2.04A Class Project: the “Tower”

with Active Damping

Problem

- Wind loading of skyscrapers causes tall building sway.
- Upper floor occupants suffer from motion sickness when the building sways in the wind since people are sensitive to accelerations as small as 0.05 m/s^2 (0.005 g).
- Too much building sway can also lead to long-term structural damage.
- The Hancock Tower in Boston had a problem with falling windows. (The Hancock Tower now has two passively controlled 300 ton sliding masses on the 58th floor.)

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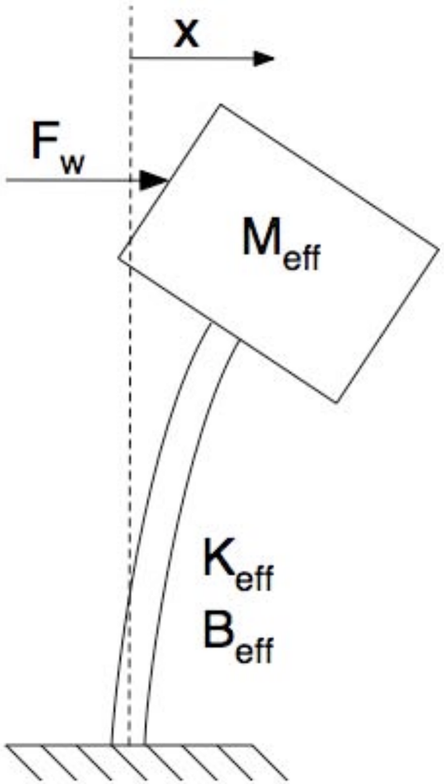
Courtesy of Rob Pongsajapan on flickr. CC-BY

Simplified Building Model

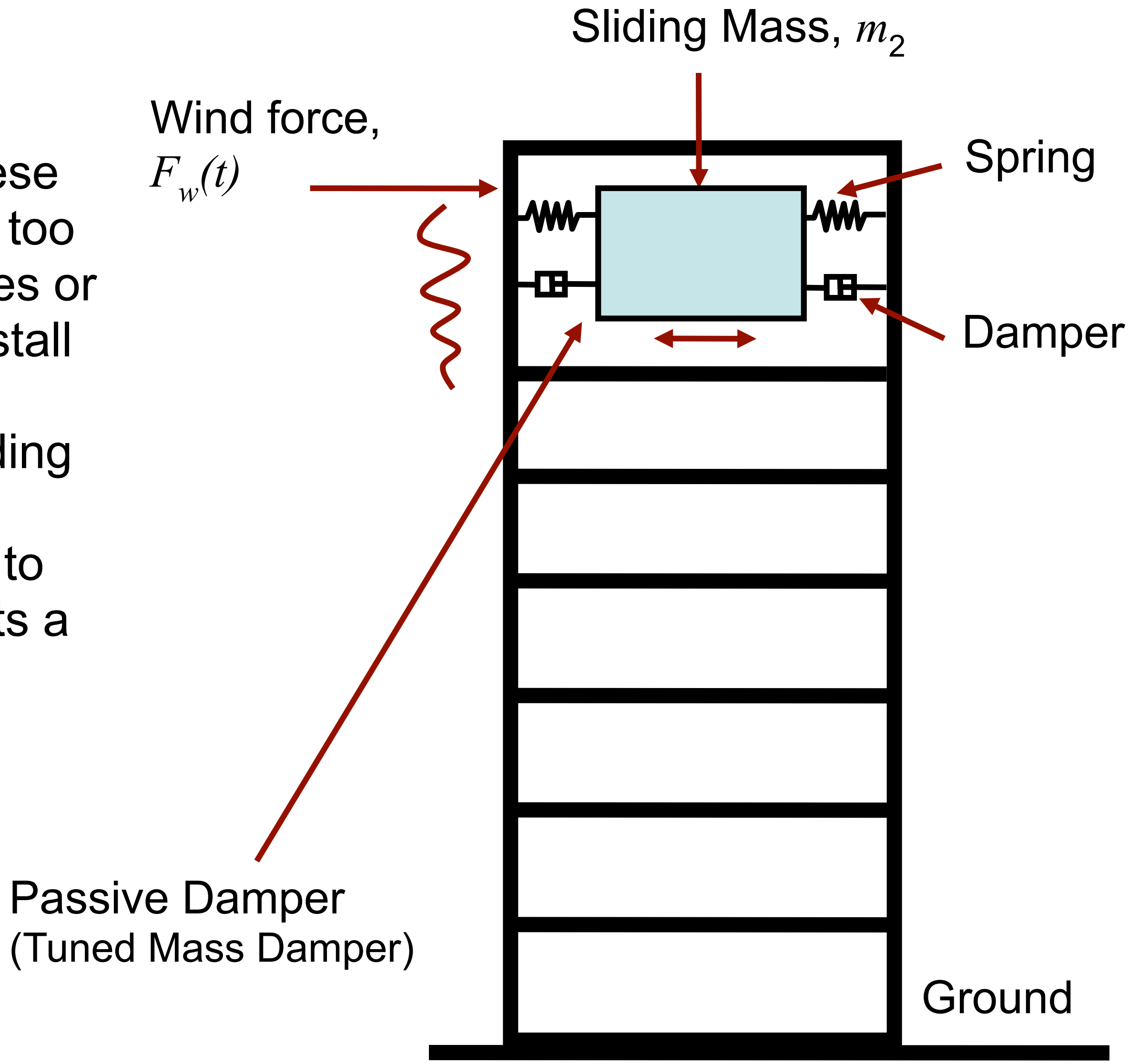
- We can model a tall building as a single degree of freedom lumped-parameter system.

