Nineteenth Australasian Wind Engineering
Society Workshop, April 4-6, 2018,
Torquay, Victoria

Development of Liquid Tuned Mass Dampers for Tall Buildings in Australia

W. H. Melbourne[1], J. Kostas[1] and M. Eaddy[1]

[1]*MEL Consultants, 22 Cleeland Road, South Oakleigh VIC 3167*
[1]*billm@melconsultants.com*

ABSTRACT

The configuration of buildings likely to require added damping to achieve acceptable levels of acceleration for human comfort have been discussed with reference to several criteria. Particular attention has been given to building slenderness ratio, frequency and aerodynamic shape to reduce crosswind response and at what level added damping becomes uneconomic. Analytical equations to define the characteristics of a Liquid Tuned Mass Damper have been summarized and limitations to these equations have been described with reference to physical model studies.

1. Introduction

As buildings have become taller and more slender the acceleration response to wind action has become the dominating factor in their design. MEL Consultants have been designing Liquid Tuned Mass Dampers (LTMD) for tall buildings in Australia for the past twenty years. Ten of these LTMD's have been installed and several others are currently under construction. From this experience there has been an emerging trend as to the aspect ratios (height/width) and building shapes at which added damping would be required up to when a building would become uneconomic to build. These trends will be discussed along with parameters and limitations for LTMD's.

2. Building Configurations requiring Added Damping

There are a number of parameters that control the acceleration response of a tall building to wind excitation and these will be discussed with reference to three buildings shown in Figures 1, 2 and 3, which have LMTD's. The LTMD at the top of the Eureka Tower can be seen in Figure 1.

- Crosswind vs Alongwind Response

  For tall buildings the highest accelerations almost always occur for the crosswind response. Exceptions can occur for wind directions onto the main face of a building with a high width to depth planform or when upstream buildings can either reduce a crosswind response or unfavorably interfere to increase an alongwind response. For the remainder of this paper only the crosswind response will be considered.

- Aspect Ratio (AR)

  The height/width aspect ratio of a tall building tends to provide a dominant indicator as to whether a building will need added damping to meet recommended acceleration criteria or be uneconomic to build. Leaving aside the obvious relationship of this aspect ratio with building frequencies for the moment, these indicators can be characterized as follows:

  10<AR<15: Added damping is increasingly likely to be required. The Soleil Tower in Figure 2 has an Aspect Ratio of 13:1.

  15<AR<20: Added damping is likely to be required along with some ameliorating building geometry. The 82 Flinders Street Tower in Figure 3 has an Aspect Ratio of 15:1.

  20<AR<25: Would need to have considerable ameliorating building geometry features along with added damping.

  AR>25: Would probably be uneconomic to build (unbuildable).

- Building Geometry

  There are many papers that have discussed the merits of tapering buildings and developing planform shapes to be more circular (as distinct from being rectangular) to reduce crosswind excitation. The planform section of the Soleil Tower in Figure 2 is slightly favorable with respect to crosswind response. The Eureka Tower in Figure 1 is tapered but had a slightly unfavorable planform section over the top third. As noted above, as aspect ratios become higher the need to develop building geometries to reduce crosswind excitation to avoid the situation where the amount of added damping required becomes too uneconomic. It is worth noting at this stage that adding damping becomes increasingly less efficient to the point where added damping much beyond 3% (of critical) becomes uneconomic.

- Modal Frequencies and Acceleration Criteria

  Modal frequencies are important for two reasons. Crosswind response is very dependent on Reduced Velocity (velocity/frequency x building width, V/nb). The peak of the crosswind force spectrum occurs at a Reduced Velocity of 10 for rectangular shapes going towards 5 for circular shapes, as shown in Figure 4. It is preferable to design a building to have the acceleration serviceability Reduced Velocity (1 to 5 year return periods) to the left of the peak and certainly not at the peak.

- Modal Mass

  Building acceleration levels under wind action are inversely dependent on modal mass (as distinct from the influence of mass on frequency). Building mass, as such, is an important factor in that very dense buildings (e.g. 400kg/cu m) will have a lower acceleration response relative to a lightweight building (e.g. 200kg/cu m).

