Sustainable Buildings and the Structural Engineer

By Christine A. Subasic, P.E., LEED AP

As green building becomes more widespread, the challenge to the design community is to move beyond simply green to develop sustainable, high-performing buildings. Sustainable, high-performing buildings are more than just environmentally "friendly"; they also must consider economics and social effects in their design and construction. For the structural engineer this means moving beyond simply using structural steel for its recycled content or using fly ash in concrete. Rather, the structural engineer must recognize his or her role as an integral part of the building team that includes the architect, mechanical engineer, civil engineer, contractor and others. The entire team must view the building and its site in its entirety, rather than focusing only on their area of expertise. The team must recognize the environmental, economic and social effects that choices by one member can have on other members of the team.

Sustainable, high-performing buildings should consider the following principles, adapted from the Sustainable Buildings Industry Council (*Ref. 1*), in their design and construction:

- Commissioning
- High performance lighting
- Daylighting
- Visual comfort
- Environmentally responsive site planning
- Water efficiency
- Acoustic comfort
- Energy analysis
- Renewable energy
- Energy efficient building envelope
- Thermal comfort
- High performance HVAC
- Superior Indoor Environmental Quality
- Safety and security
- Life cycle cost analysis
- Environmentally preferable building materials

At first glance, very few of these principles seem to be related to structural engineering. However, closer examination reveals how many of the strategies used to achieve a high-performing building can impact the structural design of the building.

High-Performance Design and Structural Design

Of the sixteen principles listed, fourteen can have a direct impact on the structural design of the building.

Daylighting and Visual Comfort

Daylighting includes orientation of the building and the use of windows, skylights, roof monitors and clerestory glazing to provide natural light to interior spaces of the building (*Figure 1*). Daylighting strategies can impact the structural design in several ways. Building orientation and the location of walls (or lack thereof) to provide views to the outside can limit the location of shear walls and other loadbearing elements in the building. Roof monitors, clerestory windows and other openings must be considered when detailing the load path for the building structure.

Daylighting strategies can also include the use of light shelves, which are externally-mounted devices used to reflect light deep within a space (*Figure 2*). The loads from these devices, as well as other external shading or cladding materials intended to provide visual comfort to occupants, must be considered in the structural design.

Figure 1: Clerestory windows. Courtesy of Wake County Public School System.

Environmentally Responsive Site Planning

Environmentally responsive site planning is a wide-ranging principle that includes issues such as storm water control, and providing shading for parking and the use of vegetated roofs. Permeable pavements designed to reduce storm water runoff must be properly designed by an engineer to function as intended. Retaining walls can also play a role in site stabilization. An increasingly popular strategy that greatly affects the structural design is the use of vegetated roofs. Such roofs may have several inches of soil and can impose much higher dead loads than a typical roof. ASTM E2397-05 *Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems* (*Ref. 2*) provides guidance to designers in determining the weight of a green roof system. Dead loads to be considered include the weight of the components of the green roof system such as the geotextiles, drainage media, and plant materials, as well as the weight of the system when irrigation or rainfall has saturated the drainage layer. Live loads are specified in Section 1607.11 of the 2006 *International Building Code* (IBC). (*Ref. 3*) Vegetated roofs designed as gardens or assembly areas must be designed for a minimum live load of 100 lbf/ft^2 (4.79 kN/m^2). Vegetated roofs that do not allow access to occupants are classified as landscaped roofs and must use a design live load of 20 lbf/ft^2 (0.958 kN/m^2).

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Figure 2: Light shelves. Courtesy of Wake County Public School System.

