Quality Assurance of Structural Engineering Design - Part 1

By Ying X. Cai, Ph.D., P.E., S.E., M. ASCE

Facing the escalating demands in both technical competence and financial accountability, practicing structural engineers are being forced into an ever-intensified, fast-pace working environment. With more and more structural design codes becoming lengthy and cumbersome, and the time allocated for structural engineering design being drastically reduced, the quality assurance of structural engineering design has become more critical.

This is the first installment of a two-part series that discusses eight aspects of quality assurance and uses several "real world" examples. The second part will appear in a future issue of STRUCTURE® magazine.

Structural Design Codes and Standards

Generally speaking, a competent structural engineer should be able to deal with various construction materials. The first step of the design procedure for a structure is to determine which design codes apply and the appropriate code date in effect.

To safeguard the public health and safety, jurisdictions throughout the United States have adopted a variety of design codes as minimum requirements for the design and construction of structures. For buildings, BOCA, ICBO, and SBCCI were the most frequently used codes in the United States in the 20th century. Thanks to the collective efforts of the engineering profession, since the year 2000, these three most dominant building codes have been integrated into a single building code, the International Building Code (IBC).

At the very beginning of the design, the structural engineer shall confirm the appropriate code, code reference standards, and the code edition. *Example 1* illustrates the need for this approach.

In addition to the general design codes/standards such as IBC, AASHTO, and AREMA, the specific material codes/standards shall also be followed in the structural design of various construction materials. These specific material codes/standards form the technical basis of the structural engineering design. In addition to the basic design codes, thorough knowledge and the correct interpretation of specific material codes/standards are the essentials for a structural engineer to be competent and successful.

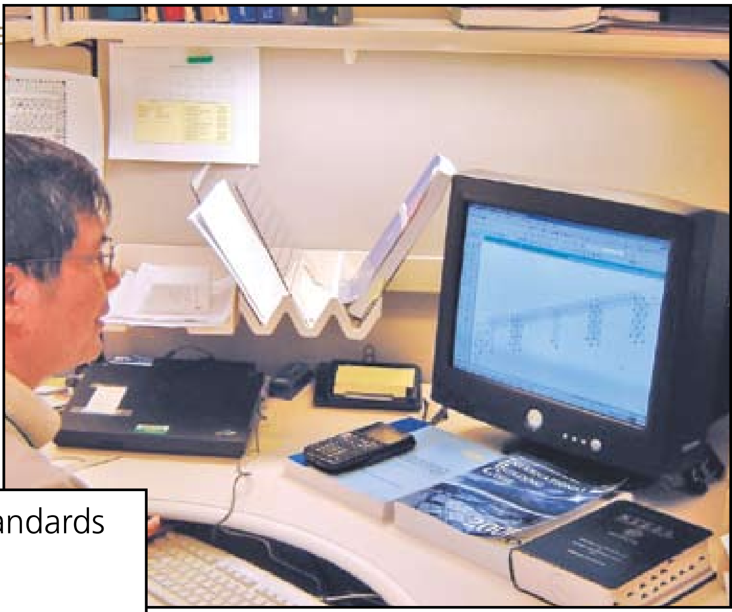
Material Codes/Standards

AA for aluminum
ACI 318 for concrete
ACI 530 for masonry
AF&PA and NDS for wood material
AISC for steel
ASCE 8 for cold-formed stainless steel
ASCE 19 for steel cable
AWS D1.1 for steel welding
AWS for welding
FEMA NEHRP for seismic design and retrofit
PCI for precast/prestressed concrete,
SJI for steel joists, etc.

Load Determination

After the appropriate codes/standards are selected, the determination of loads to be applied on the structure is a critical step in the design procedure. Although most general design codes have specified the load types to be applied to a structure, the quantitative determination of exact loads to be used for a structure is dependent on the structural engineer. It is an important task, sometimes even a challenge, for the engineer because the loading determination will have direct impact on public health/safety and the construction cost.

The code-defined minimum live loads are probability-based estimates of human-induced loads or nature's effects. They may not happen every day, but are possible during the service life of the structure. For the sake of public health and safety, a responsible structural engineer shall not compromise the use of minimum live loads, even if the engineer is under pressure from another party. *See Example 2.*

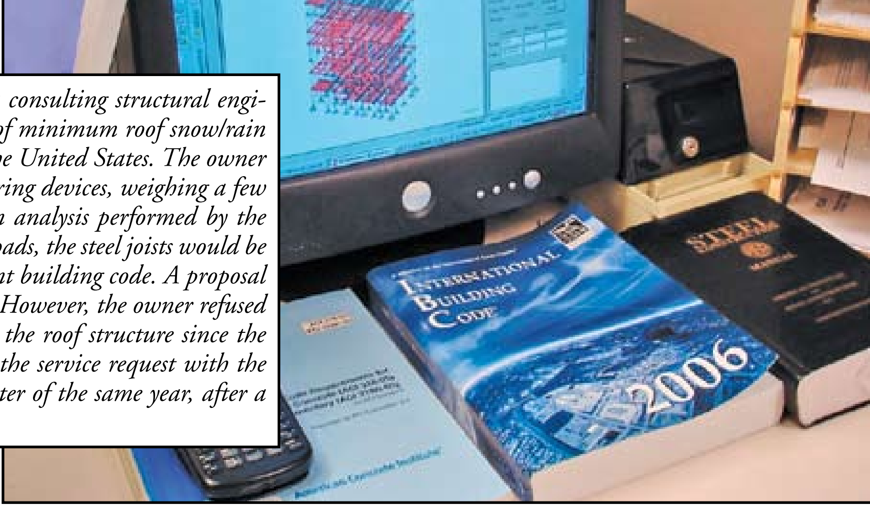


The complexity of codes in the development of wind and seismic loads on a structure can lead to engineering mistakes. It has been observed that, even for some experienced engineers with P.E. licenses, the ASCE 7-02, Article 6.5.6.1, "Wind Directions and Sectors" for the wind exposure determination, has been mistakenly applied.

