PRESERVATION ENGINEERING AND TIMBER

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Abstract

Preservation engineering and timber incorporate issues of sustainability that are critical to U.S. research and infrastructure needs; economic competitiveness; health, life and property protection; and infrastructural renewal. But few engineers are trained to address issues unique to any existing structures, let alone timber. Further, the educational and research communities are not meeting the needs for assessing and extending the life of existing structures. Research is needed to extend the service life of existing timber structures, especially in identifying hidden deterioration, designing structural repairs, and understanding connection capacity and system behavior. However, the research must be built on a solid understanding of historic wood products, historic construction methods, analytical methods appropriate for existing buildings, and modes of deterioration.

Introduction

Preservation engineering. Existing buildings. Timber. These topics should be essential components of an engineering curriculum, yet they do not receive the attention they warrant. They typically do little to advance the state-of-the-art for construction technology, they do not enhance resumes of researchers in the public or education sectors as much as more fashionable research, and they simply are not allocated funds to either improve the knowledge base or the stature of those who work in these areas. It is almost mandatory in the research community to focus on engineered wood products or innovative construction techniques rather than on saving or maintaining existing structures.

Timber, or wood, structures - buildings, bridges, utility structures - are routinely analyzed and assessed by those who lack the knowledge or tools to make informed decisions about repair or replacement of wood components. Technical areas, such as building performance, nondestructive evaluation, materials, history of technology, documentation and treatments require a knowledge of and interaction with timber to enable engineers to make informed decisions. Getting that knowledge, including an understanding of the capabilities and limitations of timber, into the hands of practitioners is given little attention by the engineering profession or academic institutions. The few courses at universities and limited opportunities for continuing education do not meet the demand for what is needed. Addressing that need is the focus of this colloquium.

Relevance of Existing Wood Structures

It is difficult to find data that paint an accurate picture of the relevance of existing wood structures to the U.S. economy. Most reports provide statistics for a particular usage, such as volume of wood used in new residential construction. Those statistics tells us little about the relevance of wood in existing structures. To give us a sense of wood usage, the Western Wood Product Association (Hill, 1993) states:

> *Repair and remodeling has grown from 28 percent of total lumber consumption in 1986 to an estimated 33 percent for this year. This growth has been so great, in fact, that in 1990 and 1991 the lumber volume used in repair and remodeling projects exceeded that used in residential construction.*

Further, the British Columbia Forest Industry Fact Book (1998) states:

> *Residential housing construction consumed 37.5 percent of all softwood lumber used in the United States in 1997. The repairs and remodeling market, including the home renovation market, consumed 30.2 percent of total softwood lumber. Other new construction, including commercial buildings, accounted for 14.6 percent in 1997, while material and handling consumed 9.3 percent. All other accounted for the balance of 8.4 percent.*

More recent data from the Wood Products Council (2005a, 2005b) indicates that of the over 43 billion board feet of lumber used in the United States in 2003, 42 percent was used for residential repair and remodeling. For structural panels, such as plywood and OSB, repair and remodeling used 25 percent of the total used in the U.S., and for nonstructural panels, the number was even higher – 33.5 percent. These few data points from the last 15 years indicate a trend of increasing usage of lumber for the maintenance and rehabilitation of existing wood structures.

Until recently, we did not know the volume of wood used in maintaining or renovating existing buildings. We certainly do not know the volume of wood that is retained or discarded (perhaps unnecessarily) from existing buildings. What we do know is that a significant percentage of wood produced in the U.S. is used for repair and maintenance of existing buildings and the percentage is increasing.

What are even more elusive are statistics about the time spent by professionals on existing structures. However, a discussion with most engineering firms across the U.S. will reveal that a significant percentage of the workload is with remodel/retrofit/adaptive reuse/assessment of existing buildings. Engineers fresh out of universities, with very little exposure to wood as an engineering material and to wood construction practices, find themselves thrown into a world of existing buildings because that is where up to half of the billable projects can be found.

