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# UK TIMBER ENGINEERING GROUP

**A MAJOR SEMINAR**

***on***

# "ENGINEERED TIMBER FLOORS – THE OPTIONS"

***to be held at***

**THE NATIONAL MOTORCYCLE MUSEUM**

***on***

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# WOOD-BASED FLOOR JOISTS – THE OPTIONS

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## 1.0 BACKGROUND

The UK market for domestic intermediate floor joists has undergone a transformation during the last decade. In the early 1990's these floors were almost universally constructed using solid timber joists of nominal depth of 8" or 9" placed at close (usually 400mm) centres. However in the early 1990's the US company Trus Joist Corporation (later to become TJM Europe) introduced engineered wood-based I-joists to the UK. In spite of having substantially greater 'materials' costs, these joists have and continue to make ever-increasing inroads into the domestic joist market. As several other companies have joined TJM Europe in supplying engineered wood-based joists to the UK construction market, their level of usage in the domestic intermediate floor market looks set to increase further over the course of the next few years. This paper seeks to outline the options for wood-based floor joists, initially and primarily for joist types already available in the UK, but later for prospective new joist options.

Section 2 categorises the joists in respect of their structural form before describing the categories into which the joists that are currently available fall. Section 3 then lays down the performance requirements for domestic intermediate floors, before assessing the degree to which the currently available joists contribute towards these requirements. Section 4 goes on to discuss how joists may develop over the next decade to further fulfil these performance requirements. Finally some concluding remarks are offered in section 5.

## 2.0 CATEGORISATION OF WOOD-BASED JOISTS

All wood-based joists, whether existing or prospective, fall into one of three broad families – solid timber joists, I-joists or open-web joists.

Solid timber joists are sawmilled from softwoods (almost invariably British Spruce or European Whitewood) and are rectangular in cross-section. Although this cross-section is clearly driven by sawmilling considerations, it is relatively inefficient from a structural perspective. The majority of joists currently in use are regularised to depths of either 195 or 220mm, are of low grade (strength class C16) and have been kiln-dried to a moisture content in the range 18-20%.

I-joists, as is transparent from their name are I-shaped, which is a highly efficient cross-section from a structural perspective. The I-joists that are currently available fall into one of two camps as shown in figure 1. The first type of I-joist comprises laminated veneer lumber (LVL) flanges separated by an OSB web of thickness 9-12mm. In the second type of I-joist, whilst the web is again generally OSB, the flanges are formed out of high grade softwood (strength class C24 or higher) finger-jointed to long lengths.

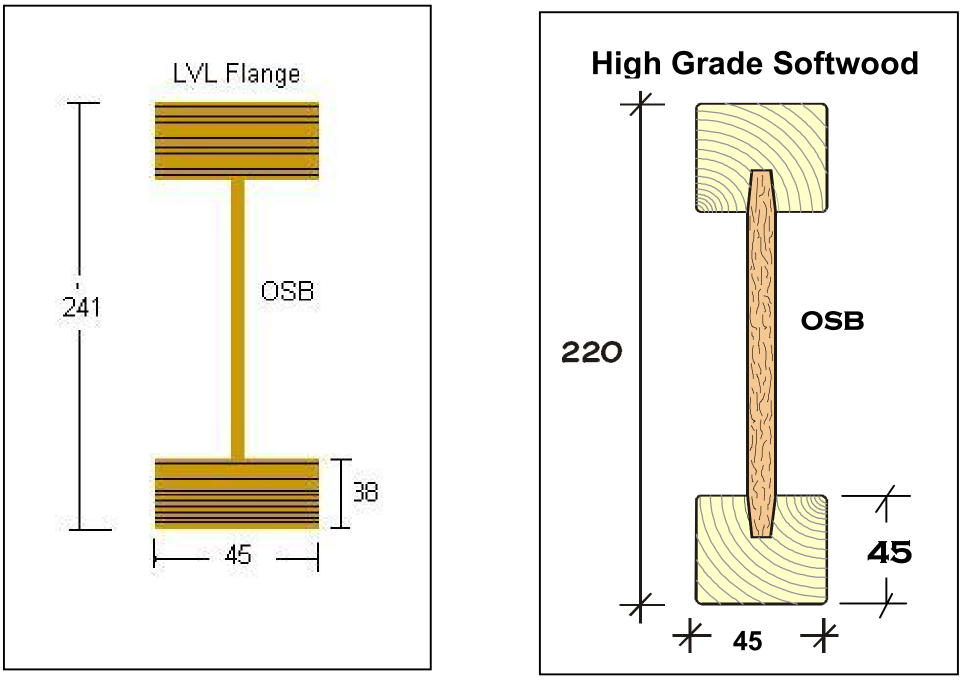


**Figure 1.** Typical LVL-flanged and Solid Timber flanged I-Joists

Open-web joists also provide a highly structurally efficient joist with the flanges connected to each other by a system of triangulation. In effect open-web joists are shallow parallel-chord trusses as shown in figure 2. The flanges are again high grade softwood (strength class TR26) end-jointed to length by nailplates. Joists are sometimes made whereby the open-web structure comprises a lattice arrangement of short timber webs connected to the flanges via nailplates. However section 3 will only appraise the more common and structurally efficient solution of open-web joists formed using profiled thin gauge steel webs (usually V-shaped) connected to the flanges by integral nailplates.

