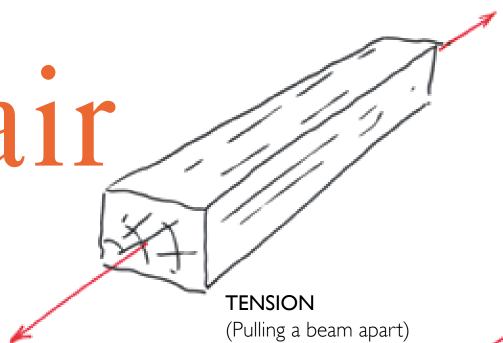
Selecting the right beam repair

This article will discuss the importance of understanding structural behaviour when making decisions about repairs. To demonstrate this it will consider variances in the scarf joints utilised in the repair of two different timbers of a 16th-century barn in Bedfordshire: the truss tie and purlin.

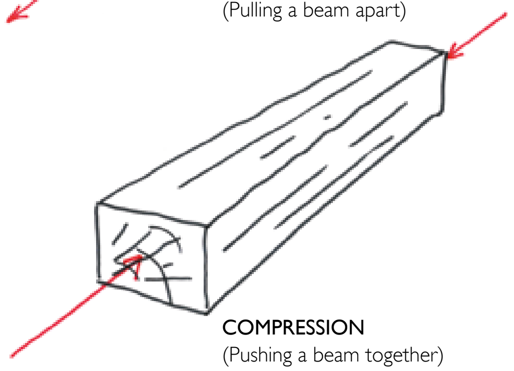
In the first instance, it is important to understand the typical forces that arise in beams.

Beams are typically subject to tension, compression, shear, bending and torsion. Torsion is not relevant to the examples given here and will not be considered further. Tension is well understood and relates to a force that tries to pull an object apart. Compression is the opposite of tension and is again well understood. It refers to forces trying to push opposite ends of an object together.

Both forces are resisted by the cross-sectional area of the member that the force is applied to. The greater the area of the section experiencing the force, the more force it can accommodate.



TENSION
(Pulling a beam apart)



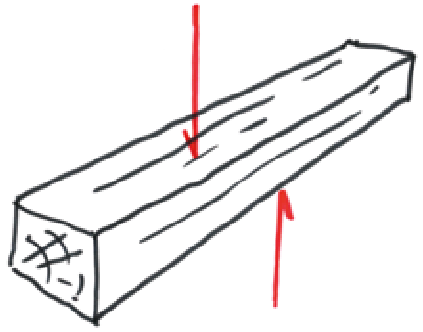
COMPRESSION
(Pushing a beam together)

Shear and bending forces are less well understood. Shear forces relate to forces in opposite directions acting side by side, very much like the blades of scissors that slide across each other as they cut. Again, the greater the cross-sectional area of the material, the greater the shear force it can accommodate.

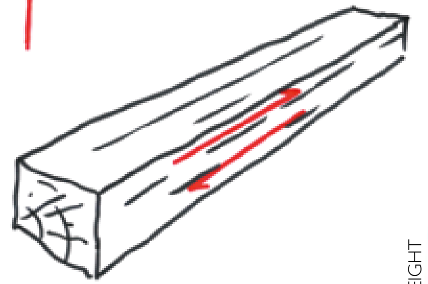
Bending is a complex mixture of tension, compression and shear forces acting together within a single beam.

When a beam is subjected to bending (in sagging), the upper fibres of the beam are forced together (compression); the lower fibres of the beam are pulled apart (tension). The distance between the compression and tension forces is what resists bending and, therefore, the deeper the section the greater the bending capacity of the beam.

With compression in the top of the beam and tension in the bottom, a horizontal shear develops in the beam between the forces acting in opposite directions. A vertical shear is also created at the supports where the weight on the beam is dragging it down and the support is holding the beam up.

