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Improving High-Rise Building Dynamics: An Analysis of Tuned Mass Damper Implementation and Occupant Comfort

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Abstract

This paper looks at using tuned mass dampers (TMDs) in really tall buildings to fix shaking problems, especially up high where the wind hits hard. It also checks how comfy people feel when the building moves around. The point is to get rid of wind sway in skyscrapers by showing how TMDs are used worldwide. We want to find cheap ways to make buildings stronger without piling on tons of extra stuff to the frame. Taipei 101 in Taiwan is a good example of using a TMD to calm down shaking when typhoons come. It's important to ensure folks are okay in today's light skyscrapers because how much the building moves can be more of a problem than how strong it is. Engineers don't have many things to play with, like how tall, shaped, or heavy the building is, and these mess with how it moves. Old ways to stop too much movement, like making the building stiffer, heavier, or shaped better, cost a lot and can make it ugly. TMDs are like a weight tied to the building with a spring and damper. We have math to figure out how it all works. Getting the TMD just right means matching its shake with how the building likes to shake. This all means TMDs could make skyscrapers work better without needing loads of materials for the frame, and more folks might start using them in their tall building plans.

Keywords: Tuned Mass Damper, Shake Control, Wind Sway, Building Work, Occupant Comfort, High-Rise Buildings.

1. Introduction

Making tall buildings is like using all the newest tech and ideas. To construct buildings that impress you need to see if the building makes sense money-wise, that they look good where they're going, and that they're well-designed, built, and looked after. When folks build these, they deal with stuff they don't see often. The structural engineers have a lot to handle. It's harder when the building's area is tough on weather, like crazy winds and earthquakes.

2. Materials and Methods

A cool way to handle building movement in the wind is Taipei 101 in Taiwan. They have a Tuned Mass Damper (TMD) that cuts down on low shakes, mainly going on during storms, especially up high. These ways of checking building movement aren't everywhere, but people are catching on. If done right, you can put up skyscrapers even where it costs more to make the frame strong enough. You also can avoid being stuck with a height limit because of comfort problems.

Tuned mass dampers are smart in skyscraper cities. It can help buildings work better and cost less. Still, we need to understand more before everyone uses them. Strong winds can wreck a building. Usually, the swinging isn't bad enough to break the building, but the people inside might feel uneasy.

For new, light skyscrapers, keeping folks happy can be more important than building strong. All movement is caused by speeding up or slowing down. The movement force equals how much the building is speeding or slowing. The most sensitive people can feel minor movements. Table 1 has details on what people can handle.

Table 1: How much movement people can feel in tall buildings

S.N.	Acceleration, m/s^2	Effect
1	< 0.05	People do not feel the swaying.
2	0.05 – 0.10	- Sensitive people may notice an acceleration. - Dangles sway slight.
3	0.10 – 0.25	- Most people feel the swaying. - Swaying disturb desk work. - Long-term exposure may cause motion sickness.
4	0.25 – 0.40	- Desk work become very difficult to unbearable. - Foot travel is still possible.
5	0.40 – 0.50	- People strongly feel the swaying. - Walking becomes difficult. - Standing people find it difficult to balance.
6	0.50 – 0.60	Most people are very uncomfortable to move; they cannot walk normally.
7	0.60 – 0.70	All people are very uncomfortable to move; people cannot walk normally.
8	> 0.85	Objects begin to fall; people can be injured.

Rules in Russia agree with this research. One rule book says the most movement the floor can have been 0.08 m/s^2 when the wind is about 70% as strong as it should be [1].
Engineers saw that just doing enough to meet comfort wasn't enough when building skyscrapers that might deal with serious storms. They noticed they could only change three things: height, shape, and weight. These mess with how the building reacts to movement [2]. To stop too much movement, you can tighten things up, change the weight, or shape the building for better wind flow [3].
These ways only do so much. Then you have money and looks to stress about. This is why engineers starting using damping stuff that gets rid of building shakes from the wind. Table 2 lists ideas for shrinking wind shakes [4-5].

