International Journal of Modern Trends in Engineering and Research
www.ijmter.com
e-ISSN No.:2349-9745, Date: 2-4 July, 2015

# Vibration isolation of structures and equipment using Wire rope isolators

**P.S.Balaji[1],M.E.Rahaman[2], Leboula Moussa[3], Lau Hieng Ho[4]**

[1]*Department of Civil and Construction Engineering, Curtin University, Sarawak, balaji.palani@postgrad.curtin.edu.my*
[2]*Department of Civil and Construction Engineering, Curtin University, Sarawak, merahman@curtin.edu.my*
[3]*Department of Department of Civil & Environmental Engineering, University of Sharjah,mlablouba@gmail.com*
[4]*Department of Civil and Construction Engineering, Curtin University, Sarawak,lau.hieng.ho@curtin.edu.my*

**Abstract-** Vibration is always been a major concern in the heavy industries and earthquake prone countries. The vibration from the operation of the heavy machinery can affect the functionality of the surrounding equipment. Similarly, the earthquake ground motions can be cause structural damage to the structures and hence, the system needs to be isolated from harmful vibrations. Wire Rope Isolators (WRI), a type of passive isolator which exhibits non-linear behavior in both elastic stiffness and damping, can be used for the purpose of vibration isolation. It can provide isolation in all three planes and in all directions. The present work reports the study on the monotonic loading behavior and also presents the shake table test for the vibrational isolation capability of WRI. The monotonic loading test was performed for the determination of the stiffness. In the present work, WRI provided 25 % energy dissipation of the input excitations as identified from the shaking table test results. The present study also shows the effectiveness of the WRI in the vibrational isolation of the equipment.

**Keywords-** Vibration; Isolation; Wire rope isolator; Vertical stiffness; Damping

## I. INTRODUCTION

Vibration is always been a major concern in the heavy industries and earthquake prone countries. The vibration from the operation of the heavy machinery can affect the functionality of the surrounding equipment[1]. Similarly, the earthquake ground motions can be cause structural damage to the structures and hence, the system needs to be isolated from harmful vibrations. Traditionally, the vibration isolation is applied using either of the two main approaches and they are passive isolation systemand active isolation system. The active isolation system has a feedback, in addition to the stiffness and damping components, which provides variable damping to the system for the vibration isolation[2-4]. On the other hand, the passive isolation system contains only stiffness and damping component for the vibration isolation. The active system can provide better isolation due to the feedback system, however, they face major disadvantage in terms of power consumptions which are generally high, required for both functioning and damping. Hence the actives system is preferred mainly for the critical applications only and major industries generally prefer passive systems due its simplicity and it doesnot require any power for its operation[5-7].

Passive systems are of two types, linear and nonlinear system. The linear systems were earlier developed system which exhibits linear behavior in force-displacement relation and they are effective only when their natural frequency is less than the external excitation frequency. However, in the cases such as random ground motions, shocks or impact loads, there can be low frequency vibrations which can potential to damage the systems. However, the linear isolation system limitations can be overcome using the non-linear systems.Several authors have developed different types of nonlinear vibration isolators and have investigated the unique dynamic behaviors[6, 8-11]. A comprehensive survey of recent developments of nonlinear vibration isolators has been conducted by Ibrahim[6], in which many cited studies reveal that the introduction of nonlinear damping and stiffness are of great benefit in vibration isolation.Wire Rope Isolators (WRI), a type of passive isolator which exhibits non-linear behavior in both elastic stiffness and damping, has become the subject of intensive studies[12-14].

### 1.1 Wire rope isolators

Wire rope isolator consists of wire rope held in the form of a helix between the metal retainers. There are two types of WRI and they are Helical WRI(Fig.1(a)) and Polycal WRI (Fig. 1(b)). The wire rope of the WRI is made from the individual wire rope strands which are in the frictional contact with each other and it dissipates the energy through their contacts and hence they are termed as the friction type isolator[15]. The major advantage of WRI is its ability to provide isolation in all three planes and all directions. The other advantages include wide temperature range between -100$^o$C to +250$^o$C, less susceptible to detrimental effects such as corrosion, fog dust[16, 17]. Helical WRI finds application in heavy industries and polycal WRI finds application in the small scale industries such as in the isolation of electronic and electrical equipments.

