

## Repairs to historic timber structures: Changing attitudes and knowledge

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**ABSTRACT:** The conservation of timber structures has improved in recent years with a growing appreciation of their historical significance. However there are still difficulties presented because of the limited number of engineers with an understanding of timber structures and the failure of design codes to consider the kind of detailing often used in historic structures. This paper will point out a number of areas where research on the behaviour of ‘traditional’ carpentry would be valuable.

### 1 INTRODUCTION

Since the eighteenth century timber in Britain has been a rather Cinderella material, essential to construction but not highly regarded compared with masonry as an architectural material. It did enjoy something of a revival during the nineteenth century for roof structures of the Gothic revival but, apart from that, it has been a poor relation to other materials for structural purposes. That is to some extent because Britain, not having large supplies of structural species has imported most of its building timbers, but also a legacy of the Fire of London and the switch to brick. The subsequent ‘Georgianising’ of timber-framed buildings across the country was probably as much a fashion statement as a concern for fire protection. One could argue that it is not having a continuing tradition of timber structures that has led to a lack of concern for the history and historic value of such structures, except for exposed half-timbering. Be that as it may, the historical significance of timber structures has only been recognized relatively recently, so that when we consider the approaches to conserving timber structures we have to consider the development of ideas about the significance of these structures as well as that of the technical solutions; an understanding of their history as much as of their structural behaviour. It is true that it has for some time been a material of interest to a few enthusiasts, people like the late Freddie Charles, and its importance was recognized in those buildings where it was a prominent architectural material: the roofs of open halls and East Anglian churches for example. But otherwise it was taken little account of.

In the nineteen sixties there was a series of studies of the major monastic barns, some undertaken through the collaboration of Freddie Charles and the American scholar Walter Horn that recognized the significance of what were the greatest timber structures of their

day (Charles & Horn, 1973; Horn & Charles, 1966, 1984). At much the same time, Stuart Rigold (1966) did work on the many timber barns in Kent, and Cecil Hewett (1967), having looked at the barns of Cressing Temple, went on to draw, examples of major medieval carpentry from all over the country, his work culminating in two large collections (Hewett, 1980 & 1985). His work did a great deal to draw people’s attention to these structures but, because of the inaccuracy of his drawings, regrettably little to advance scholarship in the area. (One could even argue that it set back scholarship since many must have assumed that this work had already been done.) Timber buildings were also a common interest of students of vernacular architecture, so that by the end of the 1970s there was an extensive coverage of medieval carpentry. In contrast little had been done at that time on later carpentry work and for that reason I chose to look at seventeenth and eighteenth century carpentry to provide an outline of development during that period that I hope others might follow up on.

This still leaves the nineteenth century, both in terms of the development of industrial structures, the transition to iron and architects’ use of exposed timber structures in both Gothic revival buildings and their later treatment of the material. Only Booth has done work on nineteenth century laminated timber. There are also significant 20th century timber structures that we are now losing. Oxford Road Station, Manchester, a group of conoids, was recently imitated in steel.

The histories of early carpentry provided an account of developments in the overall form of timber structures, their structural design if you will, but carpentry is a craft skill and we also need to consider its details. Again Hewett provided the general reader with drawings of joints but that is something requiring careful observation and measurement. In this the work that I know best is that of Richard Harris, now curator of the

Weald and Downland Museum, and Peter McCurdy, who I would describe as a scholar craftsman. These are people who have worked closely with the timbers and who have come to understand and bring to our attention the significance of setting out marks that one finds within the timbers, and have a sound understanding of the process from conversion of the log to the erection of the building. Although they have published relatively little, in their teaching they have shown us that carpenters marks are more than just the numbering cut into the timbers. For imported timbers there has been a little interest in merchant marks that indicate their sources, significant because of the changing patterns of trade, particularly during the late eighteenth and early nineteenth centuries, although this work is still in its infancy.