John Hancock Tower, Boston	
Specifications	**Best Estimate**
Height	240 m
Breadth: Depth: Height ratio	2: 5: 1
Number of stories	60
Natural frequency of fundamental mode	0.14 Hz
Damping ratio of fundamental mode	1%



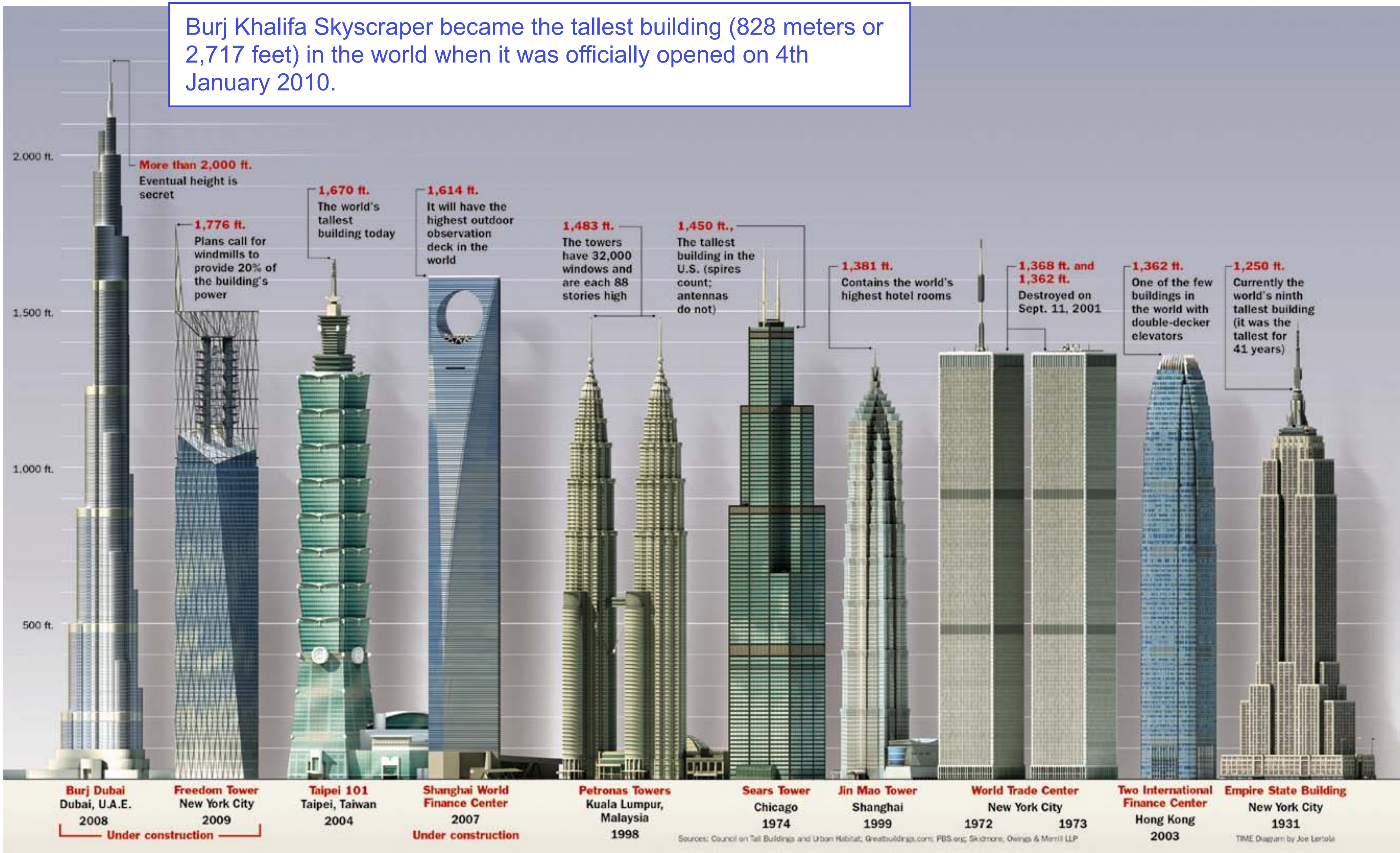
Passive Vibration Damping

One way to stabilize these tall builds from swaying too much during earthquakes or from high winds is to install enormous pendulum weights. When the building sways sideways the pendulum doesn't want to move (inertia) and exerts a pull in the opposite direction.