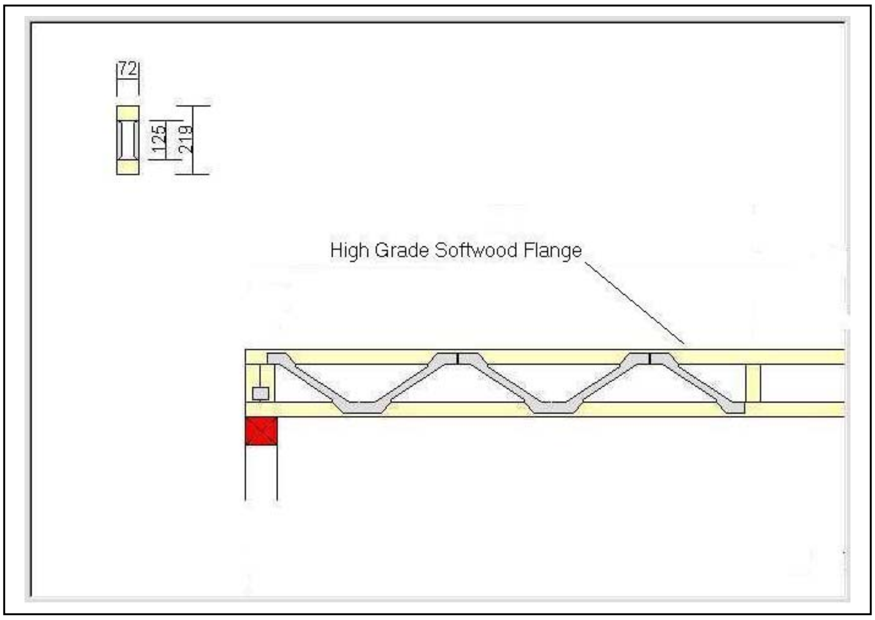


**Figure 2.** Typical Open Web Joist.

## 3.0 THE ABILITY OF EXISTING JOISTS WITHIN THE THREE 'JOIST' FAMILIES TO SATISFY THE PERFORMANCE REQUIREMENTS FOR DOMESTIC INTERMEDIATE FLOORS

The relative performance of existing joists from each of the three 'joist' families is appraised under the twelve performance requirements listed below. In sections 3.1-3.12 each performance requirement is considered firstly in general terms and secondly through specific reference to the three 'joist' families. Overall conclusions of the comparison between the three joist families, including a tabular 'at a glance' comparison embracing all twelve performance requirements, are given in section 3.13.

1. Post-installation shrinkage of joist.
2. Ease of installation on site.
3. Robustness on site.
4. Common construction details.
5. Vibrational performance.
6. Facility for routing services.
7. Contribution of joists towards fire resistance of floor.
8. Compatibility with UK joist depths.
9. Flexibility in joist length.
10. Spanning capability.
11. Technical support to joist system.
12. Cost.

### 3.1 Post-installation shrinkage of joist

Post-installation shrinkage of a joist, if excessive, will manifest itself in one or more of the following very damaging ways:

1. 'Squeaky' floors.
2. Damage to finishes.
3. Plasterboard nail popping.

Timber and other wood-based products undergo dimensional changes when changes occur in their moisture content and post-installation shrinkage of a joist will occur if its moisture content at installation is greater than the equilibrium moisture content of 10-12% which it will attain in service. A joist system can adopt one or both of the following two strategies to limit joist shrinkage. Firstly they can substantially reduce the cross-sectional timber dimension and secondly they can ensure that the timber moisture content at the time of installation is close to the expected in-service moisture content.

In the case of solid timber joists neither strategy is implemented with the installation moisture content typically being around 20%. Therefore for a 220 deep solid timber joist, based on the commonly-used rule of thumb of 1% decrease in cross-sectional dimension for every 4% decrease in moisture content, the shrinkage occurring will be of the order of 5mm. With this order of magnitude of shrinkage it is not difficult to see why the overwhelmingly most common reason builders give for discontinuing with solid timber joisted floors is the aforementioned shrinkage-related deficiencies in their performance.

LVL-flanged I-joists invoke both strategies for limiting shrinkage. Their webs comprise OSB whose cross-grain nature will restrain moisture movements in the plane of the web. This facet, together with its low moisture content at the time of I-joist manufacture, result in negligible moisture movements occurring in the web in the direction of the joist depth. The LVL flanges have the potential to undergo moisture movement but their small cross-sectional dimension in the direction of the joist depth, together with a moisture content of around 10% at the time of manufacture of the I-joist, ensure that any moisture movements of the overall joist in the direction of its depth are likely to be well under 1mm.

In the case of wood-flanged I-joists the moisture content of the flanges is likely to be in the range 16-18% at the time of joist installation with the result that some shrinkage will occur over the depth of the flanges. As again negligible shrinkage should occur in the depth of the OSB web, a slightly greater but still acceptable overall joist shrinkage (around 1mm) is likely to take place.

For open-web joists the moisture content of the flanges is also likely to be around 18% at the time of installation. However unlike the OSB web to I-joists, their steel webs extend across virtually the whole joist depth so that the joist shrinkage should again be less than 1mm.

## 3.2 Ease of installation on site

### 3.2.1 Handling of joists

The ease with which joists can be handled depends primarily on their weight and to a lesser extent on the geometry of their cross-section. The unit weight of a 47x220 solid timber joist is ≈4.6kg/m (18% moisture content assumed at time of installation), whilst I-joists or open-web joists of similar depth, in their most common configurations, weigh ≈3.5kg/m. This reduction in weight, together with the fact that their flanges form convenient handles, give I-joists and open-web joists the advantage in respect of ease of handling.

### 3.2.2 Straightening of joists during installation into floor

Prior to fixing the floor decking or plasterboard sheets the joists must be essentially straight in order to ensure all decking or plasterboard fixings obtain adequate purchase into the joists. This requirement presents a differing problem to I-joists/open-web joists to solid timber joists.

For I-joists the production tolerances for straightness are very small and certainly well within the requirements for fixing decking/plasterboard. However the stiffness of I-joists about their minor axis can be very low and, if the necessary precautions are not taken, the joists can easily ‘flex’ out of line whilst they are being lifted into position and subsequently when workmen are walking on them prior to fixing the deck. The necessary precautions usually comprise the fixing of a timber runner (nominal size of 25x100) along the mid-span of the joists to a triangulated end bay until such time as enough of the decking has been fixed down. For open-web joists although their ‘straightness’ tolerances are less stringent, this is mitigated by the fact that their flanges are usually wider than those of I-joists.

In the case of solid timber joists, the more fundamental problem is simply that a sizeable proportion of joists arrive on site bowed and/or twisted to an unacceptable degree. This involves the carpenters in the laborious task of having to straighten out the joists by means of additional noggins, temporary bracing and, if used, solid timber blocking prior to fixing the decking/plasterboard.

Experience has shown that the labour costs caused by the need to straighten out solid timber joists far outweigh those labour costs associated with the temporary bracing used for the more engineered types of joist and this is another important factor in their increases in market share.

