XLI
CILAMCE
XLI Ibero-Latin American Congress on Computational Methods in Engineering
16-19 November, 2020
FOZ DO IGUAÇU
PARANÁ - BRAZIL

Vibration control of slender structures under base motions by pendulum TMD'S

Tatiane Cristine Pereira de Carvalho[1], Omar Gutierrez Campana[1], Reyolando M.L.R.F. Brasil[2]

[1]*Structural and Geotechnical Engineering Department, Polytechnic School University of São Paulo*
Av. Professor Mello Moraes, 2373, 05508-900, São Paulo, Brazil
tatiane.cristine.carvalho@gmail.com, ing.omargutierrez@hotmail.com
[2]*CECS, Federal University of ABC*
Alameda da Universidade, S/N, 09606-045, São Bernardo do Campo, SP, Brazil
reyolando.brasil@ufabc.edu.br

Abstract. The technological progress has been making possible the building of slender constructions, but very susceptible to unwanted vibrations. To control that, it has been advised the use of TDM's, that can decrease considerably the dynamic responses. Following that line, the present work aims to realize a dynamic analysis of a tall slender tower, exposed to support motions but with a pendular TDM installed to damp out the dynamic effects. In this work a finite elements model of a 90m tall slim tower without damper is modeled in the Scia Engineer software, to achieve the natural vibration frequencies, the structure's equivalent stiffness and mass in the top end. With those values, a mathematical model with two degrees of freedom is built: the horizontal movement of the top end of the tower (q1) and the pendulum's vertical angle (q2). The equations that govern the movement of the system are derived by the Lagrange Equations. From that model, a program in the Matlab software is introduced to calculate the structural displacement with and without a tuned pendular mass damper, to verify the dynamic damper effects, and the displacement limit according to international standards.

Keywords: TMD'S, pendulum, slender structures, vibrations

1 Introduction

During the structure lifetime, in addition to usual static loads, one must consider dynamic actions such as wind, earthquakes and other time dependent excitations. These are the ones that should be analyzed with the greatest caution in terms of response, as they cause horizontal displacements and can lead to fatigue of the structure. Therefore, they must be controlled in order to make the structure safe, in accordance with ELU and ELS current regulation of the country which the structure will be built.

This work will specifically analyze the operation of a pendulum TDM, in which the damping is provided by a mass attached to the end of a wire, forming a pendulum, fixed to the main structure. A characteristic of this device is that its frequency of oscillation depends entirely on the length of the wire (assuming the case where the mass of the wire is negligible and there is no rotational stiffness). For low frequencies, excessively long wire lengths may be required.

2 The structural model

A numerical model of a slender concrete chimney was built in the SCIA software with the characteristics of the figure 1 and tables 1 and 2.

Table 1 – Project data

Nº of nodes	10
Nº of beams	9
Nº of slabs	0
Nº of sólids	0
Nº of sections	1
Nº of load cases	1
Nº of materials	1
Gravity [m/s^2]	9,810
Standard	IBC

Table 2 – Cross section of the structure data

Type	Tub	
Cross section	3000; 500	
Format	Thick wall	
Material	C4000	
Manufacture	Generic	
A [m^2]	3,927	
Ay [m^2], Az [m^2]	2,5	2,5
AL [m^2], AD [m^2]	9,4243	1,5707
$Iy[m^4], Iz\ [m^4]$	3,1907	3,1907
$It[m^4], Iw\ [m^6]$	6,1359	0

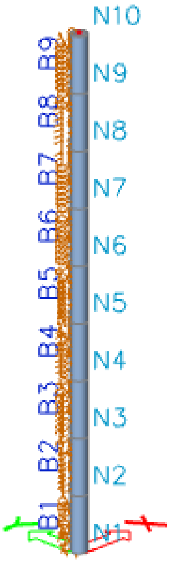

Figure 1 – Mathematical model of the high tower in SCIA

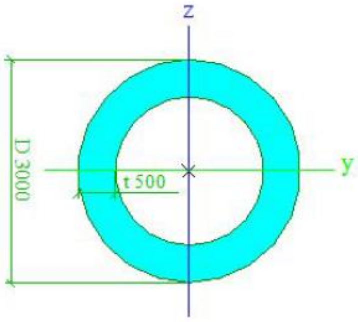

Figure 2 – Cross section of the structure

Table 3 – Material list on SCIA

Type	Name	Unit Mass [kg/m³]	Density without cure [Kg/m³]	Module E [Mpa]	Poisson	Module G [Mpa]
Concrete	C4000	2482,9	2600	2,7800e+04	0,15	1,2087e+04

