Australasian Wind Engineering Society: Seventh Workshop on Wind Engineering

Damping of Wind Induced Vibration Using Active Aerodynamic Mechanism

[1]Y.F. Li and [2]R.G.J. Flay

[1]Postgraduate student and [2]Associate Professor
Department of Mechanical Engineering
The University of Auckland
New Zealand
Email: larrybird33@rocketmail.com, r.flay@auckland.ac.nz

Abstract

This paper outlines the scope of a research project being carried out by the authors in order to investigate an active aerodynamic device for suppressing wind induced vibration on tall structures. Merits and shortcomings of vibration mitigation techniques employed in modern day buildings are discussed. Technologies of controlling boundary layers are presented, and the intended scope of the research project will be outlined.

1 Introduction

In the last few decades, lightweight and high strength materials are used in the construction of tall buildings and decreases in non-structural elements in buildings contributing to less damping. As a result, modern day buildings are more prone to vibration induced by wind action. The inherent damping of the structure may become so low that the wind response of the tall buildings often becomes quite large and the serviceability of the building is adversely affected.

2 Conventional Cure

Effort has been paid to enhance energy dissipation for buildings which have low inherent damping and there is a variety of ways to achieve this. The most well known methods are the tuned mass dampers, tuned liquid dampers and viscoelastic dampers.

2.1 Tuned mass dampers

A tuned mass damper (TMD) is one of the most common damper used in vibration mitigation. It absorbs the vibration energy through the motion of an auxiliary mass connected to the main system by springs and viscous dampers as shown in figure 1.

Performances of various of TMDs installed around the world had been evaluated by Kwok and Samali [1]. According to their results, an additional damping of 3% to 4% of critical damping and 40% to 50% reduction in wind induced response can be achieved with a passive TMD. With an Active TMD installed, an additional of 10% of critical damping or more and reduction in response by 66% can be achieved.

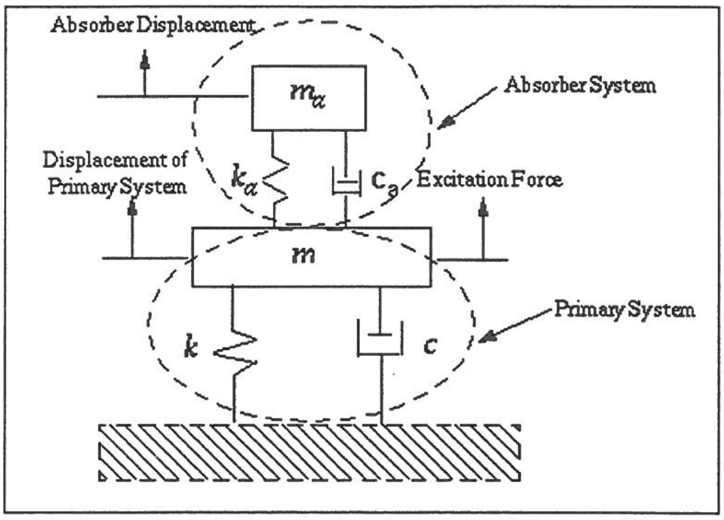

Figure 1 Schematic of a tuned mass damper

There are a few disadvantages of using TMDs. In most of the practical situations, the damper mass is about 1-2% of the first mode modal mass. It is common to have a damper mass as massive as 400 tons located at the top of buildings. This causes an extra requirement for strength and space.

Another major engineering problem with TMDs is to allow the damper mass to move relative to the building. One way of achieving that is to hang the damper mass as a simple pendulum, but for buildings with long first mode period, i.e. tall buildings, the length of suspension need to be large in order to achieve the building's natural frequency.

2.2 *Tuned liquid dampers*

A tuned liquid damper (TLD) is similar in principle to a TMD while the mass, stiffness and dissipation are all provided by liquid. The stiffness is gravitational; the energy dissipation, depending on the system arrangement, can come from mechanisms like viscous effects, turbulence and wave breaking.

TLDs offer a few advantages over TMDs. Liquid mass TLD is ready to move relative to the building whereas a TMD needs some kind of bearing underneath or suspended overhead. It is relatively cheap compare with TMD, and it is almost free of maintenance. But because it is essentially a TMD with liquid, it still has to be massive in order to be effective. Furthermore, the non-linearity behaviour gives TLD an extra bit of difficulty during design stage. Finally, the energy dissipation is relatively difficult to alter for certain arrangement and hence the performance is limited.

2.3 *Viscoelastic dampers*

A viscoelastic (VE) damper incorporates viscoelastic material which dissipates energy as heat through shear stresses in the material. This kind of damper is usually added to stiffening bracing of the building in order damp out the interstory motion.

