REPAIR AND STRENGTHENING OF HISTORIC STRUCTURES

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Introduction

This position paper discusses topics within the current state of knowledge among structural engineers now working in the field of historic preservation. Some techniques and a preservation philosophy which strives to maintain historic fabric are not well known by the majority of practicing structural engineers. Certainly, there are opportunities for research funding to benefit the construction industry with regard to evaluating and improving materials, components, and systems beyond which have been in existence for many years.

The essential competencies required in preservation or conservation engineering are inherent in the typical civil engineering degree. Certainly, steel and concrete design as well as structural analysis, surveying, graphic communications, foundation design, and engineering geology provide the essentials. What may be missing in most undergraduate courses are preservation philosophy and ethics, knowledge of *in situ* testing methods, timber design, and a strong historical viewpoint of technology and the profession.

Learning opportunities can be provided within the engineering community or within the construction industry in a crafts system of internship. Some of the topics essential to preservation or conservation engineering can be included in existing courses. For instance, an overview of archaic structural steel and concrete reinforcing materials can be included in structural steel or concrete design, whereas a review of archaic propriety structural systems should be placed in conservation of materials and systems course.

Certainly, basic preservation philosophy and law could be included in a standalone course. Various courses taught through the history department could focus on the ancient builders and their works, to the more recent. Timber and masonry design courses are badly needed. These courses should also include archaic systems and the aspects of deterioration. There is such a need for us to produce engineers with an understanding of preservation, conservation, and sustainable construction that critical course work should be presented to all at the undergraduate level, although a Master of Preservation Engineering degree should be the ultimate goal.

Essential competencies for structural engineers undertaking the repair and strengthening of historic structures should include a review of historic methods of analysis for structures such as trusses and early methods of design and construction of timber, steel, and concrete components. Steel design should also include a review of wrought and cast iron, the advantages of each, and an understanding of the physical properties and the industrial processes of production. Graphical analysis of trusses, with an understanding of Bow's notation, the force polygon and the Maxwell diagram of graphical analysis is a must. A course in the history of technology for engineers could include a review of important textbooks and handbooks such as Kidder-Parker's Architects' and Builders' Handbook by John Wiley & Sons, Inc. These topics could supplement the existing syllabus within structural analysis, steel and concrete design.

Existing structures provide an excellent laboratory for the testing of structural systems and materials in relation to long term loading of structures, deterioration and degradation of materials, and the serviceability of various structural and architectural details, and combinations of material and systems. The performance of structural systems and materials could be the subject of research with regard to the chemical and physical composition, coatings, finishes, and common assemblies of materials and how these variations relate to performance. The resulting understanding could lead to the improvement of these materials and details, and the development of new products in the industry studied.

A study of all metals traditionally used in the construction industry such as lead, brass, bronze, tin, and zinc should be included in a materials course. A history of the technology course should include materials, systems, as well as an historical perspective of the engineers and scientists involved in the development of various technologies. A history of technology course for engineers should go beyond a simple historical review and include the technical aspects of the various inventions so that the student will achieve a better understanding of the history of his profession and how previous generations solved specific problems. Some of this is included in today's courses. For example, in steel column design, most textbooks begin with Euler's Formula, the Gordon Rankin formula, and the Secant formula, and advance into current code requirements and methods of analysis.

NDT/Sensors/Diagnostics

Strain gauges are often applied to structural systems to detect changes in member forces resulting from applied loadings. Weights consisting of concrete masonry units, concrete blocks, or containers of water can be applied in a fashion similar to code mandated load tests. Known weights can be installed on a roof or suspended from the structure.

A simple application of load such as a vehicle of known weight placed in different positions on a bridge can yield useful information to an engineer. Simple measurement of deflection using standard surveying techniques is an economical solution, short of applying strain gauges, which provides useful stiffness data for trusses and beams.

Certainly, *in situ* tests and non-destructive tests, as well as destructive testing of samples obtained from non-critical locations, for masonry and concrete, provide essential data for structural analysis.