What historical significance these clues have I leave to others, but the significance of this work is that aspects of the surviving timbers are now being recognized that were simply not seen a few decades ago. Moreover, as many timbers have been reused, it has sometimes been possible to reconstruct the design of earlier structures that the timbers were a part of. For example, the earlier roof of Lincoln Cathedral has been reconstructed from timbers that now form part of the present roof (Foot et al., 1986), but which were reused from the previous. An example of more recent reuse was that timbers from the original gallery structure at Christ Church, Spitalfields were reused for the floor of later pews.

This means that surviving timbers are now being recognized as conveying evidence of the development of structural design, as evidence of craft practices and as evidence of the earlier form of the buildings in which they are found. This is a change from the scant value that they were given only a few decades ago. I recall visiting the roof of Norwich Cathedral to look at the timbers in the roof shortly before they were taken away. By that time the transepts had already been re-roofed using reinforced concrete A frames, involving the total loss of the original timbers. In today's climate an alternative and rather different solution would surely be sought in similar circumstances, perhaps using a supplementary structure rather than a complete replacement. We are perhaps beginning to recognize that structural design is a cultural activity whose history is to be valued as much as carving or wall painting. However, medieval structures still seem to be the main focus of attention with far less understanding of the history of early modern structures.

This is disappointing because without the development of new carpentry structures in the seventeenth and eighteenth centuries the forms taken by the great public buildings, churches and country houses would simply not have been possible. But the carpentry structures that made this architecture possible are largely invisible and so little attention is paid to them.

Much the same might be said of the structures of the nineteenth century and even the early 20th century, and the danger is that we will lose historically significant structures before their significance is recognized.

## 2 ANALYSIS OF THE STRUCTURE

Recognizing the value of structures is the first step to their preservation, but the second is their proper structural analysis. Here it is unfortunate to have to report that their behaviour is not always properly understood, with the result that unnecessarily heavy-handed repairs are sometimes specified leading to the loss of historic material and hence the loss of historic character. On more than one occasion I have been contacted by those concerned when their engineers have specified the use of steel connectors for timber structures that had been performing in a perfectly satisfactory manner. This can be either because of an unwillingness to treat the structure on its own terms, or simply the application of computer software better suited to steel or concrete structures.

In some cases it is clear from the places where the steel has been specified that the structural form has been analysed as if it were a steel structure, resulting in assumed tension forces that the timber joints cannot take. However, if these members are removed from the analysis what remains might be a perfectly satisfactory structure. In spite of what seems obvious foolishness, there have even been a number of papers published where finite element analysis has been inappropriately applied to historic timber structures. In one case that I was sent to referee (I will not give a reference to protect the foolish.) the author came out with the startling discovery that in a king post structure, it was the post rather than the tie beam that would be carrying the majority of the load. A moment's thought would have told him that the principal rafter/king post assembly must be stiffer than the tie beam. I have a feeling of unreality when reading such work. I have to assume that such studies are carried out to impress academic colleagues rather than as contributions to the practice of either history or conservation.

The message here is that 'work is no substitute for thought', but it remains a problem when the work is done by a computer while it is the engineer who is required to do the thinking. It is likely to remain a problem because the modelling of structures using computer programs has become a relatively simple task. Entering the data into the computer is a fairly mechanical operation that can be performed without much thought. It is a sad reflection that there seems to be a large number of people for whom thought is a painful activity to be avoided at all costs. So much easier to just put the data into the machine and let it

do the work. Of course, computer analysis can be used intelligently if one realizes that large tension forces at joints are unlikely to occur and the structure needs to be modified accordingly. Sometimes one even finds that the result is a statically determinate structure and with a little thought one could have started from there.

One also needs to recognize that the nature of the workmanship can affect the support conditions for members that in turn will affect the overall structural scheme. Also, the section properties that one can insert as data for an historic structure can often be little more than a guess. This is equally true of the behaviour of connectors, and any analysis needs to be based on a thorough qualitative grasp of the structure following close observation of its construction and the way that it has behaved. Often the uncertainties are such that more than one structural scheme has to be considered. Of course, timber is not unique in this regard but perhaps the linear nature of its elements encourages a false idea of simplicity.

