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Author:	Gary Hart, Weidlinger Associates
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BUILDING SYSTEMS AND CONCEPTS

Kidney Stones and The Structural Design of Tall Buildings

Gary C. Hart

1.1 INTRODUCTION

The author went to his doctor to report his latest Kidney Stone attack. Prior to the visit he had to take a blood test, have an X-ray session and then the latest Cat Scan imaging session. The doctor showed him the images from the sessions to impress upon him how "high tech" he had become. Then he discussed the options available to the author to stop kidney stones.

This visit to a modern "high tech" doctor and the doctor's process to meet the author's needs was enlightening. It was clear to the author that the doctor took three basic steps: First, he explained the results of his analysis in terms that the author understood, even though chemistry was the author's worst subject in college. Second, the doctor presented the options for stopping future Kidney Stone attacks. Third, the doctor, when pressed by the author, who knows probability and reliability theory, stated that there was NO guarantee that if the author followed all of the doctor's orders that those dreaded Kidney Stones would not come back again, i.e. they would stop! These three basic steps illustrated the fundaments of communication that must take place in this scientific and high tech age. What the doctor really did was to provide the bridge between the science of medicine and non-doctor descriptions of the options, and then very importantly quantified, based on his experience and the analysis of the author's case facts, the probability of success for different options that could be selected by the author. That is, science the author could not understand, options the author could understand, and then quantification of success for each option based on scientific analysis. Finally, the author had to make the decision on which option to take – not the doctor!

This is a Tall Buildings conference paper, so what does it have to do with Kidney Stones? Wait a minute and the answer will come.

Structural Engineers are professionals in this "high tech" age just like doctors. They work for clients that really have no technical training or experience to evaluate their work except when the dreaded Kidney Stone, or the Design Basis Earthquake or Wind occurs. In the structural engineers natural hazard world, it hopefully will never occur. (Some would argue that construction cost per square foot is a good measure, but then they really do not know if the great low cost building was the result of bad or good structural engineering and they really do not want to find out!). Fortunately for structural engineers, the theory of structural reliability was introduced in the 1960's and this introduction brought order to structural engineering. It enabled the structural engineer to communicate with his or her client in the same way that the doctor of the author communicated with him.

To understand the importance of the structural reliability theory and why it must form the foundation for a structural design criteria consider the following. The structural engineer that is about to design a tall building is in a unique and an especially difficult position relative to other building design professionals. The fundamental difficulty is the immense challenge faced in representing nature and its force on buildings, and also the prediction of the performance of the building due to these forces of nature. This is followed by the checking for human errors when structural engineers, usually under severe time pressure, make many complex calculations and decisions. The representation of nature and its impact and response of buildings demands the development of mathematical models that are ever increasing in both their accuracy and their complexity. For example, the author just finished a book for the publisher John Wiley and Sons entitled *Structural Dynamics for Structural Engineers*. The book started out to be about 200 pages in length and ended up being over 400 pages long. This result, even with the author's desire, was to minimize the mathematics of structural dynamics and to emphasize the physical feeling for structural dynamics. Therefore, one can imagine the shock to the author when it was discovered that the book contains over 4,000 equations! So unfortunately the world of equations is essential and because of the fantastic creativity of the architect each building has a unique optimal design.

What is the reluctance to equations and the sophisticated structural engineering theories that are available today? To answer this question consider the following. The author has had the privilege of knowing rather well many great structural engineers from around the world that are now still living and are near or past 90 years of age. Without exception they trace the modern development of structural modeling of structures from the late 1930's and 1940's. In the United States some would state that it started with the teachings of Timoshenko in the United States. Therefore, modeling the forces of nature and building response to these forces is a rather young and fast changing science. Therefore, from a quality control and business profit perspective it is a challenge.

