Historic Structures

significant structures of the past

Critical Skills for Structural Engineers Encountering Historic Structures

By Dr. Debra F. Laefer

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Unlike some parts of Europe, America has yet to develop a formal designation or description of a "Preservation Engineer"; yet many members of the structural engineering community regularly inspect, evaluate, and recommend repairs, interventions, and modifications for the thousands of buildings on national and local historic registers and the many others that qualify for such status (*Figure 1*). Because of the predominance of vernacular structures and small religious buildings that constitute this specific building stock and the proportionally modest resources generally available for their maintenance and upgrading, small local firms are often engaged on their behalf. The nature of these firms, and in fact that of most structural engineering firms, is that few have engineers on staff with specialized training in assessing historic buildings.

"Old" Buildings

Although it is true that Newton's precepts do not differ based on a building's age or architectural significance, there needs to be an acknowledgment that material production, material selection, structural systems, and joining options are all constantly evolving topics. This is problematic, as what is taught in most civil engineering programs focuses exclusively on new construction with only the rarest of curriculum providing any instruction in traditional or "archaic" technologies. This fact leaves the majority of today's engineers ill-equipped to address the problems of older structures, because these buildings include materials and structural systems that behave in ways that fundamentally differ from modern construction.

A common example of the criticality of this is in understanding the traditional role of lime-based mortars and their expected strength capacity. Portland cement's general displacement of lime as the main binder in late 20th century mortars was a failure to recognize a major role of mortar as the sacrificial element in the building fabric. As buildings move due to a wide range of external factors, from temperature-based expansion to differential settlement because of non-uniform loading,

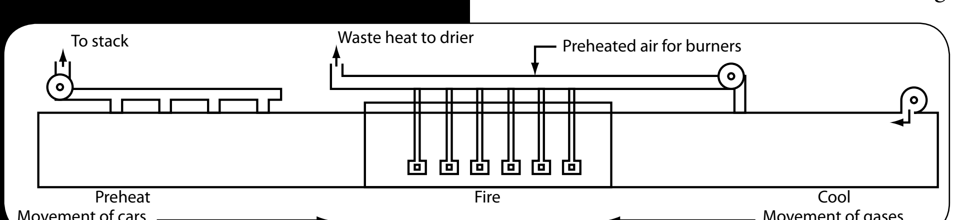

Figure 2: Tunnel Kiln. Courtesy of Dr. Debra F. Laefer.

Figure 1: Inspection of Masonry Façade. Courtesy of Dr. Debra F. Laefer.

they tend to develop small cracks. In traditional masonry, the weak lime-based mortars tend to crack, instead of the substantially stronger brick. This is intentional. In part this is because the mortar has the ability to heal itself to some extent (referred to as self-annealing), because of the carbonation based curing process which relies on air (as opposed to the hydration based curing for concrete, which is dependent upon free water). A soft mortar can also be periodically removed from between the facing side of the bricks in the process of repointing. With Portland cement based mortars, the mortar is nearly as strong, if not stronger, than the brick. Thus the brick is as likely to develop cracks,as the mortar, and periodic maintenance cycle of repointing is nearly impossible without risking damage to the bricks as the mortar is removed from the joints. As seen in this example, failure to understand material properties and their roles in distinction to those of modern ones, jeopardize the long-term viability of preserving buildings.

Not only is this problematic with respect to preserving architectural heritage but, as America tries to come to terms with sustainability, life-cycle, and embodied energy issues, two things need to be acknowledged. The first is that an existing structure represents an enormous previous investment from an environmental perspective. Thus, its replacement represents a complete loss of that investment and requires the major environmental expenditure of manufacturing new materials and energy investment in their assembly, as well as the further energy needed for demolition, removal, and disposal of the existing structure.

Another example relates to the plaster renderings over adobe walls. When removed, the structures fair much worse from a durability perspective. They also become more vulnerable to damage and subsequent collapse when exposed to seismic loading. Similarly, if the rendering is repaired with a cement-based product, the subsequent performance tends to be vastly inferior to the application of traditional, local materials. So not only are non-local materials inferior to those originally used, they often require higher levels of embodied energy as they must be shipped greater distances.

Acquiring the Knowledge and Skills

The situation is complicated. In some cases, gaining the specialty skills and background needed to sensitively and cost-effectively work with historic buildings can be relatively straight forward as is the case with documentation, where surveying skills and conservation theory are areas where the field is well established and literature is readily available. Even legislation and standards from around the world are now readily available through the power of the Internet.

Other areas, such as masonry evaluation and timber intervention, are arguably less accessible through self-study. In fact, at a recent workshop for the development of curricula in Preservation Engineering held at the University of Vermont in collaboration with the National Center for Preservation Technology and Training, there was a fairly strong consensus amongst academics and practitioners alike that to best understand masonry and timber not only did specialty content need to be developed, but that the ideal situation would include firstly the introduction of formal courses on modern masonry and timber. This approach might on the surface seem counter-intuitive. However, because current practices are based on much more homogenous materials, where the variability of performance is highly controlled through modern production and material inspection methods. Thus, first studying the contemporary design methodologies is actually much easier.

