Discussion Paper: Structural Damping

L.J.Aurelius, A.W. Rofail
Windtech Consultants, Sydney, Australia

1. Introduction

With regards to the dynamic response of a building, the structural damping is one of the most important, yet it is the most uncertain parameter. The accurate determination of the structural damping within a tall building can have a significant impact on the strength to which a building is designed and also, to a greater degree, on the assumed level of occupant comfort.

The purpose of this discussion paper is to raise awareness of new research that has been conducted in the area of structural damping and to exchange ideas as to what are suitable levels of structural damping to assume when designing tall buildings with either the aid of wind tunnel testing or relevant local standards.

2. Background

One of the main reasons that further discussion on this topic is required is the fact that throughout the world, relevant local standards regarding the issue of acceptable levels of structural damping vary significantly. This has been presented recently by Tamura *et al* (2000) and the International Association for Wind Engineering Working Group E – Dynamic Response (Tamura *et al*, (2005)). The variation in suggested levels of structural damping between different standards is shown in Figure 1. The lower levels of damping indicated within this figure relate to buildings in serviceability conditions, whilst the upper limits relate to building deformations in ultimate limit state conditions.

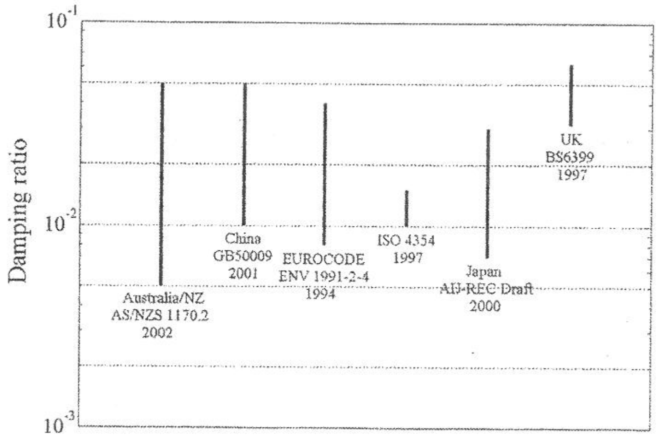

Figure 1: Design Damping Ratios for tall buildings

Based on the damping levels outlined in Figure 1 it is evident that the calculated wind load and wind-induced response can be expected to vary significantly for the same building, depending on which local standard it is to be designed to.

3. Recent Research with regards to amplitude dependency

There has been an increase in the research into structural damping of late, particularly in the field of full-scale measurements. It is considered that full scale measurement and the analysis of full scale data will provide engineers with invaluable insight into structural damping estimates.

Of noteworthy recognition is work conducted by Tamura (2005, 2000, 1996), Li (2003, 1998) and Jeary (2003, 1998, 1986) regarding the amplitude dependency of damping. The work of Jeary has suggested a damping model in which there are three regions in the damping-amplitude relationship: a low amplitude plateau region; a linearly increasing region with amplitude; and a high plateau region. The work of these authors, along with the work of many others, has led to the development of damping models that are dependant on amplitude of motion, as well as other factors such as structure height and type.

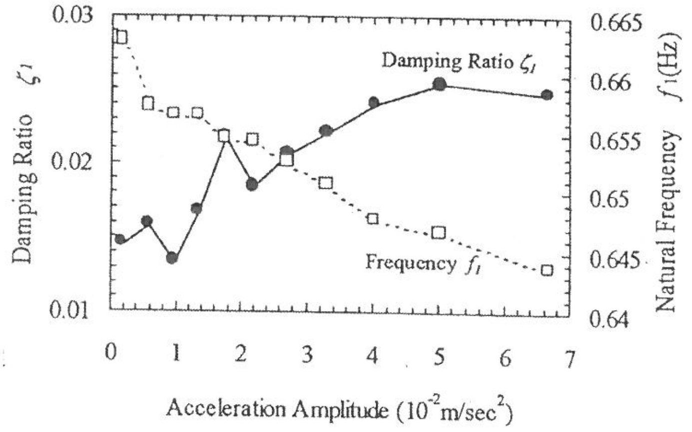

Figure 2: Variations in the fundamental natural frequency and damping ratio of a 99m high steel building with acceleration amplitude (Tamura et al., 1996)