3. Acceleration Criteria

The determination of acceleration criteria for occupancy comfort in tall buildings has been studied steadily since about 1970. Reference will be made here to the paper by Melbourne and Cheung (1988), because this paper discusses the work up to that time and has developed a methodology for determining the acceleration criteria in terms of mean and peak accelerations for various return periods and duration. Since then there have been two notable events. Firstly, new acceleration criteria have been set down in ISO 10137 (2005) and these criteria have been inserted in the methodology of Melbourne and Cheung and are given here in Figure 5. Secondly there has been an ASCE publication "Wind-Induced Motion of Tall Buildings: Designing for Habitability" edited by K C S Kwok, that has provided a very comprehensive discussion of the whole area of cause and effect.

The most significant factor for this discussion is to note the dependence of the acceleration criteria on frequency. Simply put, the acceleration criteria becomes less stringent with reducing frequency over the range of interest to tall buildings and the difference between office and residential occupation.

4. Characteristics of a Liquid Tuned Mass Damper

The LTMD is a non-linear system the characteristics of which have been developed by Vickery et al (2000). The main equations of interest from this analytical study which describe the performance of a LTMD are as follows:

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

frequency ratio $f_r = \frac{n_{tank}}{n_{building}} = \frac{1}{1+\mu}$

TMD damping ratio $\zeta_{tank} = \frac{\sqrt{\mu}}{2}$

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

ratio of damper motion to building motion $R_r = \frac{\sigma_a}{\sigma_{building}} \approx \frac{\sigma_{\ddot{a}}}{\sigma_{\ddot{b}uilding}} = \frac{1}{\sqrt{2\mu}}$

frequency of TMD $n_2 \approx \frac{1}{2\pi}\sqrt{\frac{2gD}{LW}}$

The layout and notation definitions are given in Figure 6

Unfortunately the analytical equations are not accurate enough on which to base the design of a working LTMD. However, fortunately, it is possible to determine the frequency characteristics very accurately using a scale model and Froude Scaling. MEL Consultants have modelled all the LTMD's designed by them and built with a model as shown in Figure 7. An example of the true characteristics of a LTMD are shown in Figure 8. This Figure, in particular shows the limitations of expanding the W/D ratio beyond about 2 to achieve lower tank frequencies for a given tank length L and vertical column height F.

5. Conclusions

The configurations of tall buildings likely to need added damping to achieve acceptable acceleration levels for occupancy comfort have been described. The frequency characteristics of a LTMD have been given and the limitations described with reference to model studies.

References

Melbourne W. H., Cheung J. C. (1988).,"Designing for Serviceable Accelerations in Tall Buildings". *4th International Conference on Tall Buildings, Hong Kong 1988.*

Vickery B. J., Galsworthy J. K., Gerges, (2001) R.,"The Behaviour of Simple Non-Linear Tuned Mass Dampers". *Proceedings of the 6th Council of Tall Buildings and Urban Habitat World Congress, Melbourne, Australia, Spon Press, 2001.*

