The use of resin adhesives in the repair of structural timber members

G. Davis & C.J. Mettem

TRADA Technology Ltd, Stocking Lane, Hughenden Valley, High Wycombe, Buckinghamshire, HP14 4ND, UK.
EMAIL: GDavis@TTLChiltern.Co.UK

Abstract

Structural adhesive bonding of metal parts began in the European aircraft industry in the early 1940's and is now regarded as well established. More recently, building and civil engineering applications have become accepted, with resin adhesives, principally but not exclusively epoxy-types, to the fore. Onerous repair applications have included the strengthening of existing concrete highway bridges. In the repair of timber structures, where metal inserts are commonly bonded into the parent material, resin adhesives have been known for over 20 years. However, only relatively recently has systematic research been conducted, aimed at establishing the durability of these repairs, and at formalising design procedures.

Investigations have shown that epoxy resin adhesives can produce efficient durable repairs, provided that the repairs are well designed, detailed and performed under strict quality control guidelines. Resin repairs can be carried out either in-situ or to individual members in buildings which have been dismantled. Even though resins can produce highly efficient repairs to buildings, other considerations may apply. Care should be taken not to over-stretch the technology to a point where it is either uneconomic or it is conservationally undesirable, and alternative repair methods should always be considered. TRADA Technology Ltd (TTL) have undertaken case studies, where resin repairs have been carried out successfully. These include repairs to a 500 year old trussed rafter roof, which is also the subject of long-term monitoring.

1 Introduction

There are many aspects concerning the design and performance of resin adhesives in the repair of structural members that have until recently remained unvalidated. Extensive investigations into the subject have recently been undertaken by TRADA Technology Ltd (TTL) with financial support from the
Department of the Environment, Timber Research and Development Association, and with advice from a strong team of timber repair contractors, conservation organisations and other specialists. This paper discusses the use of resin bonded systems as a repair option for structural timber members. It is chiefly written within the UK context, although many of the principles apply more generally.

The natural forces that cause deterioration in all building structures will always be present, and experience has shown that the climatic conditions for buildings in the UK are among the worst in the world, as reported by Mills\(^1\). Sheppard\(^2\) states that the temperate climate can produce shade air temperatures between \(-24^\circ C\) (Scottish highlands) and \(37^\circ C\) (London). Materials exposed to the midday sun, or to clear night skies, reach much higher and lower temperatures than the shade air temperature.

In addition to the deterioration caused by climatic conditions, the use of a building will cause it to deteriorate through wear and tear. Few historic buildings can be kept as museum pieces, most are inhabited and in use. This is often preferable, but it can cause problems in that the demands placed upon a building nowadays are more rigorous than those of previous times. Improved space standards, high environmental requirements, and new patterns of use are the norm. To fulfil such requirements, repairs and maintenance are called for on a planned basis. These may involve major repairs to various parts of the structure. In order to control repairs, alterations and changes, many old buildings are listed or scheduled, especially if they are of historic interest or importance. This means that the entire building and its ‘curtilage’ should be preserved, and any alterations or changes must be approved. Advice on listing and conservation is provided by English Heritage, and by similar national bodies for Scotland and Wales.

Many traditional timber frame buildings in the UK have survived centuries of alterations, decay and other abuses of all kinds. One of the most common causes of the need for repair is that key elements of the structure have been removed. The effect that this may have on the remainder of the frame can be serious. Broken pegs, may prevent a joint from working correctly, or the removal of a brace may destroy the triangulation that is necessary to ensure stability of the frame. Yet despite this kind of abuse, few of these types of building collapse suddenly. There are many reasons for this, but the principal ones are firstly that the frames were frequently generously over-sized in the first place, and secondly because the cladding plays a vital role in holding the structure together (Boutwood\(^3\)). Despite the redundancy which is often built into historic timber structures, serious damage from previous alterations cannot be neglected forever. For example, if the removal of key elements is neglected indefinitely, the frame is likely to continue to distort, and stability will become a problem. Eventually, repairs to the frame become highly advisable.
2 Methods of resin bonded repair

The most common adhesive and structural fillers used in resin bonded repairs of structural timber in the UK are various forms of epoxy systems. These have been used for over twenty five years. Most resin bonded repairs are designed in conjunction with reinforcing plates or bars, since this is a method of producing high strength repairs that are concealed. Even though epoxy resins have been used on a large number of repairs and have proven successful, there are still certain members of the conservation fraternity, (Charles4) who believe that historic timber framed buildings must be keep ‘pure’, and not repaired with substitute materials such as steel, and certainly not epoxy resins. Alternative repair methods are considered in a subsequent section of this paper.

