17th Australasian Wind Engineering Society Workshop
Wellington, New Zealand
12-13 February 2015

Accelerations and Dampers in Tall Buildings

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Abstract

The impact of recent trends in tall building configurations, and acceleration criteria, on the design of dampers to contain high acceleration levels has been introduced. The advantages of a non-linear liquid tuned mass damper, and the basic associated equations, have been given as a background for a discussion on complications in the design of dampers for tall buildings. Five areas for discussion and the need for further research have been summarised.

Introduction

Over recent years there have been several changes to the design of tall buildings which have impacted significantly on the acceleration levels likely to occur and consequently the design of dampers to contain these accelerations to acceptable levels. Added to this are the more stringent recommendations promulgated by ISO10137(2005) with respect to the level of accelerations acceptable for residential buildings. This paper will discuss these changes and their impact on the design of tall buildings.

Tall Building Design Changes

The move to design more cost effective buildings has seen the development of tall buildings on smaller blocks of land. This has effectively doubled the aspect ratio, height over width, of tall buildings from typically around 7 to 14 and with current designs closing in on 20. This has forced more buildings to be operating closer to the peak of the crosswind force spectrum which is primarily responsible for the highest levels of acceleration response. This trend is illustrated in Figure 1, where

C_{fs} = Generalised Crosswind Force Spectrum Coefficient

V_R = Reduced Velocity

$= \frac{V}{nb}$

V = mean wind speed at the top of the building

n = modal frequency

b = width of building normal to the wind flow

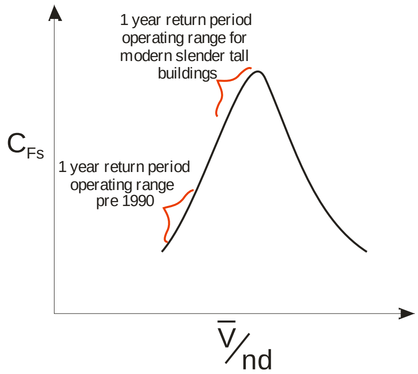

Figure 1. Crosswind force spectrum as a function of Reduced Velocity and the impact of building aspect ratio

The second significant trend is to achieve as much uninterrupted space in each floor which has had the double effect of offsetting the core and reducing the effectiveness of other structural elements such as shear walls and perimeter columns. The end result of this has been a relative reduction in modal frequencies, which impacts to increase the operating Reduced Velocity and more importantly creates an offset between the shear centre and the mass centre of the building which in turn creates significant rotation in the sway modes and displacement in the torsion modes. This effect is illustrated in Figure 2.

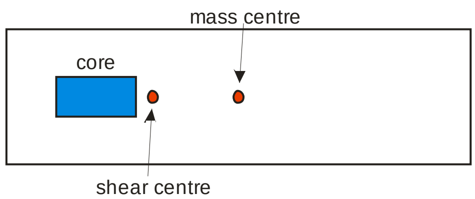

Figure 2. Offset core and shear centre

Acceleration Criteria

A summary of the acceleration criteria used in Australia (AS1170.2.1989 Commentary) before 2005 is given in the Commentary on the Australian Standard for Wind Loads, Holmes, Melbourne and Walker (2005), and that given by ISO 10137 is given in Figure 3. The relationship between peak and standard deviation accelerations and return period are given in the equation in Figure 3. The derivation of this equation is given in Melbourne and Cheung (1988). It can be seen that the acceleration criteria in ISO 10137 for office buildings is similar to that used in the Commentary on the Australian Standard for Wind Loads, but that the acceleration criteria in ISO 10137 is more stringent for residential buildings.