Fig. 1. Eureka Tower with LTMD at the top

Fig. 2. Soleil Tower

Fig. 3. 82 Flinders Street

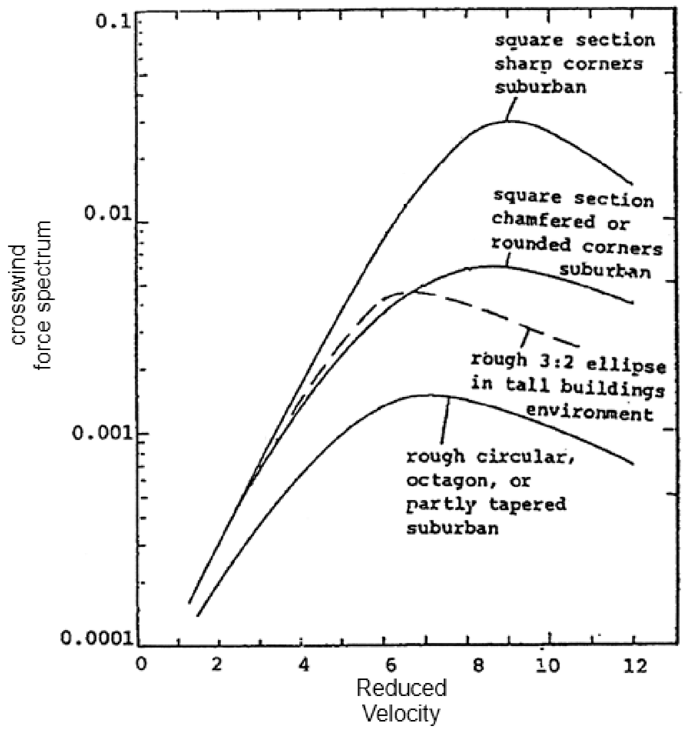

Fig. 4. Crosswind force spectrum characteristics as a function of Reduced Velocity