### 3 REPAIR STRATEGY

This brings us to the methods of repair, and here we should recognize that different approaches might be appropriate for different kinds and periods of structure. A simple contrast can be drawn, for example, between the decorative roofs of the middle-ages and the purely utilitarian structures of nineteenth century industrial buildings. In spite of both being equally visible, the former are clearly more valuable architecturally. As for all historic structures, we should begin by considering the possible historical value and hence the strategy to be adopted rather than focusing immediately on the tactics of repair. This issue of conservation strategy is one in which the engineering historian has something to contribute and about which the engineering consultant might be better informed than other members of the conservation team.

This means making some strategic assessment that should take into account:

- The historical value of the fabric.
- The overall condition of the structure and hence
- The scale of the repairs required, but also
- The options for future use.

Consider the extremes here. We might try to retain the timbers in a condition as close as possible to the original structure, i.e. as a repaired structure carrying out its original function of supporting the building. At the other extreme is provision of new structure to support the original timbers that simply remain as an historic artefact reminding one of what was there originally. The latter might well be the preferred option where the decorative nature of the timbers is of

paramount importance. Between these two there may be a choice of options that the engineer should be able to assist in deciding between. This requires the engineer have a greater involvement in the process than simply providing the technical fix after the strategic decisions have already been taken.

In considering the overall strategy the choices are between:

- repairing and restoring the as-found structure and
- providing supplementary structure

And if the first option is chosen one needs to consider the choice between

- Repairing in-situ and
- Dismantling for repair, either completely or in part.

There is often resistance from conservation officers (and possibly clients) to the latter, even though there are some cases where this might be the cheapest and safest approach. It is an option for timber structures because of their prefabricated nature, and there is almost certainly a failure to understand that where a structure has distorted over time, for whatever reasons, to repair it in its as-found condition is to preserve a cripple. It will often have locked in secondary stresses that have arisen through the distortion that has taken place and which now have to be accommodated within the repairs, a complicating factor.

I have argued (Yeomans, 2007) that in some buildings, particularly barns, the structural design is what we should be seeking to preserve. In contrast, where the timber has been treated decoratively this will take precedence and we may have to compromise the integrity of the structure in order to preserve the surface. Perhaps there are those occasions where the choice is that simple, but this dichotomy means that some judgement must often be made. In such circumstances the engineer responsible must be prepared to engage with other conservation professionals and to explain his point of view. It may be necessary to offer alternative structural strategies that would have different effects on the historic fabric. One is balancing structural safety, the heritage value of the structure, and perhaps a choice of future use. The client and other conservation professionals will be involved in such decisions, and the engineer must be prepared to explain the engineering issues in terms they can understand.

Although I have emphasised the need for conservation engineers to work with other conservation professionals in determining the overall strategy, it is also advantageous to work with the carpenters. I regard the simple model of professionals producing a design for contractors to price as inappropriate for the conservation of timber structures. We are not dealing with an empty site on which a building is to be assembled by reasonably tried and tested methods. We are dealing with unique situations where it is necessary to ensure

the continued stability of an existing structure that is being changed while it is being repaired. This is a situation in which the methods used may affect the details adopted, or in which the practicalities of a particular detail might affect the scope of the work to be carried out. In many cases an experienced carpenter may make an invaluable contribution at the design stage and, where possible, it is worth employing one as part of the design team.

I raise all these issues before discussing repair methods in detail because both the repair recommendations of ICOMOS UK's Wood Committee and the *Recommendations* of ISCARSAH, while informed by such considerations, do not draw the conclusions as clearly as they might. My view is that more consideration needs to be given to this stage of the process in the advice given to professionals.

#### 4 REPAIR DETAILS

When we turn to the tactics of repair, timber has always seemed to be a fairly contentious material the methods of repair have attracted rather strongly held positions. There has also been a developing of skills and the two together seem to have resulted in some swings in approach. (This might be true of conservation in general, it just being my own perspective that makes me think that it is more problematic for timber.) Repair methods in timber can be loosely divided into three kinds:

- Those using steel
- Those using modified traditional methods
- Those using epoxy resins with or without some reinforcement.

