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Wood Truss Repair by Epoxy Injection

Réparation de fermes en bois par injection d'epoxy

Sanierung von Holzfachwerken mittels Epoxyeinspritzungen

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SUMMARY
This report gives the results of a research study pertaining to the repair, by epoxy injection, of damaged portions of wood roof trusses. The research consisted of feasibility studies of small laboratory specimens, full scale testing of trusses constructed of old and new lumber, a small field repair project and a large field repair project. The results of this research indicate that epoxy injection can restore nearly the original strength of damaged wood trusses, at reasonable cost.

RESUME
Les résultats de recherche sur la réparation de parties endommagées de fermes en bois, par injection d'epoxy sont présentés. Des études de faisabilité sur des éprouvettes et des essais en vraie grandeur de fermes réalisées avec du bois âgé et récent ont été effectuées; des projets de réparation de petite et grande envergure ont été entrepris. Les résultats montrent l'efficacité des injections epoxy, à des prix raisonnables.

ZUSAMMENFASSUNG
Im vorliegenden Bericht werden die Ergebnisse eines Forschungsprojektes über die Sanierung von Holzfachwerken mittels Epoxyeinspritzungen beschrieben. Im Zuge dieses Forschungsprojektes wurden Durchführbarkeitsstudien (Feasibilitystudien) an Laborproben, Tests an alten und neuen Holzfachwerken und Feldstudien vorgenommen. Die Ergebnisse dieser Untersuchungen zeigen, dass durch das kostengünstige Verfahren der Epoxyeinspritzung beschädigte Holzfachwerke fast ihre ursprüngliche Tragkraft wiedererlangen.

1. DESCRIPTION OF PROBLEM

1.1 History

During the Second World War, 1941-1945, the United States Air Force constructed many large warehouses. Because of the need for large spans (approximately 16 m) and the scarcity of steel, wood trusses were used to support the roof. Many of these warehouses, now approximately 35 years old, are still in use today. Over the years, the wood trusses have deteriorated, and periodic repairs have been made. The defects in the wood trusses were in the categories of checking, cracking, splitting and rotting. The usual methods of repair utilized were member replacement, scabbing by adding metal or wood members, and stitch bolting. Because these conventional repair methods were expensive, time-consuming and disruptive of activities beneath the repair site, the use of pressure injected epoxy was proposed because of the quickness of the method, lack of disruption of activities and the possibility of cost reduction.

Thus a multi-year research program was begun in 1972 between the U.S. Air Force, Georgia Institute of Technology and Mississippi State University. The goal of the research was to determine whether epoxy repair of wood trusses was technically and economically feasible and a viable alternative to conventional repair methods.

1.2 Types of Defects

A typical U.S. Air Force warehouse was selected for in-depth study and field repair. This building had parallel wood trusses supporting the roof. The trusses were 61 m long, continuous over four spans of 15 m each. The ends of the trusses rested on the exterior concrete block walls of the building; the three interior supports were wood columns. Truss members were connected by bolts and ring timber connectors. Truss member sizes ranged from 50 mm by 150 mm to 50 mm by 300 mm. Six categories of defect were found in the trusses:

-1. End Splits of Members. - This was the most common defect found, typically at bolted connections of web and lower chord members, as shown in Figure 1. Approximately 50% of defects found were of this type.
-2. End Splits of Bolted Splice Plates. - Approximately 30% of defects found were of this type, depicted in Figure 2.
-3. Interior Longitudinal Splits. - Eighteen percent of defects found were of this type, as shown in Figure 3 (note banding repair).
-4. Broken Members. - Less than 1% of defects were in this category.
-5. Rotten Members. - An insignificant number of these were found, usually in areas of rain leakage.
-6. Warped Members. - A few cases of this defect were found, with no other visible defect in the member.

It was recognized that defects nos. 5 and 6 were not repairable by epoxy injection, and initial laboratory studies concentrated on the other defects.

2. THE EPOXY-WOOD BOND

2.1 General

Although it is generally accepted that epoxy will form a bond with wood, there are many specific factors which influence the strength of the epoxy-to-wood bond. Since epoxy is not a standard material, some formulations may provide