Table 4 – Mass Group

Name	Load Case
MG1	LC1 – Self Weight

Table 5 – Combination of Mass Group

Nome	Grupo de massa	Coef
CM1	MG1	1,0
CM1/1 - 0,21		
CM1/2 - 0,21		

Table 6 – Lean nodes

Name	Node	Sistem	Typo	X	Y	Z	Rx	Ry	Rz
Sn1	N1	GCS	Standard	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid

Table 7 – Sum of mass

Mass Type	X [Kg]	Y [Kg]	Z [Kg]
Mass in moviment	872463,4	872463,4	872463,4
Total Mass	877337,5	877337,5	877337,5

Table 8 – Project information

Mode	Omega [rad/s]	Period [s]	Freq [Hz]	Wxi / Wxtot	Wyi / Wy tot	Wzi / Wz tot
1	1,30931	4,80	0,21	0,6165	0	0
2	1,30931	4,80	0,21	0	0,6165	0

Table 91 – Natural frequencies – Combination of mass: CM1

Nº	f [Hz]	ω [1/s]	ω² [1/s²]	T [s]
1	0,21	1,31	1,71	4,80
2	0,21	1,31	1,71	4,80

3 A two degree of freedom mathematical model

With the equivalent mass and stiffness properties of the concrete tower obtained via FEM, we now present in Fig. 3, a simple two-degree-of-freedom mathematical model of the pendular TMD under base motion excitation. It was derived using a Lagrange's energy approach. The generalized coordinates are q1, the tower top displacement (m), and q2, the pendulum angular displacement (rad). Their derivatives are noted with superposed dots. Seismic base motion is given by u_s.

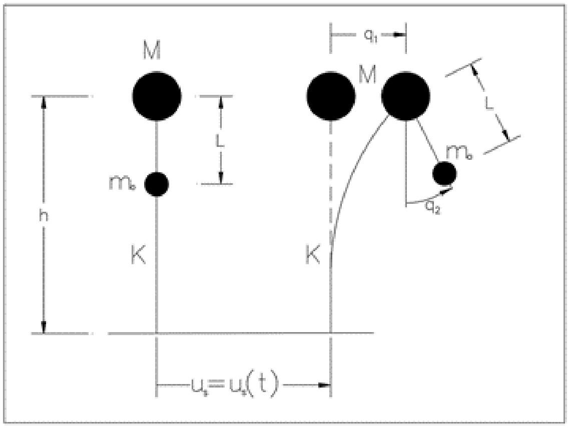

Figure 3 – The 2 DOF mathematical model

Kinetic energy, strain energy, work of wight force and Total Potential Energy are, respectively,

$$T = \frac{1}{2}\left[M\left(\dot{u}_S{}^2 + 2\dot{u}_S\dot{q}_1 + \dot{q}_1{}^2\right) + m_0\left(\dot{u}_S{}^2 + \dot{q}_1{}^2 + L^2\dot{q}_2{}^2 + 2\dot{u}_S\dot{q}_1 + 2\dot{u}_S\, L\, \dot{q_2}\ \cos q_2 + 2L\dot{q}_1\dot{q}_2\ \cos q_2\right)\right] \quad (1)$$

$$U = \frac{1}{2}Kq_1{}^2 \quad (2)$$

$$W = -m_0 gL(1 - \cos q_2) \quad (3)$$

$$V = U - W \quad (4)$$

Appling Lagrange's Equations, the following two Differential Equations of Motion are obtained:

$$(M + m_0)\ddot{q_1} + m_0 L(\ddot{q}_2 \cos q_2 - \dot{q_2}{}^2 \sin q_2) + Kq_1 = -(M + m_0)\ddot{u_S} \quad (5)$$

$$m_0 L^2\ddot{q_2} + m_0 L\ddot{q_1}\cos q_2 = -m_0\ L\,(g \sin q_2 + \ddot{u_S}\cos q_2) \quad (6)$$

Transformation of these two second order EDO into a system of four first order EDOs to use MATLAB capabilities is straightforward.