One of the earliest employment of VE dampers is the twin towers of the World Trade Center in New York City. Each of the two towers has approximately 10000 VE dampers installed. The damping of the building was measured, during Hurricane Gloria, to be in a range of 2.5-3.0%. [2]

VE damper is a cost effective and maintenance free way to suppress wind vibration. However, being viscoelastic in nature, a VE damper would add stiffness to the structure as well as damping. Sometimes it is not desirable as too much load is drawn to the top of the building. The inability to become actively controlled give limitations to performance to VE dampers.

3 Current Developments on Vibration Suppressing Technique

As modern day buildings get taller, they capture more wind force and their vibrational energy get larger. Suppressing motion by conventional method may need very large energy-dissipating devices. A very large mass or a very large stroke is needed for TMDs and TLDs to work for a super-tall building in the future, and it may not be feasible to install such device [3].

Research is now focused on stopping the building from being excited by wind. One way of achieving that is to avoid resonance by introducing artificial non-linearity, such as the active variable stiffness (AVS) and active variable damping (AVD) system by Kobori [4]. Another way of doing that is to mitigate the excitation before it excites the structure, or in the other words, make the structure more stable aerodynamically. This mechanism is used in the boundary layer control method, shown in figure 2, developed by Kubo et al [5].

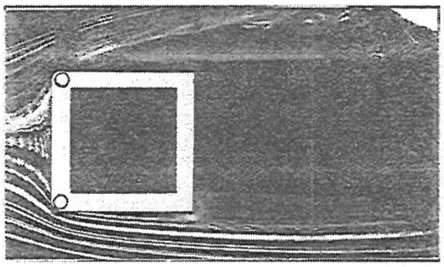

Figure 2 Flow visualization picture, upper cylinder not moving, lower cylinder rotate at 1.4 times free stream wind speed (by Kubo [5])

4 Scope of the Research

It is the aim of this research to develop an active controlled damping mechanism so that conventional, energy dissipating devices will not be used. Instead, wind excitation on buildings would be mitigated before it excites the structure by means of modifying the aerodynamic behaviour of the building. A number of researchers are working on this idea and it is the intention of this research to use actively controlled flap arrangements to modify the aerodynamic behaviour of the building. This device is likely to be free of disadvantages of the conventional device, it may also be cheaper to build and operate, however, this new system provides no protection against earthquake or other form of excitation other than wind.

Prior to the development of stabilizing flaps, the aerodynamics of flaps used in aircraft should be understood first. The effect of different angles of attack and free stream turbulence on distribution of aerodynamics forces and moments on a flap will be studied. Elementary aeroelastic theory may also be needed. After the aerodynamic behaviours of flaps are known, algorithms of controlling the flaps should be designed. The control algorithm should be able to change the geometry of the flaps, such as angle of attack, in order to provide the desirable force and moment distributions under different wind speed, direction, free stream turbulence and building movements.

Once the aerodynamic and control of the flaps are understood, stabilizing flaps can be added to structures with simple rectangular or circular plans. Positions, orientations, number of flaps will be design in this stage. Close loop control strategies will be tailor made for each arrangement and their performance will be estimated using the theories studied prior to the design. The arrangement with the best performance will be tested using a wind tunnel in order to validate the analytical performance of the damper. A number of techniques may be used in this stage such as a rigid model force balance test, a direct pressure measurement, or an aeroelastic model test.

Test results will be processed as soon as they become available. Fluctuation in wind loading or response will be quantified and additional damping provided by the damper will be evaluated.

Models of different geometry may be used in the wind tunnel testing. Design will be optimized for different high rise structures such as buildings and towers.

5 Conclusions

It is important for tall buildings to be designed against serviceability problem like wind induced vibration, method like TMDs and TLDs have been proven to work well for the last few decades. However, the ever increasing building height has given rise to a serious engineering problem where these conventional systems may not work, hence a new vibration mitigation strategy is essential for super tall buildings in the future.

Unlike the conventional device where energy must be in the system before it can be damped out, the proposed new system would focus on stopping wind energy from exciting the structure. It is very likely that it will not have the inherent shortcomings of those conventional devices, and possibly it will have advantages on capital cost and power consumption. However, as the mechanism behind this new system is modifying the aerodynamic behaviour, it gives no protection to the building against other forms of excitation such as earthquakes.

6 References

1. Kwok, K.C.S., Samali, B. 'Performance of tuned mass dampers under wind loads' *Engineering Structures*, 1995, **17**, No. 9, pp. 655-667

2. Kwok, K.C.S., Samali, B. 'Use of viscoelastic dampers in reducing wind- and earthquake-induced motion of building structures' *Engineering Structures*, 1995, **17**, No. 9, pp. 639-645

3. Fujita, T. 'Smart structures for active vibration control of buildings' Unknown source.

4. Kobori, T. 'Structural control of buildings under earthquakes and strong winds' Unknown source.

5. Kubo, Y., Modi, V.J., Yasuda, H., Kato, K. 'On the suppression of aerodynamic instabilities through the moving surface boundary-layer control', *J Wind Eng & Ind Aero*,1992, **41**, pp205-216