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Experimental study on vertical static stiffnesses of polycal wire rope isolators

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Abstract. Wire rope isolator is one of the most effective isolation system that can be used to attenuate the vibration disturbances and shocks during the operation of machineries. This paper presents the results of investigation on static elastic stiffnesses (both in tension and in compression) of Polycal Wire Rope Isolator (PWRI) under quasi-static monotonic loading conditions. 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 both tension and compression loading conditions are highly influenced by their geometric dimensions. It is found that their compressive stiffness reduced by 55% for an increment of 20% 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 is one of the most destructive means for industrial equipment or structures. The sources of vibration are either by nature such as an earthquake, wind and ocean waves or man-made such as the operation of heavy machineries and piling constructions [1, 2]. These vibrational disturbances can gradually reduce the life of machines or structural elements in the industry [3]. Hence, vibration isolation system is used to minimize the harmful effects of vibration disturbance. Polycal Wire rope isolator (PWRI) is effective in isolating the system from vibrational environment. Wire Rope Isolators (WRI) possess high damping capabilities which can help in vibrational energy dissipation [4]. Additionally, it can provide protection by limiting the amount of displacements occurred. PWRI is assembled by stranded wire ropes held with rugged metal retaining discs as shown in Figure 1. This design provides flexibility and energy absorption characteristics together with large displacement capacity to obtain its damping effect from the sliding friction between the twisted wire ropes [5]. WRI has benefits such as high damping effectiveness, low maintenance, thermal insensitivity, durability, and low cost which are the reasons for its popularity in the isolation field. In addition, the performance of WRI is highly dependent on its geometric dimensions [6]. Therefore, it is practically essential to gain better understanding of the behaviour of the WRI.

WRI is mainly governed by its stiffness (K) and damping coefficient (C) whereby stiffness represents the load-supporting and damping coefficient represents the energy-dissipating capabilities of the isolators respectively [3, 7]. There are plenty of different geometries and stiffness values of wire rope isolator available in the market. The selection of suitable wire rope isolator for any particular application generally relies on the static stiffness. Besides, the knowledge on static stiffness is also applicable in the appropriate design of WRI [8]. In other words, it indicates the load-carrying capacity of the WRI. The static stiffness in wire rope isolation system can be estimated from the monotonic loading test.





Figure 1. Polycal Wire Rope Isolator (PWRI)

Monotonic loading can be attained by applying load in vertical direction and can be presented in a load-displacement graph [3]. The slope of the load-displacement plot indicates the vertical stiffness. In the previous studies, WRI appeared to be non-linear at high displacement amplitudes but at small displacement amplitudes the load-displacement relationship can be assumed to be linear [5, 9]. Therefore, the detailed study on the static stiffness WRI is quite limited in the literatures as most literatures are available for cyclic loading [3]. Demetriades et al. [5, 10] 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, 11] 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.[12] designed an ball transfer unit to improve the vertical stiffness of the WRI. The studies [5, 10, 13, 14] available in the literature are mainly available for helical type WRI however the studies on PWRI are very limited. Hence, in this work, the vertical 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

The experimental work was conducted to understand the behaviour of polycal wire rope isolator with different geometric dimensions under vertical loading (Figure 2(a)). Vertical loading was applied in both tension and compression directions. All the polycal wire rope isolators were tested under monotonic quasi-static loading condition to determine its static elastic stiffness. The three isolators (Figure 2(b)) are tested in this experimental work. Each isolator has its own individual geometric dimensions varying with wire rope diameter, height and width as given in Table 1.