The vast majority of older brick and timber structures in America are vernacular and were designed and built without the benefit of an engineer, even when the engagement of engineers for larger structures was already common practice. Consequently, the configuration of a large percentage of these structures was based on common practices. Although some of these are documented in a few early 20th century handbooks, the texts are hard to access, arguably incomplete, and do not approach the subject in a way that would be familiar to a modern engineer. For example, modern practice is based upon a certain probability that the materials are within a particular performance range. That performance level is in part an outgrowth of testing methods that the structural engineering community has developed and adopted through consensus documents, such as those published by ASTM. Since most of these standards did not exist until recently, the limited testing data from the period of original construction is hard to evaluate in a modern context. A perfect example is stiffness. In the few available documents where deformation of masonry piers was documented, the reported results are on the final deformation at the time of failure. Current practice dictates determining the Young's modulus early in the loading curve and through a series of discrete measurements. Accurate properties are essential for the analysis of an historic structure.

The issue is further complicated by the higher variability of traditional materials compared to their modern counterparts. An easy to understand example of this is in brick making. Modern brick production employs a tunnel kiln to dry and fire the units. The equipment is highly controlled with respect to the temperature levels and exposure time of the bricks to the heat. Furthermore, the conveyor belt-like arrangement of the tunnel kiln promotes a uniform heat exposure (*Figure 2*). In traditional kilns there was little heat flow so that bricks located closer to the heat were more thoroughly fired than those further away, resulting in material variabilities with coefficients of variation in excess of 20%, even after hand culling of the material *(Figure 3)*. Finally, just to further complicate the matter, the modern engineer must evaluate what decades (if not centuries) of exposure has done to material capacity.

Another problem is that many of the subjects that the modern structural engineer needs to study in preservation engineering fall into the category of either developing technologies or emerging fields. Some examples of the former include non-destructive analysis, sensors, stabilization, repair, and treatment strategies. Base-isolation is a good example of something that was nearly completely unknown 30 years ago but is now becoming a more mainstream (although still quite expensive) option for the seismic protection of historic buildings. In the latter category is the field of disaster management, where training and expertise are rapidly evolving along with changing community expectations.

Perhaps the geotechnical community can provide a partial model on how structural engineers can move forward to incorporate fundamental training for engineering students that would be appropriate for interacting with historic buildings. Geotechnics is an area where specialty products have long been developed for heritage buildings, because of the potential liability during subsurface construction when it occurs adjacent to one of these facilities. From a financial imperative, several sub-specialties have developed including compensation grouting, jet grouting, micropiles, and screw piles, just to name a few. From 1970 through the early 1990s, these technologies faced great difficulties in gaining wide spread acceptance and adoption, especially on public projects because of an absence of widely available testing data and clearly defined specifications. Since then, the industry has gone to greater transparency, in part as a function of the expiration of patents and also in recognition that government agencies often control the means and methods used on a project. Thus, the permitted technologies must cooperate in facilitating verification of products and procedures. Increasingly, the teaching of these techniques is occurring at the master's level. Additionally, many faculty member use examples in the classroom involving major historic monuments to illustrate the criticality of understanding fundamental soil mechanics. A common example is teaching primary and secondary clay consolidation calculation using the Tower of Pisa as a mini-case history. Such an approach enlivens the classroom and introduces, in an indirect way, the fundamental role of engineers and engineering in historic preservation.

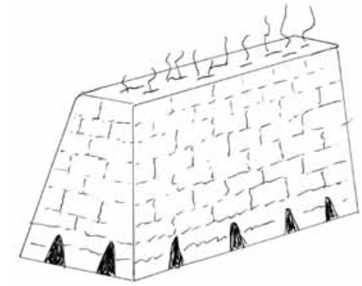

Figure 3: Traditional Scove Kiln.

Unfortunately, there are topics that cannot be addressed effectively through any of these means. Teaching forensics is a good example, as even the most fundamental skills such as conducting a load take down and understanding a building with respect to code development requires more than "chalk and talk" instruction. Teaching preservation ethics in a meaningful way is another good example. In both instances fieldwork, case histories, and mentoring by experienced engineers are inherent components to the process. Such experiential learning can only be obtained through mentored professional practice or through the creation of highly specialized graduate level courses.

Conclusion

In summary, America's structural engineers have much to learn about historic buildings, if we want them safely preserved for the sake of both architectural heritage and environmental protection. Some of this information is readily available for self study and some from specialty courses, but eventually the community will have to embrace and financially support the dual concepts of preservation engineering as a formal master's level endeavor and of preservation research as a scholarly pursuit worthy of tenure at top academic institutions and funding at a national level. Such is already the case in parts of Europe.▪