TUNNED CRADLE TYPE DAMPING DEVICE USING SIMPLE PENDULUM THEORY

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1. Introduction

Advances in structural technology over the last few decades have produced an increase in large, slender architectural structures. Vibration of such structures due to violent wind, earthquakes and various other disturbances can create problems from a serviceability or safety point of view. Many factors such as flexibility, safety, material availability and cost should be considered when building safer and more economically viable structures. Vibration of structures may cause fatigue, and in extreme cases, it may cause the structure to fail. Because the failure of structures can potentially cause significant loss of life and damage to adjacent property, it is necessary to mitigate undesirable vibrations, either in the design phase or by retrofitting the existing structures. It is generally accepted that the performance of a structure when subjected to undesirable vibrations is enhanced by an increase in internal damping in that structure. To control a structure under conditions causing vibration, passive, semi-active or active systems can be used to both mitigate undesirable vibration and to protect the serviceability of structures (Skinner, Robinson and McVerry, 1996).

This research introduces a new mechanical vibration dissipating device, the cradle type tuned rotary mass damper. This device relies on the movement of the cradle mass on a curved surface for changing the dynamic characteristics of a structure by dissipating its vibration energy. The Cradle type TRMD utilizes simple driving force, which is developed in response to the structures motion. The beneficial merits of the Cradle type TRMD are in its simplicity, compactness and ease of maintenance. Due to small ball bearings attached to the Cradle mass, which are seated and move along a curved surface, the Cradle type TRMD sustains a natural frequency closely in tune with the engineered structure. The objectives of this study are to develop a model of Cradle type TRMD and verify its soundness through experimentation. This device is developed by using simple pendulum dynamics (Thomson, 1972) which are applied to a structure with the frequency of about 1 Hz (Nakamura, 2004).

2. Device Configuration

In order to examine the Cradle type TRMD experimentally, a model of a one storey structure is used. Figure 1 shows the model of the structure. The model is made of aluminum. The column length is 840mm, the breadth 20mm, the thickness 2mm and the mass is 97g. The beam of the model is 445mm, with a breadth of 40mm, the thickness is 20mm and the mass is 308g.

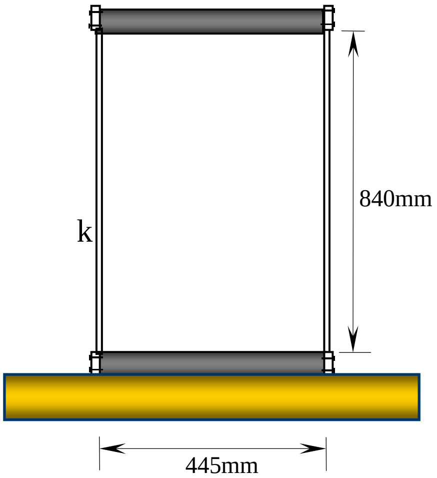

Figure 1. Simple Structure Model

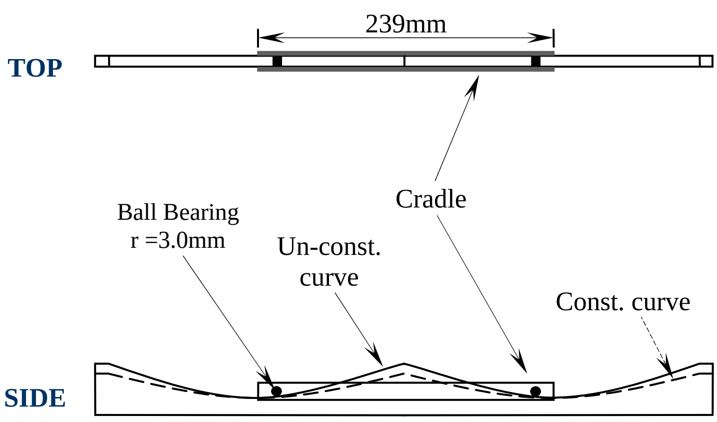

Figure 2. Cradle type TRMD

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Modeling of the Cradle type TRMD

Figure 2 shows both the top and side views of the cradle type TRMD. The figure also shows the constant and un-constant curved surfaces. The un-constant curved surface provides a constant period of cradle motion. The Cradle type TRMD is made of two aluminum slides (cradle) each in length 239mm, the breadth is 11.35mm and the thickness is 2mm. The cradle mass is 32.0g. These slides are joined by two ball bearings with a radius of 3.0mm. The Cradle is moved along a curved surface with the movement of the structure.

Free Body Diagrams of the Cradle Type TRMD and Basic Equations

Figure 3 shows the free body diagram of the cradle type TRMD. Now, we determine the differential equation of motion and period of oscillation for the cradle type TRMD, so that, we can calculate the curvature of the curve surface.

