. Several parameters such as loading speed, displacement and processes must be set properly into the Bluehill software before running the UTTM.

Figure 2. INSTRON Universal Tensile Testing Machine 5982

2.2. Test specimens

Three isolators were tested in the present study. Each isolator has its unique geometrical properties (figure 3) such as height, width and wire rope diameter which are listed in table 1. All of the isolators consist of a 6 x 19 stainless steel Independent Wire Rope Core (IWRC) wire rope. All wire ropes were held in a circular arrangement for the PWRI which are symmetric in vertical axis.



W = Width, H = Height, D=Diameter

Figure 3. Geometrical properties of PWRI

Table 1. Specification of PWRI

No	Model	D (mm)	W (mm)	H (mm)
1	GGQ 1.0-37	2.5	76	37
2	GGQ 0.9-47	2.5	77	47
3	GGQ 0.55-56	2.5	80	56

2.3. Fixture Design

In the present experiment, the fixtures were designed to hold the isolator so it can only move in a lateral direction as shown in Figure . Each end of the PWRI was bolted tightly onto each fixture before being clamped to the machine.

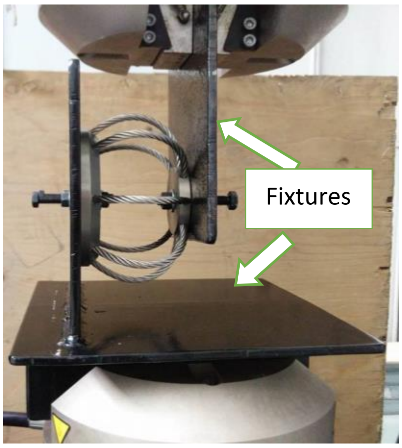


Figure 4. Fixtures used for the PWRI during lateral loading test

2.4. Experiment procedure

The isolator was attached to fixtures using bolts and nuts. The fixtures were then secured to the UTTM through the UTTM clamping device. The monotonic compressive loading method and the displacement control settings were selected in the Bluehill Software. The test was configured to displace isolators up to 1mm and then return to its original position (unloading). The isolators were controlled at a slow displacement of 2mm per minute, which was assumed to be quasistatic loading.

3. Results and discussions

Lateral monotonic compression tests have been carried out. The load-displacement graph generated was first modelled into double-linear retarding model shown as figure 5. Then, lateral stiffness was calculated using equation (1) and tabulated into table 2. Figure 5 illustrates the loading and unloading curve which was generated by the UTTM after the monotonic test. The initial loading and initial unloading stiffness was represented by K_1 while the final loading and final unloading stiffness was represented by K_2. Since the two springs constants K_1 and K_2 are connected in a series, the total lateral stiffness, K_L is given by,

$$\frac{1}{K_L} = \frac{1}{K_1} + \frac{1}{K_2} \tag{1}$$

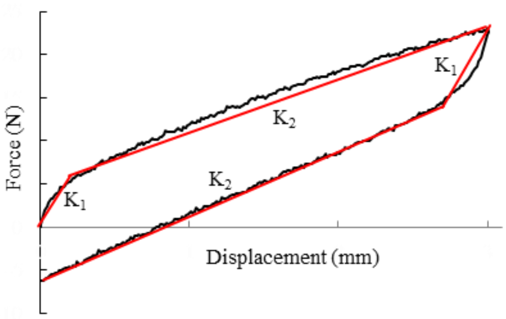


Figure 5. The double-linear retarding model of the PWRI

Table 2. Experimental results of lateral stiffness

Isolator No.	Model	Experimental Lateral Stiffness, K_L (N/mm)
1	GGQ 1.0-37	5.0
2	GGQ 0.9-47	2.2
3	GGQ 0.55-56	1.5

Isolators with different geometric dimensions have different static stiffnesses. It can be observed in table 2 that isolator 1 is the stiffest among all other isolators, and isolator 3 is the least stiff. This is becase isolator 1 has the lowest height and the width among all the isolators. Similarly, the isolator 3 hashe highest height and lowest width among all the isolators. Hence, it can be concluded that stiffness of WRI is greatly influenced by the height and width. These findings are in support of the published data in current literature [8].

3.1. Influence of height to width ratio

This section discusses the influence of height to width ratio of wire rope isolator diameter on their compressive static stiffness. The geometry of PWRI depends on its height and width. Therefore, the changing of height and width of PWRI affects the static stiffness value. The comparison among Isolator 1, 2 and 3 was made to highlight the influence of height to width ratio on the static compressive stiffness since they differ only in their height to width ratio. Figure 6 shows that the static stiffness decreases when the height to width ratio increases. An increase in height to width ratio by 20% decrease the compressive static stiffness by 55%. This decrease in static stiffness can be explained by slenderness aspect of the PWRI. Larger ratio means a slender PWRI and it may cause instability for specific application. Therefore, the compressive static stiffness of a PWRI is important to know for the selection of suitable dimensions of PWRI for any particular application.

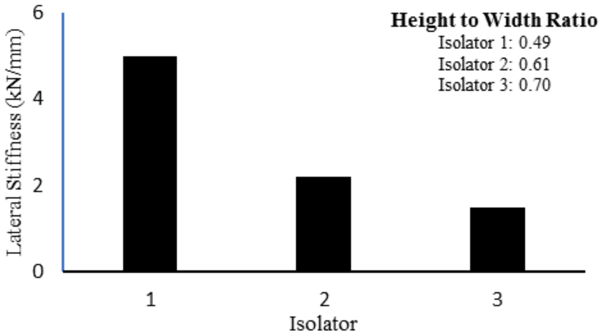


Figure 6. Comparison of Lateral Stiffness for Isolator 1, 2 and 3

4. Conclusions

In this work, monotonic loading tests were performed to study the static stiffnesses of the polycal wire rope isolators. It was observed that the static stiffnesses of PWRI were greatly influenced by their geometric dimensions. It was clearly understood that their stiffness could be controlled by their height to width ratio depending on the application requirements. High stiffness can be obtained by lowering the height to width ratio and vice versa is applicable.

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