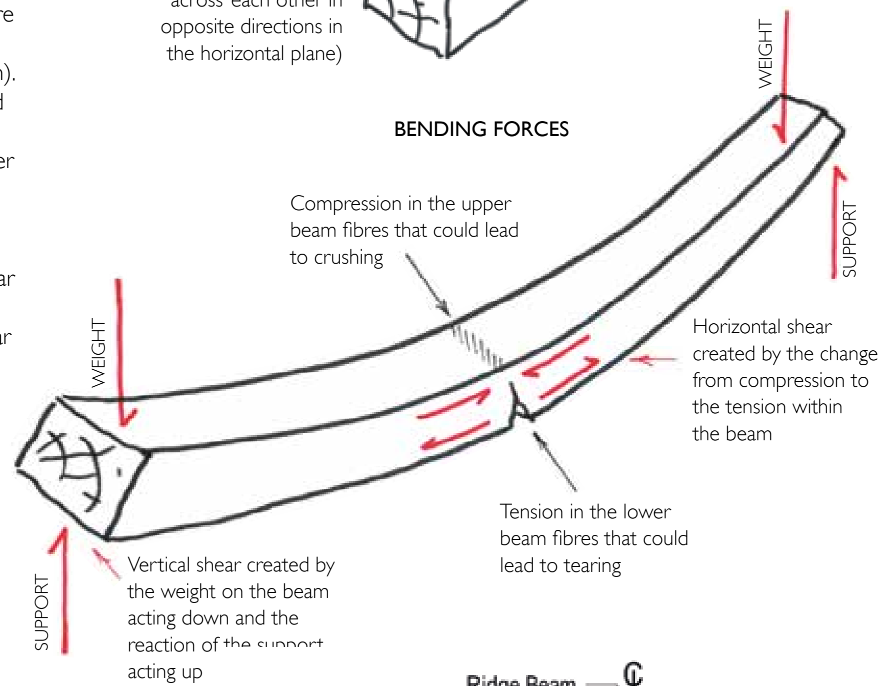


VERTICAL SHEAR
(Two forces within the same beam acting 'across' each other in opposite directions in the vertical plane)



HORIZONTAL SHEAR
(Two forces within the same beam acting 'across' each other in opposite directions in the horizontal plane)

BENDING FORCES



In this 16th century barn, the typical truss form is shown in the diagram on the right:

The truss tie experiences a vertical load applied by the purlin strut, which is supported by the knee brace. The close proximity of these two connections induces minimal bending and some vertical shear. The angle of the strut (pushing down) and the brace (pushing up) creates a horizontal reaction in the tie beam, forcing it away from its support. The angle of the rafter pushing down in the opposite direction thus creates tension in the tie beam.