Derivation of Basic Equations

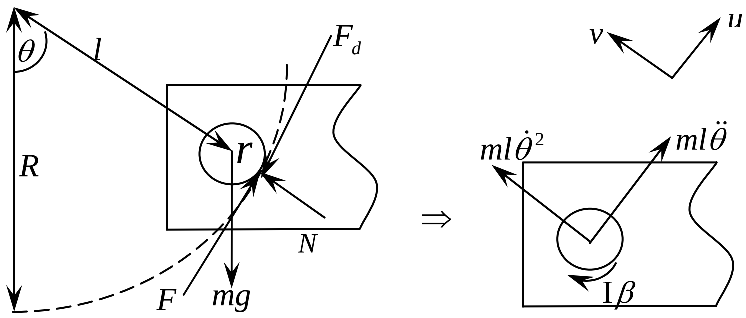

Figure 3. Free body diagram of cradle TRMD

Figure 3 shows the schematic figure of the TRMD. Here, m =Mass of the TRMD, m_t =Mass of the ball bearing, I= Moment of inertia of the ball, β =Angular acceleration of the ball, R = Radius of the curvature of surface, r = Radius of the ball, θ = Angle of the oscillation, l = $(R-r)$, F = Tangential force , μ' = Coefficient of coulomb's friction, F_d = Damping Force, c = Coefficient of viscous damping, N = Normal force.

The equation of motion of the cradle in *u* and *v* directions can be written as

u direction: $F - F_d - mgSin\theta = ml\ddot{\theta}$, (1) v direction: $N - mgCos\theta = ml\dot{\theta}^2$, (2)

where, $F_d = \mu' N \ \mathrm{sgn}\,\dot{\theta} + cl\dot{\theta}$. (3)

The equation of torque becomes

$$-Fr = \mathrm{I}\beta = \frac{1}{2} m_t r^2 \frac{l}{r}\ddot{\theta} \ , \qquad \text{where} \quad \mathrm{I} = {m_t r^2}/{2} \ \text{and}\ \beta = {l\ddot{\theta}}/{r} \ . \qquad (4)$$

Since, $m_t \cong 0$, $F \cong 0$. We then obtain the following equation from the equations (1), (2) and (3).

$$\ddot{\theta} + \mu' (\dot{\theta}^2 + \frac{g}{l}\cos\theta)\,\mathrm{sgn}\,\dot{\theta} + \frac{c}{m}\dot{\theta} + \frac{g}{l}\sin\theta = 0 \cdot \qquad (5)$$

For oscillations of small amplitude, we may assume $\sin\theta \simeq \theta$. The simplified equation of motion in terms of θ can be written as

$$\therefore \ \ddot{\theta} + \frac{g}{l}\theta = 0 \cdot \qquad (6)$$

The time period (T) of the equation (6) becomes

$$T = 2\pi\sqrt{\frac{l}{g}} \ . \tag{7}$$

We can calculate constant curve radius“l” from the equation (7).This is the approximate expression for the time period.

When $\sin\theta$ is under consideration, the exact expression for the time period T_e becomes

$$T_e = 4\sqrt{\frac{l_e}{g}}\int_0^{\pi/2}\frac{d\phi}{\sqrt{1-\sin^2(\theta_m/2)\sin^2\phi}} \ . \tag{8}$$

We can calculate un-constant curve radius“l_e” from the equation (8).

3. Result

Experimental measurements are made to clarify the characteristics of the new Cradle type TRMD. The cradle motion both on the constant and an un-constant curved surface, are observed. The vibration energy dissipating effect of the model structure while effected by the action of the TRMD is obtained. In response to vibration stimuli the Cradle type TRMD showed that the free vibration motion of the model structure could be controlled to within a frequency range about 1Hz. In addition, good energy dissipation is obtained when the cradle motion on the un-constant curved surface is considered. Figure 4, 5 and 6, show the structural responses. When Cradle mass moved on the un-constant curved surface, the damping ratio becomes two times greater than that of the constant. The results are summarized in table 1.