## 3.3 Robustness of joists on site

Site practice on building sites often leaves much to be desired and the ability of a construction material to remain functional having sustained a degree of misuse/abuse would be considered a worthwhile attribute by many contractors. Solid timber joists have a proven track record in this regard. I-joists, on the other hand, are much more vulnerable to bad site practice. Two such examples are:

1. Whilst solid timber joists can tolerate considerable site wetting before their structural integrity becomes affected, prolonged wetting of I-joists can cause swelling of the OSB webs and raise questions about the continued structural integrity of their web-flange joints.
2. Whilst solid timber joists can usually tolerate a degree of over-notching by plumbers or similar, any notching whatsoever in flanges of I-joists is likely to necessitate remedial action.

Open-web joists, which are not so vulnerable to the effects of wetting, fall somewhere between solid timber joists and I-joists in respect of robustness on site.

Although I-joists/open-web joists are clearly less robust than solid timber joists, their manufacturers have largely offset this by adopting a prevention rather than cure approach to the issue. This approach has manifested itself through the distribution of site installation guides and generally much better levels of technical/site support than has ever been provided by the suppliers of solid timber joists.

## 3.4 Common construction details

Construction details will be looked at in more detail in the later paper to this seminar entitled ‘Practical Detailing’ and this section is limited to comparing the ease of forming some of the more common details, as listed below, with each of the three joist families:

- Building joists into a masonry wall
- Use of joist hangers
- Formation of trimmers from multiple joists
- Installation of wall restraint straps

### 3.4.1 Building joists into a masonry wall

I-joists are more difficult to build into a masonry wall than solid timber joists. This is because whilst solid timber joists present the mason with a vertical surface against which they can place the mortar perpend, I-joists, on account of their I-section, present the mason with a more laborious task. Some builders have solved this difficulty by insisting that the fabricator provides the I-joist with web stiffeners at its ends, thereby presenting the mason with a vertical surface as in the case of solid timber joists. Irrespective of the chosen solution, additional costs and time are incurred for I-joists if they are to be properly built into the masonry. The commonest end detail adopted for open-web joists is to infill between the two flanges with short solid timber blocking pieces as shown in figure 2. These blocking pieces are of the same width as the flanges and therefore as with solid timber joists, the mason is presented with a vertical surface against which to place the mortar perpend.

Although the need to properly build in joists might appear a trivial issue, it is being taken very seriously by the Regulatory Authorities to the extent that the Building Regulations relating to heat loss and sound transmission will in future encourage all joists to be supported on hangers rather than being built into masonry.

### 3.4.2 Use of joist hangers

Although there are differences between the configurations of masonry hangers suitable for solid timber joists and for I-joists/open-web joists, the more substantial differences in the use of joist hangers occur for joist-to-joist connections. More specifically there are differences in the construction of the receiving joist. This construction is most simple for solid timber joists where the hanger is directly nailed to the joist as shown in figure 3a. For I-joists the construction is complicated by the need to fix backer blocks each side of the OSB web prior to fixing the hanger as shown in figure 3b. Similarly for open-web joists, plywood of ≈18mm thickness has to be fixed via its flanges to the sides of the joist before the hangar can be fixed in place as shown in figure 3c. There is clearly an increase in both material and labour costs for the I-joists/open-web joists in comparison with those relating to solid timber joists.

