Site, Foundations, and Sustainable Construction

By Robert Field, P.E. and Russ Miller-Johnson, P.E.

Since foundation structures are predominantly concrete, they can tend to fall outside the normal "what material is most sustainable" argument which we structural engineers may be part of. But while their material *may* default to concrete, the real "sustainability" of the solution lies in how we do it: both in our overall system selection strategy, as well as in our execution and detailing. This argument is true for almost everything that contributes to sustainability on a project. Foundations, more than most other components of the building, tend to be overlooked by the architect or other designers. If structural engineers have a solution that can be built more economically, then they may be given leeway toward creative solutions. Thus, because foundations system economics are usually proportional to using less material and energy, there is the potential for making a significant impact on sustainability with foundations.

In our context, foundations are those systems which deliver the structural loads to the earth, acting as the support for a larger structure, such as a building, a site structure, or the on-grade surface that we walk on, such as a slab-on-grade. The decisions made by structural engineers regarding excavation, fill, and deep foundations have potential for significant savings. Those savings can also correspond to lower embodied energy, carbon dioxide release, or reduced life cycle impact of the material or system.

*Figure 1: Fabric Formed concrete wall footing. Courtesy of Fab-Form Industries, Ltd (**www.fab-form.com**).*

The Building as a System

Foundations are an integral part of the building system, or envelope, and therefore sustainability considerations must include their impact on the envelope's insulation or conduction of heating and cooling. Closely tied to this thermal performance is an understanding of the moisture movement, including that which occurs through concrete slabs and walls. Although these *building science* topics are often left to the lead of the architect and their energy consultants, as we move to the foundation, proper system selection and design for thermal considerations can be incorporated into the requirements for the structural load path.

Another thermal consideration with foundations is the possibility of using a passive solar design strategy in conjunction with the concrete mass of a slab design. A grade slab that is located properly in relation to the south facing windows can be used in winter months to accumulate heat during the day from solar gain. The slab must be a carefully specified component, with insulation and jointing compatible with an overall design. This is a great example of the need for integration between disciplines in sustainable design. There are many examples of poorly designed passive solar systems that become more of a liability than an asset, heating at the wrong time or contributing to moisture problems.

Material Considerations

Before the structure of the foundation is placed, there is a base, an important part of the foundation design. For slabs, the fill aggregate, which often acts as the base for the slab, can itself be a topic of as much discussion for structural engineers as the slab itself. When a coarse aggregate base is called for, a crushed concrete material can substitute for a virgin material such as granite. In the Atlanta metro area for example, Dykes Paving has used their portable crushers and magnetic rebar separator for onsite demolition of concrete, then stockpiling it onsite for use in new construction. In markets where crushed concrete is available, especially in metropolitan areas, it is a great option for avoiding the extraction and transportation impact of quarrying for aggregate. Testing has shown that this recycled material can be used for both coarse and well-graded aggregate. At the LEED Gold rated Klaus Advanced Computing Building in Atlanta, a crushed concrete aggregate base was used, after it was washed to alleviate the fear of infiltration of high-alkalinity fines into the groundwater.

In addition, recycled concrete aggregate is a potential source for concrete aggregate for foundations, due to the fact that they are often the lowest stressed concrete members in a building and they may be the least susceptible to aesthetic concerns, such as cracking. The Texas Department of Transportation has excellent documentation for the use of recycled aggregate, both coarse and fine, in their concrete pavement mixes.

Because concrete is the primary material used for foundations, the numerous sustainability aspects for concrete material should be considered, not least of which is the replacement of portland cement with other supplementary cementitious materials (SCMs), such as fly ash and slag. Foundations often have a substantial time lag between placement and their ultimate design load, making them great candidates for higher than normal use of these SCMs known for having slower strength gains than portland cement. As with most discussions of sustainability, reducing the amount of material used through optimizing the design is a straightforward way to reduce the impact of the structural system.

continued on next page

Web Resources

Dykes Paving
www.dykespaving.com/materials/recycled-aggregates

Texas Department of Transportation
www.txdot.gov/news/017-2009.htm

Constructing the System

Other than the "what" of a material, the "how" plays a significant part in achieving sustainability. With concrete, the first step is how it is formed. Traditional timber or steel formwork is inherently wasteful of material and transport energy, even with reuse, simply because the materials do not end up in the structure. As an alternative, a new technique of fabric-formed concrete has been gaining fans by using far less material, by weight, in a given application. The fabric is usually a common geotextile that is used purely as a tensile material and can be reused for additional forming or for site purposes. Spread footings and foundation walls have good potential for the application of fabric formed concrete. When designed properly, it can significantly reduce materials and transportation fuel consumption. As shown in *Figure 1 (page 33)*, a spread footing can be created with a fabric bag designed for the required volume and footprint. The potential reduced waste volume is significant, and it can make construction more economical in hard-to-reach areas that may be difficult to access with construction materials for formwork.