History of Technology/Engineering Codes

There is a tendency to reinforce, by underpinning, historic structures which lack modern foundations simply because they are “not in compliance with today’s code.” Obviously, for historic masonry structures which are in good condition, i.e. do not contain diagonal settlement cracks, underpinning may just be a gross waste of money. Input from the geotechnical consultant should be able to satisfy structural concerns unless the geotechnical engineer applies overly conservative factors of safety simply through the “fear of the unknown” aspects associated with litigation and liability insurance concerns.

Seismic upgrades such as retrofitting masonry reinforcing, introducing seismic frames, and the “bolts-and-nuts” method of tying floor and wall diaphragms into masonry walls are all solutions for which feasibility is impossible to determine without extensive measurement, testing and analysis.

Engineering codes for existing buildings should allow for a simplified seismic analysis so that structures which have survived for a long time are afforded some benefit. Components such as parapets, chimneys, freestanding or un-braced walls should be specifically addressed during a proposed restoration.

Preservation Ethics, Standards Legislation

Preservation ethics and standards must incorporate the judgment of the structural engineer of record. This assumes that the engineer’s judgment is tempered by a preservation philosophy which recognizes the value of the historic fabric which constitutes the structure of the cultural resource. Obviously, the architectural finishes are part of that resource which should be considered in designing a repair or reinforcing scheme. In the end it is not only the engineer's preservation ethics which govern the design, but also his responsibility as engineer of record to protect the health, safety, and welfare of the public.

Sustainability

The LEED system encourages the use of recycled materials such as timber beams and flooring, and recycled concrete, bricks, and asphalt ground up and used for new products or as filler and aggregates.

Unfortunately, the idea that the most sustainable building is an existing building has not had an impact. It would seem obvious that the embodied energy in an existing building has value and that demolition, transport, and recycling of material components all demand energy which is not required if the building were to simply remain in service.

Disasters

The liability issues associated with disasters are many. Insurance companies propose settlements based on engineer's reports. Qualified contractors and craftsmen with experience repairing traditional structures many not be available. In any case, engineers can lose control of a project where their report recommendations are not followed and the engineer's ability to provide consultation, observation, and additional design is not possible because of travel distance or limited contractual ties beyond the initial consultation. The engineer responding to a disaster must also be willing to provide recommendations with regard to shoring and bracing, temporary structural repairs, and other issues related to “means and methods”, normally the responsibility of the general contractor. This is difficult enough when the engineer and disaster site are in close proximity.

Other engineers permitted into disasters areas include university engineers studying flood, wind, or seismic damage for the sole purpose of publishing information on the performance of various structural systems or materials, based on information gathered. In addition, engineers representing various manufacturing associations or manufacturers travel to disaster sites to establish the serviceability of their products or assemblies of their products. The supposed benefit is to improve standards of practice and ensure their input in the next building code as code officials “tweak” the code in response to the latest disaster.

Disasters pose a very real dilemma for structural engineers. Since these are not planned events, the need to mobilize quickly prevents many engineers from participating. Registration laws prevent engineers from practicing in states that they are not registered. In a perfect world every state would have a sufficient number of engineers willing and able to respond to a disaster. Of course, this is not the case. The tendency of state engineering societies, and preservation organizations to recruit volunteer engineers to travel to disaster zones is quite misguided. The solution of some of these entities is push for legislation to hold responding engineers harmless for decisions and recommendations.

Unfortunately, often, some of the engineers who respond are under employed, inexperienced, or retired. For Katrina, the call went out for volunteer engineers willing to travel to the Gulf and live in their personal automobiles for as much as a week.

Materials/Deterioration/Testing

With regard to repair and strengthening timber structures, the exposure characteristics of the structure should be one criterion central to the type of repair implemented. Buildings and structures and their parts vary greatly with regard to the range of temperature and moisture fluctuations. Attic spaces undergo severe changes in temperature whereas crawl spaces may vary greatly in moisture content. Unheated structures such as barns vary from covered bridges which may experience elevated moisture contents during certain seasons, merely by spanning a water feature. In many covered bridges splash, spray, and condensation greatly affect truss bottom chord members and floor framing. Within these exposure conditions replacement-in-kind or reinforcing materials of different types may be introduced. Of course, dissimilar materials often do not produce a permanent repair simply because of the inequality of the physical characteristics. For example, a reinforcing steel splice plate epoxied into a timber component may result in issues in an unconditioned space simply through different thermal properties of the two materials.

