Stress level on sustainable vibration isolator using numerical method

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ABSTRACT – This paper represents the stress distributions study on sustainable vibration isolator using numerical method. Rubber materials were used and modeled because it is a hyperelastic material and it also accepted as an isotropic and incrompressible behavior. Mooney-Rivlin model were used to investigate the stress and strain indicator. Numerical analysis were chosen as a tools to model the sustainable vibration isolator due to stress distributions. According to the analysis, by increase the number of metal plate, it was found that the deformation is reduced, however the stress distributions become higher.

1. INTRODUCTION

Seismic isolation is a technique that has been widely used around the globe to protect building structures, bridges, liquid storage tanks, oil lines and nuclear reactor plants from the detrimental effects of earthquake ground shaking. Construction of buildings with seismic isolation has increased at an almost exponential rate since the 1980s in Japan and China [1]. An isolator is used to decouple the ground vibration from reaching the structure. This is significant to prevent injury to the occupants and damage to the content.

Essentially, all isolation systems can be separated into two primary classes. They are frictional type sliding isolator and laminated rubber bearing isolators with and without lead-core. Friction base isolation decouples a structure from the soil by introducing flexibility and energy absorption system between the construction and its creation. A laminated rubber bearing consists of rubber layers bonded and alternated by rigid steel shims. It has high hardness and strength-to-weight proportions, long fatigue life and immunity to electrochemical corrosion. Many of seismic isolated structures now use laminated rubber bearing as the seismic isolation device.

There are two basic concepts of vibration isolating motions which are horizontal and vertical isolation systems. The basic concept of horizontal motions is described by a simple pendulum that swing from right to left while vertical motions is described as mass-spring vertical isolator that move upward and down endlessly. The horizontal isolation system usually used for constructions that has high seismic movement, such as earthquake while the vertical system, for a structure that located near vertical vibration sources such as railway stations.

Recent growth and research widely focuses on the isolation of vibration causes by the earthquake which is mainly horizontal vibration and of vertical isolation system for buildings and structure should be taken into consideration to control the vertical vibration problem.

Carrying out of laminated bearing is only meant to work well for earthquake protection which is mainly for low frequency and horizontal oscillation. Investigation on the bearing for horizontal vibration, especially during high frequency region is therefore of interest.

This study was conducted to understand the behavior of the sustainable vibration isolator due to axial vibration at high frequency using numerical analysis.

2. MATERIALS AND NUMERICAL ANALYSIS

Rubber materials were modeled by a hyperelastic material and accepted to be isotropic and incompressible. From the tensile test done along the rubber material, namely unfilled rubber, the stress and strain reading indicate close behavior with Mooney-Rivlin constitutive model. The constitutive model is expressed as

$$W(I_1, I_2, I_3) = \sum_{i,j,k}^{\infty} (C_{ijk}(I_1 - 3)^i (I_2 - 3)^j (I_3 - 3)^k) \qquad (1)$$

Where W is the strain energy potential and I_1, I_2, I_3 are the first three invariant of the Green deformation tensor [2]. Since the rubber used is almost incompressible, I_3 = 1, the expression can be reduced to

$$W(I_1, I_2) = \sum_{i,j}^{\infty} (C_{ij}(I_1 - 3)^i (I_2 - 3)^j) \qquad (2)$$

The material parameter of the rubber stuck in in the Ansys Workbench data properties can be stated in terms of initial shear modulus G and initial bulk modulus K where $G = 2(C10+C01)$ and $D1 = 2/K$. This type of rubber can withstand up to 600% of strain before it fails.

The steel was modelled with linear elastic properties only (E=2×10^{11} Pa, ν = 0.3) because the loads should not be large enough to cause inelastic deformations. The properties of materials used in the numerical analysis are shown in Table 1.

The finite element modelling of the sustainable vibration isolator was carried out using the ABAQUS finite element analysis (FEA) software. The static analysis can be measured the total deformation, total stress and total strain. The vibration characteristics of the isolator were defined in terms of the transmissibility frequency response function which is the ratio of the displacement response of the output end plate to the input displacement excitation applied to the input end plate for future analysis.

