Topic:Vibration Control of Tall Buildings With Damper Outriggers

Nando Tezoh Franky Kevin, Pr. Nana Nbendjo

AIMS-Cameroon

July 13, 2018

OUTLINE

Introduction

Nowadays, there are many tall buildings in the world and there is a need for buildings to be constructed higher. These structures are a result to the fast development of urban population and the request by business activities to be as close to each other as possible.However there are few issues with those high-rise buildings mostly in the regions where there is earthquake, turbulent winds because they cause the buildings to vibrate and can damage them. This is the reason why civil engineers and researchers have tried to find the solution to suppress the vibrations of those elevated structures.

Vibration control is a technique of reducing the amplitude of vibrations of mechanical structures subjected to different loads with the help of control devices.

AIMS African Institute for Mathematical Sciences CAMEROON

Introduction

Nowadays, there are many tall buildings in the world and there is a need for buildings to be constructed higher. These structures are a result to the fast development of urban population and the request by business activities to be as close to each other as possible.However there are few issues with those high-rise buildings mostly in the regions where there is earthquake, turbulent winds because they cause the buildings to vibrate and can damage them. This is the reason why civil engineers and researchers have tried to find the solution to suppress the vibrations of those elevated structures. Vibration control is a technique of reducing the amplitude of vibrations of mechanical structures subjected to different loads with the help of control devices.

Objectives of the work

In this work, our objectives are:

- To model a tall building with damper outriggers under the action of the turbulent wind flow,
- To see how the control gain parameter affect the vibration of the tall buildings,
- To find an optimal value of the control gain parameter C_d for a maximum of reducing of amplitude of vibration of the tall buildings.

Objectives of the work

In this work, our objectives are:

- To model a tall building with damper outriggers under the action of the turbulent wind flow,
- To see how the control gain parameter affect the vibration of the tall buildings,
- To find an optimal value of the control gain parameter C_d for a maximum of reducing of amplitude of vibration of the tall buildings.

Objectives of the work

In this work, our objectives are:

- To model a tall building with damper outriggers under the action of the turbulent wind flow,
- To see how the control gain parameter affect the vibration of the tall buildings,
- To find an optimal value of the control gain parameter C_d for a maximum of reducing of amplitude of vibration of the tall buildings.

Types of Control

Passive Control

Its aim is to dissipate part of the input energy (vibration), it does not add energy to the system. It is the most used because of its low cost and its ease to be used or implement. There are mainly two types of passive controls: Base isolation and Passive energy dissipation (PED).

Active Control

In this situation, the control system will add energy to the system. It is generally constituted of a sensor and an actuator. The role of the sensor is to estimate the amount of force (excitation) receive by the system and the actuator has to role to act to the system with a command signal come from the controller. There are two types of active control: feedback and feed-forward control.

Types of Control

Passive Control

Its aim is to dissipate part of the input energy (vibration), it does not add energy to the system. It is the most used because of its low cost and its ease to be used or implement. There are mainly two types of passive controls: Base isolation and Passive energy dissipation (PED).

Active Control

In this situation, the control system will add energy to the system. It is generally constituted of a sensor and an actuator. The role of the sensor is to estimate the amount of force (excitation) receive by the system and the actuator has to role to act to the system with a command signal come from the controller. There are two types of active control: feedback and feed-forward control.

Types of Control

Passive Control

Its aim is to dissipate part of the input energy (vibration), it does not add energy to the system. It is the most used because of its low cost and its ease to be used or implement. There are mainly two types of passive controls: Base isolation and Passive energy dissipation (PED).

Active Control

In this situation, the control system will add energy to the system. It is generally constituted of a sensor and an actuator. The role of the sensor is to estimate the amount of force (excitation) receive by the system and the actuator has to role to act to the system with a command signal come from the controller. There are two types of active control: feedback and feed-forward control.

Description

Physical model of tall building

A tall building is modeled as a cantilever beam of length ℓ with square cross-section because its core is a very high rise beam, depicted in figure 1

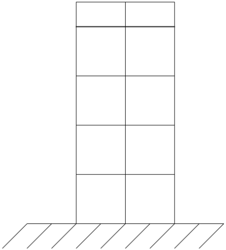


Figure: cantilever beam.