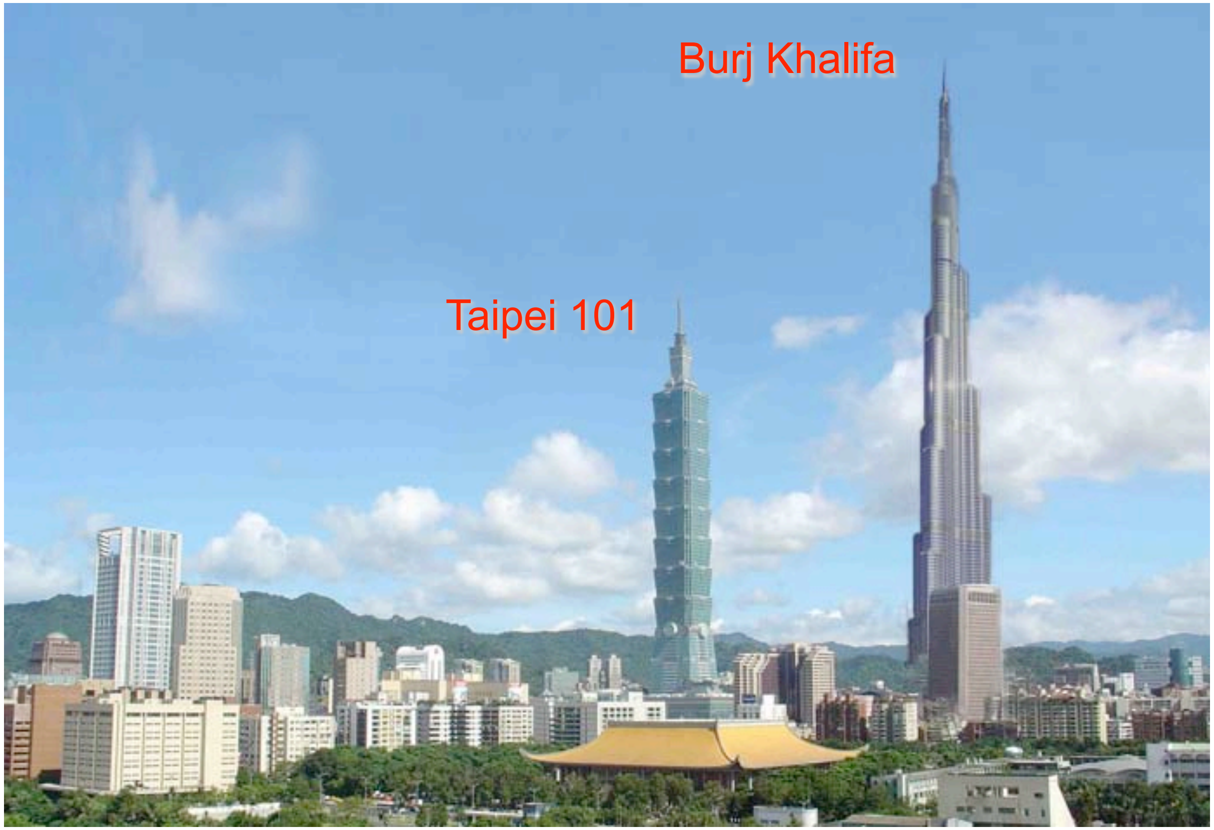


Skyscrapers

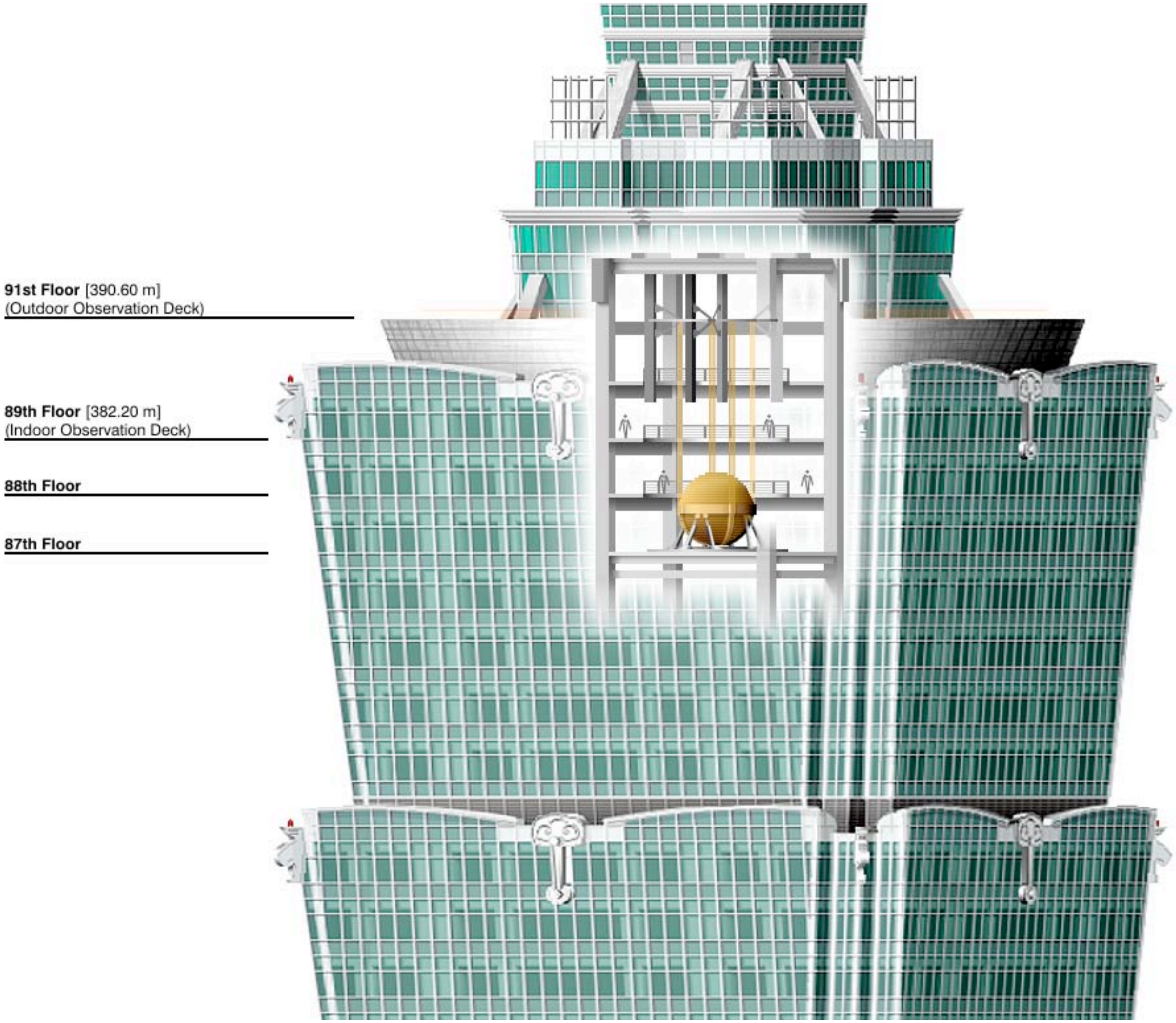
Burj Khalifa Skyscraper became the tallest building (828 meters or 2,717 feet) in the world when it was officially opened on 4th January 2010.



