Full-Scale Study of the Behavior of Tall Buildings under Winds

Fall 2002 Quarterly Report

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INTRODUCTION

In order to keep you abreast of the progress of our study, our findings, and their implications for your building, we plan on sending out quarterly updates. These updates will overview our activities relative to the ***************, present any relevant findings, and outline future activities involving the building. As we accumulate more data, these reports will serve as a chronicle of your structure’s behavior under a variety of wind conditions. It is our hope that sustained storms, particularly in the turbulent winter months, will enable us to do more detailed investigations of the structure’s dynamic properties and response characteristics and permit comparisons with our analytical predictions and wind tunnel tests.

MOTIVATION

The simplest and most valuable feedback on the state of a structure is the measurement of its natural periods of vibration from the ever present ambient vibrations, which result from occupant activities, traffic and wind action. Measuring the natural period is analogous to measuring the pulse of a human to determine the heart rate – it can be used as a direct descriptor of structural “health”. A meaningful sample of the dynamic response of a structure can be analyzed to establish its in-situ dynamic properties, such as the periods of its various modes of vibration, its effective damping and, where necessary, its associated mode shapes. This information can then be used in the following applications:

i) Feedback on the “as-built” vs the “as-designed” structure provides a valuable confirmation of structural performance and leads to improvements in design procedures. This is of great value for future generations of buildings and structures.

ii) Full-scale measurements provide a valuable diagnostic, which can, on an ongoing basis, determine the in-situ stiffness and other dynamic properties of the structure and can flag significant changes. This provides a valuable capability for rapidly assessing the significance of possible damage to the structure and/or the consequence of some other unexpected action.

iii) Ongoing feedback on the performance of the structure made possible by a continuous analysis of its response can provide a valuable assistance for day-to-day operations. Feedback on building motions for the effective operation of elevator systems is but one example. There are many other valuable applications.

The particular instrumentation system in place in the ***************, as part of this NSF-sponsored study, is intended to address item i), however, it can be readily expanded to provide diagnostic and operational information, as suggested in items ii) and iii).

INSTRUMENTATION OVERVIEW

On June 14, 2002, accelerometers and a data logger were installed on the 98th floor of the *************** The approximate locations of the accelerometers are marked by 1 and 2 on the floorplan at the right. At both locations, there are two accelerometers oriented to measure the N-S and E-W motions of the building. From these accelerometers, we can determine how much the building is moving in both sway and torsion. Each pair of accelerometers is in a small enclosure, clamped to beams at each location. The data from these sensors is logged and downloaded off-site through the data logger, wall-mounted near the core.
EXAMPLE OF DATA

Everyday a log of **'s response is generated, every 10 minutes. This log monitors the maximum motions of the building, defined in terms of accelerations, as well as the average value of these motions. Additional information is also gained from the standard deviation of these motions, in essence revealing, in an averaged sense, how much the building moves relative to this mean. Though the weather has been fairly calm this summer, we have selected a relatively active week in July to give you an indication of the structure’s response characteristics.

The first of the attached plots shows the wind speed, measured at a meteorological station out in Lake Michigan, about three miles offshore. This plot shows the mean wind speed over a 5-minute interval (in blue) and the maximum wind speed or gust over that same interval (in red). The second plot is the maximum acceleration of the structure in the N-S direction over a ten-minute interval. Note that we employ the units of acceleration commonly associated with the discussion of tall building motion, the millig, each being one-thousandth the acceleration due to gravity. The third plot is the maximum acceleration of the structure in the E-W direction over a ten-minute interval. Both plots show the measurement of building motion in these two directions measured at the two installation points shown schematically on page 2. By having two sensors measuring motion along the same building axis but at different locations, we have a reliable backup and means to verify if fluctuations are due to the electronics or some local disturbance, e.g. maintenance work, or physically a measure of the global building motion. This also allows us to extract torsional accelerations in our detailed analyses.