For seismic loads, the mapped spectral response accelerations S_S and S_1 can be conveniently obtained from FEMA/USGS's "Zip Code Lookup" website with high accuracy. That being said, there is no precise "estimate" for site soil classification, and an incorrect estimate can amplify greatly the Adjusted Maximum Considered Earthquake (MCE) Spectral Response Acceleration parameters S_{MS} and S_{M1}, up to 160% and 240%, respectively. It has also been observed that even some veteran professional engineers had mistakenly used S_S and S_1 as S_{DS} and S_{D1} in determining Seismic Design Category.

Example 1 *A consulting engineering firm once worked as a sub-contractor of a prominent A/E company for the structural design of a high-profile facility at a metropolitan international airport. The design criteria provided by the A/E company cited BOCA 1999. When the consulting engineering firm delivered 90% submittal to the owner of the facility for approval review, they learned that the local city government having jurisdiction in the airport had adopted IBC 2000 as their building code. Because the IBC 2000 had more restrictive requirements for wind and seismic loads at this site, the lateral structure system and component/cladding of the facility structure needed to be re-designed. The project was only completed on time because the structural engineer worked 24/7 to correct the mishap. The structural engineers learned a painful yet valuable lesson.*

Example 2 *There was an example for such a dispute between a consulting structural engineering firm and a business owner regarding the use of minimum roof snow/rain loads on a balling facility located in the Midwest of the United States. The owner of the balling facility wanted to hang a number of scoring devices, weighing a few hundred pounds each, on existing roof steel joists. An analysis performed by the structural engineer showed that, even without adding additional loads, the steel joists would be overstressed under the minimum snow loads required by the current building code. A proposal for reinforcing the existing steel joists was presented to the owner. However, the owner refused to consider the proposal by saying that there was no problem for the roof structure since the building had been there for ten years. The owner then cancelled the service request with the consulting structural engineering firm. Unfortunately, in the winter of the same year, after a snow/ice/rain event, the roof joists of the balling facility collapsed.*



Structure Modeling

The modeling of a real world structure may be a routine duty or may be a challenging task, depending on the level of complexity of the structure being considered. The basic requirement is that the structural members shall be modeled accordingly as beam/columns, truss members, or tension-only members. However, the most frequently encountered problems are the modeling of the connections and supports of a "real world" structure. Because the type of connections and supports may drastically affect the stress and deformation of a structure and its individual members, the engineering principles and scientific reasoning, as well as construction feasibility, shall be considered in the modeling procedure. In most situations, the connections and supports are not pure theoretical pinned or fixed connections. Certain types of spring connections or supports should be used to better predict the real performance of the structure and it's members. Prudent engineering judgment plays a key role in the modeling of a "real world" structure as demonstrated in *Example 3*.

Accuracy, Limitation and Pitfalls of the Design Tools

To facilitate the structural design, a variety of design assistance tools have been developed. Recently, most of the design assistance tools have been computerized analysis and design software. The use of these design tools should always be guided by the complete understanding of the design tools and sound engineering judgment. Misuse of certain design tools, especially computer-aided design software, can result in severe errors.

Frequently observed structural analysis/design mistakes are: using model member length (distance between nodes of a structure model) as the unbraced member length; using software-default rigid connections for pinned end supports; using wrong section orientation (like Beta value in STAAD) for steel columns. With the development of computer technology, more and more design software is using windows-type input to make software more user-friendly. However, most of the software does not provide efficient functions for less-experienced users to check the completeness and accuracy of the input data and overall structure model. Facing the escalating demands for production, computerized design software has become a basic design assistance tool in most structural engineering firms. Quality assurance of the design software use should receive more attention than ever.■

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The author greatly appreciates the guidance and help provided by Mr. Craig E. Barnes, P.E., SECB, in the publishing of this article.

Example 3 *A consulting engineering firm was requested to design a one-million gallon sludge tank for a waste treatment plant. The tank would be a reinforced concrete structure with a diameter of 90 feet and a wall height of 24 feet. A preliminary design of the tank modeled the connection between the tank wall and bottom slab as a rigid connection. The bending moments resulting from such a connection model were so large that, if the tank were designed by this kind of modeling of the connections, the construction cost of the tank would far exceed the client's budget. To better serve the client, the layout of reinforcing steel in the junction of the tank wall and bottom slab was revised and a pin/spring type connection was used to model the tank wall-slab junction. The re-modeled tank design resulted in a significantly reduced wall thickness and area of reinforcing steel, which brought the construction within budget.*