4 Numerical simulations

Initially a MATLAB program simulated the vibrations of the top of the tower without the pendular TDM, with the following characteristics:

M= 235 Equivalent mass of the structure

K= 400 Equivalent stiffness of the structure

C= 12 Damping coefficient

ρ= 0,15 amplitude of the base motion excitation

ω= 1,3 radians/s frequency of the base motion excitation

The adopted base seismic motion is fictitious and at the same frequency of the structure to consider the worst case, that is, resonance.

Figure 3 shows the displacement of the top of the structure “q1 (m)” time history, showing that after approximately 124s the displacement amplitude is about 2,1m.

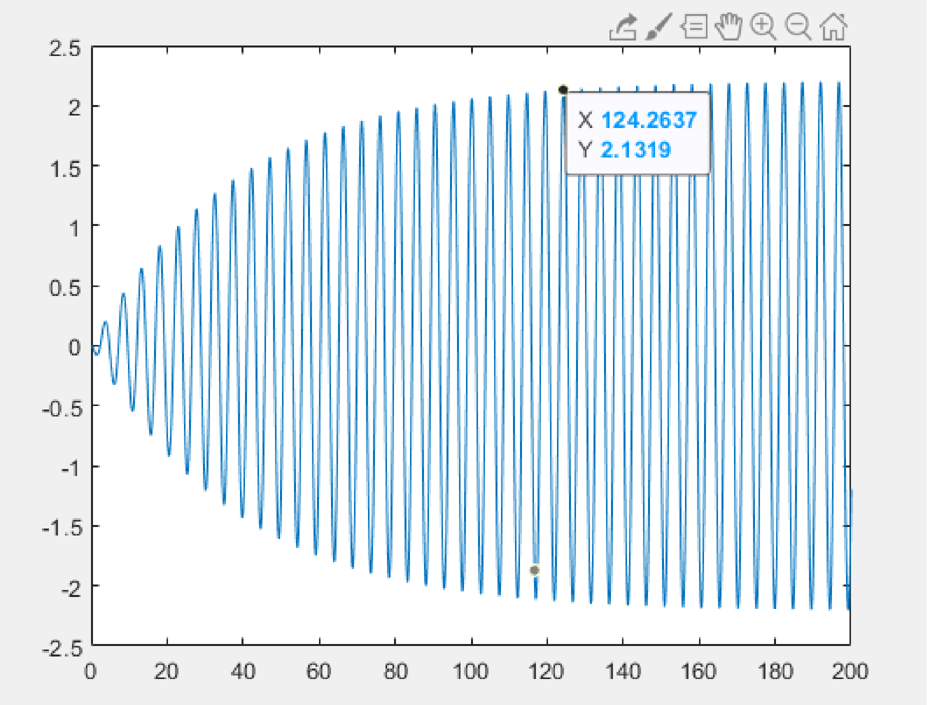

Figure 3 – Displacement Graphic q1 (m) X time (t) withought dumper

Next a MATLAB program simulated the vibrations of the top of the same tower with the pendular TDM, with the following characteristics:

M= 235 Equivalent mass of the structure

mo= 6 kg pendulum mass

K= 400 Equivalent rigidty of the structure

L= 5,9 m Pendulum lengh

g= 10 m/s²

c1= 12 M’s dumper coeficiente

c2=0,25 mo dumper coeficient

ρ= 0,15 amplitude

ω= 1,3 1/s acceleration frequency

Figure 4 below it is possible for one to see that the maximum displacement decreased significantly to 0,7m amplitude, proving the efficiency of the system

