Stiffness characteristics of a polycal wire rope isolators

Aaqib Hussain*1 and P S Balaji2

1 M-Tech(CAD) Student, Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu, India
2 Research Assistant Professor, Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu, India
*Corresponding author: aaqibhussain_s@srmuniv.edu.in

Abstract. Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The source of vibrations can be either natural or man-made. The vibrations caused by such source affect the operation of heavy machines and structures. Polycal Wire rope isolator (PWRI), a type of passive isolator can be used to attenuate the harmful effects of vibration. The main advantage of PWRI is that isolation in all the directions and in all planes can be provided. For a given mass, the key to achieve isolation is by reducing the natural frequency of the system lower than the excitation frequency. This is achieved by applying a flexible isolators and hence, the stiffness of the isolator plays a major role in the isolation applications. In this study, stiffness characteristics of polycal wire rope isolators are determined through experimental and numerical work. The numerical model of the polycal WRI is developed following the equivalent diameter approach using the flexural rigidity of the wire rope. It was found that the wire rope diameter greatly influences the stiffness of a PWRI. This work will enhance the understanding of the wire rope isolator for vibration isolation applications.

1. Introduction

Mechanical vibrations have devastating effects on sensitive equipments or engineering structures. Vibration is a to and fro motion about an equilibrium point. Vibrations are either caused by natural means such as seismic, wind waves, ocean waves etc. or by artificial processes such as operations of heavy machines. It is tolerable in cases such as motion of a vehicle on unpaved road. However, in many cases vibration is not desirable, which include operations of a heavy machinery equipments e.g. the vibrational disturbance resulting from the operations of heavy engines. The harmful vibrational effects progressively reduce the life span of sensitive equipments or structural components. In addition, temporarily sustained vibrations are a common source of undesirable effects such as wear, fatigue, etc. The cases in which the level of vibration is unacceptable, it is required to isolate the receiver from the vibrational disturbances [1].

1.1. Vibration Isolation

There are three components in the vibration isolation namely, Source, path and receiver as discussed [2]. Source of vibration can be natural or artificial. Path refers to the medium through which vibration is transmitted, such as in machinery components. The receiver is a part which may get affected by the vibrational effects as shown in Figure 1. Therefore in order to
isolate the receiver from vibrational effects, it is mandatory to examine the system and to utilise a vibration isolation system to attenuate the vibrational effects and disturbances while operating the mechanical structures [3]. Isolation of equipments and structures from the harmful effects of vibration due to operation of heavy equipments or seismic effects is a major thing in industries and countries that are vulnerable to earthquake or susceptible to wind induced turbulences [4]. Isolation of vibration can be used for mitigating the dangerous vibrational outcomes. Because of sliding friction between the stranded wires and internal friction of wires, the isolator exhibit non-linear hysteric behaviour [5]. Other than mechanical damping characteristics of PWRI in three principal axis, they have other uses such as attenuating strong shocks, aging and thermal insensitivity while having low cost [6].

![Vibration isolation](image1)

Figure 1. Vibration isolation.

1.2. Polycal wire rope isolator

PWRI efficiently isolates the devices and sensitive structures from vibrational disturbances. It is composed of a stranded wire ropes held with metallic rigid discs Fig:2. The Stiffness (k) and damping (C) are the two characteristics of PWRI, Whereby K represents its load-carrying capacity and C represents the vibrational energy dissipation capabilities of the PWRI respectively. The wires move relative to one another having frictional contact [7]. The frictional contact between the wires leads to the depletion of vibrational energy of wire ropes in PWRI. Appropriate selection of PWRI is based on the static stiffness required for any particular application [8]. There are numerous geometries and stiffness values of WRI already available in the market. It has got major advantage that it can withstand in a wide range of temperature and is less vulnerable to the harmful radiation and high temperature, etc. One of the advantages of using this PWRI is in micro-electronic devices and sensitive electronic equipments [9].