The kind of repairs once commonly carried out by engineers, cutting back the decayed timber and putting in supplementary steelwork (Fig. 1), was later deprecated by those who favoured a more 'traditional' approach, although that usually meant carpentry methods supplemented by modern steel fasteners. It has more recently been recognized that while such an approach is more visually attractive, and so appropriate for medieval timber frames, where the results are both visible, and have to form a junction with secondary materials, it does involve a greater loss of historic fabric. In that respect the use of supplementary steelwork is perhaps to be preferred where the repair is not seen. Repairs using epoxy resins had a 'bad press' for a while and suffer from a regrettable lack of research into their long-term performance, but lack of research also affects other areas of repair work.

One of the major repair projects carried out early in the 20th century was to the roof of Westminster Hall (Baines, 1914) where substantial decay had been found. That used steel connectors, but in locations

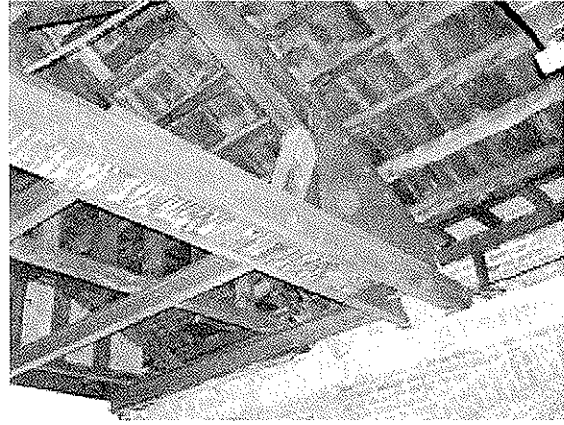


Figure 1. Repairs using steel carried out to the heel joint of a Wren roof truss at Hampton Court.

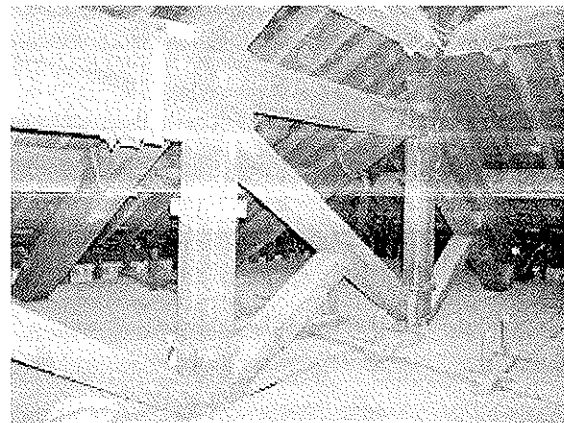


Figure 2. A truss in the Banqueting House, Whitehall with unnecessary reinforcing.

where it would not be visible. One wonders whether there was general concern at the time for the adequacy of timber structures simply because they were timber. The roof of the Banqueting House, Whitehall, built by Soane in 1824 to replace Inigo Jones's original, was a fine combination of timber and iron. Nevertheless, sometime in the inter-war period it was felt necessary to add steel to all the joints (Fig. 2) and to insert steel ties to take over the job that the tie beams seem to have been doing adequately till then. Clearly the reinforcing shown in Figure 2 is having no useful effect. The steel structure added to the roof over the hall at Greenwich Hospital also seems to be an unnecessary supplement to the original structure because in neither case is there obvious structural distress. But excessive use of steel can still be seen in use today because it is the material that engineers are familiar with and so may instinctively turn to even though timber repairs would be perfectly satisfactory.

In the 1970s the use of epoxy-resins as either a consolidant, or to replace lost timber appeared to offer a solution for those who wanted the minimum loss of historic fabric, but this ran into technical difficulties. Early research in the US on this method, where they were interested in it for repairing softwood trusses in the roofs of aircraft hangars, showed the difficulty of controlling the run of what was a liquid and the obvious change in the structural characteristics of joints. However, it is questionable whether or not this work was noticed by those in Britain who were enthusiastic for the use of the material and there are some unfortunate results of its early and inexpert use. Baguely Hall, on the outskirts of Manchester, is an example of the kind of thing that can go wrong. Epoxy-resin was used to repair the main frames of this fine medieval hall but was allowed to run over the surface of timbers and is now a permanent disfigurement. Many early repairs using this material were carried out by a firm who appeared to have little technical knowledge and even less interest in the proper training of their operatives. The result was a number of failures, sometimes because of the use of the technique in unsuitable locations where exposure to the weather seems to have resulted in accelerated decay of timber adjacent to the epoxy-resin repair.