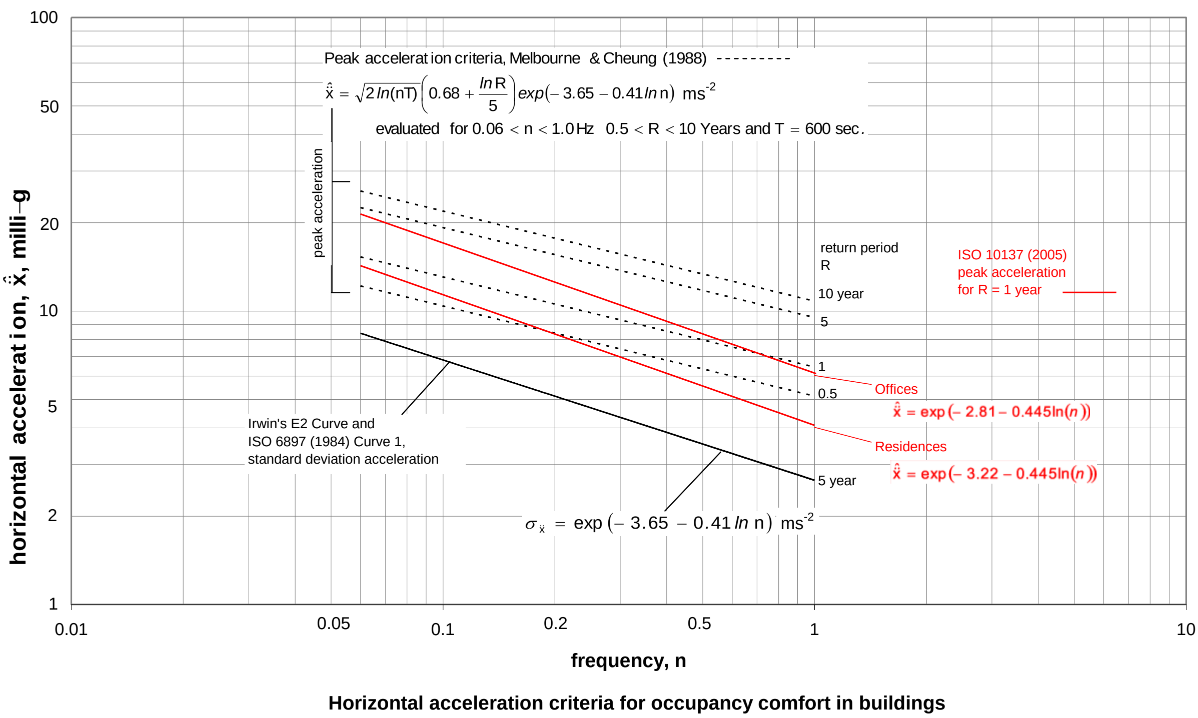

Fig. 5. Horizontal acceleration criteria for occupancy comfort in buildings

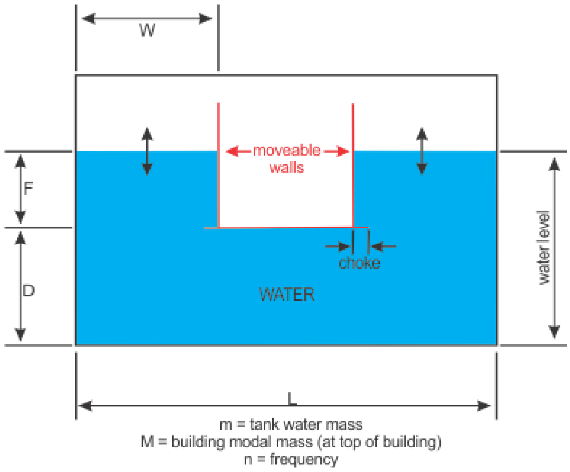

Fig. 6. Liquid tuned mass damper tank   Fig. 7. Model of liquid tuned mass damper

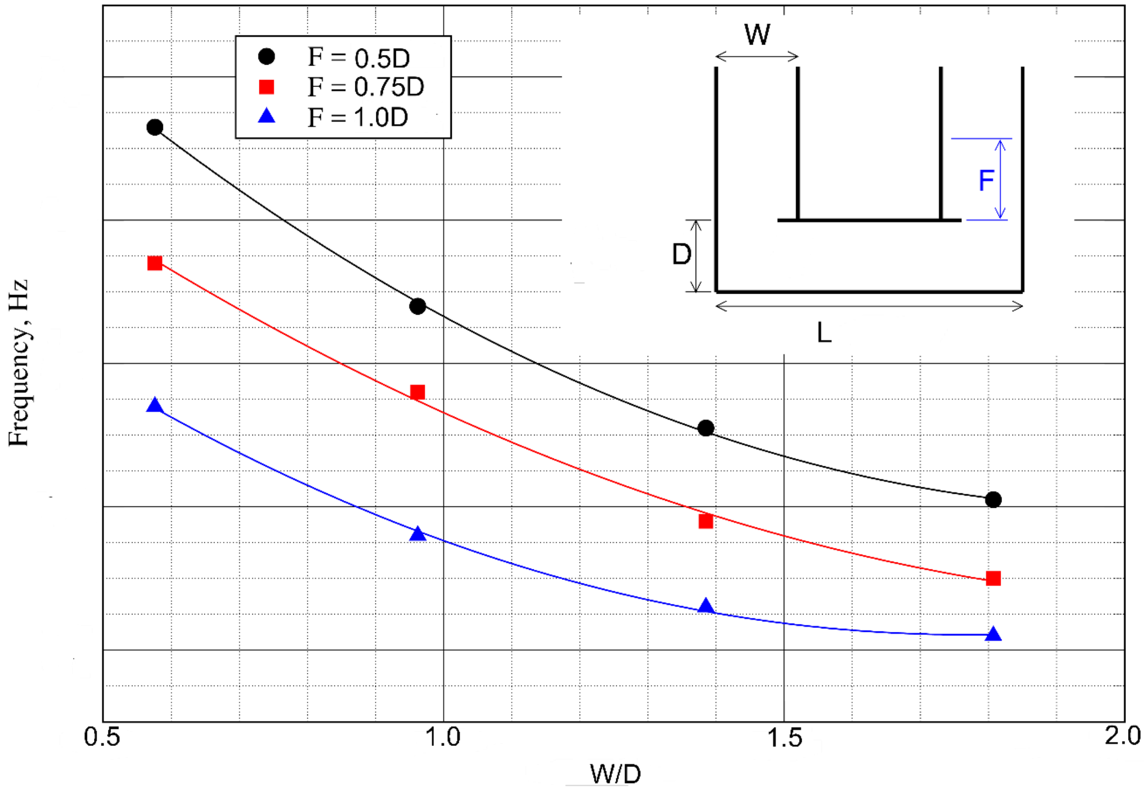

Fig. 8. Model LTMD frequency characteristics