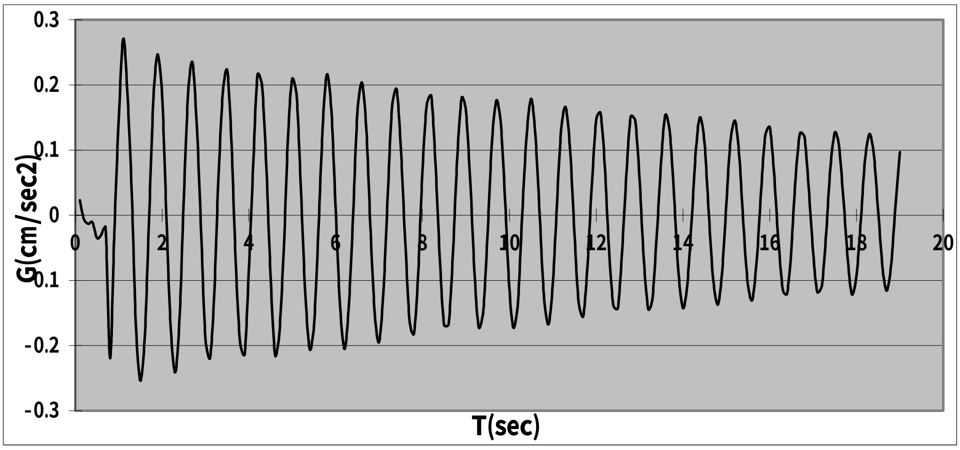

Figure 4. Without damper

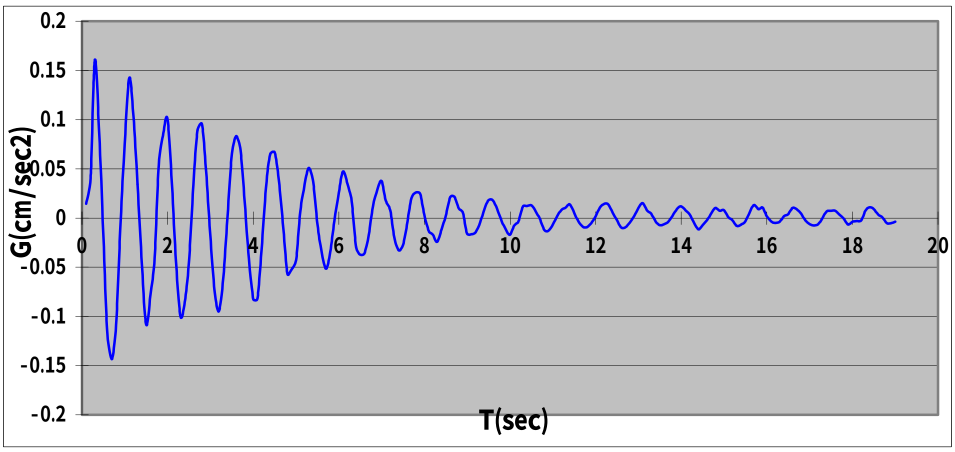

Figure 5. Damper on a constant curve

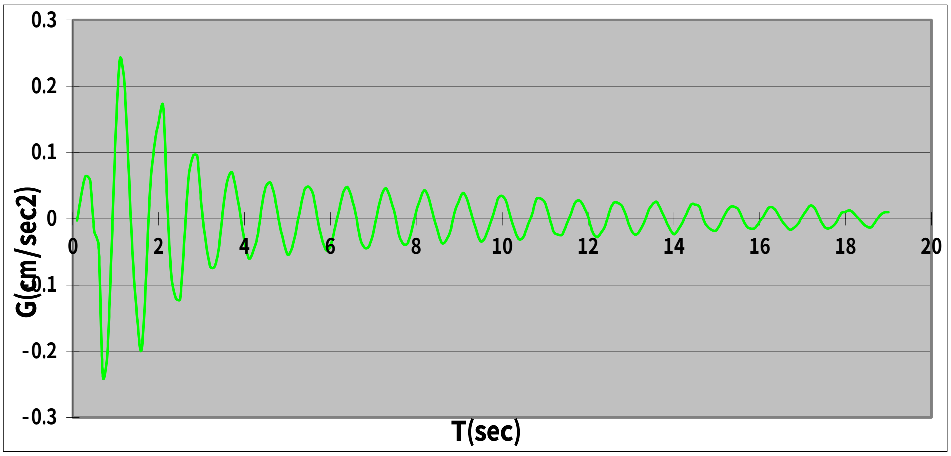

Figure 6. Damper on an un-constant curve

Damping Condition		Natural frequency of the structure(Hz)	Damping ratio
Without Damper		1.289	0.6%
With Damper	Constant surface	1.172	3.2%
	Un-constant surface	1.133	5.9%

Table 1. Comparisons of structural responses.

4. Apparatus

One storied rigid frame, A sensor (AS-GB YY2810074 with a coefficient 0f of 0.001183) and KYOWA digital memory recorder EDX-1500A.

5. Conclusions

A Cradle Type Tuned Rotary Mass Damper was developed using the simple pendulum theory. With the new Cradle type TRMD, undesirable vibration energy in the structure is efficiently dissipated.

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