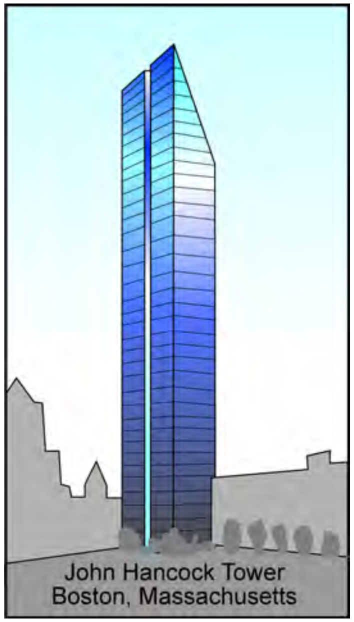
Skyscrapers and Harmonic Motion

The John Hancock Tower is one of the tallest skyscrapers in New England. This 60-story building is 240.7 meters (790 feet) tall and was completed in 1976. With 10,344 windowpanes, the most striking feature of this building is that it is completely covered in glass!



While this skyscraper was being built in 1972 and 1973, a disaster struck—windowpanes started falling out from all over the building and crashing to the ground. So many fell out that, with the boarded up window holes, the Hancock Tower was nicknamed the "plywood palace." Some people said the windows fell out because the building swayed too much in the wind—they thought the problem was due to the natural harmonic motion of the skyscraper.

Why does a skyscraper sway?

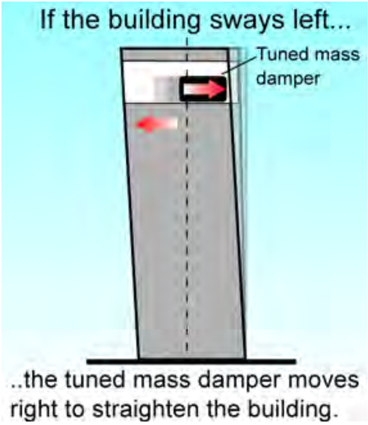
Just like trees which experience harmonic motion in strong winds, skyscrapers also sway side to side. Skyscrapers or any buildings, even though made of steel and concrete, begin to vibrate when the wind blows or an earthquake occurs. All buildings have a fundamental frequency of vibration. For example, the fundamental frequencies for buildings range as follows: 10 hertz for one-story buildings, 2 hertz for a three- to five-story buildings, 0.5 to 1 for tall buildings (10 to 20 stories high), and 0.17 hertz for skyscrapers.

On the top floor of some skyscrapers, with a strong wind, the amplitude of their side-to-side motion ("sway") can be several feet. Therefore, engineers have carefully designed skyscrapers to handle a large swaying motion. Engineers strive to keep the amplitude very small so that the people inside will not be disturbed. When the falling windowpanes of the Hancock Tower were blamed on the building's sway, engineers were quick to point out that the John Hancock Tower was designed to sway slightly. Engineers did not think the sway of this building was causing the falling windows.

Swaying is a form of simple harmonic motion. Swaying starts with a disturbing or force such as the wind pushing on the side of the building. A restoring force keeps the motion always accelerating back towards its equilibrium point. In a skyscraper, the equilibrium point is when the building is perfectly straight. For a skyscraper, the restoring force is provided by the mass of the structure of the skyscraper. The Hancock Tower has a stiff backbone made up of steel columns and beams in the skyscraper's core. That extra sturdiness allows the building to bend slightly and then ease back towards its center point. Some skyscrapers get their restoring force from hollow, rigid tubes at the perimeter of the structure. The advantage of the tubes is that they are a strong core design, with less weight.

The Citicorp Center in New York City was the first building to have a mechanical means for providing a restoring force to counteract swaying. A 410-ton concrete weight housed on the top floors of the building slides back and forth in opposition to the sway caused by wind. Thus, the restoring force in the Citicorp Center is accomplished by

shifting the center of mass of the building so that gravity pulls the building back towards its "straight" or equilibrium position. The device used in the Citicorp Center is called a wind-compensating damper or "tuned mass damper."



William LeMessurier, an innovative engineer, installed the tuned mass damper in the Citicorp Center. LeMessurier was also involved in installing a tuned mass damper in the Hancock Tower. This device wasn't necessary to stop windows from falling, but was used to keep the building from twisting as it swayed — a very disturbing affect felt by the people on the top floors of the building.

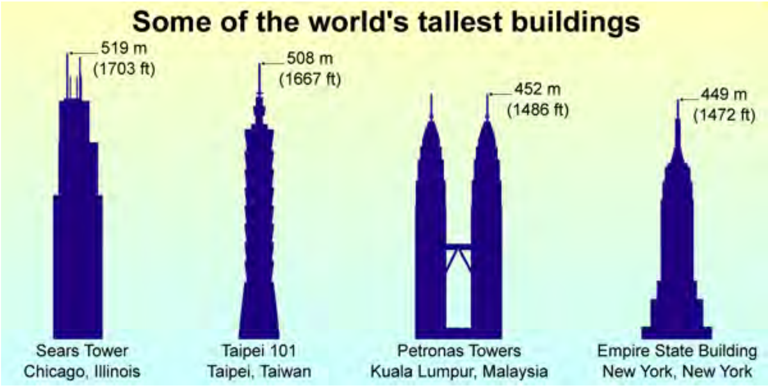
What is the tallest building in the world?

The current world champion of skyscrapers (2004) is Taipei 101 located in Taiwan. It is 508 meters tall (1,667 feet) with 101 floors above ground. Since both earthquakes and wind are concerns in Taiwan, the building's engineers took extra precautions. The 800-ton wind-compensating damper at the top of the building is a large spherical shape hung as a simple pendulum. The damper is visible to the public on the 88th and 89th floors where there is a restaurant! When the building begins to sway either due to wind or an earthquake, the damper acts as a restoring force. The Taipei 101 is built to withstand an earthquake greater than 7 on the Richter scale!

Other countries are currently constructing skyscrapers that will be even taller than Taipei 101. So, this world record holder will not be the tallest building for very long. With modern materials, and future innovations yet to come, the main limitation to the height of future skyscrapers is the cost to build such tall buildings!

The reason for the falling windows

The windows of the Hancock Tower fell out because of how the double-paned glass was bonded to the window frame. The bonding prevented the glass from responding to temperature changes and wind forces. Because the windows were held too rigidly by the bonding, the glass fractured easily and fell out. The modern John Hancock Tower sways slightly in the wind just like before, but without twisting thanks to the tuned mass damper. Also, the bonding of the windows has been fixed, and now the windows stay in place.



Questions:

1. From the reading, why were the windows falling out of the John Hancock Tower?
2. Describe the sway of a building. Use the terms force and harmonic motion in your answer.
3. Research and write a brief report about William LeMessier's work on the Citicorp Center.
4. Research the John Hancock Tower and find out what its tuned mass damper looks like and how it works.
5. Find out why Taipei 101 "beats" the Sears Tower as the world's tallest building.