Mathematical model

When a beam is submitted to a transversal load or when it is bended, a transversal displacement $y(x,t)$ which depends on space and time can be noticed. Due to that displacement, there is creation of a bending moment and shear deformation. In the case where the cantilever beam is subjected to an external excitation of type turbulent wind, we can describe the dynamics of the structure by equation (1), which is coming from Euler-Bernouili Theory:

$$EI\frac{\partial^4 y(x,t)}{\partial x^4} + \lambda\frac{\partial y(x,t)}{\partial t} = -m\frac{\partial^2 y(x,t)}{\partial t^2} + 2C_d r^2 \frac{\partial^2 y(x,t)}{\partial x \partial t}\bigg|_{x=a} \frac{\partial \delta(x-a)}{\partial x} + F(t), \tag{1}$$

where $F(t)$ is the external excitation and it is given by:

$$F(t) = \frac{1}{2}\rho b\left[c_0 + c_1\dot{y} + c_2\dot{y}^2 + c_3\dot{y}^3\right], \tag{2}$$

cont'd

and with,

- $c_0 = \mathcal{A}_0 \left(\overline{U}^2 + 2\overline{U}u(t)\right)$,
- $c_1 = \mathcal{A}_1 \left(\overline{U} + u(t)\right)$,
- $c_2 = \mathcal{A}_2$,
- $c_3 = \mathcal{A}_3 \left(1/\overline{U} - u(t)/\overline{U}^2\right)$.

Where $\mathcal{A}_i$ are the aerodynamics coefficient corresponding to the square cross section.

Modal equation

Definition

A modal equation is the equation which describes the amplitude of vibration of the mechanical structure. In our work, we will just consider the first mode of vibration.

Derivation of the modal equation

In order to get the modal equation, let us consider the method of separation of variables. We set

$$y(x,t) = \sum_{n=1}^{\infty} \phi_n(x) q_n(t), \tag{3}$$

Where $\phi_n(x)$ is the spatial solution of the free cantilever beam and it is given by equation (4)

Modal equation

Definition

A modal equation is the equation which describes the amplitude of vibration of the mechanical structure. In our work, we will just consider the first mode of vibration.

Derivation of the modal equation

In order to get the modal equation, let us consider the method of separation of variables. We set

$$y(x,t) = \sum_{n=1}^{\infty} \phi_n(x) q_n(t), \tag{3}$$

Where $\phi_n(x)$ is the spatial solution of the free cantilever beam and it is given by equation (4)

Modal equation

Definition

A modal equation is the equation which describes the amplitude of vibration of the mechanical structure. In our work, we will just consider the first mode of vibration.

Derivation of the modal equation

In order to get the modal equation, let us consider the method of separation of variables. We set

$$y(x,t) = \sum_{n=1}^{\infty} \phi_n(x) q_n(t), \tag{3}$$

Where $\phi_n(x)$ is the spatial solution of the free cantilever beam and it is given by equation (4)

cont'd

$$\phi_n(x) = (\sin(k_n x) - \sinh(k_n x)) + \alpha\,(\cos(k_n x) - \cosh(k_n x))\,, \qquad (4)$$

where

$$\alpha = -\frac{\sin(k_n\ell) + \sinh(k_n\ell)}{\cos(k_n\ell) + \cosh(k_n\ell)}.$$

So to derive the modal equation, let us insert equation (3) into (1) and using the orthogonality relationship, we get equation (5):

$$\ddot{q}_n(t) + [d_1 - e_1 c_1]\,\dot{q}_n(t) + d_2 q_n(t) - e_2 c_2 \dot{q}_n^2(t) - e_3 c_3 \dot{q}_n^3(t) = c_0 e_0, \qquad (5)$$

with : $d_1 = \frac{-2k_n^2\cos(k_n a)C_d r^2\beta + \lambda\Gamma}{m\Gamma}$, $e_1 = \frac{\rho b}{2m}$, $d_2 = \frac{EIk_n^4}{m}$, $e_0 = \frac{\rho b}{2mk_n\Gamma}$,
$e_2 = \frac{\rho b J_1}{2m\Gamma}$, $e_3 = \frac{\rho b J_2}{2m\Gamma}$,

cont'd

$$\Gamma = \left[-\frac{\alpha}{2k_n}\left[(-1)^{n+1}\sinh(k_n\ell)\right] + \left(\frac{\ell}{2} - \frac{1}{2k_n}\left[(-1)^{n+1}\cosh(k_n\ell)\right]\right)\right],$$

$$\begin{aligned} J_1 &= \int_0^\ell \left[(\sin(k_nx) - \sinh(k_nx)) + \alpha\left(\cos(k_nx) - \cosh(k_nx)\right)\right]^2 sin(k_nx)dx \\ &= \frac{1}{60k_n}\Big[32(2+\alpha^2) + 12\cosh(k_n\ell)\left(-5-(1+2\alpha^2)\right) \\ &\quad -40\alpha(-1)^{3n} + 24\alpha(-1)^{n+1}\cosh(2k_n\ell) - 96\sinh(k_n\ell) \\ &\quad +12\left((1+\alpha^2)(-1)^{n+1}\sinh(2k_n\ell)\right)\Big], \end{aligned}$$