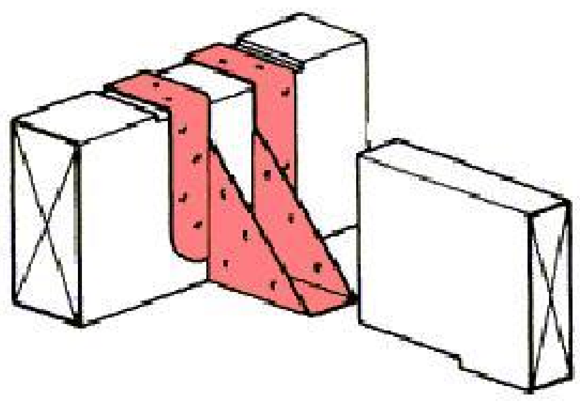

**Figure 3a.** Typical Solid Timber Joist Hanger Detail.

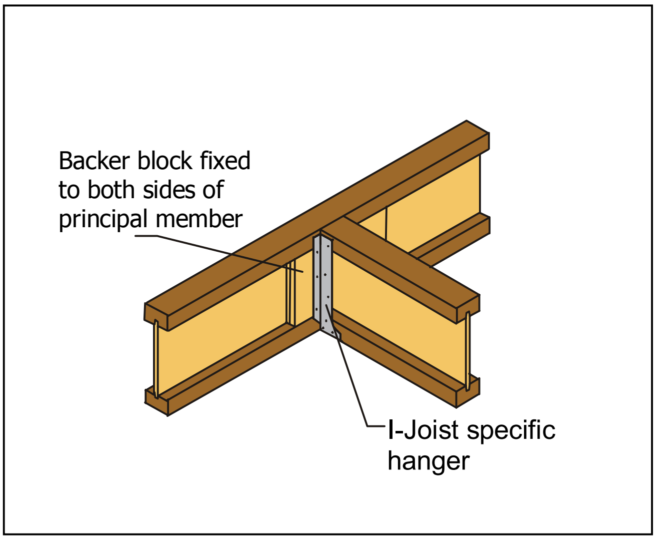


**Figure 3b.** Typical I-Joist Hanger Detail.

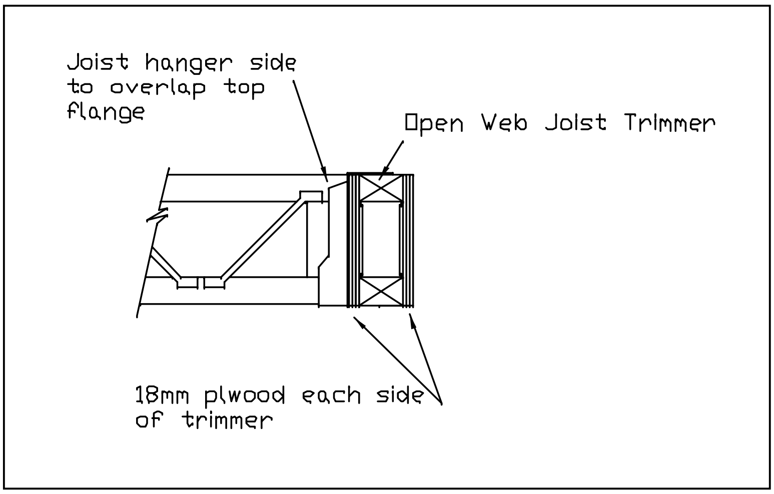


**Figure 3c.** Typical Open Web Joist Hanger Detail.

### 3.4.3 Formation of trimmers from more than one joist

The loads on trimming and trimmer joists around stairwells often necessitate that they be formed out of multiple joists. However, frequently for a trimming or trimmer joist all or nearly all the load is applied to one of its joists and an adequate connection is necessary with the other constituent joists before it becomes fit-for-purpose. In the case of solid timber joists this connection is easily formed by nailing or bolting the joists together at close centres. For I-joists a typical equivalent connection is shown in figure 4 and can be seen to be more complex involving a timber filler block of precise dimension located between and nailed to the webs of the two adjacent I-joists.

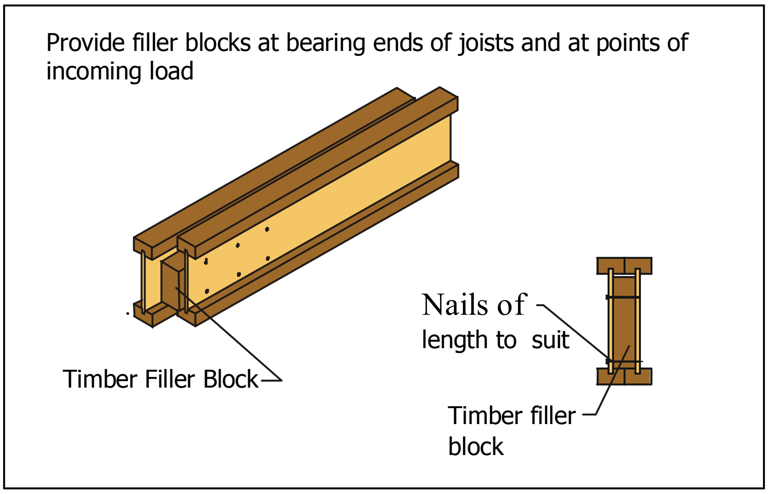


**Figure 4.** Typical Multi-Ply I-Joist Fixing.

Open-web joists are rarely combined to form multiple joist trimmers. Instead wherever possible the flange width is increased in order to make the trimmer/ trimming joist structural adequate. If additional shear capacity is required, then this is mobilised using plywood fixed to each side of the joist bearing in mind that these plywood strips are likely to have already been stipulated in order to facilitate the fixing of joist hangers.

The formation of multiple-member trimming or trimmer joists can be seen to be most straightforward and therefore least expensive for solid timber joists, both in terms of material and labour costs.

### 3.4.4 Installation of wall restraint straps

The typical details used for wall restraint straps are shown in figures 5a, 5b and 5c for solid timber joists, I-joists and open-web joists respectively. From inspection of these details, it can be concluded that the most buildable detail is that relating to the open-web joists. This is because the timber can be inserted in one length rather than several short blocking pieces and its end can be readily positioned hard against the face of the block wall. The detail for the solid timber joists is also readily buildable and is the detail in which the steel strap is most easily aligned with a mortar bed. However the concern with this detail is that shrinkage of the joist cross-section negates the effectiveness of the short timber blocking pieces in resisting compression forces from the block wall.

The installation of wall restraint straps is most difficult and therefore prone to error for I-joists. Part of the reason for this is that ensuring that the timber blocking pieces are the correct length requires a great deal more care, as unlike in the case of solid timber joists, the clear distance between the webs is not readily visible to a carpenter stood on top of the joists. The installation of the final blocking piece adjacent to the block wall is a particular problem in this regard.