2.1 Repair concepts

Dismantling, repairing and rebuilding as a means of conservation is clearly not the most highly preferred method. The principle followed is minimum intervention to achieve maximum conservation. However, it is sometimes necessary to dismantle buildings, to move them to a different site for example. Dismantling and re-erection should only be considered if the alternative is total demolition, otherwise the building should be restored in-situ. The timber frame is often considered to be the most important feature of the building and little regard is paid to the cladding and hidden structural features. This is misguided, as these may also have important historical value.

There are three main phases required in planning to dismantle a timber frame building: the initial survey and investigation, then the dismantling itself, and finally the post-dismantling phase of analysis. Skill and experience are needed in knowing the best ways to unpeg various joints, and in being able to plan and execute safe handling systems for heavy timbers. The main rule when dismantling a timber frame is that no timber, however rotten or apparently unusable, should be disregarded. If a member has to be replaced in the reconstruction, then the original will be a better template for the carpenter than any number of drawings. Another reason to save original timbers is they have information embedded in them. These take the form of carpentry marks, and may even include marks which are thought to be magical or to provide ritualistic protection to the building. It is very important to preserve and record these marks (Harris5).

It is sometimes thought that it is more practicable to take out a timber member and to repair it in a workshop, rather than making a repair in situ. The demounting of a complete frame or truss, with re-framing on the floor may be contemplated. The state of the structure will determine the ease of removal of such members, as well as the amount and kind of repairs required. However,
removal often appears easier than is actually the case, since creep may have occurred in many of the members. This will cause the members to remain in a deflected form, even when unloaded, making them more difficult to extricate. An in situ resin repair offers the advantage that the deflected form of the member can be maintained.

2.2 Repairing in situ with resins

Resin repairs in situ normally entail low disturbance of the original fabric of the building, and therefore follow the preferred principle of minimum intervention. There are a wide variety of details practised in the UK. Differences between jobs arise from factors such as structural form, member sizes, species of timber, original built design, the amount of access, and the type and extent of the defects which require repairing. In addition, variations are introduced by the preferred methods of the various repair specialists, which have been studied by TRADA6.

3 Alternative repair methods

It should remembered that the requirements of each repair are different in every case, and the professional should never approach a project with preconceived ideas. The alternatives for each repair should be considered on their own merits. Often it may appropriate to use more than one technique in the repair of a building (TRADA7). There are three broad groups of technique into which repair methods other than adhesive systems can be categorised: alternative supports or replacement of members; mechanically fastened repairs; and craft-based carpentry repairs.

3.1 Alternative supports or replacement of members

The load bearing capacity of a structure can often be restored by the addition of members, which provide an alternative method of support. It may be possible for example to move the support location of a decayed beam end to a position where the timber is sound, by the use of bracket beneath the beam, or by the addition of a post to reduce the span of the beam. Uzielli8 illustrates a typical bracket system of this nature. Although principles such as these inevitably introduce conceptual changes to the structure, they do have the merit, if skillfully designed and performed, of leaving an indication of how the structure first behaved, and leaving the historic fabric undisturbed.

Replacement of members using matching timbers can often maintain the original structural concept. Even original jointing techniques may be possible. However, this can cause large amounts of disruption to the structure, and considerable loss of original material. Obtaining large section replacement material, of sufficient quality, may be difficult. It is often almost impossible to
obtain timber with a moisture content in balance with the modern requirements for an internal heated dwelling. On the other hand, if green timber is used, as would have been the case when the building was originally constructed, the replacement member drying in service will cause movements and stresses in surrounding parts of the structure. This can cause other problems, if the repair is not correctly detailed with provisions for shrinkage.