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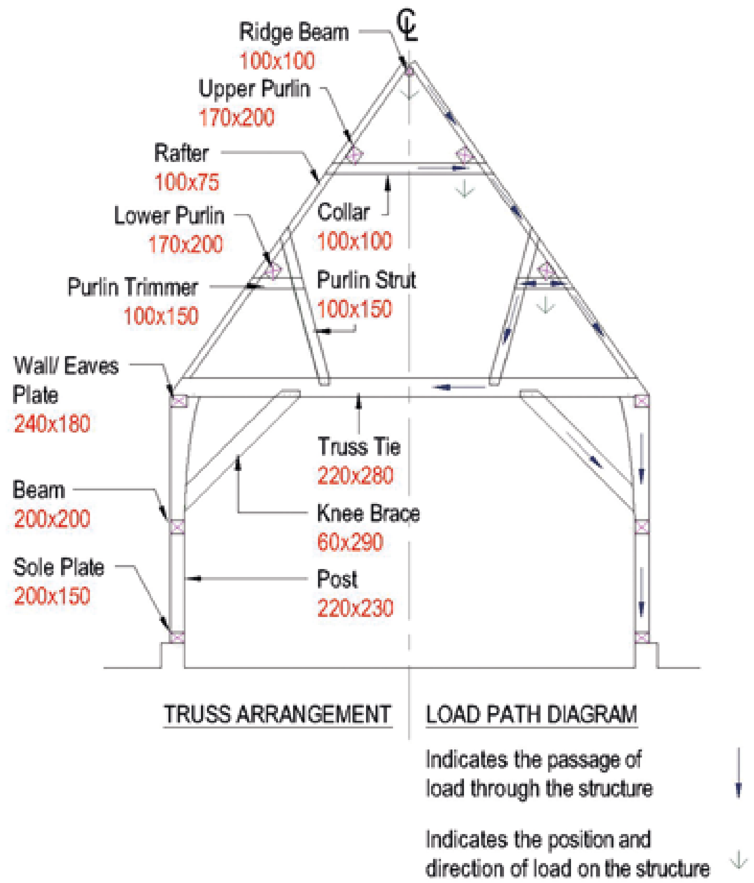
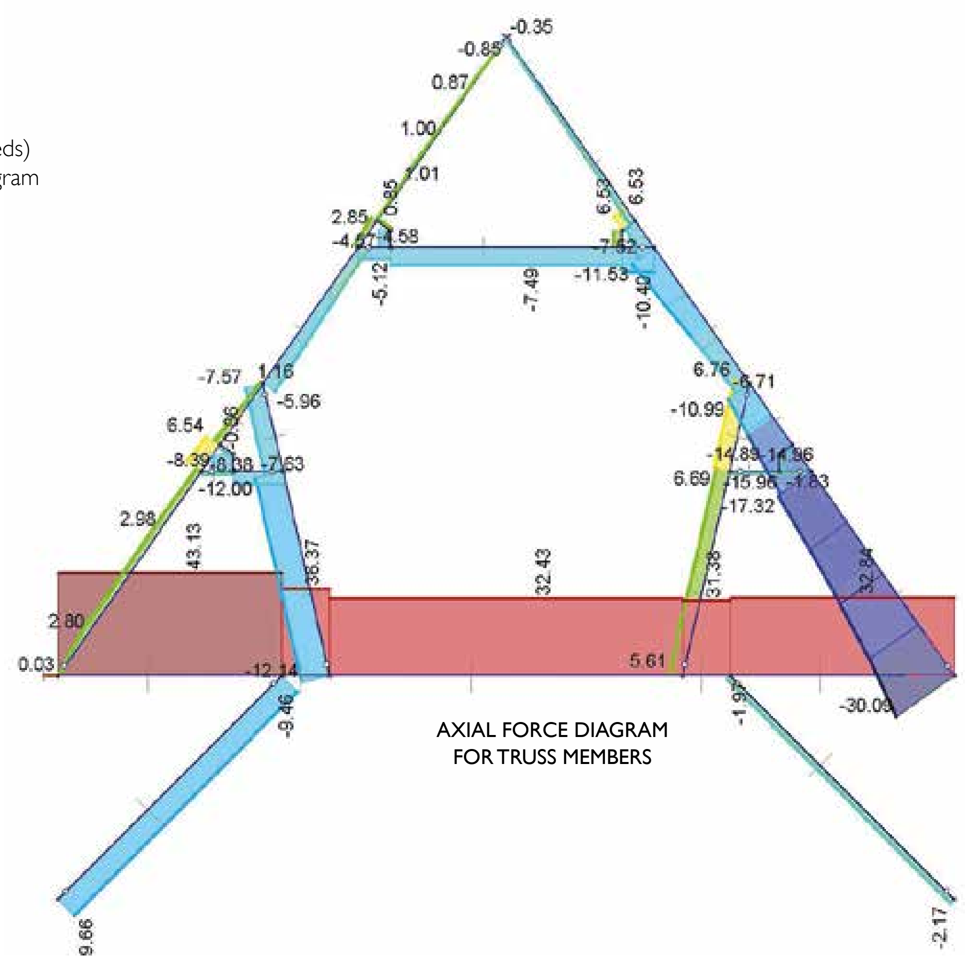
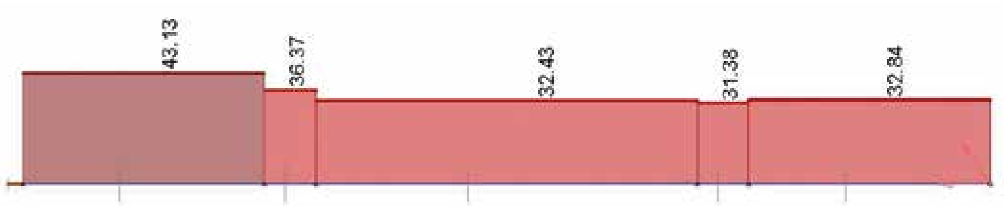