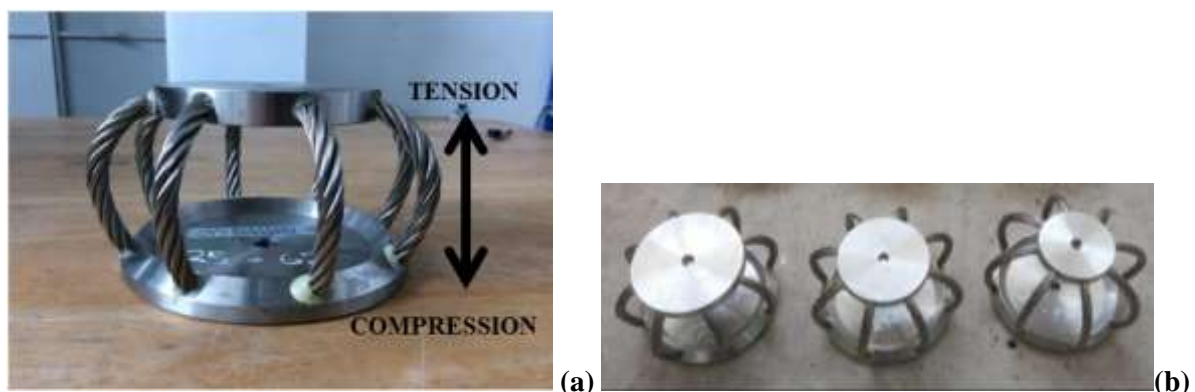
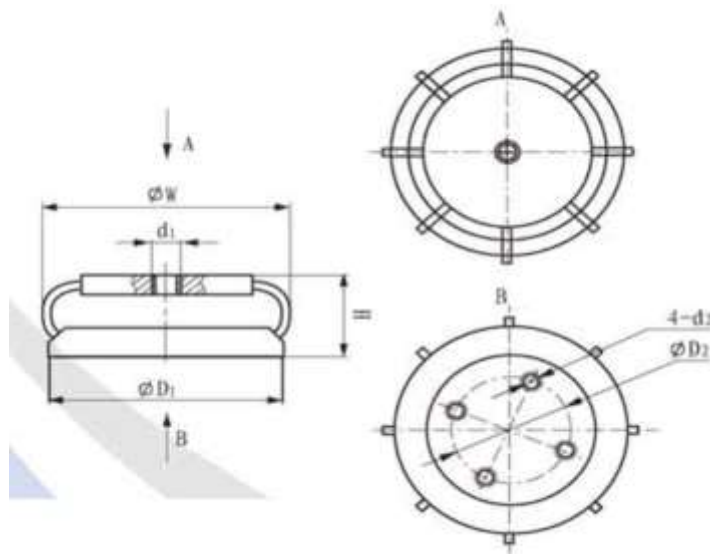


Figure 2. (a) Loading directions of PWRI for Experiment Work (b) Polycal Wire Rope Isolator for Experimental Work

Table 1. Specifications of WRI

Isolators No.	Wire Rope Diameter (mm)	W (mm)	H (mm)	D1 (mm)	D2 (mm)	d1 (mm)	d2 (mm)
1	6.4	124	62	102	60	M8	M6
2	6.4	120	71	102	60	M8	M6
3	6.4	120	76	102	60	M8	M6

$\varnothing W$ = Width Dia., H = Height, D_1 = Outer Dia. at bottom, D_2 = Inner Dia. at top, d_1 = Bolt Dia. at top, d_2 = Bolt dia. at bottom. The dimensions are illustrated in Figure 3.

**Figure 3.** Dimensions of WRI (WU XI HONGYUAN)

3. Experimental Set Up

All experimental tests were conducted in Curtin University, Malaysia, using the INSTRON Machine 5982 available in the laboratory as shown in Figure 4. It can produce up to 100kN of loading which is sufficient for the test. It provides high accuracy data acquisition facilitated by Bluehill Software. By using it, the load-displacement graph is displayed in the computer during the test. In order to apply monotonic loading in vertical direction, suitable fixtures were designed. The loading rate is 2 mm/min both in tension and in compression. The test was done in the displacement control mode. The INSTRON top and bottom grip is controlled by the hydraulic power for effective gripping. Furthermore, the top and bottom plate of PWRI are not compatible for directly gripped by the loading machine. Hence, there is a need of a fixture for of the PWRI. The drawing of the fixture used in this work is shown in the Figure 5-6. These fixtures enable the INSTRON machine to apply the desired loading. Figure 5-6 showed the designed fixtures for both tension and compression loading conditions.