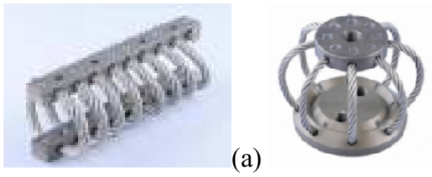
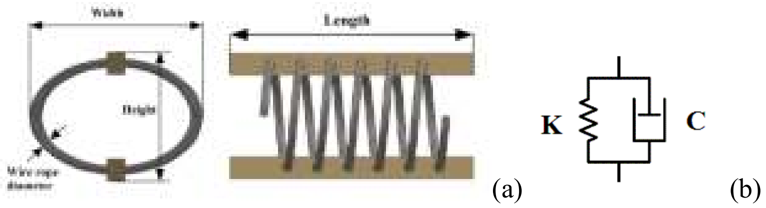

(a) (b)

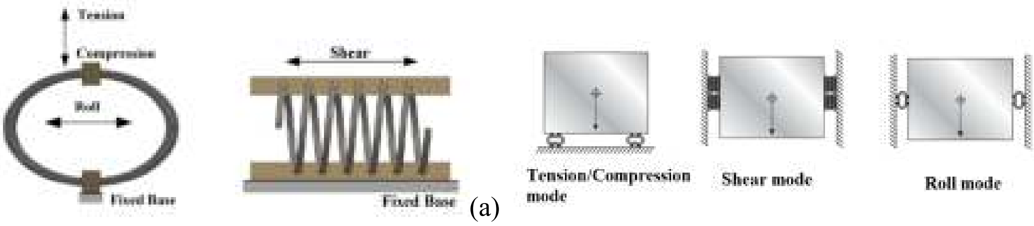
***Fig 1. (a) Helical Isolator (b) Polycal Isolator***

Fig. 2(a) shows the geometrical characteristics of WRI. The WRI can be represented as the combination of spring-damper element (Fig. 2(b)), where spring has a stiffness of K and damper has the damping coefficient of C. The characterization of WRI requires the identification of the K and C. The static stiffness can be identified using the monotonic loading test and damping can beidentified from the cyclic loading test. The monotonic loading is the loading in one direction and cyclic loading refers to a set of loading-unloading sequence. There are three loading modes (Fig. 3) in which WRI can be used-tension/compression load, shear load and roll load [16-18]. This multi-loading behaviour provides the flexibility in the application and can be used in any loading mode as required.



(a) (b)

***Fig 2. (a) Geometric characteristics of WRI (b) Spring-Damper element***



(a) (b)

***Fig 3. (a) Loading on the WRI (b) Orientation of the WRI in the practical applications[18]***

Tinker and Cutchins [13, 14] presented an experimental study on the phenomenon of damping and identified that the energy dissipation occurs through the friction between the individual wire strands. Demetriades et *al.*[12] studied the WRI using cyclic load and suggested that it exhibits hysteresis curve under cyclic loading and the hysteresis curve is symmetric for shear and roll load and asymmetric for tension\compression loading.They also found that WRI provides 10 % and 20-30% damping for large and small deformations respectively. Balaji et *al.*[15] presented an experimental study on the hysteresis behaviour under cyclic loading in vertical and lateral directionof WRI and found that the wire rope diameter significantly influence the hysteresis behaviour.Massa et *al.*[19]introduced a ball bearing in the middle of polycal WRI to consolidate the vertical stiffness. Ball bearing provided an additional support in the vertical direction to support the weight of the equipment. Paolacci and Giannini [20]performed a study on the steel cable damper effectiveness for the purpose of seismic protection of electrical equipment. The study showed the effectiveness and significance of WRI for the application of base isolation.

Endine Inc.[18] manufactures a series of vibration and shock isolators of many types and sizes including WRI and have suggest the orientations of WRI that can be used in real time applications as shown in Fig.3. The selection procedure of WRI for a real time application is provided by Endine Inc [18] in their catalogue and it is based on the estimation of static stiffness of the WRI, using the inputs such a static load, number and orientation of WRI, and input excitation frequency. Upon estimating the required static stiffness for 80% isolation, the selection of WRI is made which has the required stiffness in the required loading mode from the catalogue. Despite the previous studies [12-14], the literature lacks the study on the static stiffness and also on the isolation capabilities. The objective of the present work is to identify the static stiffness and also to study the isolation capabilities of the WRI

## II. EXPERIMENTAL SET UP

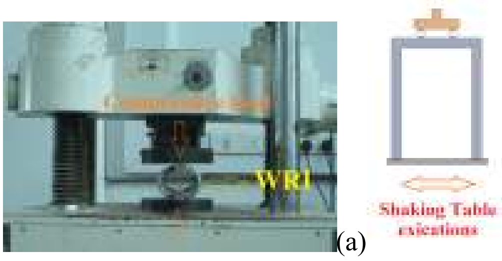
The present work has performed two experimental work and they are monotonic loading test and the shaking table test. The monotonic test is performed to determine the static stiffness of the WRI and the shaking table test is performed to study the isolation capabilities of the WRI. Fig.4 (a) shows the monotonic loading set up, the compressive load was applied and the response of the WRI is plotted in terms of the load - displacement curve. WRI exhibits linear behavior of small displacement and becomes non-linear for higher displacement. Table 1 shows the specification of the WRI used for the monotonic loading test. The shaking table test was performed by placing the equipment over the steel structure and base was excited using the harmonic excitation with the frequencies such as 0.5 Hz, 0.75 Hz, 1 Hz and1.25 Hz. The steelstructures used in the test were having the overall dimension of 0.9 mx 0.9 mx 1.2 m and having the rectangular cross section of 100 mm by 6 mm. The concrete block was used as the equipment on the top floor of the steel structures as shown in the Fig.4(b) .

