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Sustainable of Laminated Rubber-Metal Spring in Transverse Vibration

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Abstract

This paper presents the sustainable of laminated rubber-metal spring (LR-MS) in transverse vibration. The free-fixed boundary condition, longitudinal and rotational force are chosen to represents the transverse behavior of the LR-MS model. The mathematical model is developed and finally the dynamic stiffness matrix for all elements inside the LR-MS are obtained. By using the dynamic stiffness matrix for each element in LR-MS model, the prediction of stiffness level during transverse vibration are determined. Furthermore, it was pointed the comparison of stiffness level between all elements when the forces apply. Finally, the mathematical model developed in this study is accomplished to represent the stiffness level of LR-MS model in actual value when transverse vibration occurred.

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1. Introduction

In practice, natural rubber (NR) is a versatile and excellent material because in 150 years, it was successfully used in many engineering applications. It is a type of sustainable material and very popular in Malaysia as well as around the world for many applications[1] such as in the automotive industry, manufacturing, civil, railways, offshore, aerospace, and defense. It becomes an important material due to its ability to withstand large deformations and store more elastic energy per unit volume compared with other elastic materials. It also has inherent damping in term of vibration resonance. NR also has a unique response which is small compressibility during the application of excitation force.

A rubber bearing was introduced as the isolator to suppress the level of vibration especially in building structure for earthquake protection. It is made from layers of rubber with thin steel plates between them, and a thick plate locate at the top and the bottom of the rubber materials. These rubber bearings are located between the bottom of a building and its foundation. By embedding the metal plates, the combination provides better performance in terms of stress and strain level when heavy load is applied and prevents the bulging effect in the horizontal direction [2]. It is designed to be very stiff and strong for vertical load, therefore it can carry the heavy weight of the building. Imbimo and Luca (1998) studied the rubber bearings to investigate the effect of the shape factor on the stress distributions and stress concentration of the NR elastomer subjected to axial load [3]. Finite element analysis (FEA) approach was used to produce approximated solution. The numerical results found in that study then are compared with analytical approximate solution. Based on this comparison study, a beneficial effect of the shape factor is shown to give a higher stress distribution and stress concentration parallel with the reduction of edge effects. In 2007, the study was fulfilled other researchers who studied the use of rubber bearings for new highway construction in Greece to support for highway bridges [4]. Two samples of rubber bearings were located at the bridge column. The test results showed that the stiffness and damping ratio have a good relationship with axial load as well as the frequency of the horizontal displacement. The total displacement of rubber bearings is proportional to the force applied to the bearing. It is found that by employing the isolation strategy, the superstructure motion is decoupled from the piers motion during the earthquake. The inertia forces can be reduced and at the same the energy is dissipated by the vibration isolators which finally reduce the transmitted acceleration into the superstructure.

Bhuiyan (2010) modelled the hysteretic behavior of rubber bearings under uni-directional horizontal displacement and constant horizontal compressive load [5]. Three types of bearing were used in these studies, namely NR bearing, lead rubber bearing and high damping of rubber bearing. Several experiments were conducted to analyse the performance of the bearings such as basic test, multi-step relaxation, cyclic test and simple relaxation. It is found that the NR bearings give the best result in terms of the rate-dependent rheology. This represent the typical shear stress-strain responses of a high damping rubber bearings where the strain rate dependency of hysteresis occurs.

Most recently, the rubber bearing has successfully been applied in the Penang second bridge in Penang, Malaysia. The bearings were mainly aimed at avoiding the stemming effects from the natural environment, such as earthquakes and ocean wave. Fig. 1 shows the overall view of Penang second bridge and Fig. 2 shows the location of the rubber bearing in Penang second bridge.

The rubber bearings in Penang second bridge is designed to shift the fundamental resonant frequency of the bridge away from earthquake ground motion frequencies[6]. Several studies had been conducted including the quasi-static (refer to inertial effect of motion), static (refer to acting force at the bridge is zero), dynamics and elastomer tests. Based on the quasi-static and dynamic tests, the rubber bearing prototype was developed and the bi-axial test was carried out in longitudinal direction. The compression-shear tests in double shear configuration was also conducted to investigate the shear stiffness and damping ratio. If the results obtained did not meet the standards used for the Penang second bridge, new prototype was developed with new formulations. In the elastomer test, each compound was tested according to the international standard conducted by Lembaga Getah Malaysia (LGM). Similar trial-error approach was applied where new compound was redesigned the requirements were fulfilled.

In this study, NR materials are used as an isolator in enhancing the conventional rubber bearing for vibrating structural especially in bridges. The new rubber bearing is known as Laminated Rubber-Metal Spring (LR-MS) and it is capable to block vibration energy from longitudinal and rotational direction. The mathematical modeling of LR-MS is developed and finally the dynamic stiffness matrix can be used to predict the stiffness levels of the isolator when the excitation force and rotational force applied to the isolator. All of the model development and also stiffness results are discussed in next section.