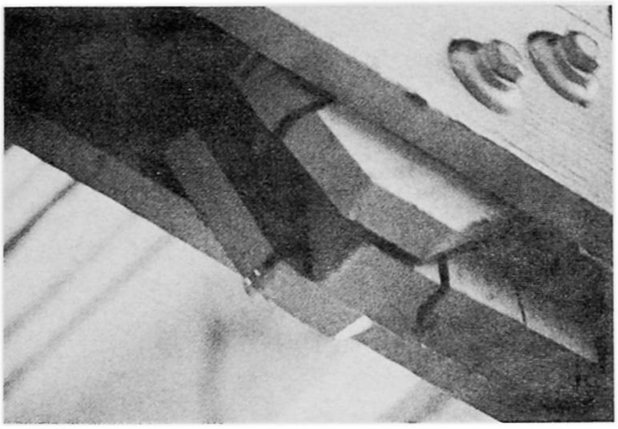

Fig. 1 - End Splits of Members

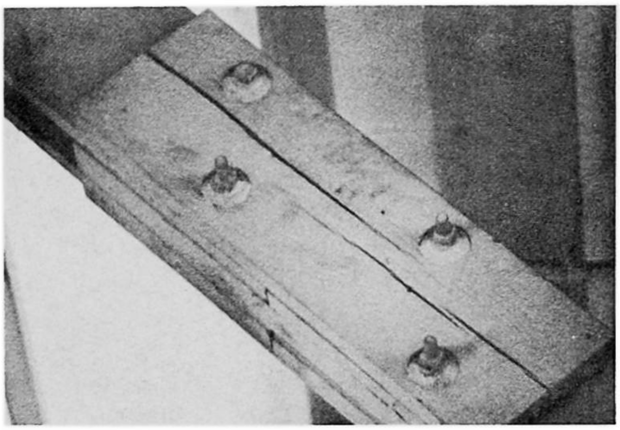

Fig. 2 - End Splits of Bolted Splice Plates

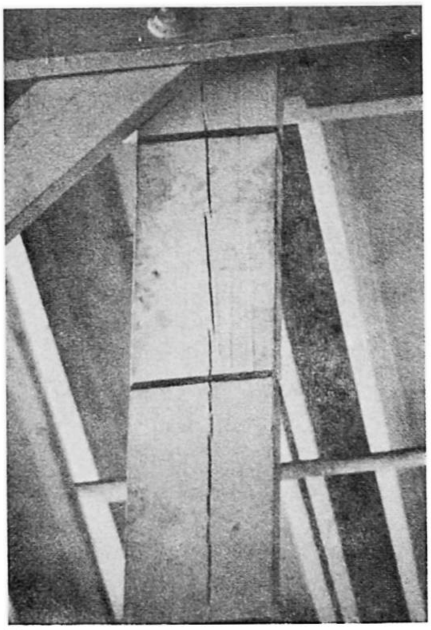

Fig. 3 - Longitudinal Split, Interior of Member

a stronger epoxy-to-wood bond than others. Also, the properties of the wood: species, surface preparation, crack width, grain direction, age and moisture content, may affect the epoxy-to-wood bond. In addition to these inherent factors, aspects of quality control also affect the epoxy-to-wood bond: proper mix proportions (epoxy is a two-part material that hardens when the parts are mixed), temperature control and surface cleanliness. Because of these many factors which influence the epoxy-to-wood bond, preliminary testing, closely duplicating field repair conditions, is always required.

2.2 Specimen and Joint Tests

The results of small specimen tests reported by AVENT, ET AL. [1] showed that an epoxy-to-wood bond of significant strength could be formed, either in tension or shear. The specimen tests, however, were not adequate to predict the behavior of approximately 98% of the defects found, most of which involved a joint where lapped wood members were connected by bolts and ring timber connectors. Therefore full-scale joint and truss tests were conducted. AVENT ET AL. [1] reported on the results of testing double-lap tension joints made up of two 50 mm by 150 mm elements and two 76 cm long splice plates. Each element was connected to the two splice plates by two 6 mm diameter bolts and four split ring timber connectors. The wood used for these tension tests was of two types: (a) No. 2

dense kiln-dried Southern Pine and (b) Southern Pine taken from a 25 year old roof truss. The test procedure was as follows:
- Apply tension force until failure
- Seal failure area with an epoxy gel
- Inject failure region with a low viscosity epoxy, filling all voids
- Apply tension force to repaired specimen until failure

The result of these tests showed a remarkable 30% to 60% increase in ultimate capacity after repair. This increase was attributed to the change in behavior of the joint due to the epoxy injection. It was observed that the epoxy not only filled up the cracks caused by the initial failure, but also filled the bolt holes and space between overlapping members. This transformed the joint from one with stress concentrations at the bolts and split ring connectors, to a rigid joint with stress evenly distributed over the cross section.