The difficulty then was that with considerable anecdotal evidence about failures following the use of epoxy-resin, and with little scientific evidence, there was deep concern among some over the long-term performance of such repairs. This was especially so where they might be used in timbers with high or fluctuating moisture content. If there were to be deterioration of the adjacent timber it would have an effect on the strength of the joint. One might also be suspicious of its behaviour when used as an adhesive to join steel reinforcing plates to timber and the effects of temperature changes. As the steel must move more than the timber what is happening at the interface between the materials? Here we have no information and can only wait and see.

Opinions on the use of the material seem to still be divided between those with long memories and an instinctive distrust of these techniques and those for whom it is a valuable tool. TRADA (2001) have published a book on its use and at the Whitbread Brewery, London, Hockley and Dawson used it to effect in the repair what may well be the largest surviving eighteenth century trusses. More recently the Weald and Downland Open Air Museum has been developing skills in the use of epoxy resins for repairing structures that have been dismantled. (Their techniques are not suitable for *in-situ* work.) Richard Harris points out that this material allows one to make repairs that retain a lot more of the historic fabric. He has also argued that if something is going to be lost through decay and epoxy-resin will prolong its life, then it is

sensible to use it – but this is an argument normally applied to non-structural elements.

## 5 FASTENERS AND DESIGN CODES

Once the forces in a structure have been determined, and unless there is particular concern over deflections, our engineering problems become a series of connections with members in between; member stresses are generally low. Unfortunately the jointing methods used in new structures are not always appropriate for historic structures. Moreover, historic structures use details that are not used in modern carpentry and therefore for which there is no guidance within design codes framed for new buildings, using modern materials and modern methods. This was never so clear as during the lacuna when the newly introduced British Standard (BS5268) in 1984 failed to include oak as a structural material and conservation engineers had to continue to use the obsolete code (CP112). While that issue has been resolved, there are still questions over the performance of traditional joints and the values that one might use for metal fasteners.

The British code of practice is even inadequate in the information given for steel fasteners. One example is that safe loads for screws in shear are only given up to 10 mm diameter when carpenters may well wish to use 12 mm diameter screws. (Even that is an improvement on the earlier editions of the code where loads were only given up to 8 mm diameter.) An engineer who is unfamiliar with timber may be unwilling to go beyond the limits of the table, particularly as the formulae for determining the loads from first principles are rather daunting. Bolts can be seen used in circumstances where screws would have been better but where M10s were presumably inadequate. Moreover it might not be clear to those unfamiliar with the code that the spacings and edge and end distances for bolts rather than screws apply to these larger sized screws.

There is the serious question about how we should view the allowable loads on bolts and screws used in green timbers that will dry in service. The problem for conservators is complicated by the fact that one side of the joint will be dry timber and the other side green. I have no idea what reasoning or experimental results lie behind rather draconian reduction factor required by the code. If it is to allow for the possibility of splitting as the timber dries one would have thought that such an event might well reduce the capacity of the joint to zero.

## 6 TRADITIONAL JOINTS

The terminology is a little loose here because there are traditional joints, either surviving in existing structures or used in repair work that are no different from



Figure 3. In loading to determine shear capacity of timber the forces are applied at each end.