In this diagram the cool colours (blues) indicate compression; warm colours (reds) indicate tension. It is clear from the diagram that there is significant tension in the tie beam.



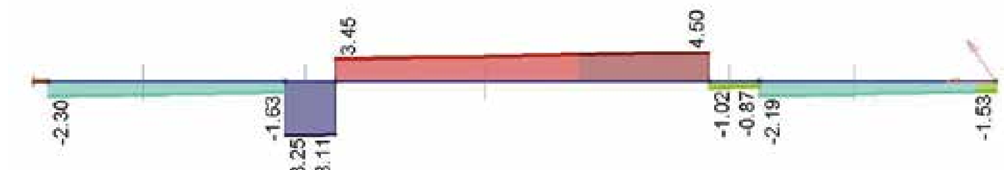
AXIAL FORCE DIAGRAM FOR TRUSS MEMBERS

If we were to separate out the tie beam and consider it in isolation, it can be seen how the different forces vary:



TENSION FORCES (kN)

BENDING FORCES (kNm)



SHEAR FORCES (kN)

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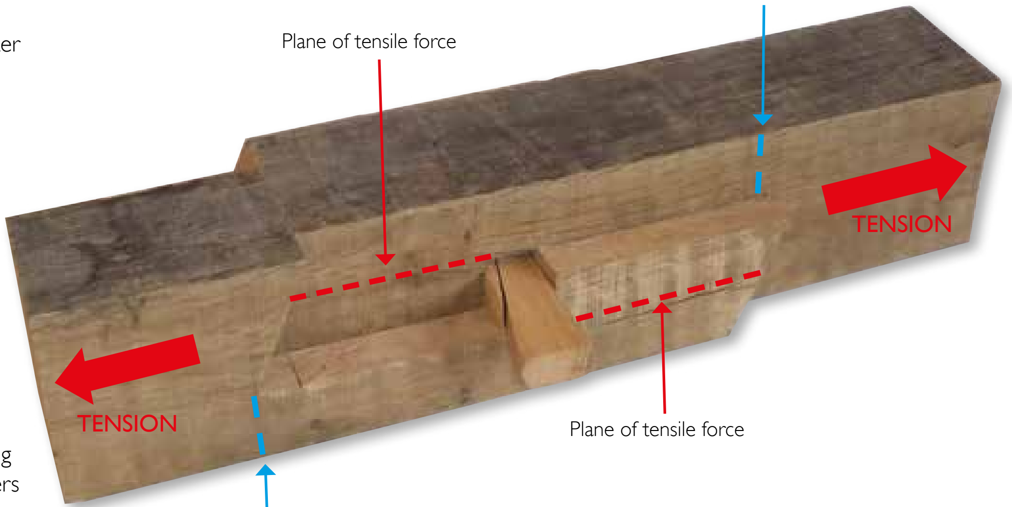
In the barn, the tie beam had cracked due to the weakening of the timber from beetle attack and the loss of wall plate, again through beetle attack, that meant the tie beam was unsupported directly below the rafter connection.

To repair the beam a new piece of wall plate was required, and the tie beam end required replacement.

A new piece of oak was proposed to replace the tie beam end, which needed jointing into the rest of the original tie beam being retained. A scarf joint with horizontal beds was adopted for this purpose.

This form of scarf joint is poor in resisting shear forces as the load prises the timbers apart along the line of the grain. The image above indicates the reduced section of timber that takes shear forces.