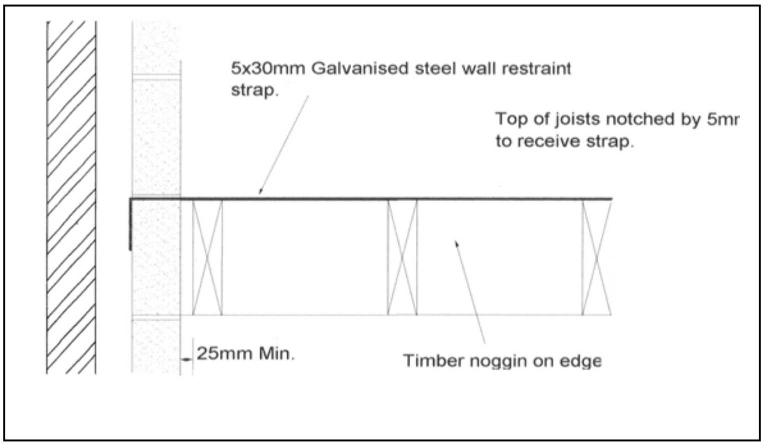


**Figure 5a.** Wall Restraint Strap Detail for Solid Timber Joists.

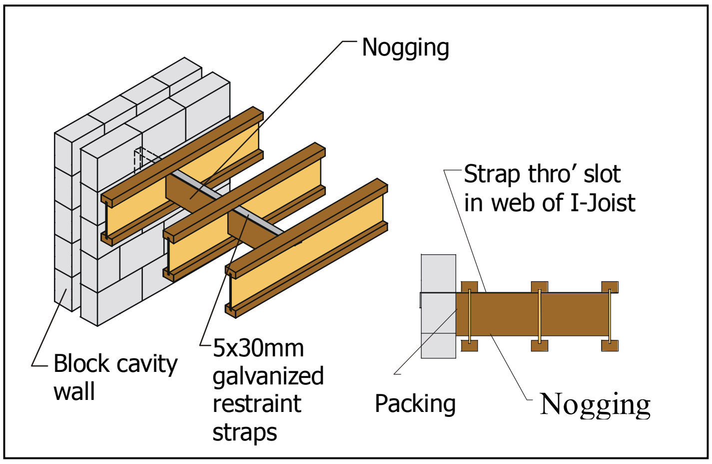


**Figure 5b.** Wall Restraint Strap Detail for I-Joist Floors.

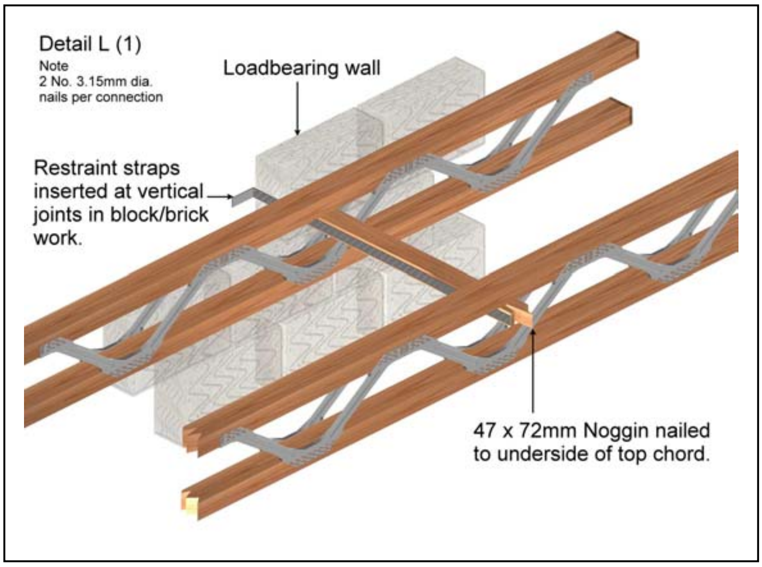


**Figure 5c.** Wall Restraint Strap Detail for Open Web Joist.

### 3.4.5 Summary

The common construction details are easier, and therefore less expensive, to form with solid timber joists than I-joists, with open-web joists falling somewhere in between the other two joist systems. However at the current time this advantage for solid timber joists is largely, and probably inequitably, offset by the fact that strutting, as specified in Building Regulations Approved Document A, is installed for solid timber joists but not for I-joists. Open-web joists, on the other hand, are able to provide an effective and yet low cost form of strutting by inserting a continuous piece of timber, often referred to as a 'strong-back', through their open web structure at or close to mid-span.

## 3.5 Vibrational Performance

The vibrational performance of floors does not depend only on the properties of the joists, but also on the overall floor construction. It primarily depends on the following three parameters:

1. Dead load of the floor, though for domestic intermediate floors there is only limited scope for varying this parameter.
2. Longitudinal stiffness of the floor (ie..parallel to joists).
3. Transverse stiffness of the floor (ie..perpendicular to joists).

For floors containing solid timber joists or I-joists, improvements in vibrational performance can be achieved by increasing either the longitudinal or transverse floor stiffness, with neither option being satisfactory. Increasing the longitudinal floor stiffness would be achieved by increasing the stiffness of the joists. This would certainly increase the cost of the floor and probably its depth. An increase in the floor's transverse stiffness would be achieved by following the Scandinavian practice placing transverse timber battens over the top of the joists, which again would increase the depth of the floor. In view of the finding in the earlier paper to this seminar entitled 'What matters to builders', that only a small proportion of builders considered excessive bounce to be a problem, both these steps are likely to be unnecessary in most cases.

Open-web joists, on the other hand, are much better placed to improve the vibrational performance of a floor. This is because they would be able to achieve this without either significantly increasing the cost of the floor or its overall depth. This would be done by inserting timber members through the open web structure in a direction perpendicular to the joists, thereby greatly increasing the transverse stiffness of the floor and therefore its vibrational performance.

## 3.6 Routing of services

The primary advantage of open-web joists over the other joist types is the saving in time and labour costs in routing plumbing and electrical services facilitated by their open web structure. Neither solid timber joists nor I-joists are particularly helpful to the builder in this regard, though historically for both products any difficulties that have arisen in routing services have been overcome. I-joists are generally preferred over solid timber joists as they require less drilling on account of their thin webs and wider joist centres. I-joists also give the builder greater flexibility with regard to the size and location of the holes that can be accommodated within the joist. The exception to this is builders using copper plumbing which can be inserted in top notches in solid timber joists but not in I-joists where notching of flanges is prohibited.

## 3.7 Contribution of joists towards fire resistance of floor

The Building Regulations require a floor to demonstrate a specified period of fire resistance in terms of insulation (limiting temperature on unexposed face), integrity (no continuous flaming/no hot gases/no gaps over a specified size on unexposed face) and load-bearing capacity (no collapse or excessive (ie. gross) deflection). Only the load-bearing capacity is materially affected by the behaviour of the joists and for the remainder of this section the term fire resistance will be used to denote fire resistance in respect of load-bearing capacity.

The fire resistance required from intermediate floors (30 minutes for floors in houses up to 3 storeys) is usually made up of two contributions - the main contribution being from the plasterboard ceiling with a somewhat smaller contribution being required from the joists.

There is a distinct hierarchy in the contributions towards fire resistance provided by the different joist types with solid timber joists providing far the best contribution but with I-joists making a better contribution than open-web joists. Solid timber joists provide a better contribution towards fire resistance (at around 15 minutes) than I-joists (4-7 minutes) because more 'section' has to become charred than in the case of 9mm thick I-joist webs before their structural integrity becomes jeopardised. In respect of open-web joists, tests have shown that nailplate joints will only support load for 2-4 minutes in a fire and their open web structure is likely to permit the more ready spread of the fire across the floor cavity. Clearly in the context of the overall fire resistance for the floor a greater contribution from the joists may permit a reduced specification for the plasterboard.

Suppliers of engineered joists currently rely on fire tests to demonstrate compliance with requisite periods of fire resistance. However this is a system that can be taken advantage of. As has just been mentioned, the plasterboard ceiling makes a greater contribution towards the fire resistance of a floor than the joists and it therefore follows that by careful selection of the plasterboard used in a fire test, a reduced contribution towards fire resistance becomes possible for the joist.