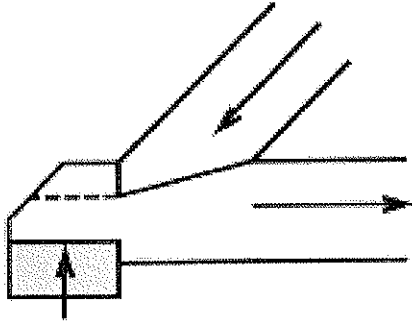


Figure 4. In atypical heel joint restraint is provided by the tie beam behind the notch.

joints contemporary with the original construction. At the same time there are those joints that have a superficial resemblance to traditional joints but which rely on modern fasteners, the most common being the scarf joint. The difficulty is that any tests to determine working loads for such joints must be affected by the workmanship in the carpentry. One can envisage the problem of relating test results to the performance of historic joints, both with very uncertain standards of workmanship and the effects of time and chance – or perhaps that should be wind and weather.

One wonders whether the standard test for shear resistance is a suitable basis for the design of traditional carpentry joints relying upon shear along the grain? The test loads the timber at either end so that one might expect a sensibly uniform shear stress along the plane of failure – the dotted line in Figure 3.

The joint where timber is loaded in shear parallel to the grain is a typical heel joint where the normal condition in practice is for restraint to be provided by the tie beam behind a notch (Fig. 4) or a mortice and tenon joint. In such configurations one would expect the shear stress along the plane of failure to fall off towards the unloaded end; but in what way? A complicating factor in some buildings is that this timber may be rather exposed and have a higher than normal moisture content.

Pegged joints is one of those areas where there is an overlap between new-framed construction and conservation, the question being whether such joints can be relied upon to transmit tensile forces. The difficulty is that pegs do not behave in the same way as steel bolts or dowels so that Johansen's equations cannot be applied to find the allowable loads. Experimental work shows that the pegs fail in shear close to the tenon/mortice

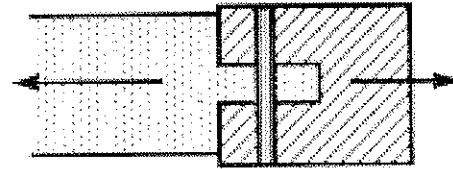


Figure 5. A pegged mortice and tenon joint. The peg will fail at the interface between the two timbers.

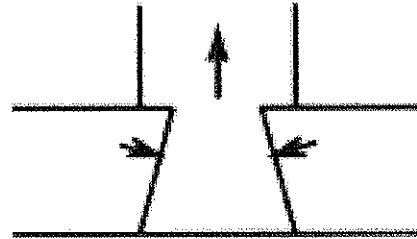


Figure 6. Forces on a lap-dovetail joint used between tie beams and wall plates.

boundary without the kind of rotation that occurs in bolts.

Unfortunately what work has been done so far has produced conflicting results. Drawing on the work of Jonathan Shanks carried out at Bath (Shanks & Walker, 2005), Ross et al (2007) have given possible working loads for pegs in oak, whereas a formula derived from quite different tests by Schmidt (2004) at the University of Wyoming suggests a working loads of less than half their figures. Given such a wide discrepancy, prudence suggests one should use the lower figure for design, but science surely requires some explanation for this large difference. The Bath tests were carried out on complete joints while those in Wyoming in more 'traditional' laboratory experiment that allowed the effects of varying density in both pegs and member timbers to be explored. What surprises me is that the Bath tests that used carpenter-made joints, and presumably subject to variations of workmanship, nevertheless resulted in the higher figure.

The behaviour of dovetail joints is another problematic area as these rely on timber loaded across the grain (Fig. 6). When there is drying shrinkage in the timbers there is a change in the angles of the two parts of the joint resulting in a reduced contact area and a correspondingly higher compressive stress. The stress might be well above the elastic limit with collapse of some of the cell walls. However there is no readily available data from which one can estimate the movement that might result.

A serious problem occurs when existing structures requiring repair incorporate details that are 'prohibited' by the present code. An example occurred where rafters had birdsmouth cuts over the supporting plate with the depth of the cuts exceeding half the depth of



characteristics of this material in their analysis of its behaviour. At the detailed design stage, there have been some developments as a result of the present fashion for green-oak structures. However, work in this area is still patchy and rather inconclusive. If this seems a little pessimistic, what I have not discussed is the quality of the pool of carpentry skills that has been growing over the last few decades that facilitate good standards of conservation

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