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 **************, 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 **************, 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 15, 2002, accelerometers and a data logger were installed on the 56th floor of **************. The approximate locations of the accelerometers are marked by 1 and 2 on the floorplan on 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, the project team can determine how much the building is moving in both sway and torsion. Each pair of accelerometers is in a small enclosure, bolted to the concrete beams inside the false ceiling. The data from these sensors is logged and downloaded off site through the data logger enclosure. The data logger system is wall-mounted in a telephone closet in the core, denoted by the number 3 in the accompanying floorplan.
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 E-W direction over a ten-minute interval. Note that we employ the units of acceleration commonly associated with the discussion of tall building motion, the milli-g, each being one-thousandth the acceleration due to gravity. The third plot is the maximum acceleration of the structure in the N-S 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, in both directions, over the course of that week. On July 24, the winds switched gradually to due east and then southeasterly by nightfall. Under this change in wind direction, the once magnified N-S response dropped off to similar levels as the E-W response. 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 southwest, yet the response in both directions is approximately the same, reiterating the significance of the northeasterly wind direction in inducing the amplified N-S building motion. The wind remains strongly from the south to southwest for the remainder of the week with the response in both directions retaining their equivalence. As ************** is largely shielded from the southwesterly winds, and to some extent from the easterly winds, the findings from this week of data support the fact that winds from the northeast have a more critical impact on the structure, particularly inducing more significant N-S motions.

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.

FUTURE DIRECTIONS

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. In addition, we are coordinating the installation of up to two anemometers in the downtown area that will provide us the capability to better map the wind field characteristics in the city and provide us with a better indication of the wind speeds at **************. In the interim, we will continue to use the Lake Michigan meteorological data as a gauge of wind activity in the city. From our dialogues with the structural engineers involved in the design of **************, we are now poised to begin construction of 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.

06.15.02 : Accelerometers and datalogger cabinet installed in ***************, 57th floor.

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

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).