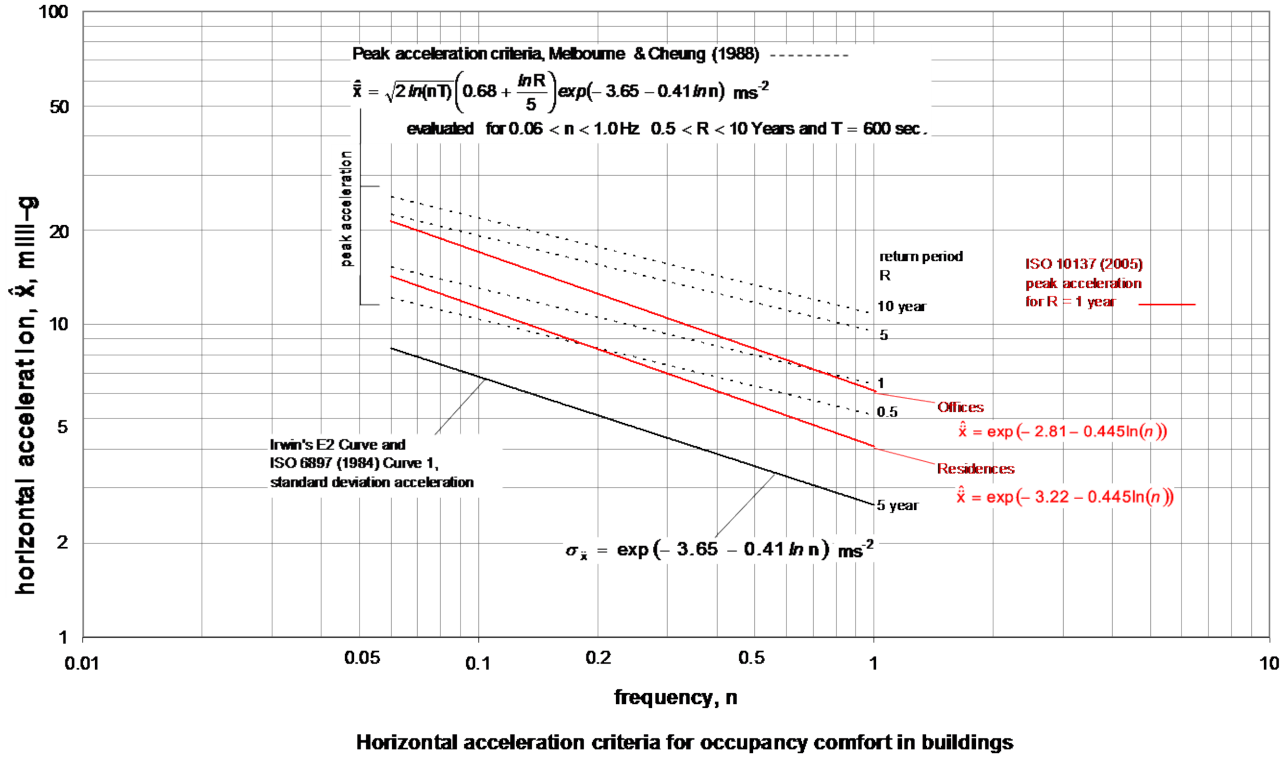

Figure 3. Acceleration Criteria used in Australia before 2003 and the criteria from ISO 10137 (2005)

Dampers for Tall Buildings

The theoretical development for dampers in tall buildings is given by Vickery Galsworthy and Gerges (2000). In this paper Vickery develops the design parameters for linear dampers (mechanical) and non-linear dampers (liquid tuned mass). The advantages non-linear liquid tuned mass dampers relative to linear mechanical dampers is the lower cost (making use the water storage for fire applications) and not having to make costly internal damping or stroke range in the damper to cope with Ultimate Limit State conditions. The layout of a liquid tuned mass damper is shown in Figure 4

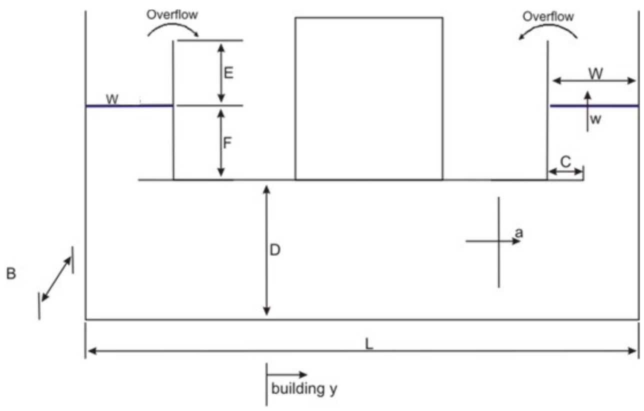

Figure 4. Definition of Damper Tank Parameters on an Elevation View of a Liquid Tuned Mass Damper

The basic equations for the liquid tuned mass damper are as follows:

added damping = $\zeta_e = \frac{\sqrt{\mu}}{4}$

frequency of TMD $n = \frac{1}{2\pi}\sqrt{\frac{2gD}{LW}}$

mass ratio $\mu = \frac{m}{M}$

g = gravitational acceleration

m = mass of damper

M = modal mass of building

D, L and W as defined in Figure 4

Complications with Acceleration and Damper Design

There are a number of stages in the design process which are still relatively approximate and which need more research and understanding to improve the process as follows:

1. The frequency equation for the liquid tuned mass damper given above is only valid for a limited range of D/W and a generic modification to cover this and the internal damping of the damper, needs to be developed. In particular the ability to get lower frequencies with shorter tanks and higher frequencies with longer tanks needs to be explored.

2. The modal correlations used when combining the accelerations from three (or more) modes to arrive at accelerations that are felt by a person are not well understood.

3. The effect of misalignment of the damper axis with respect to modal principle axes and the effect of modal cross-coupling needs considerable exploration to arrive at economic design of dampers in complex modal situations.

4. The performance of tuned dampers for off-design situations needs to be better quantified, i.e. as building frequencies change, how often is re-tuning necessary?

5. More evidence is required to substantiate the criteria for acceptable acceleration levels for human occupation given in ISO 10137 for residential buildings.

These items will be discussed at the Workshop.

Conclusions

This paper has presented some key parameters and processes in the determination of acceleration levels in tall buildings and the design of dampers to contain those accelerations. In particular the paper has highlighted areas requiring more research to assist with the design of dampers for discussion at the Workshop.

References

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