There are numerous publications and symposia where wood engineering research findings are reported. Taking one of those, the World Conference on Timber Engineering, for 2006 and 2008, there are approximately 19 papers that address historic structures, 11 that address joint analyses, 8 on nondestructive testing, 12 on maintenance and repairs, and 7 on "in-situ" experimental testing. Less than 15 percent of the papers and posters presented addressed issues directly applicable to existing structures because of their focus on new products and technologies. Similarly, within the field of nondestructive testing, approximately 15 percent of the papers at the 2007 International Symposium on NDT of Wood specifically address existing wooden structures or materials. Other publications and symposia report even less research activity that has relevance to existing structures, including the ASCE Journal on the Performance of Constructed Facilities or the ASCE Journal of Structural Engineering.

Education and research needs for timber structures are typically conveyed by practitioners that have questions that arise during the course of their work. The questions cross boundaries between structural engineering, wood preservation, architecture, and construction technology. Within the context of engineering, the following topics frequently arise during discussion on existing buildings:

- Hidden deterioration
- Structural repairs
- Connection capacity
- System behavior
- Rating systems
- Impact of alternate uses
- Fatigue
- Replacement material
- Material specification
- Remedial preservative treatments for durability
- Creep and load duration
- Construction errors and quality control during construction

A curriculum that will address needs of the engineering community is certainly open to interpretation of its details but this author feels that the following topics not currently taught as part of an engineering program need to be addressed. Other speakers will address some of these topics at this colloquium. However, to illustrate the relevance to engineering, a few of these areas are discussed briefly below. Reference documents and supplemental reading are provided at the end of the paper. At a minimum, the following subjects should be part of a preservation engineering curriculum.

- Historic construction methods
- Historic materials / Grading
- Analysis methods
- Mechanisms of deterioration and how to identify them
- Connections

Academic faculty have numerous responsibilities that typically limit their own experience. Any successful curriculum must have the participation of knowledgeable persons beyond the faculty, including:

- Practicing engineers
- Practicing architects
- Consultants
- Craftspeople

For a course or curriculum in preservation engineering to be successful, course materials should not be limited to a single textbook and should include:

- Textbooks
- Case studies
- Technical reports
- Journal publications
- Hands-on field experience

Although many of the topics will be discussed in more detail in other papers and during the colloquium, a few examples of pertinent subject matter are given below.

Hidden deterioration

The detection of hidden deterioration using nondestructive testing (NDT) has been practiced for decades. Unfortunately, detection alone is insufficient to address the concerns of practicing engineers. Quantifying the extent of deterioration is paramount to making reliable decisions about the capability of existing structural wood members to carry required loads. Assessing the potential for future or on-going deterioration is also essential. However, predicting future deterioration is a more global phenomenon that relies on moisture diagnostics or building pathology rather than simply localized quantification of deterioration.

Advances in quantifying deterioration in recent years have brought this capability into the hands of practitioners. The use of resistance drilling has been the primary mechanism for quantifying deterioration. For decades, wood researchers have published papers on the ability of various technologies to quantify the extent of deterioration due to decay or insect damage but the reality is that practitioners do not use those technologies to make decisions about repair and replacement, except in isolated instances. Resistance drilling is the only field technique in practice today that can identify both the location and extent of deterioration. Knowing whether a girder has two inches of sound wood on the tension face or six inches makes a considerable difference to an engineer calculating the section modulus of a beam.

While useful in identifying the location and extent of deterioration at a point location, resistance drilling is unable to either provide the ability to rapidly assess an entire structure or investigate inaccessible locations. Rapid assessment is desirable to reduce cost. Although an assessment of a large industrial building with heavy timber framing may take several weeks, the cost of the assessment is a small fraction of the cost of rehabilitating or renovating the building. Nonetheless, engineers, architects and owners often have a desire to do an assessment at reduced cost and within a tighter schedule than is typically feasible today.

Inaccessible locations have presented problems during assessment of existing buildings. The most common areas are beam pockets where timbers bear on masonry walls and where roof rafters or trusses bear on a top plate. Connections, either beam-column connections or where timbers are connected to other materials, are also difficult to assess in-situ. Unfortunately, these are areas where moisture penetrates porous bricks or mortar joints and roof leaks or ice dams provide means of water ingress. Deterioration is often the result. Yet we have no reliable means to locate and quantify this deterioration. Resistance drilling, digital radioscopy and stress wave measurements fail to give us the information needed to determine whether the wood is sound and if adequate bearing exists.