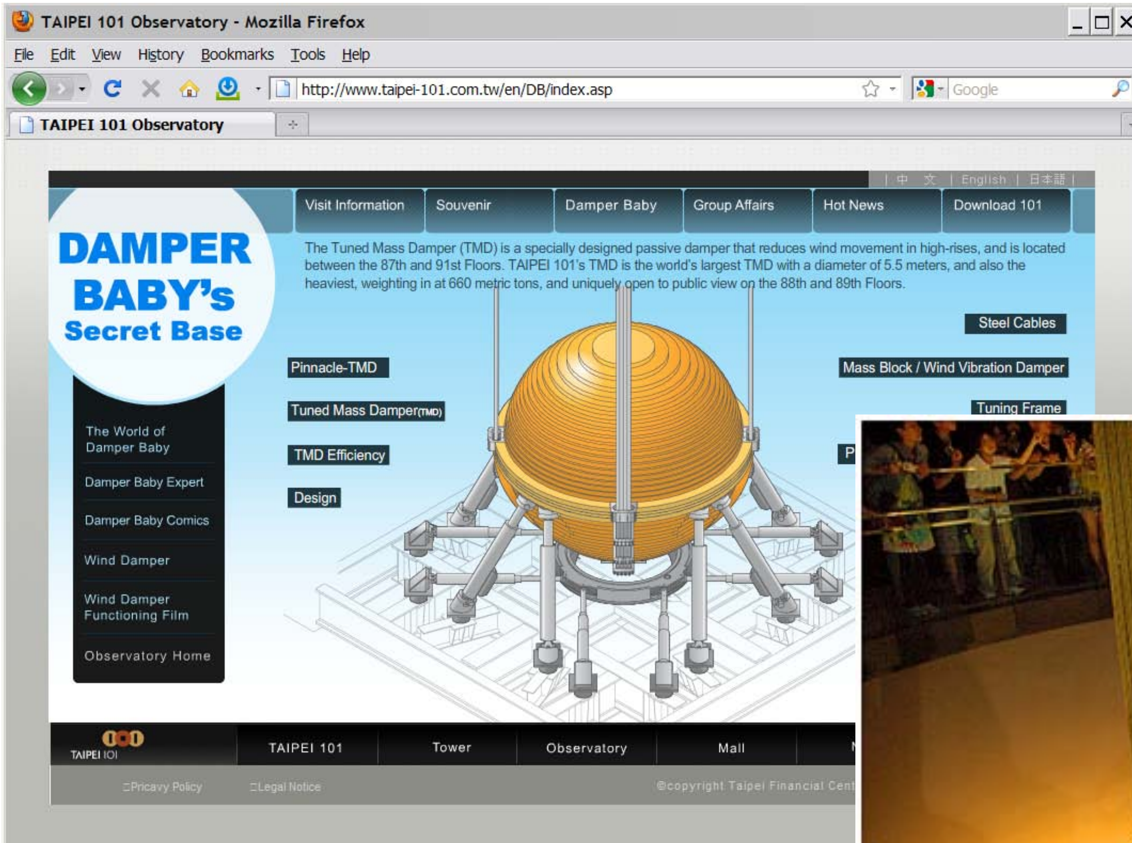
Burj Khalifa (http://www.burjkhalifa.ae/)



Taipei 101 (http://www.taipei-101.com.tw)