As noted above, structural reliability theory, which must form the basis of modern structural design criteria, demands and uses these complex theories and corresponding equations. However, the reward is that it is the communication bridge that is used by doctors. On one end of the bridge structural reliability theory demands that the performance of the building be described to the lay person – in non-structural engineering words. For example, the behavior of the building will be such that the computers will not fall off the table due to an earthquake motion in the next 10 years. Or for example, the motion of a building's 35th floor in the wind will be such that the occupants not feel any building motion in the next 5 years. Or, for another example, the steel bar in that beam on the 30th floor near the nursing room will stretch in earthquakes that will occur over the next 30 years, but after the earthquakes are over the length of the steel bar will be the same as it was before the earthquake.

The structural engineer like the doctor can explain the possible responses that the building can experience when subjected to, for example, nature's wind and earthquake loads. Then the structural engineer can identify the structural engineering options that are available for the design of the building that can eliminate the undesirable building responses. Finally, the structural engineer can quantify using what is often called a risk analysis the real probability or chance that these undesirable building responses will occur.

1.2 THE LIMIT STATES

Modern structural engineering for tall buildings demands that the structural engineer and the building owner discuss at least three basic options or as in the vocabulary of Structural Reliability limit states.

The first limit state is the classic limit state that is considered in all building codes. It is life safety protection. This limit state must be quantified in terms of element performance and usually in today's modern structural engineering the strain in the steel or the concrete of the building. The goal here is to insure that no persons will die in the building as a result of the collapse of one or more members in the building for the largest earthquake or wind that will occur during the life of the building. We want a building design that provides a life safe behavior. This limit state must be discussed with the building official and the members of the community because the people are in the building and are being exposed to a risk often not of their own choosing – they may have to work or bank in the building. Because the structural engineer does not know with certainty what the largest earthquake will be in the building during the life of the building the discussion must be carried out in probabilistic terms. This is not unlike the terms that each person over 50 must address when asked how long he or she will live. The age of death and the associated estate planning must be carried out in probabilistic terms.

The second limit state is a damage control limit state using the relative displacement between the floors of the building. The goal here is to provide a cost-effective design when the costs associated with the consequences of different between floor displacement magnitudes are balanced with the cost to reduce the response to different magnitudes. This is a business decision and not a life safety decision. It does not require public input and is no person's business but the building owners. Unfortunately, all too often the structural engineer can not perform such a cost benefit analysis and therefore makes the decision without the owner's knowledge.

The third limit state is another damage control limit state that this time uses the acceleration of the floors in the building. Simply speaking the acceleration on the floor multiplied by the weight of an object or content on the floor must be small enough not to cause the object to tip over and break. The acceleration is also critical in the occupant's perception of the motion of the floor and the negative cost impact of feeling this motion. These acceleration limit states are not life safety decision limit states. The cost to reduce the response must be balanced against the damage for each response level. Again this is a cost-benefit analysis that is called a risk analysis.

1.3 THE LIFE SAFETY LIMIT STATE

Because most structural engineers prefer to perform a three-dimensional elastic analysis of the building, the life safety approach involves two levels of earthquakes and winds.

The life of the tall building, and therefore the time it is exposed to nature's forces, is assumed to be 100 years.

The elastic analysis design earthquake or wind is called Level I and it is used as input to an elastic structural analysis computer program.

LEVEL-I:

An earthquake ground motion represented by an acceleration response spectrum or a set of wind forces on the building that have a 50-percent probability of being exceeded within a 100-year period.

The non-linear analysis design earthquake or wind is called Level II and it is used as input to a non-linear structural analysis computer program.

LEVEL-II:

An earthquake ground motion represented by an acceleration response spectrum or a set of wind forces on the building that have a 2-percent probability of being exceeded within a 100-year period.

All buildings shall have a site-specific earthquake ground motion study. The study shall account for the regional seismicity and geology; the expected recurrence rates and maximum magnitudes of events on known faults and source zones; the location of the site with respect to these; near source effects if any; and the characteristics of subsurface site conditions. A review of the site-specific earthquake ground motion study shall be performed by an independent State of California Licensed Professional Geotechnical Engineer experienced in methods used to perform a site-specific ground motion study.

All buildings shall have a site-specific wind study as defined in the 2000 IBC. A review of the site-specific wind study shall be performed by an independent Licensed Engineer experienced in methods used to perform a site-specific wind study.