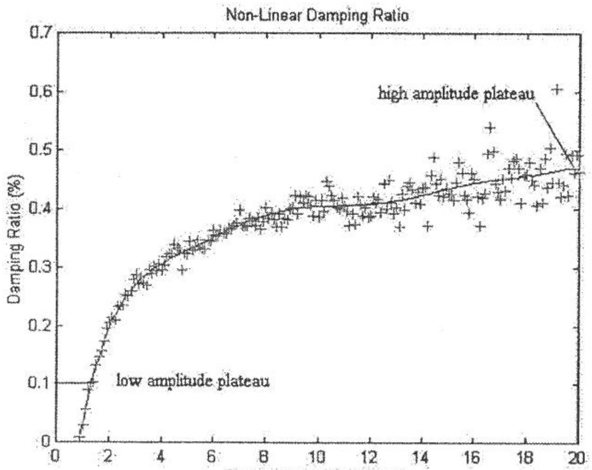

Figure 3: Amplitude dependant characteristics of a super-tall building (367m) (Li, Jeary et al., 2003)

Based on these figures, it is clear that the damping model will differ depending on the amplitude of vibration. The Li/Jeary results seem to suggest that the structural damping has not peaked once it has entered the high amplitude plateau, whilst it seems Tamura suggests that the damping will remain constant or decrease once a particular amplitude is reached. However, it is recognised that there must be an upper limit to the structural damping. The main question is whether or not this is reached as soon as the damping enters the high amplitude plateau or can there be a further increase in damping after the transition area.

It should also be noted that these results are based on relatively small measured amplitudes. In the case of Li and Jeary's work amplitudes of 20mm were measured (for a building height of 367m this equated to a tip/height ratio of $5*10^{-5}$), whilst Tamura's work is based on tip/height ratios mainly below $2*10^{-5}$. However, tip displacements are at least an order of magnitude higher than these values in the case of ultimate limit state design.

4. Conclusions

It is clear that there are issues that need more discussion with regards to amplitude dependency and its effect on structural damping. However, due to the increasing amount of research in this area, particularly in full scale research, it seems likely that internationally consistent empirical formula that take into account height, structure type and amplitude may well be ready for use within the near future.

We are in need of full-scale data based on much higher amplitudes than those currently published. The current work by Kareem involving continuous monitoring a number of tall buildings in Chicago using Global Positioning Systems (GPS) has the potential to provide very valuable data once a significant wind event occurs.

A number of tall buildings have been demolished over the past decade in Australia to make way for taller ones. These would have been excellent subjects for testing to higher amplitudes. We hope that these opportunities are not missed in the future.

With the current lack of full scale measured data, particularly for high amplitude vibration in tall buildings (tip/height ratio greater than $5*10^{-4}$), perhaps some measured conservatism should be employed, particularly for tall buildings operating in ultimate limit state design conditions.

5. References

M.J. Glanville *et al*, "Full scale damping measurements of Structures in Australia", *Journal of Wind Engineering and Industrial Aerodynamics* Vol. 59 (1996).

A.P. Jeary, "Damping in structures", *Journal of Wind Engineering and Industrial Aerodynamics* Vol. 72 (1997).

A.P. Jeary, "The description and measurement of nonlinear damping in structures", *Journal of Wind Engineering and Industrial Aerodynamics* Vol. 59 (1996).

J. Kilpatrick *et al*, "Full Scale Validation of the Predicted Response of Tall Buildings: Preliminary Results of Chicago Monitoring Project", Proceedings of the 11th International Conference on Wind Engineering, June 2-5 2003, Texas, USA.

Q.S. Li *et al*, "The effect of amplitude-dependant damping on wind-induced vibrations of a super tall building", *Journal of Wind Engineering and Industrial Aerodynamics* Vol. 91 (2003).

Q.S. Li *et al*, "Full Scale measurements of wind effects on tall buildings", *Journal of Wind Engineering and Industrial Aerodynamics* Vol. 74-76 (1998).

L.C. Pagnini *et al*, "Serviceability criteria for wind-induced acceleration and damping uncertainties", *Journal of Wind Engineering and Industrial Aerodynamics* Vol. 74-76 (1998).

G. Solari, "Evaluation and role of damping and periods for the calculation of structural response under wind loads", *Journal of Wind Engineering and Industrial Aerodynamics* Vol. 59 (1996).

Y, Tamura *et al*, "Aspects of the dynamic wind-induced response of strcuctures and codification", *Wind and Structures Journal* Vol. 8 (2005).

Y, Tamura *et al*, "Damping in Buildings and Estimation Techniques", Proceedings of the Sixth Asia-Pacific Conference on Wind Engineering, 12-14 September 2005, Seoul, Korea.

Y, Tamura *et al*, "Damping in Buildings for Wind Resistant Design", International Symposium on Wind and Structures for the 21st Century, 26-28 January 2000, Cheju, Korea.

Y, Tamura *et al*, "Evaluation of amplitude-dependent damping and natural frequency of buildings during strong winds", *Journal of Wind Engineering and Industrial Aerodynamics* Vol. 59 (1996).

Standards Australia, SAA Structural Design Actions, Part 2, Wind Actions. AS/NZS 1170.2:2002.