Masonry/Earthen Structures

Un-reinforced masonry, adobe, tabby, and rammed earth structures all can be repaired or strengthened. The best repair in each case is to use the traditional materials. Enhanced materials and reinforcing elements may be possible strengthening methods, depending upon compatibility.

Treatment Systems

Treatment systems are divided into four broad categories. First, there is replacement-in-kind where a deteriorated or undersized component is replaced in its entirety. In some cases engineers have justified the total replacement of a covered bridge structure saying that if “the idea remains” the replacement bridge is still historic. Treatment systems may include reinforcing with steel. Many engineers faced with reinforcing a timber structure automatically reach for the A.I.S.C. Steel Construction Manual.

Timber repairs include reinforcing, splicing, Dutchmen and supplementing with additional elements. These are usually the most appropriate types of timber repairs. Attachment can be through metal connectors such as nails, screws, bolts, shear plates, split rings, lag screws and an assortment of special screws and other fasteners. Other attachment methods may be as diverse as timber pins and pegs or an epoxy specially formulated for wood construction.

Treatment systems for steel and iron usually involve replacement-in-kind, recognizing that the welding of different iron and steel components is a difficult obstacle to overcome.

Concrete treatments include various crack repair methods, overlays, surface finishes and coatings for concrete and reinforcing. In most cases, thorough analysis based on measurement, testing, and observation is required prior to applying a treatment method. In some cases more stabilization efforts can be applied to deal with superficial damage needing repairs.

Timber Structures

A strong background in the analysis and repair of timber structures is essential for the structural engineer interested in historic preservation. The great variety of timber structures building in the past and the advantages in engineered wood products and associated connectors provides a number of ways to repair or strengthen timber structures while maximizing the amount of historic fabric retained.

Geotechnical Design

Geotechnical design issues relating to historic structures can greatly impact the engineer's conclusions with regard to the feasibility of putting a historic structure back into service. Most of the issues which will affect historic structures in the future will include the impact of seismic design on underlying soils with regard to liquefaction and its effects on heavy non-reinforced masonry structures. Building improvements which include seismic upgrades such as base isolation are extremely expensive. Many un-reinforced masonry structures will certainly meet the wrecking ball because seismic analysis and recommendations, based on extensive testing, will dissuade owners from conserving these buildings. The engineer of record should be given some leeway to pass judgment on the seismic resistance of an historic structure based on a simplified analysis.

In my experience, I have received the following response from a geotechnical engineer when questioned about a low bearing pressure recommendation for a stiff soil: He said that recommending a higher allowable bearing capacity “was against company policy”.

The other major issue with regard to geotechnical design is the fact that many foundations of historic structures are supported on all manner of footings very different from the code mandated concrete footings of today. In some cases, the stone or brick masonry walls simply stop at a certain depth. Some brick walls are simply corbelled (stepped) to a width wider than the wall. Many rest on mud sills of timber. In the coastal southeast some brick masonry buildings bear on footings of tabby.

Building Performance

Consideration must be given to serviceability issues associated with structural repairs. For instance, in a floor system located above a crawl space where deteriorated joists have been sistered, spliced, or replaced, a consideration should be given to using pressure treated wood for the new material and applying a brush on preservative to the original material to remain. Any repair to a timber frame structure which includes both new material and existing timber framing, must consider the effects of differential shrinkage of the new and existing which has had a chance to reach it s equilibrium moisture content. It is hoped that building performance can be enhanced by dealing with the causes of deterioration readily observable in the structure during the observation, measurement, testing, and analysis, phases of the work.

Documentation/Recording

Documentation and recording of historic structures can be accomplished in a number of ways. The structural engineer should be familiar with the requirements of HABS/HAER for measured drawings. Measurements can be made by hand, or with the benefit of digital and photographic methods. Licensed land surveyors have the skills and equipment to assist in the measurement of historic structures. Certainly base points and existing dimensions can be obtained through the use of traditional or electronic surveying equipment and methods. Simple photographs placed in the design documents can be used to describe existing conditions and direct or inform the contractor or craftsman. These can be inserted “not to scale” or easily inserted in a drawing at an approximate scale based on baseline dimensions determined in the field.