***Table No. 1. Specifications of the WRI***

| Isolator No. | Wire rope diameter (mm) | Number of turns | Width(mm) | Height (mm) | Length (mm) |
|---|---|---|---|---|---|
| 1 | 6.4 | 8 | 64 | 54 | 146 |
| 2 | 9.5 | 8 | 84 | 71 | 216 |
| 3 | 12 | 8 | 105 | 90 | 216 |
| 4 | 15.9 | 8 | 112 | 99 | 268 |

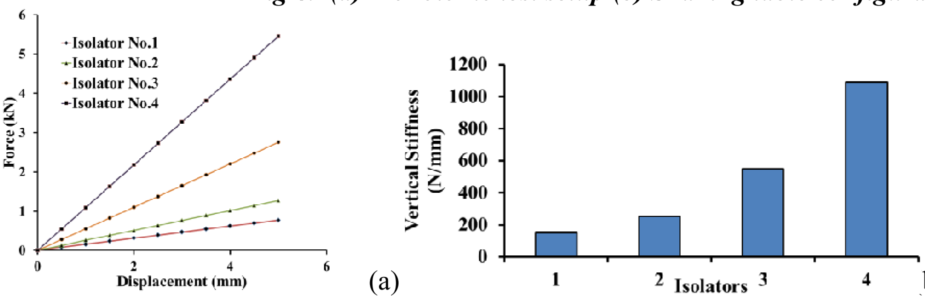
## III. RESULTS AND DISCUSSIONS

This section presents the discussion on the results obtained from monotonic loading test and shaking table test. Fig.5(a) shows the load displacement of the WRI under compressive load. The static stiffness is obtained from the slope of the curve and Fig.5(b) shows the slope of the load-displacement curve which is the static stiffness of the WRI. The stiffness of the isolation plays a major role in the isolation of the system. It is required to apply the WRI with the natural frequency less than the lowest frequency of the external disturbance. The static stiffness influences the natural frequency of the isolator and hence,it is mandatory to determine the value in order to select the proper WRI for the application. The monotonic loading test provides the simple technique to determine it. Friction between the wire rope strands significantly influences the resistance to the displacement which is displayed as stiffness of the WRI. Hence the higher diameter of the WRI provides the better sitffness. Previous studies[12, 13, 15] also indicates the significant involvement of the wire rope diameter in the stiffness.




(a) (b)

*Fig 4. (a) Monotonic test setup (b) Shaking table configuration*




(a) b)

*Fig 5. (a) Load-Displacement plot for the WRI (b) Vertical stiffness of the WRI*

Fig.6 shows the shaking table test results. It shows the comparison of the top floor acceleration of the supporting steel structure and equipment acceleration.The base of the structure harmonically excited in four different frequencies such as 0.5 Hz, 0.75 Hz,1 Hz and 1.25 Hz. The equipment is isolated from the top floor of the structure using the WRI. In general, the excitation on the top of the floor will be amplified than the lower floor and hence the equipment on the top floor was provided with the isolation system. It was observedin the present case, the WRI was found to reduce the acceleration on an average by 25 % for different frequencies. The behaviour is found to be useful since it can provide the isolation over the wide range of the excitation frequency.

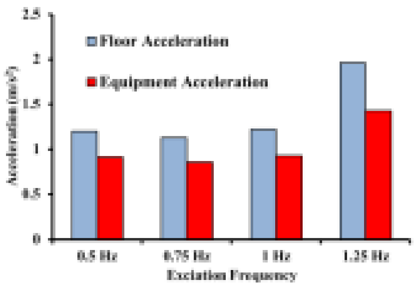



*Fig 6. Comparison of the top floor and equipment acceleration*

## IV. CONCLUSIONS

Wire rope isolator can provide the vibration isolation of the equipment and structures. The major advantage of WRI is that, it can provide isolation in all three planes and in all orientations. The behavior of WRI can be studied under monotonic and cyclic loading to understand its stiffness and damping behavior. The present work presented a study on the vibration capabilities and determined the stiffness of the WRI using the monotonic test results. It was found for the present that the WRI provided a 25 % reduction in the external excitation.

## ACKNOWLEGMENT

This paper is based upon work supported by both the Ministry of Higher Education (MOHE), Malaysia under the ERGS grant scheme and the University of Sharjah through the SEED funding scheme.

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