![Polycal Wire rope isolator](image2)

Figure 2. Polycal Wire rope isolator

2. Literature Survey

Balaji et al [10] did an experimental research on vertical static stiffness of polycal wire rope isolators. In both tension and compression under monotonic condition was applied for
compression were conducted to the PWRIs with different geometric dimensions. It was observed that the static stiffness in the vertical direction of PWRI to be less stiff in compressive loading as compared to the tensile one, that can be due to the more frictional contact in case of tensile loading as compared to compressive loading. It is also concluded that the static stiffness of PWRI were significantly affected by their height to width ratio. The increase in height to width ratio decreases the stiffness value and vice versa. It is found that by increasing height to width ratio by 20% reduces the compressive stiffness by 55%. Therefore, adjustable changes in geometric dimensions can done to the stiffness of PWRI for the desirable applications.

Balaji [3] did an analytical study for the vertical stiffness of WRIs. By using Castiglianos second theorem, model for the static stiffness was developed analytically in the vertical direction. For validation of the model, monotonic loading tests were conducted. Bending tests in the transverse direction were conducted in order to get values of flexural rigidity on several wire rope cables. They reached a conclusion that the stiffness varies linearly to the number of turns and wire rope diameter unlike other geometric parameters. By increasing the diameter of wire rope by 2.5% leads to increase in the vertical stiffness by 10%. Therefore, the developed analytical model can be explicitly utilised for the design and evaluation of wire rope isolators.

Rashidi [11] examined the effect of quasi-static and dynamic loadings on mechanical vibrations, experimentally and numerically for the wire rope isolators. Since WRIs are utilised in diverse industrial machinery and sensitive equipment, correspondingly fixtures were designed and manufactured for the preferred loading. Using a universal testing machine, it was concluded that the hysteresis loops are independent of the applied loading velocity for quasi-static loading, even though area of the hysteresis loops is increases as amplitude of the loading increases and the stiffness of the isolator decreases on increasing the initial load. Horizontal and vertical excitations were studied in series of experiments for both quasi-static and dynamic loadings. Further, under quasi static loads the Bouc-Wen model was utilised to model the working of the isolator. An artificial neural network model was proposed for a comprehensive prediction of behaviour of the isolator. The model was convergent and for a set of data it was used to predict the experimental cases that were not present in the training process. Finally, the results obtained indicated that the neural network model could predict the hysteresis behaviour of the isolator to a good level of accuracy.

Demetriades [12] analysed analytically and experimentally the WRI systems for protection of components from seismic activity as WRI's are applied in the isolation of machinery. For the two methods of installation where the equipments have been supported by WRI. It was observed that hysteric damping demonstrated by WRI decreases with an increase in motion amplitude. Moreover, it was found that the wire rope system imparts some shielding by allowing for small displacements. Analytical response of a sensitive equipment for WRI's that was forecast were in agreement with experimental results. The floor response spectra is used for the development procedure. This usually represents an input vibration and excitations caused by earthquake for floor supported equipment.

2.1. Summary from Literature Survey

In literature many experimental and analytical studies have been done on WRIs, however very few researches have been carried on the design and workings of Polycal WRIs. Concluding, owing to the widespread applications of Polycal WRIs, it is highly beneficial to examine the stiffness characteristics develop numerical models on PWRI.

2.2. Objectives

The objective of this work is to develop a numerical model for the stiffness of polycal wire rope isolator in the vertical and lateral direction. The developed numerical model was validated experimentally, using a series of monotonic loading tests on the isolators. The numerical model also used to study the effect of height, width and wire rope diameter on the stiffness
characteristics on the PWRI's.

![Lateral and Vertical Displacement](image)

(a) Lateral displacement  (b) Vertical displacement

**Figure 3.** Polycal Wire Rope Isolators.

### 3. Methodology

In order to perform numerical analysis, different geometrical models of Polycal wire rope isolators were modelled using suitable CAD tools. Equivalent diameter concept was used while modelling, in which, instead of modelling the wire rope, an equivalent diameter curved beam was modelled [10]. By importing this model into FEA solver system, stiffness was found. From the force-displacement curve, elastic stiffness was found at smaller displacements. At large displacement, the amplitude curve is non-linear and hence numerical model has limitations at larger displacements. The work is associated with small displacements (linear) and stiffness model is applicable for linear approach. In Experimental work, monotonic loading test were conducted on all the isolators in order to calculate the vertical and lateral stiffness. The five isolators with different geometric dimensions were tested under monotonic quasi-static loading condition to determine stiffness characteristics. (Figure 3).