Another formwork system, Insulated Concrete Formwork (ICF) is mentioned here because it is utilized in foundation walls in both residential and commercial construction. As shown in *Figure 2*, this ICF is a modular system that incorporates a two-sided insulation material (most commonly extruded polystyrene with plastic ties) and that acts as a concrete formwork system. The concrete is the structural system, and is designed to carry all the loads independently. The lower weight of this form also makes it viable for sites that are difficult to access. However, this system results in the thermal mass of the concrete wall being insulated from both the interior and the exterior, therefore, it may not be ideal if the designer intends to take advantage of this thermal mass.

Durisol is a brand-name for a block formwork system that is unique for using a mineralized wood material made of a proprietary combination of portland cement and wood chips. The system is a relatively permanent and light form. If insulation is required, a special block includes a mineral-wool insulation insert. This system requires a fully designed waterproofing barier system.

Precast foundation walls have been used in residential construction and, similar to most precast structures, result in potentially reduced formwork waste due to factory fabrication. However, transportation for precast solutions is often greater, since their manufacturing plants are found in limited locations. This takes away from one of the advantages of concrete or masonry, which uses local sourcing of materials and labor.

Figure 2: Modular Insulated Concrete Formwork. Courtesy of Russ Miller-Johnson.

Concrete masonry basement walls are one of the most common foundation wall systems. Their use is subject to the considerations of masonry and concrete materials. Materials for site structures also frequently employ traditional masonry, as well as other stacked masonry or concrete products, to create gravity-based or tied-back retaining systems.

Sustainable Strategies

Strategies of foundation design, which consider the building envelope, have large potential impacts for reducing energy use throughout the life of the building. Preventing moisture flow into the building has a significant effect on material durability and indoor environmental quality (IEQ) from the possibility of mold growth. Detailing an insulated and encapsulated foundation can make it part of the whole building envelope system.

One example of detailing foundations to complete the envelope is in the use of insulated column bearing blocks under steel building columns to prevent thermal bridging. Thermal bridging means a loss of heat to the exterior, as well as increased condensation in the interior due to the colder surface of the steel member. It can be a particularly acute problem for columns that bear on exposed foundation walls or for columns located outside of the building envelope (*Figure 3*). Insulated bearing blocks employed here are a new application brought over from cold storage facilities that are detailed to keep the sub-grade from freezing. These foam blocks commonly have bearing capacities in the 1000 to 1800 psi range. The design team's energy consultant rarely considers the effects of such local thermal bridging in their idealized envelope rating. However, the performance improvements resulting from the addition of an insulated layer in the foundation system to prevent thermal bridging are potentially significant.

In addition, the use of shallow frost-protected foundations is a solution which can reduce thermal bridging between the foundation and the outdoors or earth, while also reducing both the volume of structural materials and excavations. This technique has seen years of study and light use in cold weather regions such as Minnesota and Vermont, and is in common practice in much of Scandinavia.

Impacts of excavation and backfill for preparation of foundations can be an important consideration in sustainability. Whether on delicate sites, which are vulnerable to damage during construction, or in areas of contaminated soils, which if excavated would require remediation, minimizing the amount of excavation results in a better solution. This can be achieved by selecting the appropriate foundation system. While weaker soils require larger foundations, the tradeoffs in costs and sustainability may make this a better approach than more excavation to reach better bearing material at a deeper elevation, or in bringing in structural fill. Another approach to consider may be options of deep foundations, such as piles or piers, which are frequently used to reduce the excavation impact of foundation work.

Conclusions

In short, foundations are an often overlooked area of focus for sustainability. Since they are, to a great extent, left alone by the other designers, structural engineers have a greater opportunity to exert creativity in finding solutions that reduce the impact of the system.▪

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Figure 3: Insulated Column Base to reduce thermal bridging. Courtesy of Russ Miller-Johnson.