Lessons learned from evaluation and repair of vintage timber-frame church trusses

Philip Westover[1]

Abstract Many nineteenth-century church structures were constructed based on traditional design and construction techniques using native non-stress-graded timbers. Despite the frequent lack of engineering design with quality timbers, many vintage timber-truss structures have performed satisfactorily for over 100 years. Hidden truss failures are often present near the supports, and modern analysis methods almost always show that some timber-truss components fail to meet the strength requirements of our current design codes. This paper presents a brief review of codes and standards relevant to timber evaluation and repair. Four example projects are presented showing common structural challenges and practical methods of assessment along with repair and strengthening schemes designed to reutilize and extend the service life of existing timber components.

Keywords timber-trusses, evaluation, repair, building codes, allowable design properties, wood shrinkage, biological deterioration, in situ evaluation and repair

1. INTRODUCTION

Most vintage timber truss systems were built based on variations of traditional truss forms. Often, different wood species were used for the same or similar components in a truss and early timber design values were not standardized. Timber stress-grading to account for strength reducing characteristics were not developed until the 1930s; before then, published design values were often inconsistent, and not related to timber quality. Many vintage timber trusses remain in service and continue to perform satisfactorily despite the fact that their original design/construction often fails to meet the strength requirements of current codes and standards. It is therefore important to understand the Codes and Standards which give guidelines for evaluation and repair of structures, but some specialized methods and skills are required to efficiently reutilize and extend the service life of existing timber components.

2. EVALUATION OF TIMBER-FRAME ROOF STRUCTURES

In theory, structural evaluations and repairs are not required unless a change is made to the structure that affects the loads and/or stresses in the existing structure, or some sign of deterioration, damage, or distress in the structure is found. Relevant changes to an existing structure include; changes in use that result in different loads, additions to the building, and alterations that change the loads or load paths. Signs of possible deterioration, damage, or distress include: excessive deflections, cracks and fractures, water stains, and fungal decay.

[1]Philip Westover, Structural Engineering, Simpson Gumpertz & Heger Inc., Waltham, MA., USA, plwestover@sgh.com

Building codes stipulate when to evaluate structures, the level of investigation required, and criteria for necessary repairs. Full code upgrade is not always required and differing degrees of evaluation are based on sometimes complex criteria set in the codes. Most U.S. building codes stipulate using one of three compliance methods: the prescriptive method, the work area method, or the performance method.

A preliminary investigation is needed to ascertain structural concerns, code requirements, the extent and causes of distress, anticipated loading, and immediate safety concerns. For more detailed investigation the actual in situ conditions, sizes, and configuration of members and connections need to be determined, along with timber species and quality for structural analysis and evaluation. Close visual inspection is invariably most important. Iterative structural analyses are sometimes needed to accurately model truss behavior during failure, or during jacking and repair installation.

3. COMMON PROBLEMS IN VINTAGE TIMBER-FRAME TRUSSES

All timber trusses were built with green timbers, and all timbers shrink and develop drying checks during service. Vintage timbers should always be evaluated based on their current dry condition. Checks are generally not a problem unless they affect connections or are associated with steep sloped grain. Wood decay is the most common form of biological deterioration, is always associated with water, and is sometimes accompanied by wood-destroying insect damage. Timbers can also suffer mechanical damage where member cross sections are reduced for notched, dapped, or mortise-and-tenon joints as shear and bending failure often occurs at these joints.

4. REPAIR AND STRENGTHENING SCHEMES

Repair and strengthening schemes come in almost unlimited variety, but most fall into one of four basic types: total removal and replacement, in-situ full-capacity replacement, in-situ partial replacement using traditional joinery, and in-situ capacity augmentation. In-situ capacity augmentation is usually most economical and involves adding supplemental members to augment capacity, and accounts for the remaining strength of the existing timbers. Sometimes in-situ capacity augmentation requires more complex engineering to account for load sharing between new and existing components. Usually in-situ capacity augmentation will economize on the supplemental strengthening required while reutilizing and extending the service life of existing timber components.

5. EXAMPLE PROJECTS

A brief review of four example projects is presented showing common structural challenges and practical methods of assessment along with repair and strengthening schemes to reutilize and extend the service life of existing timber components.

6. CONCLUSIONS

Many vintage timber-frame structural systems were built using native non-stress-graded timbers, based on rule of thumb and past experience. Structural analyses almost always shows that vintage timber trusses, even when not damaged, fail to meet the strength requirements of current design standards. Current building codes allow controlled departure from full compliance for evaluating and repairing existing structures, but lack specific criteria for when to strengthen non-damaged existing structural components that are not subjected to new loading. Vintage timber trusses often have mechanical damage associated with the reduced cross sections at traditional joinery and the initial fracture/failure is often hidden. In-situ capacity augmentation is usually the most economical solution to reutilize and extend the service life of existing timber structures.