The joint is, however, strong in tension, which was the principal force in the tie beam. The tensile strength derives from the length of timber resisting tension forces, which is also displayed on the image to the right.



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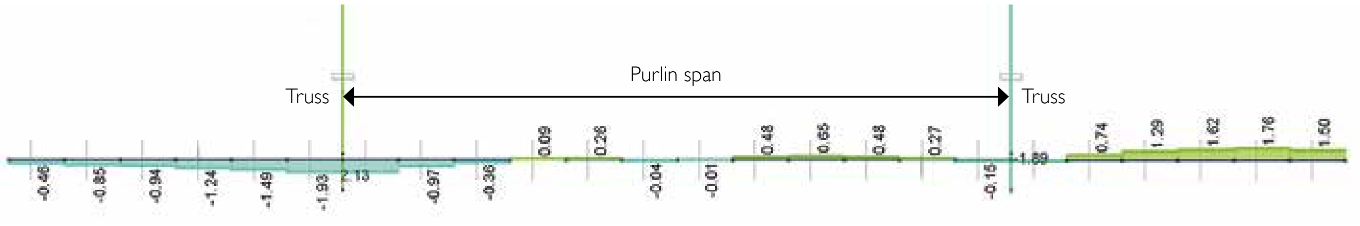
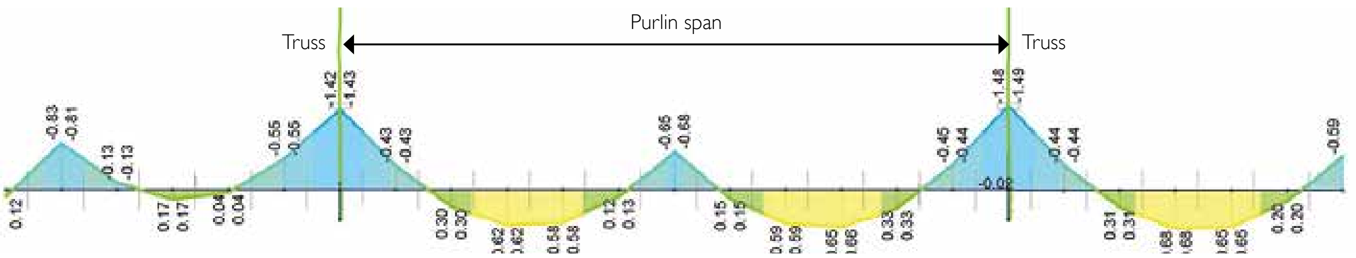
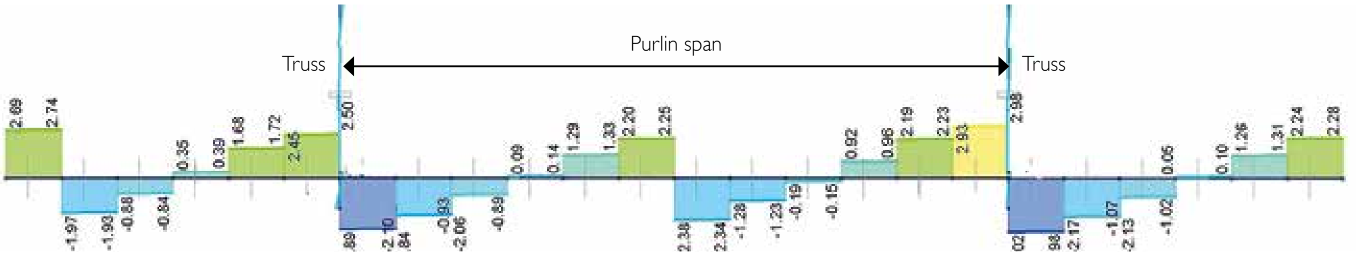


TENSION FORCES (kN)



BENDING FORCES (kNm)



SHEAR FORCES (kN)

This scarf joint was used to repair the tie beam since the repair was required to take relatively large tensile forces and relatively small shear forces.