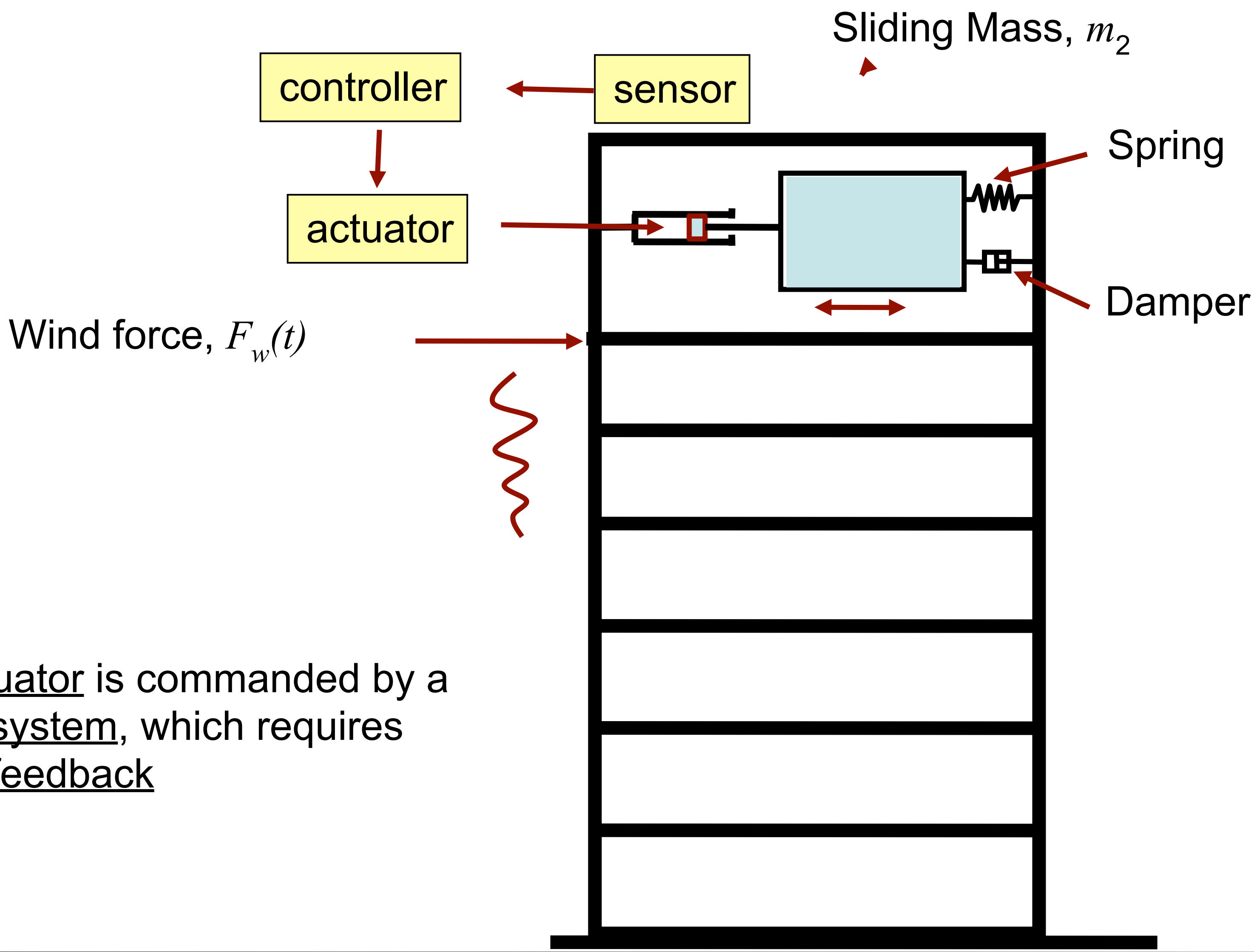
The Tuned Mass Damper in Taipei 101



The passive wind damper with a diameter of 5.5 meters and weighting 660 metric tons, is also the largest in the world now.

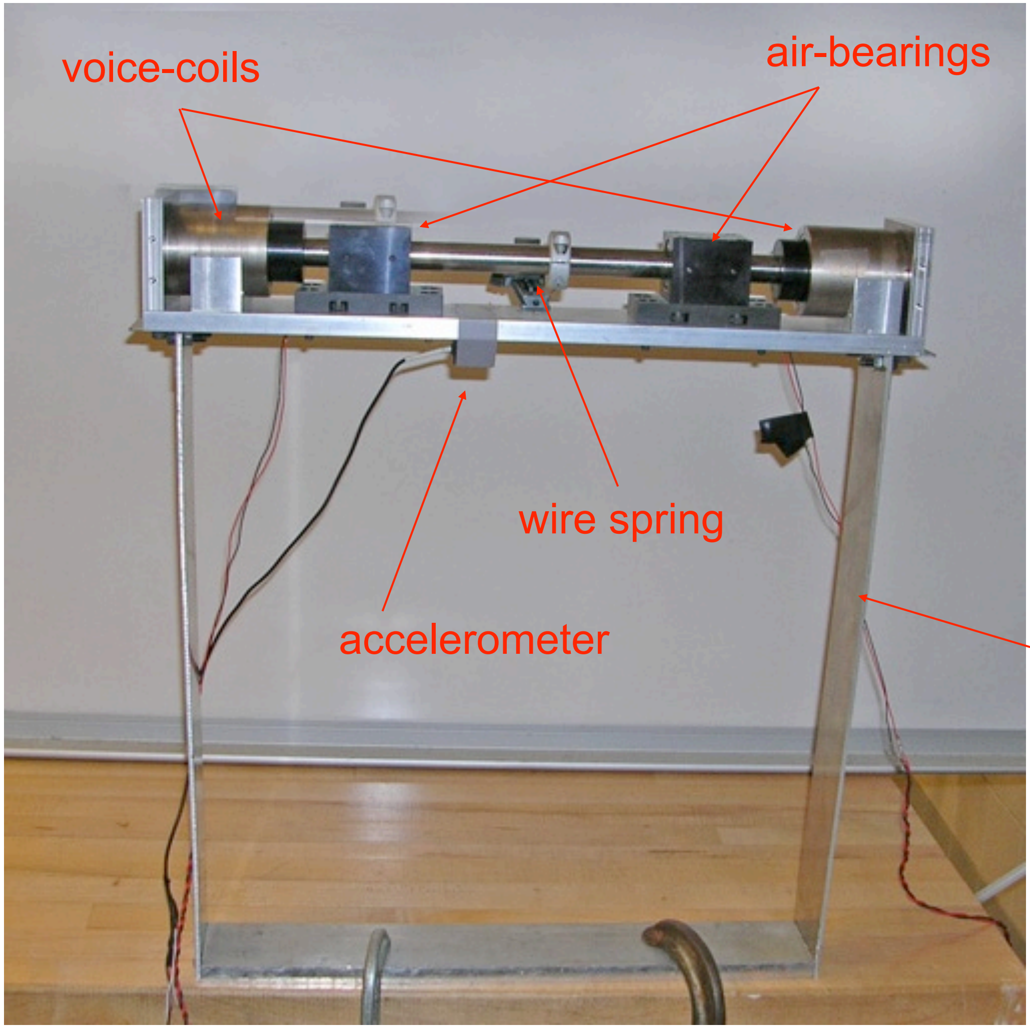
Courtesy of Daniel M. Shih. Used with permission.