On July 23, relatively strong winds were coming from a northeasterly direction over the lake. These were found to produce the largest response of the building for the E-W direction, while a storm later in the week induced the largest response in the N-S direction. On July 24, the winds switched gradually to due east and then southeasterly by nightfall. On July 25, the winds came directly from the south, causing the E-W motion dominate, an example of acrosswind motion -- accelerations perpendicular to the oncoming windfield that are often critical for tall buildings. The wind speed again ramps up from July 27-28 and achieves similar wind velocities as the storm earlier in the week, however, blowing from the west to southwest. The level of response in the N-S direction markedly increases in comparison to the storm earlier in the week, due to the fact that again, the westerly wind component is critical in inducing the acrosswind motions along the N-S axis. Meanwhile, the E-W response shows no enhancement and perhaps even a slight reduction compared to its response in the earlier storm. The winds following this second event continued to blow from the west to southwest for the remainder of the week. From this data, this west to southwesterly wind appears to be far more critical in exciting the N-S building motion, while the northeastern and southern winds have a more considerable impact on the E-W response. The overall dominant response in the N-S direction is reasonable, considering that it corresponds to the building’s softer axis.

While more significant future wind events will induce greater response and provide more opportunity for detailed study of the building characteristics, the data collected thus far affirm not only the performance of the data acquisition system but also the ability of the sensors to successfully capture low-amplitude, low-frequency response with minimal electronic noise. Interestingly, on June 18, 2002, a trace of motion along the building’s softer N-S axis was detected devoid of any considerable change in wind speed or direction. The spike in the building’s 10-minute response characteristics was at exactly 1:40PM (EST), corresponding to the occurrence of a magnitude 5.0 earthquake in southern Indiana, near Evansville. The quake, which was felt in the Northern regions of the state, still had sufficient energy by the time it reached Chicago to produce a minor excitation in the **************.

FUTURE DIRECTIONS

In early September, we anticipate completing the installation of the GPS monitoring system on the **************. The addition of this new technology will allow us to accurately track the displacements of the structure and recover static components of wind-induced response and thermal expansion over the
course of the day. This data will also provide a secondary venue for estimation of the structure’s dynamic properties for comparison with our accelerometer data. As traditional accelerometers cannot recover static displacements of a structure, the inclusion of this system would make the **first** tall building in the world to have such a comprehensive monitoring system in place to track both its accelerations and displacements. In parallel, we have continued interest in including an anemometer on one of the building masts to provide a more reliable measure of wind speed at the Hancock and the capability to better map the wind field characteristics in the city. In the interim, we will continue to use the Lake Michigan meteorological data as a gauge of wind activity in the city.

As more data is acquired, particularly as strong winter fronts move through the city, the team hopes to undertake detailed dynamic analysis of the structural response in order to identify its characteristics more completely in both sway and torsion. Skidmore Owings and Merrill has been active in updating an analytical model of the building, which will be calibrated against the measured data we collect, as well as the wind tunnel studies conducted at the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario. With our continued accumulation of data, we will be able to conduct detailed comparisons of the structural properties and response with the predictions made during the building’s design. Future quarterly reports will continue to document our progress towards this end. In closing, the project team again would like to thank the owners, management and engineers associated with *************** and *************** for their continued support of this vital tall buildings research and their commitment to the success of this project.

**APPENDIX: PROJECT LOG**

This project log will be expanded throughout the course of the project and included in each quarterly report. All times in CST for Chicago.

06.14.02 : Accelerometers and datalogger cabinet installed in **************, 98th floor.

06.17.02 : Operation of system is confirmed and first data downloaded.

06.18.02 : Earthquake in Evansville detected along soft axis of structure.

07.23.02 : Mean wind speeds of 14-15 m/s (31.32 –33.56 mph) from 4-7 am.
Gusting to 17 m/s (38.03 mph). Wind direction 45 degrees (Northeast).

08.05.02 : Mean wind speeds of 14.5-15 m/s (32.44-33.56 mph) from 8 pm-midnight.
Gusting to 17 m/s (38.03 mph). Wind direction 45 degrees (Northeast).

08.06.02 : Mean wind speeds of 13.5 m/s (30.20 mph) from 12-3 am.
Gusting to 15 m/s (33.56 mph). Wind direction 75 degrees (Northeast).