Table 1 gives the specifications of all the isolators, in which each isolator has its own geometric dimensions varying with width, height and wire rope diameter.

**Table 1.** Specifications of Polycal Wire Rope Isolators

| Isolator No's | Wire Rope Diameter (mm) | W (mm) | H (mm) | D1 (mm) | D2 (mm) | d1 (mm) | d2 (mm) |
|---------------|-------------------------|--------|--------|---------|---------|---------|---------|
| 1             | 0.7511                  | 85     | 43     | 76      | 42      | M4      | M6      |
| 2             | 0.7511                  | 91     | 57     | 76      | 42      | M4      | M6      |
| 3             | 0.7511                  | 96     | 71     | 76      | 42      | M4      | M6      |
| 4             | 1.509                   | 110    | 45     | 102     | 60      | M6      | M8      |
| 5             | 1.509                   | 113    | 62     | 102     | 60      | M6      | M8      |
3.1. Numerical Solution

Numerical analysis on have PWRI with different geometrical dimensions were carried out to find the vertical and lateral stiffness characteristics. These stiffness values were calculated in both tension and compression mode by applying certain displacement on them. In addition, one PWRI model was selected and its height, width and wire rope diameter were varied to observe the effect on change in stiffness characteristics.

4. Results and discussions

This section presents the results of numerical and experimental tests. The numerical models were validated using the monotonic test results conducted on isolators. The corresponding values of numerical and experimental results are tabulated in Table 2 and Table 3. It was also observed that the numerical results were in accordance with the experimental values within 15% error margin. The numerical model evaluates the static vertical and lateral stiffness of PWRI. The numerical model was further extended to determine the effects of height, width and wire rope diameter on the PWRI's vertical and lateral stiffness (Table 4). In order to design the suitable polycal wire rope isolator the developed numerical model may also be extended to obtain a desired stiffness.

### Table 2. Numerical and Experimental Stiffness values.

| Isolator No | Numerical Vertical Stiffness (N/mm) | Experimental Vertical Stiffness (N/mm) |
|-------------|-----------------------------------|--------------------------------------|
| 1           | 30.372                            | 32.054                               |
| 2           | 8.7435                            | 7.317                                |
| 3           | 4.435                             | 3.995                                |
| 4           | 23.5                              | 24.75                                |
| 5           | 32.095                            | 31.56                                |

### 4.1. Influence of Geometric parameters

The geometric parameters that influence the stiffness characteristics are Width, Height and Wire Rope Diameter. So the Stiffness values of PWRI's are also affected by changes in geometric parameters.

### Table 3. Numerical and Experimental Stiffness values

| Isolator No | Numerical Lateral Stiffness (N/mm) | Experimental Lateral Stiffness (N/mm) |
|-------------|-----------------------------------|--------------------------------------|
| 1           | 3.736                             | 3.325                                |
| 2           | 1.2578                            | 1.015                                |
| 3           | 0.7128                            | 0.615                                |
| 4           | 2.715                             | 2.023                                |
| 5           | 4.812                             | 4.325                                |

### 4.2. Influence of Width

This section discusses the influence of Width on stiffness characteristics of Wire Rope Isolator Fig:4. On varying the width while keeping the other parameters as constant, the increase in 10% (approx.) width contributed to a decrease in 42% of vertical stiffness and 36% of lateral stiffness value. The additional increase in width of 10% contributed to a 17% decrease of vertical stiffness value and 24% decrease of lateral stiffness value.
4.3. Influence of height

This section discusses the influence of height on stiffness characteristics of polycal wire rope isolator. Figure 5 shows that the Static vertical stiffness decreases approximately by 2% and lateral stiffness by 24% on increment of height by 18%. Additional increment in the height by the same value decreases the stiffness value vertically and laterally with more amount.