Active Damper Design

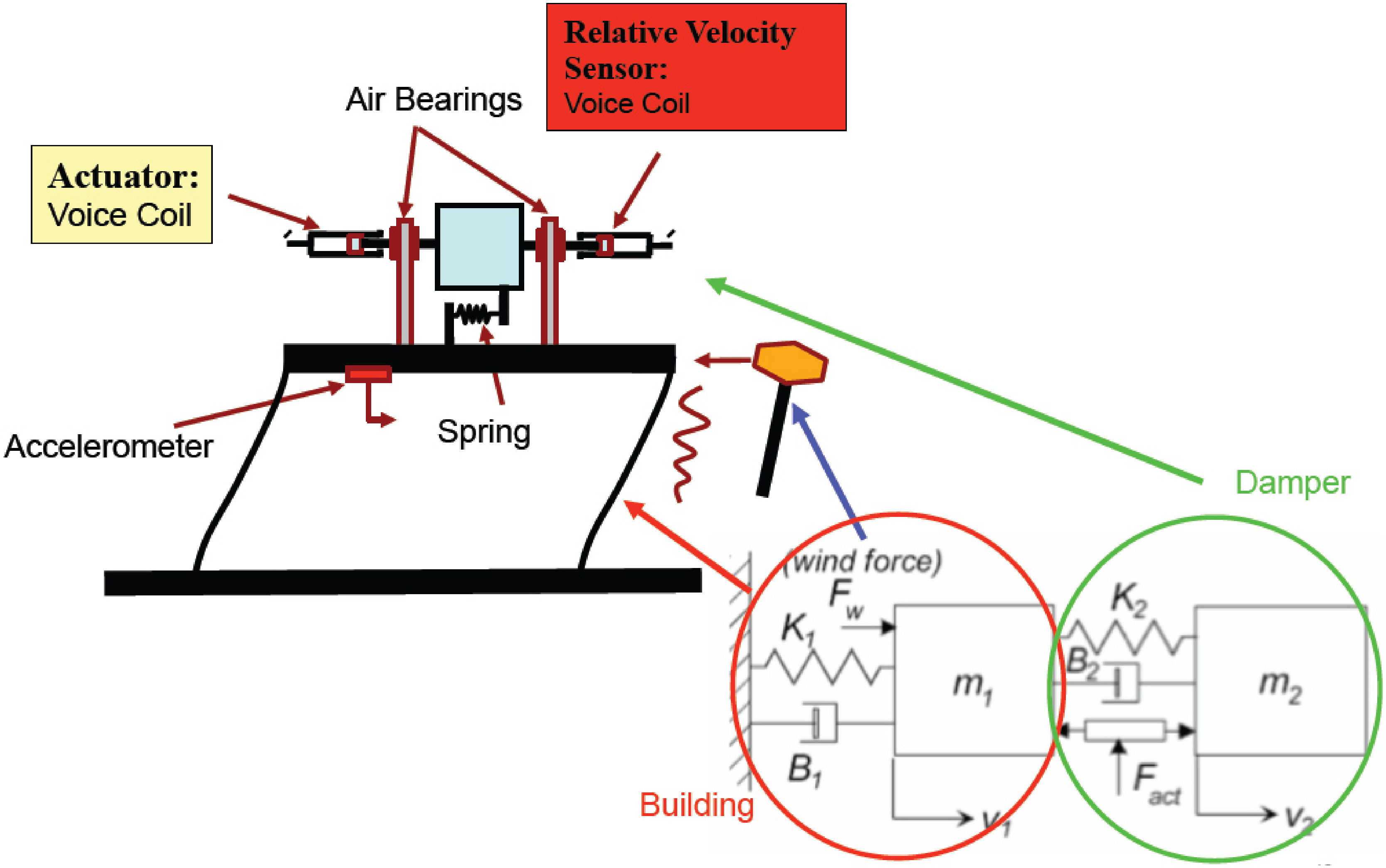


The actuator is commanded by a control system, which requires sensor feedback

Experimental System

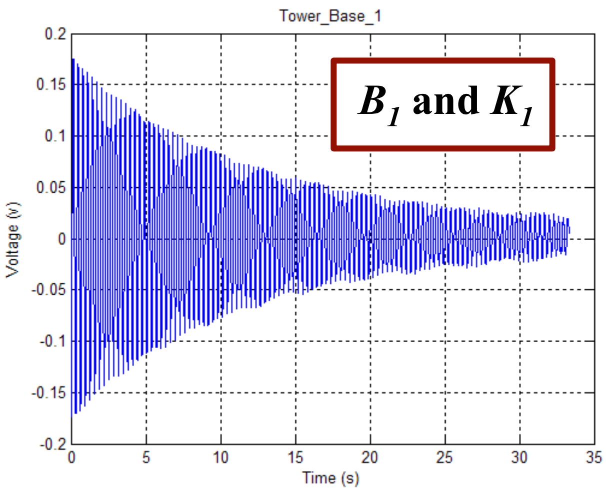


System Modeling

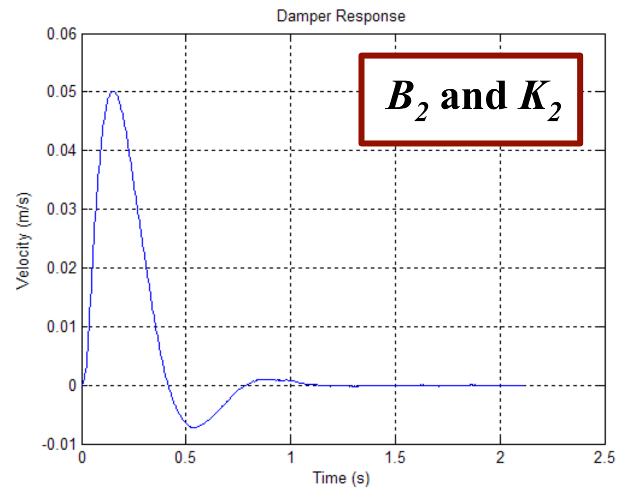


Available Impulse Response Data (Course Lockers\2.004\Labs\Tower Data)