It should also be noted that with the forthcoming advent of EN Standards, the requirements for domestic floors will change as described fully in the next seminar paper entitled 'Adequacy in fire –yesterday's and tomorrow's requirements'.

## 3.8 Compatibility with UK joist depths

Until 3-4 years ago, both I-joists and open-web joists required the builder to accommodate joists with a minimum depth of 241mm. Not only is this depth incompatible with the traditional UK depths of 8” or 9”, but it also impinges on the brick/block coursing as well as the staircase layout. There is no question that this incompatibility in joist depth has slowed take-up of engineered joist systems and LVL-flanged I-joists in particular. However at the current time joists from all three broad ‘joist’ families are available in the traditional UK depths of 8” and 9” and so this obstacle has largely been overcome.

## 3.9 Flexibility in joist length

This section gauges the ease with which a joist type can be cut to any length (in the domestic span range) to suit the specification of the builder placing the order. It is clear that joists which have a constant cross-section along their entire length (solid timber joists and I-joists) have a considerable advantage in that they can be produced simply by cutting them out of the stock lengths for the joist type concerned. Open-web joists, on the other hand, have the major shortcoming that any joist length for a particular span has to be specially made. Although the steel webs of open-web joists come in fixed increments of length (600mm/300mm), by varying the length of a central vierendeel bay any particular joist length can be manufactured.

I-joists, whose stock lengths are generally in the range 12-15m, also have the major advantage over solid timber joists that they can be utilised as continuous joists across two or more spans, running from the front to rear walls of a house picking up support on an internal wall(s). This is very efficient in respect of joist installation, as there are fewer joists to be lifted in place, and material utilisation, as smaller cross-sections than the equivalent simply-supported design can often be justified. Open-web joists, on the other hand, are less easily and frequently designed as continuous joists because of the logistics of detailing all the associated joists to have a node (either bottom flange or top flange via a timber blocking piece) directly over each internal wall.

## 3.10 Spanning capability of joists

The spanning capabilities of solid timber joists, I-joists and open-web joists clearly all depend on the joist depths, section sizes and timber grades being used. There are far too many permutations of these parameters for all the associated spans to be given in this paper. However a few general points are made about the spanning capabilities of the most commonly used joists in the three broad ‘joist’ families as below. These joists are all of nominal depths in the range 220-245mm.

1. When considered as individual joists, I-joists and open-web joists are better than 47x220 C16 solid timber in respect of the important properties relating to bending strength and deflection.
2. However because solid timber joists are at 400mm centres, rather than at 600mm centres as is the case for I-joists and open-web joists, their maximum span (≈4.5m) when used as a single simply-supported span is greater than the equivalent spans for I-joists/open-web joists used at 600 centres (≈3.9-4.1m).

3. However when I-joists are used as continuous joists then, as intimated in the previous section, their spanning capacity increases significantly and in fact becomes broadly equivalent to that of 220 deep C16 solid timber joists spaced at 400mm centres which are not used in a continuous manner.
4. I-joists and open-web joists, using exactly the same solid timber flange specification, would have similar simply supported spans.

The above comparisons indicates that whilst spanning capability of a joist is important, it is certainly not the sole factor determining whether a joist system will succeed in the domestic floor market.

## 3.11 Technical support to joist system

One of the main reasons why I-joists and open-web joists have been successful in gaining market share is that their manufacturers have provided a level of support to their customers that has never been matched by the suppliers of solid timber joists. This support has a number of strands to it which include the following:

1. Computer software to assist in the design, layout, cutting schedules and pricing of floors. Calculations and layout drawings are provided automatically for all jobs.
2. Support engineers to provide training and technical advice to dealers and end users.
3. Provision of site installation guides and other technical literature.
4. Ongoing marketing of the product benefits to both builders and the general public.

## 3.12 Cost of joists

This section compares the costs of domestic floors constructed using joists from the different 'joist' families, with all the joist costs relating to the most commonly used joist specifications in the joist depth range of 220-245mm. A 50m$^2$ footprint is assumed for the floor. It is important to note that the joists are only one of three main components making up the materials' cost of an intermediate domestic floor, the other costs being the chipboard floor decking and the plasterboard ceiling.

The costs per unit length of I-joists are 2-2.5 times those of 47x220 solid timber joists. However because I-joists are installed at 600mm rather than 400mm centres the differential in cost for the overall floor between the two joist types reduces to broadly 50%, which for a 50m$^2$ footprint translates to broadly £125. As solid timber joists are at closer centres than I-joists, reduced thicknesses can be used for both the chipboard decking (18mm instead of 22mm) and plasterboard ceiling (12.5mm instead of 15mm). In view of these differences in flooring and ceiling specifications, it is estimated that the differential in overall materials' costs for a 50m$^2$ footprint floor is broadly £175.

In view of the wider joist centres and the absence of strutting for I-joists, experience has shown that installation times for I-joists are broadly half those of solid timber joists, resulting in a saving to the builder of about £75. It therefore follows that the overall installed cost of an I-joist floor over a $50m^2$ footprint is broadly £100 more than that of solid timber joisted floor.

We have already seen from the earlier paper entitled 'What matters to builders' that the main reason for builders converting from solid timber joists to I-joists is to avoid being called back to undertake remedial work usually to rectify the effects of post-installation shrinkage of the joists. As, from those builders willing to hazard an estimate of call-back costs, the average cost was £140, the increasing trend of builders to convert from solid timber joists to I-joists is readily understood.

The unit cost of open-web joists is usually higher than that of I-joists, primarily because the cost of their steel webs is significantly higher than the cost of the OSB web of I-joists. However open-web joists have the benefit of reducing the costs of routing electrical and plumbing services and each individual builder has to decide whether this cost saving outweighs the increased joists' cost for the floor.

### 3.13 Overall summary

A tabular 'at a glance' comparison between the three 'joist' families for all twelve performance requirements is given in table 3.1 at the end of this paper. Clearly some of the judgements made in this table are subjective but the table could be used as a template upon which builders could base their own decisions with regard to choice of floor joist. From table 3.1 and sections 3.1-3.12, the following overall conclusions are drawn:

1. The share of solid timber joists in the domestic intermediate floor joist market is likely to decrease further unless a number of shortcomings in this product, notably relating to the effects of post-installation shrinkage, are addressed as discussed in section 4.1. This is in spite of a number of advantages, notably with regard to cost, that solid timber joists enjoy over the alternative joist systems.