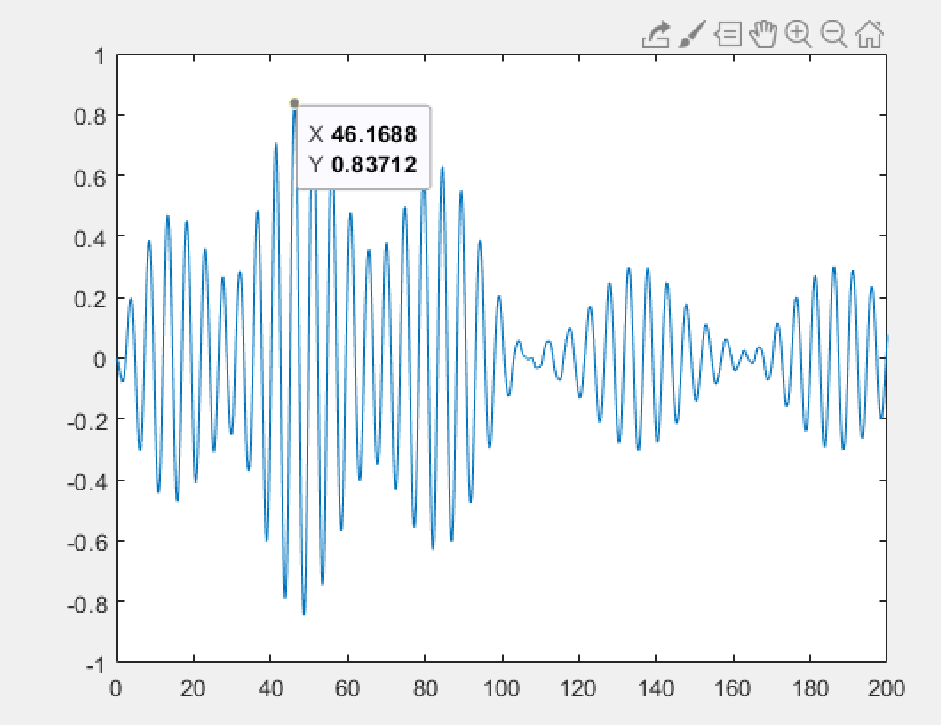

Figura 1 – Graphic of displacement q1 (m) X tempo (t) with o TDM

5 Conclusion

In this work, a dynamic analysis of a slender structure excited by seismic ground motions was carried out, considering an oscillations control system by a pendular TDM damper.

A review about the subject was made and a case study of a tall slender concrete tower analyzed with a FEM software. A pendular vibration absorption action was verified using a two degree of freedom model derived by Lagrange's equations and implemented in Matlab language.

It was concluded that this device is very effective to reduce vibration displacements amplitude.

As a proposal for future studies, there is a line of research to be developed by applying the mathematical theory of Optimization to arrive at the optimal parameters of mass and cable length of these pendulums for each practical application.

Acknowledgements.

The second author acknowledges support by FAPESP and CNPq, both Brazilian research funding agencies.

Authorship statement.

The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

References

[1] SOUZA, Catarina Mendes Alves e. Controlo de respostas dinâmicas em estruturas através de TMD's pendulares. 2012. 79 f. Dissertação (Mestrado) - Curso de Engenharia Civil, Engenharia Civil, Faculdade de Engenharia Universidade do Porto, Porto, 2013. Disponível em: https://pdfs.semanticscholar.org/8f82/f39606f6557595233ab5acc824c21fbecf26.pdf. Acesso em: 12 mar. 2020.
[2] PARISENTI, Ronaldo. Estudo de Análise dinâmica e métodos da NBR 15421 para projeto de edifícios submetidos a sismos. 2011. 219 f. Dissertação (Mestrado) - Curso de Engenharia Civil, Universidade Federal de Santa Catarina, Florianópolis, 2011. Disponível em: <https://repositorio.ufsc.br/handle/123456789/96022>. Acesso em: 24 jul. 2019.
[3] BRASIL, Reyolando M. L. R. F.. Introdução à dinâmica das estruturas: para a engenharia civil. Para a Engenharia Civil. 2. ed. São Paulo: Blucher, 2015. 268 p.
[4] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 6123:1998 – Forças devidas ao vento em edificações-Procedimento. Rio de Janeiro, 1987.
[5] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 6118:2014- Projeto de estruturas de concreto — Procedimento. Rio de Janeiro, 2014. 238 p.
[6] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 8800:2008 - Projeto de estruturas de aço e de estruturas mistas de aço e concreto de edifícios. Rio de Janeiro, 2008. 237 p
[7] PURDUE COLLEGE OF ENGINEERING (Estados Unidos) (ed.). Tuned Mass Damper Systems. 2002. Disponível em: https://engineering.purdue.edu/~ce573/Documents/Intro%20to%20Structural%20Motion%20Control_Chapter4.pdf. Acesso em: 12 mar. 2020.
[8] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 15421:2006 - Projeto de estruturas resistentes a sismos – Procedimento. Rio de Janeiro, 2006. 21 p.