Table 2: Ways to make buildings shake less in the wind

Approach	Type	Method and goal	Comments
Aerodynamic Design	Passive	Improvement of aerodynamic properties to reduce aerodynamic coefficients.	Corners with chamfers or holes; holes in the core.
Structural Design	Passive	Increasing the mass of the building to reduce the effect of wind pressure.	Increase of cost.
		Increase stiffness and natural vibration frequency.	Adding bonds, increasing wall thicknesses and column stiffness.
Supplementary Damping	Passive	Use of materials and design joints with additional dissipative properties to increase the damping of the structure.	Steel damper, Steel joint damper, Friction damper, Viscous-elastic damper, Viscous damper, Oil damper
		Adding supplementary mass to increase the level of damping.	Tuned mass damper, Tuned liquid damper
	Active	Generation of inertia forces to soften dynamic reactions.	Active mass damper, Hybrid mass damper, Active gyrostabilizer
		Generation of aerodynamic forces to reduce aerodynamic coefficients.	Screws, Turbines, Aerodynamic elements.
		Change in stiffness to avoid resonance.	Active stiffness controller

3. Results

The spring can hold the weight to the structure really tight. Here, we look at tuned mass dampers, including springs. It links the building's frame and the weight, forming a pendulum.
Calculations use a system similar to the pendulum with matched stiffness and damping. This mixes things up because of these formulas. The sideways motion matches this:

$$T * \sin b + W_d / g *(u^{11} + u_d{}^{11}) = 0 \tag{1}$$

Where, W_d – is the weight of tuned mass damper, H; T – Tension load in the mount, N- At small values of the force, T- the following simplification is possible:

Then the equation of motion reduces to the following:

$$M_d * u_d + W_d / L * u_d = - m_d * u^{11} \tag{2}$$

Then equivalent stiffness k_d, N/m is

$$K_d = W_d / L \tag{3}$$

The pendulum mount's length sets how good the damper is. The vibration should match one of the building's natural vibrations. The weight should shake the other way from the building, and blowing off shake energy should be something special [6]. A benefit when the mounts are a spring is that you can still tweak the stiffness underneath. How much the weight moves can change, depending on how much weight it's carrying or if the frame gets looser. For damping, things like oil buffers are normal. These are cylinders with liquid and pistons move loosely. When the piston moves, the liquid forces motion that fights the movement based on how fast the piston moved. The oil needs to stay the same. Each time the weight sways, more power is removed to try and stop the shaking from the building.

The weight itself is a small part of the building. Using a damper that's 1-5% of the shaking is likely the best. Many tall buildings use dampers. Table 3 shows a few.

Table 3. Some buildings with tuned mass dampers

Name and Height	City or Country	Number of Dampers	Year of Erection	Own frequency and/or mass of damper
Taipei 101, 508 m	Taipei	1+2	2004	730 t; 2 to 4.5 t
Trump World Tower, 262 m	New York	1	2001	600 t
Canadian National Tower, 533 m	Toronto	1	1976	18 t
Akita Tower, 112 m	Akita	1	1994	0.41 Hz
Sydney Tower, 305 m	Sydney	1	1980	0.1 Hz; 0.5 Hz / 370 t
City Corp Center, 278 m	New York	1	1978	0.16 Hz / 370 t
John Hancock, 241	Boston	2	1977	0.14 Hz/ 2 300 t

4. Conclusions

This paper goes through dampers in skyscrapers to lower wind shakes and keep folks comfy. Taipei 101 is a nice example, and the challenges engineers deal with are shown. Those include not being able to tweak a lot and wanting cheap answers. The dampers are made of a weight, spring, and damper, and math checks the system. It stresses needing the damper to match its shake with the building. The paper gives the idea that dampers do better with making the building stronger without using so much of the structural frames and getting them used more by people putting up skyscrapers.

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