2. A comparison of the relative performances of open-web joists and I-joists indicates that open-web joists are superior to I-joists in respect of routing services but inferior to I-joists under the three performance requirements of fire resistance, flexibility in length and unit cost of joist. For many builders this choice may well reduce to deciding whether the increase in the cost of open-web joists is recovered by a saving in the cost of routing electrical and plumbing services.

## 4.0 PROSPECTIVE DEVELOPMENTS IN WOOD-BASED FLOOR JOISTS

Prospective joist solutions are considered under three broad 'joist' families, as in section 3 for existing joists. Also in the same vein as section 3, a tabular 'at a glance' assessment of prospective new joists across all twelve performance requirements is given in table 4.1. Table 4.1 is located at the end of this paper immediately adjacent to table 3.1 to enable the changes in performance levels from the existing joists in the same 'joist' families to be readily apparent.

## 4.1 Prospective solutions for solid timber joists

### 4.1.1 Prerequisite requirements

Before considering in detail the potential options for the solid timber family of joists there are believed to be three requirements which are prerequisites if any of the options are to succeed commercially.

Requirement 1 – Reduction of post-installation shrinkage

As solid timber joists inherently contain cross-sectional timber across their entire depth, the only strategy available to solid timber joists for the limitation of shrinkage is to ensure that the joists are installed at a moisture content close to the expected in-service moisture content. Application of the rule of thumb given in section 3.1 to 220mm deep joists indicates that this depth of joist can only tolerate changes in moisture content of 2-3% before the post-installation shrinkage would become unacceptable. For the joist moisture contents to be contained within such a narrow band two issues have to be resolved as follows:

1. *The timbers have to be kilned down to or preferably just below the in-service moisture content.* Kilning schedules have already been developed for both British Spruce and European Whitewood to achieve a target moisture content of 10% and upper bound moisture content of 12%.
2. *During the time period between when the joist exits the kiln and when the building in which the joist is installed becomes weathertight, the increase in its moisture content must not exceed 2-3% greater than its in-service moisture content which equates to 13-14%.* The only way of achieving this is to treat the joist with a water-repellent surface coating which slows down fluctuations in the joist's moisture content such that its moisture content still does not exceed 13-14% when the building becomes watertight. Although considerable commercial and government-sponsored research has been undertaken in this area, as yet no coating has been developed to meet the above described specification.

Requirement 2 – Development of a more automated method of installing strutting

At the current time strutting is installed for solid timber joists (as directed by Approved Document A of the Building Regulations) but not for I-joists. Although this constitutes a commercially inequitable situation for solid timber joists, there is little likelihood of a change to the current status quo. Solid timber joist systems therefore need to develop methods by which strutting can be installed more rapidly, thereby minimising the handicap of the cost of its installation.

Requirement 3 – Provision of technical support to solid timber joist systems

As mentioned in section 3.11 the suppliers of engineered wood-based joists have provided a level of technical support in the form of computer software, technical literature, training and support engineers that to-date has never been matched by the suppliers of solid timber joists. For a solid timber joist system to start to retain or even recover market share, its manufacturer(s) must start providing the same level of technical support that is available from competitive joist systems.

#### 4.1.2 Prospective option 1 – 'Super-dry' high grade top-notched joists

Rationale behind joist

An obvious, though surprisingly infrequently used, improvement to solid timber joists would simply be to specify a higher grade than strength class C16. An increase in the grade of the joists from C16 to TR26, a grade which has a proven supply record in the truss industry at commercially competitive rates, gives 47x220 joists a permissible span at 600 centres that matches those of the commonly used I-joists in the depth range 220-245mm. This makes the use of TR26 joists at 600 centres a very economically attractive option.

However closer inspection of the maximum spans under the various design requirements shows for TR26 joists that the design requirement for limiting deflection is very much more onerous than that appertaining to bending strength. The implication of this is that localised losses of cross-section may only have a limited impact on the spanning capability of TR26 joists. This is because whilst joist bending strength might be markedly reduced by a localised loss of cross-section, this design criterion is a long way from limiting the joist's permissible span. For joist deflection on the other hand, although any increase will have a direct impact on the permissible span, this design criterion depends on the properties of the joist along its whole length and therefore will be much less affected by localised losses of cross-section.

A prospective solution for solid timber joists is therefore a TR26 solid timber joist with 35 deep by 150 long top notches cut into it at 1200 centres along its whole length as shown in figure 6. This notching would be undertaken under factory conditions prior to the joist arriving on site. The rationale behind the top notches is as follows:

1. The level of distortion for joists kiln-dried down to 10% moisture content is greater than that of those kiln-dried down to 18%, making paramount the need for an efficient method of straightening out the joists prior to fixing of floor decking/ plasterboard ceiling. The notches, suitably aligned, facilitate the ready insertion of 35x60 timbers to fast-track the straightening out of bowed joists.
2. The 35x60 timbers would be left in the floor as permanent bracing. As these timbers are continuous past the joists, they, unlike conventional strutting, will significantly enhance (by 65%) the transverse stiffness of the floor and therefore improve its vibrational performance. This improvement is also much less susceptible to poor workmanship than conventional strutting.
3. As the 35x60 timbers are only at 1200 centres there will always be one within 600mm of joist mid-span available to facilitate the ready installation of wall restraint straps. A tight bearing against the inner cavity wall leaf is also more easily achieved than the current detail of having to tightly fit a blocking piece between the edge joist and the masonry.
4. The fact that the notches are wider than the transverse timbers leaves a gap of 35mm deep by up to 90 wide available for the insertion of services and in particular copper plumbing pipes.