Water Efficiency

Strategies used to improve water efficiency of a building often include the use of low-flow fixtures. Harvesting of rain water is a strategy that can also be used. Sloping roofs and water storage with its associated weight are issues that can impact the structural design. Building water storage systems may be located on the ground, inside or outside the building, or they may be located within the building at a height that provides distribution without pumping. Such loads can be significant. In some cases, water storage within a building can be used as part of structural damping system. Section 1611 of the IBC includes provisions for rain loads. When roofs are equipped with hardware to control the rate of drainage, a secondary drainage system must be provided at a higher elevation so the total accumulation of water on the roof is limited. Such roofs must also be checked for instability caused by ponding according to IBC Section 1611.2.

Acoustic Comfort

Acoustics hardly seems related to structural design except when you consider many of the strategies used to improve acoustic performance include the use of heavier materials. Increasing material mass is one of the primary means to decrease sound transmission. In most cases, the increased weight of extra gypsum board over studs or the use of interior masonry walls will not have a significant effect on the structural design, but it is something the structural engineer should be aware of. The use of interior masonry walls for acoustic purposes also provides an opportunity for walls to serve multiple purposes when designed as part of a loadbearing masonry structure. Traditional concrete masonry or clay masonry can be used as sound-isolating loadbearing interior walls, or special acoustical block can be used. Acoustic block can take many forms, depending upon the manufacturer. In most cases, acoustic block incorporates chambers within the block to capture the sound and/or an irregular surface to diffuse sound. Acoustic block can be loadbearing units, and some can incorporate reinforcement if desired (*Figure 3*).

Energy Analysis

Energy analysis can lead to a more energy-efficient building. Because energy analysis allows for innovative approaches, structural engineers may be impacted by the building orientation, earth-sheltered walls, and the use of mass (heavier) walls.

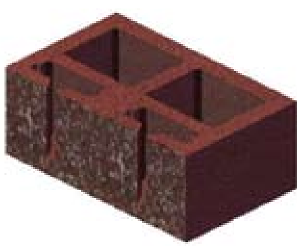

Figure 3: Reinforceable acoustic block (underside view). Courtesy of Adams Products Company/Trenwyth.

Renewable Energy

Renewable energy sources such as photovoltaic panels are most often mounted on the roof of the building. Structural engineers need to allow for such loads and equipment support in their design. In some cases, solar panels may influence the shape of the roof itself.

Energy Efficient Building Envelope

One key to achieving an energy efficient building envelope is to control air movement. Detailing of air barriers is critical. Structural engineers need to work with architects to achieve adequate support of the cladding while providing a continuous air barrier with proper details.

Thermal Comfort

Thermal comfort refers to control of temperature and humidity within the building. One strategy used to minimize interior temperature swings is the use of thermal mass, or interior masonry or exposed concrete walls. As mentioned before, this increase in building weight must be designed for, but can also be an opportunity for an efficient loadbearing design.

High Performance HVAC

A high performance HVAC system can encompass many strategies. One that may affect the structural design is the use of natural ventilation in the building. The influence of wind inside the building must be examined. In some cases the building may include thermal chimneys, or vertical spaces designed to draw heat and air out of the building.

Superior Indoor Environmental Quality

One way to improve indoor environmental quality is to reduce the amount of volatile organic compounds (VOCs) present in the building. By leaving the structure exposed, without site-applied paints or coatings, VOCs and extra building materials can both be avoided.

Safety and Security

A sustainable building must be safe and secure. Going beyond simple life safety of the structure, the structural design must also account for many unique aspects of safety and security including blast resistance, impact resistance, and fire resistance. Many structural engineers are familiar with the requirements for blast resistance for government buildings. Impact resistance can refer to large impacts such as from a truck, or resistance to wind-borne debris. Both can affect the design of the structure. In the case of fire resistance, one strategy that can be used is compartmentation. Compartmentation uses concrete or masonry walls to subdivide, or compartmentalize, a building to prevent spread of a fire. Such walls can be incorporated into the load-resisting components of the building.

