Structural Design and Embodied Carbon

Considerations over a Building's Service Life

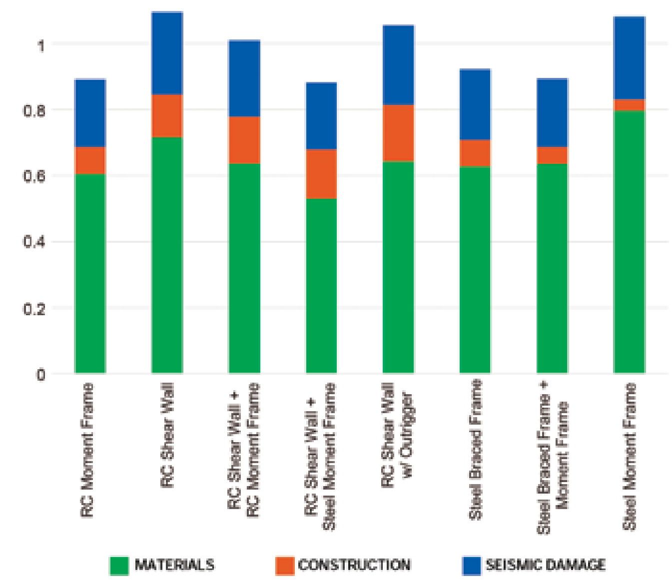
By Chris Horiuchi, S.E., LEED BD+C, and Nicole Wang, P.E.

The structural engineering design profession needs to carefully reconsider design approaches. Embodied carbon of structural systems in buildings has been established to be a considerable influence on the detrimental environmental impact of structures. Embodied carbon is defined as the CO_2-equivalent emissions into the atmosphere caused by the production of a material, product, or system. Embodied carbon impacts of a building's structural system are primarily associated with the different life cycle stages: material extraction, manufacturing and production, construction, damage and repair during service life, and end-of-life considerations.

The ASCE/SEI Sustainability Committee is focused on reducing the global climate change impact of structural components and has completed significant research into the many opportunities for structural engineers to reduce the embodied carbon of buildings. It is critical to consider these options early in the decision process such that they become important aspects of the project. Some possible strategies include the use of alternative materials, particular structural system selection, and incorporation of enhanced seismic-resisting systems.

Alternative Materials

Material decisions can help reduce embodied carbon. For example, cement is the most significant contributor to the embodied carbon of concrete. Replacing cement with supplementary cementitious materials (SCM) like fly ash and slag can reduce the overall environmental impact without negatively affecting concrete performance. Additionally, wood is a renewable material and can be considered a carbon sink as it sequesters carbon when sourced from a sustainably managed forest. While timber has been traditionally used for low-rise construction, mass timber components have become more common in taller construction and longer span conditions, and serve to reduce the amount of steel and concrete used in construction. For additional information on embodied carbon of structural materials, refer to the ASCE/SEI technical report *Structural Materials and Global Climate*.



Normalized comparison of embodied carbon values of various lateral systems based on survey of previously-designed buildings.

Structural System Selection

Surveys of previous buildings have been analyzed to determine trends in structural system selection. Based on previous studies, it is estimated that utilizing a slab and beam system over a flat slab system can save 15 – 20% of embodied carbon. The more efficient gravity framing depths translate into lower material quantities in the framing and lower lateral demands. Other considerations are required when selecting structural framing systems, but the intensity of structural embodied carbon should also factor into the decision process.

Lateral system selection can also affect overall material quantities. The *Figure* shows average structural embodied carbon values based in a database of previously designed buildings with particular lateral force-resisting systems as compared to buildings of similar height and seismicity. For steel structures, systems incorporating axial resistance (e.g., braced frames) can reduce embodied carbon impacts by 20% when compared to similar structures using moment frames. For concrete structures, shear wall buildings show trends of higher structural embodied carbon over moment frame buildings. Even though moment frames are a less efficient method of resisting lateral load, shear walls may include underutilized concrete material.

The examples of trends exhibited by this data are not expected to be absolute rules for lateral system selection. Rather, they should serve to encourage engineers to use embodied carbon as another decision variable in structural design. The results for any particular project may vary depending upon many factors, including the seismicity, the geographic location, the assumed service life, and the building program and configuration.

Resilient Seismic Systems

Buildings have a probability of experiencing a design-level earthquake over their service life. Damage resulting from a seismic event requires repair and designs include a particular failure probability of complete demolition and replacement of the structure, thereby causing further use of natural resources and emitting additional carbon.

Enhanced seismic systems can limit the expected damage during a future earthquake. These systems enable the more efficient use of the required structural materials by reducing the likelihood of repair or demolition and replacement in the event of a collapse. These effective seismic systems localize displacements to allow the majority of the structure to behave as essentially elastic. Isolators reduce seismic demands on the superstructure and fuse systems localize ductility to a particular location which can be easily replaced after a damage-inducing seismic event. A previous building study on a mid-rise residential building in San Francisco showed a possible 15–20% reduction in overall embodied carbon when considering probabilistic seismic damage using base isolation. Considering these long-term structural impacts with respect to embodied carbon impacts reinforces the importance of seismic design methods that target improved performance beyond code minimums.

One could also argue that structural engineers are among those who can have the most significant impact on climate change since they decide the structural materials and system performance. As a profession, we need to create greater awareness of the damaging carbon emissions in the construction and maintenance of building structures negatively impacting global climate change. It is important for the engineering profession to embrace the most advanced systems available and create a holistic awareness of their benefits to building performance, damage repair cost and extent, and environmental impact. With a goal of minimizing the built environment's impact on the natural environment, engineers need to focus on intelligent use of materials and incorporating resilient systems.

Structural engineers interested in participating in the further development of sustainable structural design ideas are encouraged to connect with the ASCE/SEI Sustainability Committee (**www.seisustainability.org**) or their local organization.▪

Chris Horiuchi is an Associate at Skidmore, Owings & Merrill LLP in San Francisco and is chair of the ASCE/SEI Sustainability Committee's Disaster Resilience Working Group. (christopher.horiuchi@som.com)

Nicole Wang is a Project Engineer at Skidmore, Owings & Merrill LLP in San Francisco and is chair of the SEAONC Sustainability Committee. (nicole.wang@som.com)