Figure 4. Loading Test of WRI in Vertical Directions

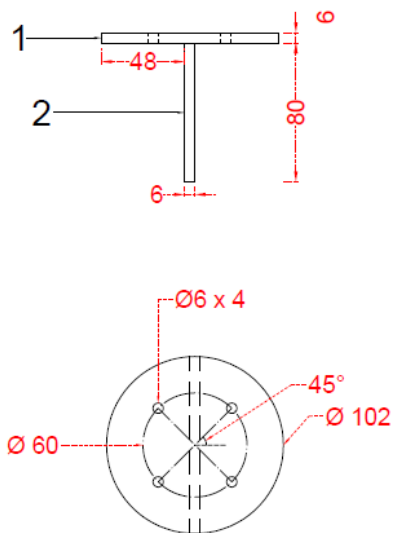


Figure 5. Bottom fixture for gripping the bottom metal retainer of PWRI

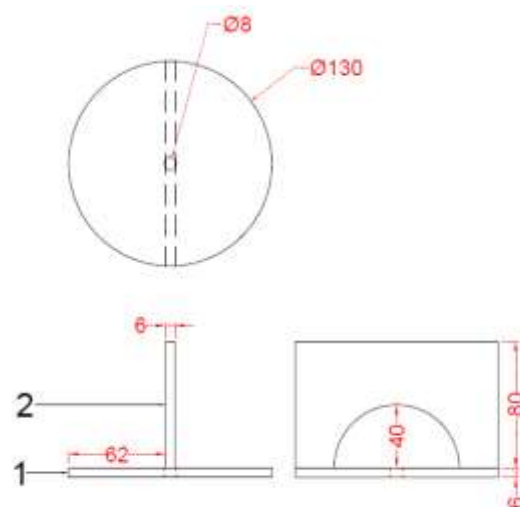


Figure 6. Top fixture for applying tension/compression loading

4. Results and discussions

This section presents the result of the monotonic loading tests. The static elastic stiffness of WRI was determined from the behaviour in monotonic loading condition. The slope of the load-displacement graph represents the static stiffness of WRI and it is obtained by best-fitted linear curve from the experimental data points.

4.1. Static Vertical Stiffness

Load-displacement plot in the vertical direction are presented in Figure 7-8 and the vertical stiffnesses data are presented in Table 2. It can be seen from the Table 2 that the vertical stiffness value under the compressive loading condition is less than the stiffness value in tensile loading condition. This can be explained by the hardening and softening phenomenon in PWRI material. Hardening occurs under tensile loading, which gives more frictions between the wire strands, while softening occurs under compression loading which gives lower frictions between the wire strands. Hence, the isolators will have higher stiffness under tension and lower stiffness under compression loading conditions.

Apart from that, isolators with different geometric dimensions have different static stiffnesses. It can be observed in Figure 7, Figure 8 that isolator 1 is the stiffest among all other isolators, and isolator 3 is the least stiff. This is because isolator 1 has the lowest height and the width among all the isolators. Similarly, the isolator 3 has the 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].