Unknown beam condition and bearing area within masonry wall

Structural repairs

There is a general lack of data on structural repairs. As a consequence, practitioners are uncertain what repairs can be implemented. There is a wealth of knowledge about repair of glued-laminated timbers but only limited knowledge about epoxy repairs or timber splices. Yet, epoxy repairs are commonly used to repair section of timbers that have deteriorated. Rarely, except perhaps by timber framers, are timber splices used as structural repairs.

Many epoxy-type repair systems are marketed as structural repairs, sometimes in conjunction with steel or fiberglass rods, sometimes without. Remarkably, little, if any, data exist on the performance of these repair systems on full-size timbers. Material properties are listed for the epoxy separate from the wood properties as though, once combined, the properties of the repair are then known. Simply because an adhesive has a greater modulus of rupture for a small adhesive sample does not mean that once incorporated into a deteriorated timber, that the modulus of rupture of the timber will be the governing factor.

Engineers in the field will often use a steel splice to repair broken or deteriorated timbers. That is, if they leave the timber at all. Most practitioners simply choose to remove the questionable timber and replace it with steel.

Makeshift structural repair using steel strap and plate

Connection capacity

Under design loads, wood members seldom fail in a structure unless they are severely deteriorated. Failures that do occur generally do so at connections. We have a wealth of knowledge about wood properties, but little is known about the behavior of connections in historic timber construction. NDT techniques were developed to give us information on strength, stiffness or deterioration in the wood. Why? Because those were the questions we could answer. Unfortunately, connections are critical in structure performance, particularly in existing structures that have been subjected to a variety of load conditions, and yet we do not have a reliable means to assess their condition or capacity. Techniques, such as digital radioscopy, can reveal the internal construction of a joint or connection, and even whether voids in the wood or corrosion of metal fasteners are present. But these techniques cannot give us any indication of the capacity of the connection.

Beam-column connection with unknown capacity

System behavior

Much research today focuses on system behavior. Existing structures have systems that were seldom researched or even modeled. As a consequence, we do not have a good understanding of how different materials or assemblies behave. Once a structure has been subjected to loads and environmental conditions, it behaves largely as a single unit. But within that unit are systems – floor systems, wall systems, roof systems – that may involve a variety of materials and assemblies.

Paramount to understanding any system behavior is a basic understanding of material behavior. For this, we rely on grading of structural lumber and timber, often without understanding that the inherent variability of strength properties and the conservative nature of the design process leave the vast majority of undeteriorated wood members with "hidden capacity". This hidden capacity often explains why a structure is still standing in defiance of sophisticated structural analyses. We often simply do not understand, or fail to take into account, the variability of the inputs to our computer models.

Building code requirements dictate that the structure behavior be understood, at least to the point where it satisfies some code requirement, such as diaphragm action to resist lateral loads. Lacking the knowledge or tools to satisfy such code requirements, engineers often are overly conservative with their reinforcements or simply decide to replace the entire system with one that they understand.

Beam-column-decking system with limited diaphragm action

Continuing Education

While no curriculum exists for preservation engineering, several opportunities are available for practitioners. The Association for Preservation Technology International (APTI) offers workshops at their annual meeting that address topics such as nondestructive testing of historic buildings, historic masonry and wood structures. The two-day workshops typically provide an introduction to technology, materials or methods that practicing engineers can use. However, the workshops are limited to two days. APTI has a preservation engineering committee and a building codes committee that are active in education of practicing engineers but the current audience is only a fraction of the engineers that work on historic buildings.

The National Center for Preservation Technology and Training (NCPTT), under the U.S. National Park Service, offers courses for approximately two weeks that cover condition assessment and engineering analysis of historic buildings. Targeting practitioners that are seeking to gain experience and understanding on existing buildings, the course content is based on field experience and case studies.

Similarly, the American Society of Civil Engineers (ASCE) offers a two-day workshop on condition assessment of existing buildings. However, the workshop primarily covers nondestructive testing of masonry, wood and concrete from more of an academic perspective rather than being geared for practitioners. The techniques discussed are not widely used and practicing engineers sometimes question the value of the workshop content.

