# Practical Experience with Wind-Tunnel Predicted Tall Building Motions

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## Summary

Predictions of peak accelerations from wind tunnel studies of 19 tall buildings are described and compared with full-scale reported experience. All buildings considered in this study were tested and built prior to 2000. More than a third of them have been occupied for more than twenty years. In the early years of this period the target criterion used by RWDI for residential buildings was for the 10-year return period peak acceleration not to exceed 15 milli-g. However, in some cases this proved difficult to achieve structurally, and after the structural designer had done all that was practically possible in terms of adding stiffness and mass, the results came in as high as 18 milli-g. The remaining measure that could be taken was to add a supplementary damping system. Space was set aside for the damping system but, in view of the subjective uncertainties in the 15 milli-g criterion, it was decided only to install such a system if experience proved that it was necessary. While there were rare reports of occupants noticing motion, no major complaints materialized and in those buildings in the 15 to 18 milli-g range no damping system has been installed. Therefore this range was subsequently treated by RWDI as acceptable on other projects. Wind tunnel studies for fourteen of the buildings discussed here predicted peak resultant 10-year accelerations within the 15-18 milli-g range, with no supplementary damping system. For the remaining five buildings, wind tunnel studies predicted peak resultant accelerations in the range of 23-28 milli-g, and supplemental damping systems (SDS) were installed to reduce acceleration responses to the 15 to 18 milli-g range. The only adverse experience we are aware of occurred on one of the buildings with a damping system when the system had inadvertently been immobilized when a windstorm arrived. Therefore our experience indicates that a 10-year criterion in the 15 to 18 milli-g range works in practice. More recent criteria are tending to be couched in terms of the 1-year return period acceleration and we agree with this approach, but the abovementioned experience still serves as a useful benchmark, provided the accelerations are appropriately scaled to compensate for the change in return period.

**Keywords:** wind-induced motion, tall building design, human comfort criteria, wind tunnel testing, supplemental damping system, building performance.

## Acceptable Motion for Human Comfort

Peak horizontal acceleration has emerged as the most common index for describing motion effects in tall buildings. From motion simulator studies and full-scale experience with wind-induced

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motions in tall buildings criteria are defined as limits that should not be exceeded more than once in a particular return period. The Council on Tall Buildings and Urban Habitat (CTBUH) recommends 10-year peak resultant accelerations of 10-15 milli-g for residential buildings, 15-20 milli-g for hotels and 20-25 milli-g for office buildings. Based on the RWDI's experience with the prediction of wind-induced motions using wind tunnel testing and discussions with the designers of numerous tall buildings, it has been found desirable to relax the acceptable motion criteria for residential towers to a range of 15-18 milli-g. The limiting 10-year peak acceleration is indicated as a range in recognition of the subjective nature and uncertainty in any such a criterion involving human response.

## Tall buildings considered

Recognizing the importance of the full-scale feedback or anecdotal evidence in validating the wind-induced motion criteria used for the design of tall buildings, 19 high-rise residential buildings tested in the RWDI's wind tunnels were investigated. Their heights vary from 94m up to 260m, while the natural frequencies of first order sway and torsional modes cover a range of 0.12-0.46 Hz. All buildings considered in this study were tested and built prior to 2000. More than a third of them have been occupied for more than twenty years. Wind tunnel studies for fourteen of the buildings investigated predicted peak resultant accelerations within the 15-18 milli-g range. For the remaining five buildings, wind tunnel studies predicted peak resultant accelerations in the range of 23-28 milli-g, and therefore SDS were designed and installed to reduce acceleration responses to RWDI's recommended acceptable levels for occupant comfort at a 10-year return period.

## Performance of the Buildings

For all buildings considered in this study, to our knowledge there have never been any serious complaints of building performance in terms of excessive motion, except on one building when the SDS had been inadvertently immobilized. This building is outfitted with a Tuned Mass Damper (TMD) designed to reduce the wind tunnel predicted peak total acceleration of 24 milli-g down to the 15 to 18 milli-g range. There were no recorded complaints of excessive building motions during windy days with the TMD working at the roof-top mechanical floor of the building. However, during one storm when the TMD had been inadvertently left locked up after maintenance of other equipment in the mechanical room, tenants started to complain to the building manager. The manager realized what had happened and unlocked the TMD mass. No further complaints of excessive building motion came in. This serves as a good indication that the building's behavior [24 milli-g] without the TMD would have been unacceptable, and that with the TMD [≈17 milli-g] it was acceptable.

## Concluding Remarks

Based on the experience with the 19 buildings considered in this study, it appears that if wind tunnel predictions of the 10-year peak resultant acceleration can be kept to within 15-18 milli-g, or lower, then the building performance will be satisfactory.

More recent criteria are tending to be couched in terms of the 1-year return period acceleration and we agree with this approach, but the abovementioned experience still serves as a useful benchmark, provided the accelerations are appropriately scaled to compensate for the change in return period.