| Isolator No. | W (mm) | H (mm) | D (mm) | K1 (mm) | K2 (mm) |
|--------------|--------|--------|--------|---------|---------|
| 1            | 91     | 57     | 0.7511 | 8.7435  | 1.2578  |
|              | 101    | 57     | 0.7511 | 5.1166  | 1.0463  |
|              | 111    | 57     | 0.7511 | 3.2649  | 0.7913  |
| 1            | 91     | 57     | 0.7511 | 8.7435  | 1.2578  |
|              | 91     | 67     | 0.7511 | 8.5613  | 0.9566  |
|              | 91     | 77     | 0.7511 | 7.9048  | 0.6074  |
| 1            | 91     | 57     | 0.7511 | 8.7435  | 1.2578  |
|              | 91     | 57     | 0.8511 | 14.595  | 2.2825  |
|              | 91     | 57     | 0.9511 | 22.1214 | 3.5401  |
4.4. Influence of Wire Rope Diameter

This section discusses the influence of Wire rope diameter on stiffness characteristics of polycal wire rope isolator.

It has been observed from the Fig 6 that the Static vertical stiffness increases approximately by 67% and lateral stiffness by 80% on increment of Wire rope diameter by 14%. Additional increase in the wire rope diameter leads to further increase in both static vertical and lateral stiffness value.

5. Conclusion

Polycal wire rope isolator is used to reduce the vibrational effects wherein stiffness is an important parameter that affects performance of the isolator. In this work, a numerical model is developed for an isolator, using equivalent diameter concept to determine the vertical and lateral stiffness. The work shows that the equivalent diameter concept is in good agreement with
experimental results at smaller displacements. From the parametric study it is found that the wire rope diameter (D) and height (H) of a PWRI considerably influences the lateral stiffness as compared to vertical stiffness, whereas the width (W) of a PWRI substantially influences the vertical stiffness as compared to lateral stiffness.

6. References

[1] Paolacci F and Giannini R 2008 Study of the effectiveness of steel cable dampers for the seismic protection of electrical equipment Proceedings of 14th World Conference on Earthquake Engineering, 12-17

[2] Tinker M L and Cutchins M A 1992 Damping phenomena in a wire rope vibration isolation system, Journal of Sound and Vibration. 157, 7-18.

[3] Balaji P, Moussa L, Rahman M and Ho L H 2016 An analytical study on the static vertical stiffness of wire rope isolators, Journal of Mechanical Science and Technology. 30,287-295.

[4] Sauter D and Hagedorn P 2002 On the hysteresis of wire cables in Stockbridge dampers, International journal of non-linear Mechanics. 37, 1453-1459.

[5] Gerges R R and Vickery B J 2005 Design of tuned mass dampers incorporating wire rope springs, Engineering Structures. 27, 653-661

[6] Araki Y, Kawabata S, Asai T and Masui T 2011 Response of vibration-isolated object to ground motions with intense vertical accelerations, Engineering Structures. 33, 3610-3619.

[7] Alujevi N, akmak D, Wolf H and Joki M 2018 Passive and active vibration isolation systems using inerter, Journal of Sound and Vibration. 418, 163-183

[8] Loyd T M 1989 Aerospace Engineering, Auburn University.

[9] Ibrahim R 2008 Recent advances in nonlinear passive vibration isolators, Journal of sound and vibration. 314,371-452

[10] Balaji P S, Leblouba M, Rahman M E and Ho L H 2016 Static lateral stiffness of wire rope isolators, Mechanics Based Design of Structures and Machines. 44, 462-475.

[11] Rashidi S and Ziaei-Rad S 2017 Experimental and numerical vibration analysis of wire rope isolators under quasi-static and dynamic loadings,Engineering Structures. 148, 328-339.

[12] Demetriades G F, Constantinou M C and Reinhorn A M 1993 Study of wire rope systems for seismic protection of equipment in buildings, Engineering structures. 15, 321-334.