2.3 Full-Scale Truss Testing

While joint tests showed an increase in ultimate strength after epoxy repair, it was recognized that the behavior of a truss, after epoxy repair of a few damaged locations, would be different. This difference in behavior would be caused by a major portion of a truss being unmodified by epoxy injection. In order to investigate this difference, tests on wood trusses were performed. Seven trusses were tested, as reported by AVENT, EMKIN and SANDERS [2]. The first six of the seven trusses were constructed of new 50 mm thick No. 2 kiln dry Southern Pine members connected by bolts and split ring connectors. Member widths were selected so that several potential failure locations were created. The allowable short term load [3] for the trusses as designed was 41.4 kN. The seventh truss was identical to the first six except that the wood was taken from a 30 year old roof truss. The test sequence was as follows:
- Apply equal load to the four interior top panel points until failure
- For three trusses, the conventional repair technique of metal banding was used to repair the failure site, since the failures were all of the end split type similar to Figure 1. Then these three trusses were again loaded to failure.
- After initial failure for the other four trusses, and after the second failure for the first three trusses, damaged areas were repaired by the epoxy injection techniques. Twenty-four joints or members total were repaired by epoxy injection in the seven trusses. Since each truss consisted of 16 joints and 21 members, the number of repairs was realistic.
- Then the epoxy-repaired trusses were tested to failure

The results of the truss loading tests can be summarized: (1) The average ultimate load for the initial test of all seven trusses was 96.3 kN. (2) The average ultimate load for the three trusses after conventional repair was 76.8 kN. (3) The average ultimate load for all seven trusses after epoxy repair was 104.4 kN. A statistical analysis of the effect of epoxy repair showed that the probability, that the ultimate load after epoxy repair was greater than 90% of the initial test, was 0.90.

These full-scale truss tests indicated that, whereas the ultimate strength of single-joint specimens was increased by epoxy repair, the ultimate strength of trusses was restored only approximately to original level. The difference in behavior between specimens and trusses is due to the multiplicity of failure locations in the trusses as compared to specimens. The trusses were only partially repaired by epoxy, and the specimens totally. Epoxy repair locations in the trusses were selected by visual observation of damage. Other locations, which appeared relatively undamaged and not repaired, became failure sites when trusses were loaded after epoxy repair.

3.0 FIELD REPAIR PROJECTS

3.1 Small Scale Repair

In 1976, a small-scale field repair project was completed at Robins Air Force Base, Georgia; the details of this project were reported by SANDERS, EMKIN and AVENT [4]. Two 61 m long trusses were selected for repair by epoxy injection. The number of repair sites selected was 39, of which 37 were at joints or splices where more than one member was repaired by epoxy. The total number of defects repaired was 76. The total cost for this repair project was US$4,610 (1976 dollars). The biggest problem encountered was leaking of repair sites during injection. This caused a delay for the injection crew while sealing material was prepared and placed to seal leaks.

3.2 Full-Scale Repair Project

Because of the favorable result of the small-scale repair project, U.S. Air Force engineers decided to contract for a large repair project at Robins Air Force Base in 1977. Engineering personnel visually inspected roof trusses in five warehouse buildings and identified 695 locations, mostly joints, which were to be repaired by epoxy injection. The low bid for this project was US$87,100, or US$125 per injection site (as compared to US$118 per injection site for the small-scale repair project). The full-scale repair project was successfully completed over a four month period during the winter of 1977-78. Details of the project were reported by AVENT, SANDERS and EMKIN [5].

4.0 ECONOMIC COMPARISON WITH CONVENTIONAL REPAIR COSTS

After the successful repair projects, data on conventional repair costs were gathered from U.S. Air Force bases in the 48 states. The average 1976 cost of replacing a single wood truss member was US$279 for a web member, and US$310 for a chord member. In order to properly compare costs, the following must be considered: (1) member replacement repairs both ends of that member only, and (2) Epoxy injection repairs all members meeting at that repair site, but does not affect the other ends of these members. Thus, if both ends of a single member are damaged, replacement would cost approx. US$300, and epoxy injection would cost approx. US$250. However if, as was often the case, two or three members at a joint were damaged, and their other ends undamaged, replacement would cost US$600-900, and epoxy injection would cost only US$125.

5.0 QUALITY CONTROL

Quality control concepts and procedures are of much greater importance in epoxy repair projects than they are in conventional repair or construction projects. The two main reasons for this are:

- Epoxy is a complex chemical which must be mixed in exact proportions and applied under proper conditions.
- Injection is a "blind" process, the completeness of which can only be inferred by monitoring leakage from neighboring injection ports and observing the amount injected.

Failure to maintain quality control can result in improperly or partially injected repair sites that are difficult and very expensive to repair. For example, a partially injected site discovered after curing of the epoxy will usually not be re-injectable and will, if seriously deficient, require extensive conventional repair. A completely injected site with non-curing epoxy adds no strength to the structure and, since it cannot be reinjected, must be conventionally repaired.

6.0 CONCLUSIONS

During periods of a scarcity of steel, when the use of steel, a non-renewable resource, may be undesirable, wood may be increasingly used for truss members. Current practice is to join the wood members by steel bolts and split rings. This however, creates stress concentrations which ultimately cause cracks and splits. The useful economic life of wood trusses can be lengthened by periodic epoxy injection of damaged sites. The epoxy injection process has been found to be economically and technically feasible in the multi-year research and development project described herein.

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