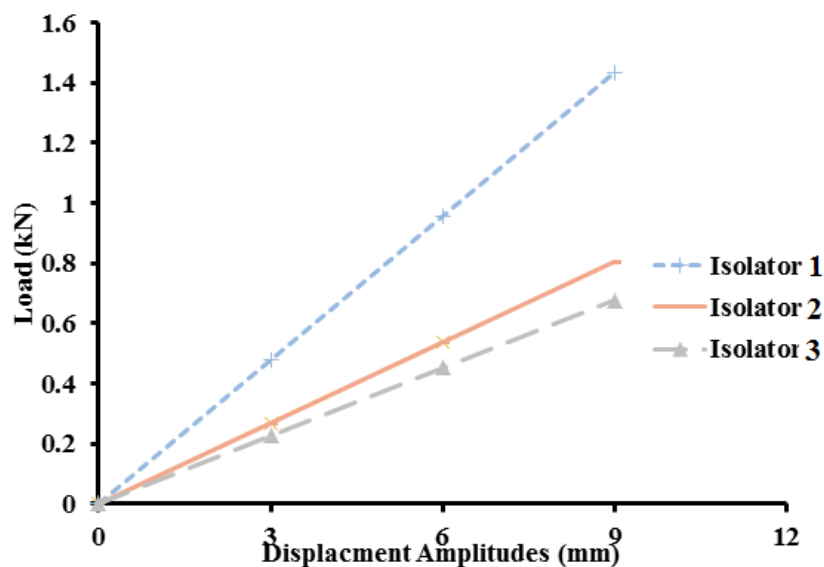


Figure 7. Load-Displacement plots in Compression

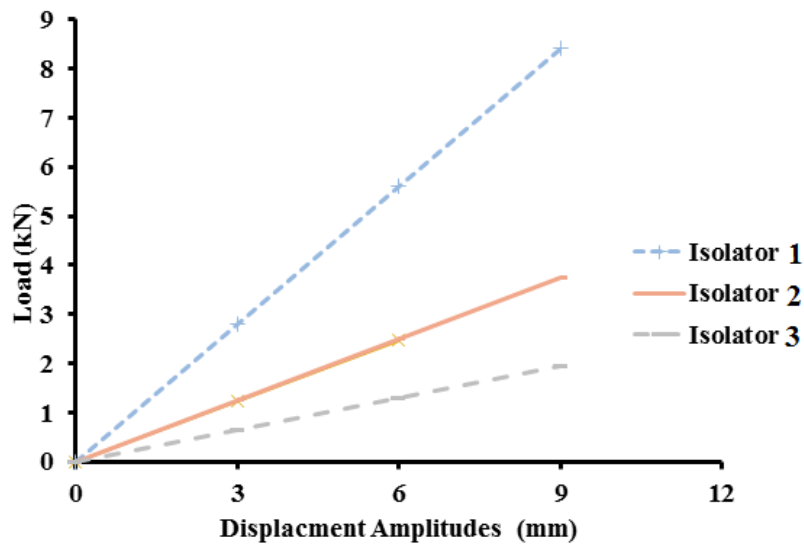


Figure 8. Load-Displacement plots in Tension

Table 2. Static Stiffness for WRI in compression

Isolators	Static Stiffness (N/mm)	
	In compressive loading	In tensile loading
1	160	933
2	89	416
3	75	216

4.2 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 9 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.

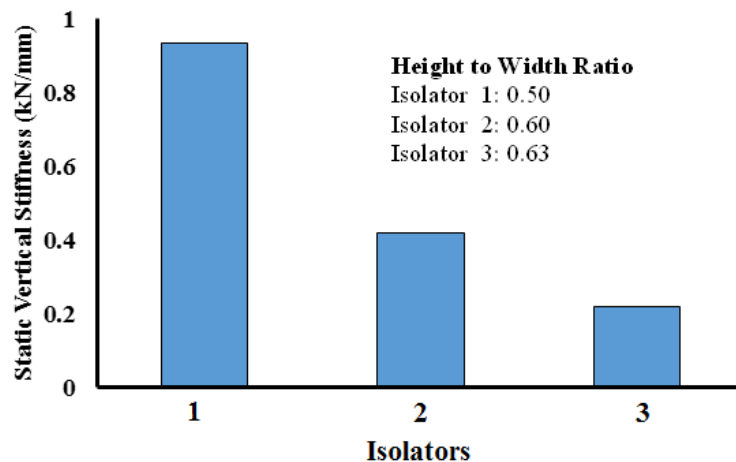


Figure 9. Comparison of Static Vertical Compressive Stiffness for Isolator 1, 2 and 3

5. Conclusions

In this work, monotonic loading tests were performed to study the static stiffnesses of the polycal wire rope isolators. The stiffness of PWRI was observed to be less stiff due to compressive loading as compared to the tensile loading, which can be attributed to the hardening and softening behavior of the wire rope material. It was also 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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