Life Cycle Cost Analysis

Life cycle cost analysis goes beyond initial ecomonic cost to examine the total cost over the life of the building. Life cycle cost analysis includes determination of the life span of the building materials used, the required maintenance, as well as the initial cost. Consideration may also include demolition and recycling costs at the end of the building life. Environmental "costs" should also be examined over the entire life of the building and include environmental impacts of maintenance as well.

Environmentally Preferable Building Materials

Selection of building materials must consider budget, availabilty, construction impacts, durability, performance, as well as environmental impacts. When considering the environmental impacts of building materials, several aspects should be examined. These include manufacture of the material (including raw materials used and manufacturing processes), how the finished material is used (including efficiency of use in design and waste during construction), and finally the building life. This is the area we tend to think of first when discussing building materials. How much recycled content does it have? How much fly ash is used? Though these are important questions, they reflect only a part of what makes a material environmentally preferable.

Things to consider when evaluating the environmental preferability of a building material include:

- Abundance of raw materials
- Regionally located raw materials
- Biobased content
- Durability
- Energy efficient qualities in the finished product
- Enhanced indoor environmental quality
- Land reclamation
- Low embodied energy
- Recyclable or reusable components
- Recycled-content
- Reduced environmental impact over the lifecycle
- Reduced or eliminated toxic substances
- Reduced waste both during manufacture and during construction

• Responsible stormwater management
• Used efficiently in the design
• Uses renewable energy or alternate sources of fuel
• Water efficiency
• Water reuse and recycling

No single building material will encompass all of these traits, but the structural engineer should consider these aspects when evaluating building material choices.

Conclusion

As you can see, there is more to sustainable design and the structural engineer than just recycled content of building materials. Numerous sustainable design strategies can have a direct impact on the structural design of the building. Structural engineers can benefit from becoming familiar with sustainable design and the common green building rating systems. Sustainable design is characterized by an all-encompassing approach to building design. Numerous resources are available for those interested in sustainable design. The Whole Building Design Guide (**www.wbdg.org**) is a valuable website that provides design guidance, references, and information on high performance, sustainable buildings through a collaborative effort of federal agencies, private sector companies, non-profit organizations, and educational institutions. Another resource is the 2007 ASTM International Advantage Award-winning paper, *ASTM Standard Breaks Barriers to Global Sustainable Development*, by Dru Meadows. In her paper, Meadows provides a history of sustainable design and an examination of green building in the United States. (*Ref. 4*)

Of course, the structural engineer is one member of the larger design team, and it is the entire design team that is increasingly charged with developing green buildings. Familiarity with the most widely used green building rating system, the LEED®-NC for New Construction Rating System, is especially helpful. Though much of the burden associated with achieving LEED-certification of a building rests with the architect and contractor, by working with other members of the design team, the structural engineer can be an integral part of the synergy that occurs with a high-performing building design. The LEED®-NC rating system is available for free from the U.S. Green Building website at **www.usgbc.org/leed**. To fully understand the details of the LEED®-NC rating system, consider taking a seminar or online training course and/or purchasing the LEED®-NC Reference Guide. If you find that more and more of your business centers on green building, consider striving to become a LEED Accredited Professional (LEED AP). LEED AP's have passed an exam that demonstrates their familiarity with the LEED rating system, certification processes, and sustainable design strategies.

As an educated member of the design team, the structural engineer can make significant contribution to achieving a high performance, sustainable, building.▪

REFERENCES

Ref 1: *HighPerformance School Buildings Resource and Strategy Guide*, Sustainable Buildings Industry Council, Washington, DC,

Ref 2: ASTM E2397-05 *Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems*, ASTM International, West Conshohocken, PA, 2005.

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Ref 4: Meadows, Dru, "ASTM Standard Breaks Barriers to Global Sustainable Development," *ASTM Standardization News*, ASTM International, November 2007.

Ms. Subasic is a consulting architectural engineer located in Raleigh, NC where she specializes in masonry and structural engineering and sustainable design. She may be reached via email at ***csubasicpe@aol.com****.*