ASCE publishes a Guideline for Structural Condition Assessment (American Society of Civil Engineers, 2000) that describes methods for inspection and testing various materials and structures. The publication is an excellent summary of research on building assessment technology but, unfortunately, most of the techniques listed are not commercially available. As such, engineers are frustrated when searching for a technique for a particular application and resort to using a less appropriate but available technique. The consequence is the collection of data on a historic structure that does not provide the information necessary to make informed decisions about repair or replacement.

The Technical Council on Forensic Engineering of the ASCE has an active education committee that conducts workshops to train faculty on how to teach forensic engineering. Although the focus is building failures, the model of teaching the teachers is an excellent one that perhaps has a role in preservation engineering. Further, the technical content of the workshops is appropriate for preservation engineers in that much discussion of why buildings fail or why they continue to function when "codes" indicate otherwise is in line with what needs to be taught to preservation engineers. Forensic Engineering congresses provide opportunities for engineers to learn about building assessment, a subject at the heart of any preservation engineering curriculum.

The Preservation Trades Network and Timber Framers Guild offer hands-on workshops targeting craftspeople but have limited, but excellent, content for practicing engineers for understand how historic buildings were constructed and why they perform the way they do. Exposure to historic materials and construction methods not typically taught in universities gives engineers knowledge difficult to obtain elsewhere except in historic textbooks and through personal experience.

These continuing education opportunities are examples that can be used to form the basis of education curricula for academic programs. The basic knowledge exists (although the need for research on the performance of historic materials and existing buildings cannot be disputed) but what is missing is the delivery system for entry-level engineers. Be it a course or graduate program, there is a need for preservation engineering in the U.S.

Research Funding Opportunities

Successful graduate programs (as defined by most U.S. universities) require sustained research programs supported by outside sources such as contracts and grants and, at a doctoral level, systematic fundamental research generating new knowledge. Fundamental research requires significant funding and, in the case of the civil engineering discipline, is rarely supported by related industries. Establishing a new graduate program almost always requires demonstrated external funding or a strong chance of external funding, which, in the case of historic preservation, is not the reality (if it were, several programs would exist in U.S. engineering schools). While the educational aspect and need for such a program can be clearly demonstrated, the economic reality may make its inception difficult.

Collaboration with international preservation engineering programs seems to offer one of the best opportunities to overcome the disadvantage of low funding in view of efforts to bring global education to the engineering curriculum. It can also minimize the costs associated with establishing and maintaining a graduate program that may not have critical faculty mass at any given university. The National Science Foundation supports such collaboration. Collaboration with existing preservation engineering programs in Europe and elsewhere may reduce the burden of significant initial investments with a start-up program. Of course, administrative pressures will still exist to generate research funds and support graduate students but since mechanisms exist within the U.S. to support international education within engineering curriculum, this funding opportunity should be considered.

Conclusion

This paper outlines the role of timber within a preservation engineering curriculum. I have attempted to explain some of the realities that might be limiting factors in such efforts. While existing structures and historic preservation is not a lucrative area of research funding that will be actively pursued by most institutions, opportunities exist for a niche program that can meet the needs of society.

For wood construction, including new construction, to have economic competitiveness, we must be able to reliably demonstrate that timber in existing buildings can continue to provide reliable service. In spite of our technical efforts to show this, the fact is that, at most universities, engineers are not taught wood engineering and design. When they are, the focus is on engineered wood products. Once they encounter a project with historic construction (e.g. heavy timber), they are typically ill-prepared to know where to begin their engineering analysis. If we want new engineers to be competitive, we must make the next generation of engineers comfortable with wood construction, including historic construction materials and methods. Without that understanding, they quickly migrate away from any wood construction.

Existing buildings account for a significant percentage of wood used in the U. S. and time spent by practicing engineers. Understanding the behavior and condition of wood in existing buildings is essential for extending service life while providing protection for health, life and property. Education and research on understanding existing timber structures contributes to infrastructure renewal, preservation of our cultural heritage and sustainability.

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