Table 1. Material properties

Material parameter	Rubber	Steel structural
Density [kg/m^3]	920	7850
Material Model	Hyperelastic	Linear Elastic
Young Modulus [Pa]	1.5×10^6	2×10^{11}
Poisson Ratio	0.49	0.3
Yield Strength [MPa]	250	31.026
Material Constant C_{10} [Pa]	1.5×10^5	-
Material Constant C_{01} [Pa]	0.9×10^5	-
Incompressibility Parameter D_1	8×10^{-8}	-

For purposes of analysis, it is assumed that the springs and dampers are separate elements. The metal plates were modelled using fully integrated axisymmetric solid elements of type CAX8 in the ABAQUS element library, whereas axisymmetric solid element CAX8H was used to model the rubber portion of the isolator. The elements CAX8H are hybrid, fully integrated axisymmetric solid elements which are formulated for incompressible or nearly incompressible material behavior.

The cylindrical shape sustainable vibration isolator were designed with same total distance and width. Only the number of metal plates were differ in each isolator which made the rubber pad thickness also varies in each model. The dimensions of each isolator model are given in Table 2.

Table 2. Dimensions of each isolator

Model	Type of isolator	Metal plate thickness	Total rubber thickness	Diameter	Single rubber layer thickness
1	Solid	3	140	225	140.00
2	1 Metal	3	140	225	68.50
3	2 Metal	3	140	225	44.67
4	3 Metal	3	140	225	32.75
5	4 Metal	3	140	225	25.60
6	5 Metal	3	140	225	20.83
7	6 Metal	3	140	225	17.43

3. RESULTS AND DISCUSSION

Static analysis was done for all the model isolator on the total deformation, total elastic stress and total elastic strain behavior. Table 3 depicts the result for each model, including the safety factor for each fabric. It is observed that the reduction in total length of the isolator after applied with force is progressively decreased by increasing amount of interlayer metal plate. Increasing number of metal plate has increased the stiffness of the isolator. Highest total deformation can be seen in model 1 which was 8.5465 and improves at about 77% as the spring added with six plates. Based on the maximum total deformation in Table 3, model 7 had the lowest total deformation, which was 1.8901 mm and made it the most stable model. The bulging effect was cut when the vertical stiffness increased, thus the spring has become more stable.

From the maximum total stress distribution result, stress distribution was discovered to be centralized in the steel layers. Rubber is an easily deformed material, thus in this composition of rubber and metal, steel plate is the layers that carry the stress occurred. The largest maximum stress occurred on model 5, isolator with 4 metal plates while the lowest was model 1, solid rubber isolator. Model 5 and model 1 had maximum equivalent stress of 40.819 MPa and 0.22651 MPa each. Multiple plate isolators have higher stress distribution because the vertical stiffness has increase. The force imposed on the top surface of spring were spread and passed through the steel layers and the closest steel to the input force experienced greatest stress. First steel layer absorbs most of the stress exerted and the balance, stress gone through the next layer and then along. When only single layer steel existed in a spring, the force will be concentrated on it. Yet with more interlayer steel added, the power had been shared within existing steel layers. Even though the stress distribution had increased for multiple plate isolator, the safety factor for metal plate were still high which show that it was safe to be used.

Table 3: Results of static analysis

Model	Max. Total Deform (mm)	Max. Eq. Stress -Von Misses, (MPa)	Max. Eq. Elastic Strain -Von Misses, (MPa)	Angle of Buckling Deform (°)	Min. Safety Factor for Metal Plate	Min. Safety Factor for Rubber Layer
1	8.5465	0.22651	0.147860	14.5	-	34.4356e 6
2	5.5531	12.916	0.124930	14.0	19.36	41.13
3	4.0105	32.108	0.096122	13.0	7.786	53.73
4	3.0944	40.114	0.081612	11.2	6.232	63.41
5	2.5161	40.819	0.079524	10.8	6.125	65.07
6	2.0837	35.662	0.081506	9.9	7.0102	63.43
7	1.8901	33.465	0.071662	9.7	7.4705	72.58

4. SUMMARY

Static analysis of a sustainable vibration isolator has been modelled using the finite element method. It was found that the deformation of the rubber due to load can be reduced by embedding layers of metal plates. However, this generates higher stress distributions compared to pure solid rubber and the stress concentrates mainly on steel plate layers.

5. REFERENCES

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