3.2 Mechanically fastened repairs

These may be defined as repairs where the primary connection between the original structure and the replacement material is through dowel-type fasteners, as described in a TRADA information sheet. The design calculations for these types of repair are normally carried out in line with accepted codes such as BS 5268:part 2 ‘Structural use of timber’ and EC5:Part1.1 ‘Design of timber structures’. Common examples are through-bolted metal side plates, flitch beams, bolted joints and additions to members by nailed or screwed connections. To some, mechanical fastened joints appear to be out of place in historic structures. However, if well designed and detailed, such repairs can be partly or wholly concealed, or may be conceived so as be keeping with the rest of the structure.

3.3 Craft based carpentry repairs

These use scarfs, tenons and sometimes dovetails of various designs. Carpentry jointed repairs are usually thought of as being broadly comparable with the types of original joint found in traditional timber framed buildings. It should be realised however that the original connections were conceived as part of a prefabrication process for what was, at the time, a ‘new build’ situation. Experience can be gained from studying reconstructions such as the Globe Theatre, as reported by McCurdy. The techniques used for repairing members have been adopted from the splices used in extending timbers for new construction. Typical of these are timber-to-timber scarf joints, which rely on their geometry, plus timber pegs, to resist the applied forces. These types of joints are difficult to assess in engineering terms, but tests have been carried out by TRADA to estimate their efficiency. Scarf joints are not capable of carrying large moments, and should therefore be located at or near points of contraflexure in bending members. This is in keeping with the manner in which they were used when the buildings were new.

4 Case studies

In order to assess the condition of epoxy resin repairs to timber which have been in service for some time, a number of sites have been visited. A report describing five of these case studies was produced in 1995 by Mettem. The
choice of sites was based on the expected exposure conditions of the epoxy resin repairs, the structural location of these repairs and their age. At one of the sites chosen, the epoxy resin repairs had been reported as having failed. Apart from this one site, the general condition of the epoxy resin repairs and of the historic timbers was found to be good. There was no evidence of preferential attraction of moisture by the resins at the resin/timber interface, which was one of the concerns that had been expressed. The failure at the one site was found to have been caused by an inappropriate choice of repair method, inadequate surface preparation prior to the application of the resin repair system, bad detailing, and an unsuitable resin formulation.

In one of these case studies, repairs had been carried out to the oak roof and floor of the south range of a very important English Heritage structure named Blackfriars Friary, shown in Figure 1. The techniques included resin bonded repairs, craft based carpentry repairs and mechanically fastened repairs, shown in Figures 2 to 4 respectively. The site itself had the highest possible listing a structure can be given by English Heritage. The repairs at this site have been monitored for a period of three years to date, and the installation and the results from the first eighteen months have been reported in Davis. Moisture monitoring probes have been installed at 24 locations in the roof and at 11 locations in the floor. In addition to these, two automatic meters for recording the atmospheric humidity, and two temperature monitors have been installed. This monitoring has shown that there have been large fluctuations in the moisture content of the timber members, both close to and away from the resin repairs. The temperature and relative humidity monitors have shown equally large fluctuations with the different climatic seasons, as shown in Figure 5. These large fluctuations in the moisture content of the members have not affected the performance of the resin bonded repairs. The monitoring at Blackfriars is continuing, with similar work also started on the resin bonded repairs to an early engineered softwood truss over the stage of The Theatre Royal, Haymarket, London.

In addition to this monitoring work, long-term tests have been set up at the Chiltern Open Air Museum, in Chalfont St Giles, Buckinghamshire. These tests have been derived to establish the duration of load performance of an axially loaded bonded-in rod. The specimens are left under a tensile load, fully exposed to the weather for set periods of time, before being brought back to the laboratory at TTL for tensile testing to failure. The failure loads will then be compared with a datum set of tests on unexposed specimens, and with a predictive model.
Figure 1: Blackfriars Friary, South Range showing the 500 year old trussed rafter roof.

Figure 2: Blackfriars Friary, resin bonded repair to one of the refters (centre of picture).
Figure 3: Blackfriars Friary, a carpentry joint used in the repair of one of the sissor members of the roof.

Figure 4: Blackfriars Friary, a mechanically fastened frame used to support two of the rafters above the position of an old chimney, where the bases of the trusses is missing.
Figure 5  Typical relative humidity and temperature fluctuations during one year, in the south range of Blackfriars Friary roof.

References


540 Structural Studies, Repairs and Maintenance of Historical Buildings