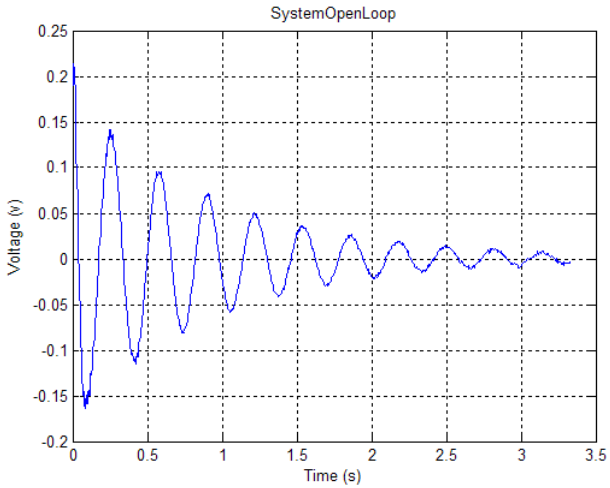
Building Response



Damper Response

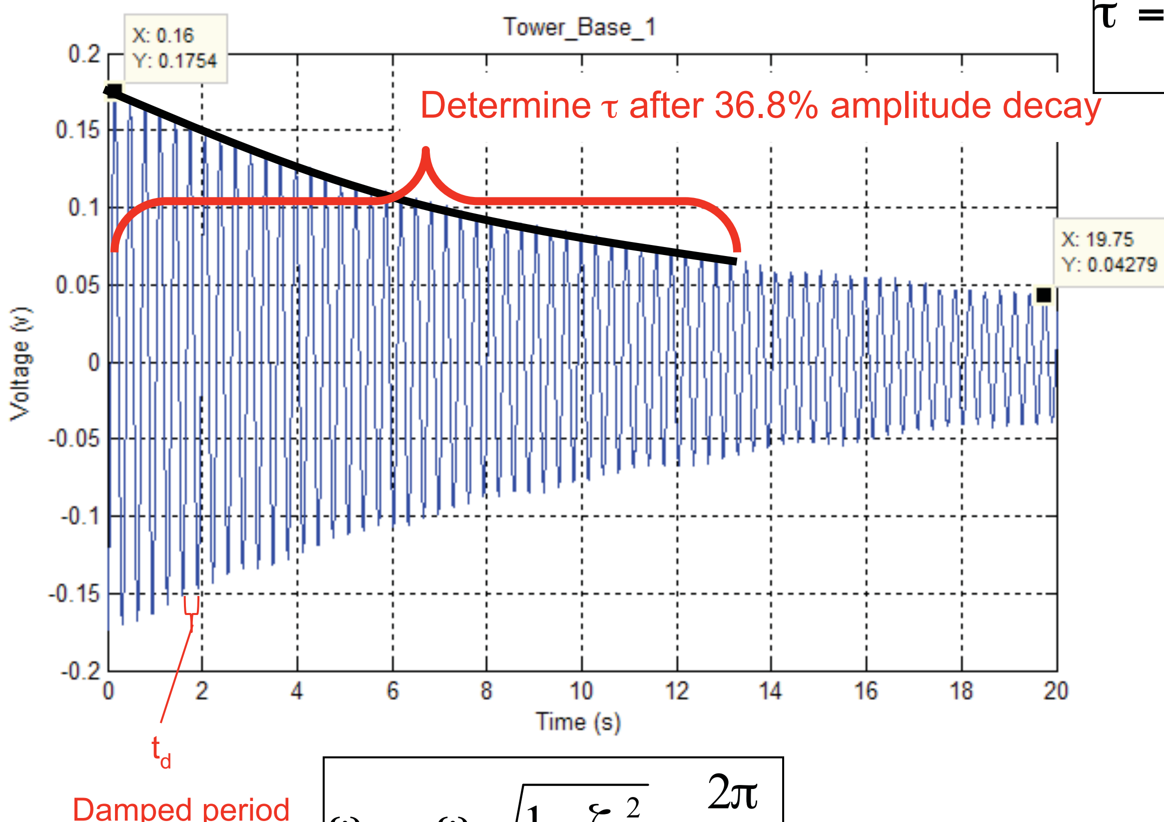


Compare your transfer function impulse response to this one.



Open Loop System Response

Estimating Parameters (Building)



$$\tau = \frac{1}{\zeta\omega_n}$$

Logarithmic decrement method

$$\delta = ln\frac{x_1}{x_2} = \frac{1}{N-1} ln\frac{x_1}{x_N}$$

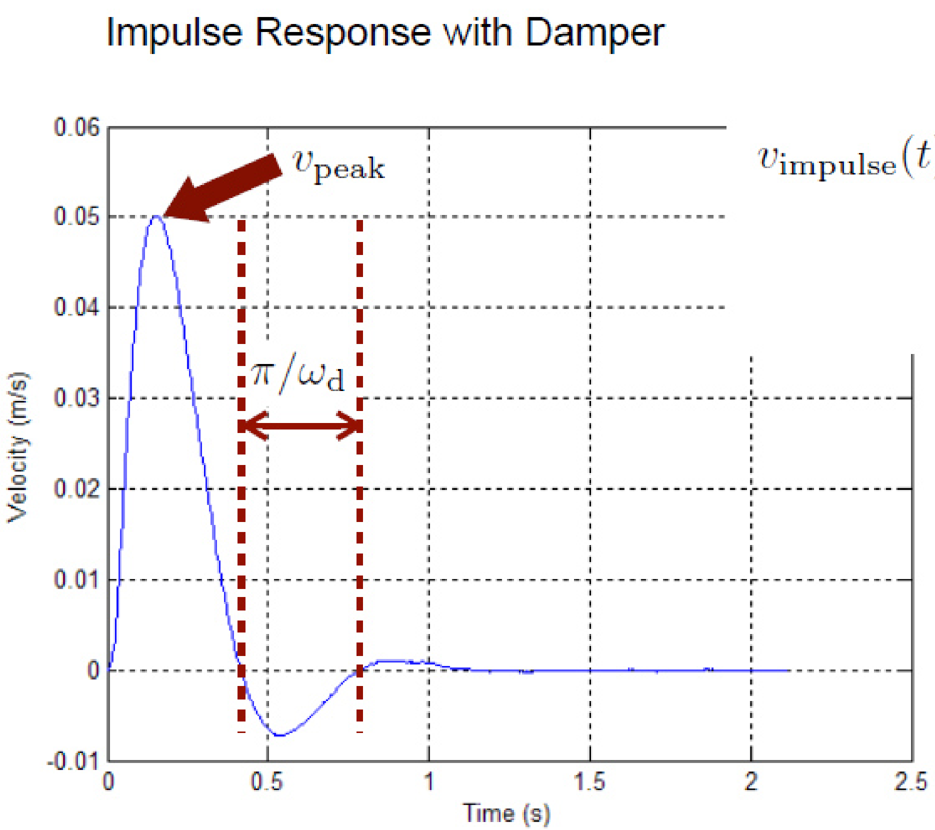
$$\delta = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \Rightarrow$$

$$\zeta = \frac{\frac{\delta}{2\pi}}{\sqrt{1+\left(\frac{\delta}{2\pi}\right)^2}}$$

$$\omega_d = \omega_n\sqrt{1-\zeta^2} = \frac{2\pi}{t_d}$$

$$m\ddot{x} + b\dot{x} + kx \Longleftrightarrow s^2 + 2\zeta\omega_n s + \omega_n^2$$

Estimating Parameters (Damper)



Impulse response:

$$v_{\mathrm{impulse}}(t) = 4\omega_{\mathrm{n}}\sqrt{1-\zeta^2}\mathrm{e}^{-\zeta\omega_{\mathrm{n}}t}\sin\left(\omega_{\mathrm{n}}\sqrt{1-\zeta^2}t\right)$$

From this (after some algebra) we obtain

$$\zeta = \frac{c}{\sqrt{\pi^2+c^2}}, \qquad \text{where}$$

$$c \equiv -\ln\frac{v_{\mathrm{peak}}}{4\omega_{\mathrm{d}}}$$

$$m\ddot{x} + b\dot{x} + kx \iff s^2 + 2\zeta\omega_n s + \omega_n^2$$