The purlins were subjected to bending and shear forces principally and had little pure tension or compression forces acting upon them. The diagrams above show the typical forces expected in the purlins.

The revised joint has sloping, interplanar faces, such that the bearing surface between the sections of timber take nearly the full depth of the beam (it is critical that the joint is positioned in the correct orientation for the forces: one side should bear onto, and not hang from, the other). This joint utilises nearly the full depth of the section to resist shear and is therefore stronger in resisting shear than the previous joint.

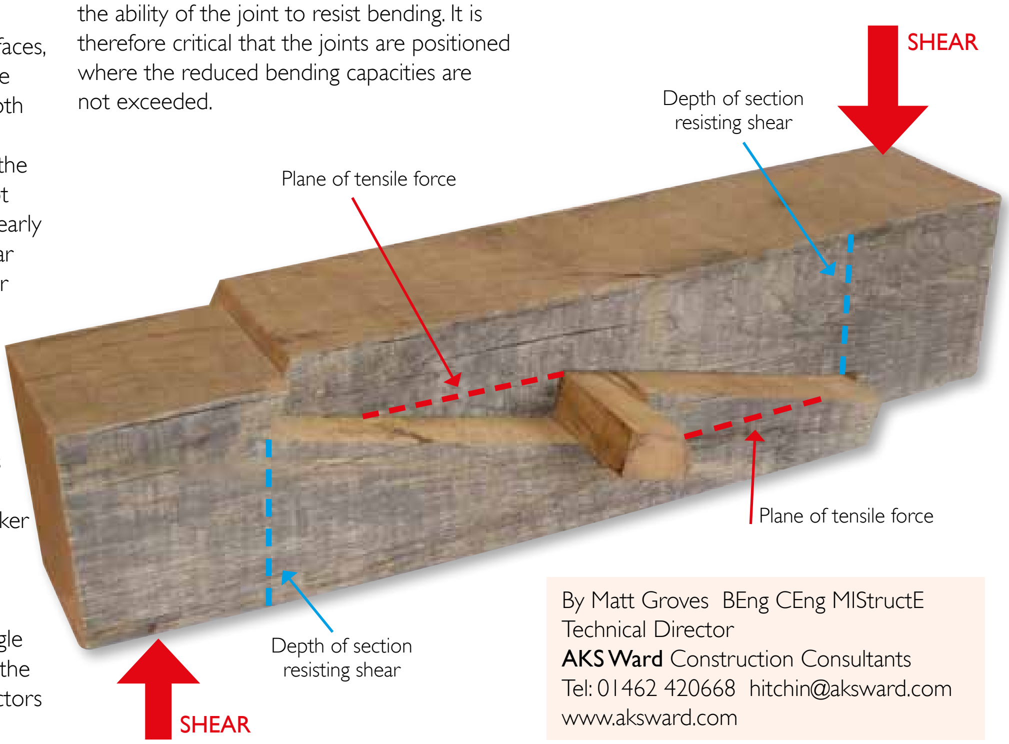
The sloping interface, however, reduces the length of the plane of the joint resisting tension and it therefore has a lesser tensile capacity than the previous joint: the steeper the interplanar slope, the shorter the tensile zone and the weaker the joint becomes for resisting tension.

It is clear that each joint is of benefit in different situations and the length and angle of the interplanar junctions, the depth of the wedges transferring tension and other factors need careful design and calculation to ensure the specific forces acting on the joint are resisted.

In both joints, tension forces are developed at the centre of the beam through the wedges and not the bottom of the beam as in an undamaged section of beam. As previously described, the shorter distance between the compression fibres and tension fibres reduces the ability of the joint to resist bending. It is therefore critical that the joints are positioned where the reduced bending capacities are not exceeded.

The examples provided explain the importance of interpreting the behaviour of the building structure when designing joints and repairs generally, and gives an insight into the depth of understanding required by the engineer to determine the best repair for any given situation.

Both of the illustrated joint types have recently been used on a barn in Bedfordshire.



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