and

$$\begin{aligned} J_2 &= \int_0^\ell \left[(\sin(k_nx) - \sinh(k_nx)) + \alpha\left(\cos(k_nx) - \cosh(k_nx)\right)\right]^3 sin(k_nx)dx \\ &= \frac{1}{160k_n}\Big[-5\alpha(\alpha^2-3) + 12(-1)^{3n}\left((5\alpha^2+1)\cosh(k_n\ell) - \alpha(\alpha^2-7)\sinh(k_n\ell)\right) \\ &\quad +12(-1)^n\left[10\alpha(\alpha^2+2)\sinh(k_n\ell) + \alpha(\alpha^2+3)\sinh(3k_n\ell)\right] \\ &\quad +12(-1)^n\left[10(2\alpha^2+1)\cosh(k_n\ell) + (3\alpha^2+1)\cosh(3k_n\ell)\right] \\ &\quad 15\left[-3(\alpha^3+\alpha) + 4(3\alpha^2-1)k_n\ell + 4(\alpha^2+1)\sinh(2k_n\ell) + 8\alpha\cosh(2k_n\ell)\right] \\ &\quad +10\left[8\alpha^3 + (9\alpha^2+3)\sinh(2k_n\ell) + 3\alpha(\alpha^2+3)\cosh(2k_n\ell)\right]\Big]. \end{aligned} \quad (6)$$

AIMS African Institute for Mathematical Sciences CAMEROON

Analytical Solution

If we suppose that the turbulent part of the wind flow is periodic, we will take it as:

$$u(t) = \sum_{j=1}^{\infty} u_j \sin(j\Omega t). \tag{7}$$

To find the analytical solution, we use harmonic balance method (HBM).it allows us to set the general solution of equation (5) as:

$$q_n(t) = q_{0n} + q_{1n} \sin(\Omega t - \varphi). \tag{8}$$

Let us take into consideration the following data:
$EI = 1153180000$ Nm^2, $\ell = 36$, $\mathcal{A}_0 = 0.0297$, $\mathcal{A}_1 = 0.9298$, $\mathcal{A}_2 = -0.2400$, $\mathcal{A}_3 = -7.6770$, $b = 16$, $\rho = 1.25$ kg/m^3, $\Omega = 0.29$, $\overline{U} = 8$ m/S, $\lambda = 0.1$, $C_d = 10$, $u_1 = 0.14$.

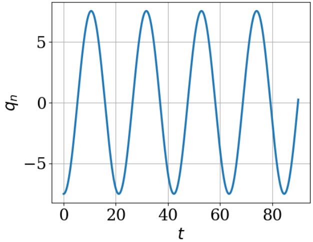
cont'd

In order to find the values of q_{0n}, q_{1n} and φ, let us insert equation (8) into equation (5) and equate the coefficients of $\sin(\Omega t)$ and $\cos(\Omega t)$ in the left hand side to those at the right hand side, neglecting the higher harmonic terms of the vibration.

The amplitude of vibration of cantilever beam is therefore:

$$q_n(t) = 0.017095425950957824 - 7.53293260928245\cos(\Omega t), \quad (9)$$

The plot of $q_n(t)$ as a function of time is given by figure 2.



Numerical solution

We will now solve the modal equation (5) using the fourth order Runge-Kutta,which is a numerical solution. To do that, we use the Python implementation of Runge-Kutta with appropriate initial conditions. Plotting the amplitude of vibration of cantilever versus the time, we obtain figure 3.

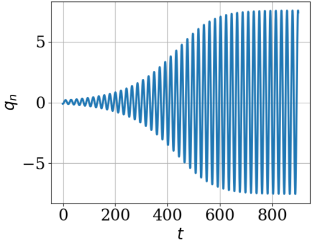


Figure: Amplitude of vibration for the first mode in the case of Numerical solution.

Effect of Damping Coefficient

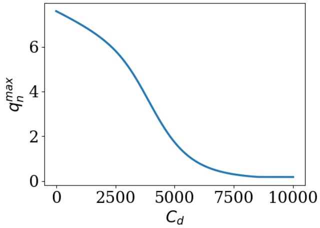


Figure: Effect C_d on the Amplitude of Vibration q_n^{max}

It can be observed that, as C_d increases, the maximum amplitude of vibration decreases and asymptotically approaches q_{n0}^{max}. Particular for $C_d > 7500$, the amplitude remains approximately at $q_{n0}^{max} = 0.25$, hence any values $C_d > 7500$ is an optimal value of the control gain parameter.

Effect of the speed of the wind $\overline{U}$

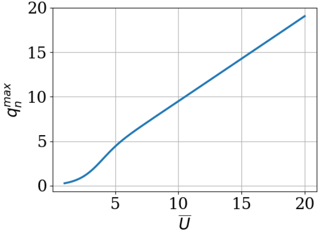


Figure: Influence of the Speed of the Wind $\overline{U}$ on the Amplitude of Vibration of Cantilever Beam.

Remain Part of the work

The remain part of the work is to study the stability of our structure.


THANK YOU
FOR YOUR
ATTENTION