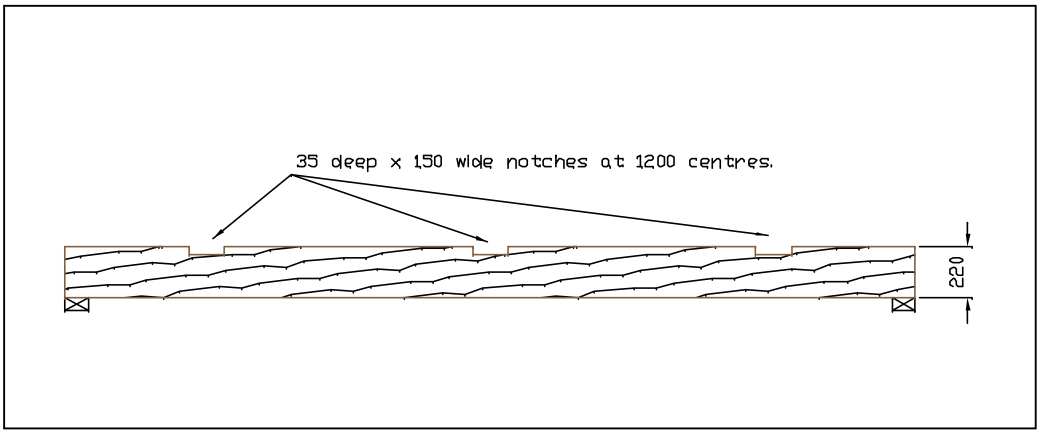


**Figure 6.** Elevation of top-notched TR26 Joist.

Effect of top notches on spanning capability of joist

1. *The permissible bending strength*. Although there is clearly a significant decrease in bending strength relative to the un-notched joist, the associated maximum span still greater than the maximum span of un-notched TR26 joists as limited by deflection.
2. *The flexural rigidity* of the top-notched joist has been shown by test (see reference 1) to be on average 85% of that of the un-notched joist. This decreases the permissible span under domestic floor loading of the top-notched TR26 joist to ≈4m, which is a 5% reduction of the span of the un-notched TR26 joist, but means that the use of the top-notched TR26 joist at 600 centres will remain possible for the majority of domestic floors.

Summary of attributes of top-notched TR26 joists

In addition to achieving the prerequisite requirement of reducing post-installation shrinkage to acceptable levels, top-notched TR26 joists offer the following advantages:

1. Fast-track method of straightening out joists by means of permanent bracing placed in factory-formed top notches.
2. Continued use of the simpler construction details appertaining to solid timber joists as opposed to the more involved details for I-joists/open-web joists. In addition a simpler detail even than that used with conventional solid timber joists can be used for the installation of wall restraint straps.
3. Increased transverse floor stiffness leading to improved vibrational performance.
4. An easier method of routing plumbing services than for either existing solid timber joists or I-joists.
5. A contribution towards fire resistance in respect of load-bearing capacity better than that of I-joists or open-web joists.
6. Compatibility with traditional UK joist depths.
7. Sufficient spanning capability to allow, for most domestic floors, the joists to be spaced at 600 centres rather than the usual solid timber joist spacing of 400mm.
8. A very cost-competitive solution.

The only technical drawback of note is that its use is limited to simply-supported spans. This is because in a continuous joist, parts of the top edge of the joist are placed in tension and tests (refer to reference 1) showed that notches present on a tension edge reduce bending strength to an unacceptable degree.

The importance of the third prerequisite requirement of section 4.1.1, namely technical support for the product, should also be re-stated. Clearly software is essential so that the supplier can produce floor plans showing the layout of the joists and 35x60 battens as well as cutting schedules to ensure that the notches line up when installed in the floor.

#### 4.1.3 Prospective option 2 – 'Super-dry' high grade joists finger-jointed to 12-15m lengths

Section 3.9 described how availability in long lengths has proven to be an advantage to I-joists in that they can be utilised as continuous joists running from front to back of a house. The advantages of this step were easier fabrication (*less cutting to length*), easier installation (*lower piece count than for houses where all joists are single-span*) and a more efficient design (*often smaller section sizes*).

A prospective improvement to solid timber joists would be simply to manufacture them in long (12-15m) lengths using finger-jointing technology that has been available for many years. This straightforward step would afford solid timber joists the above described advantages of I-joists, though a high grade (strength class C24 upwards) would be necessary if finger-jointed joists are to fully mobilise the advantage of smaller section sizes than those appertaining to simply-supported joists.

One potential reservation about 'long' solid timber joists is that their weight might make handling on site difficult. However the low moisture content of the joists has a beneficial impact on their weight and, as described in reference 2, in a site trial with 10m long 47x220 C24 solid timber joists (installation moisture content of 10%) there were no installation difficulties in this regard.

### 4.2 Prospective solutions for I-joists

Considerable amounts of time and money have already been expended in the development of I-joists and there is therefore less scope for further optimisation than in the other two 'joist' families. Nevertheless it is surmised that the changes to I-joists likely to take place in the next decade will be as follows:

1. *Improvements to flange specifications*. The performance of their flanges is fundamental to the viability of any I-joist system. It is therefore certain that all manufacturers of I-joists will continue to investigate alternative flange specifications either with a view to reducing their unit costs or improving their structural performance. However any changes to flange specifications are likely to be incremental and the manufacturers will have to be vigilant that they don't overstep the somewhat subjective boundaries associated with adequate joist robustness or vibrational performance of the floor.

2. *Increased amounts of fabrication undertaken under factory conditions*. The decreasing skill and supervision levels on site have been well-publicised in recent years and it is therefore likely that the trend of I-joist suppliers undertaking more of the fabrication under factory conditions will continue. The areas of fabrication that will increasing be undertaken off-site include fixing of web stiffeners, formation of trimmers from multiple joists and the pre-drilling of holes for services.

### 4.3 Prospective solutions for open-web joists

As in the case of I-joists, open-web joists formed using profiled thin gauge steel are already a highly optimised product, limiting the scope for further development. However one aspect of these joists where improvements can be expected is in relation to flexibility of joist length. In North America hybrid 'I-section/metal web' joists are commercially available and may well arrive in the UK over the course of the next few years. These hybrid joists maintain the advantages of an open web structure over most of their span but contain short lengths of I-section at their ends to increase flexibility in cutting joists to varying lengths.

As mentioned in section 3.12, a more fundamental drawback to this form of open-web joist is the high cost of their steel webs. A substantially cheaper option would be to form the webs out of timber if a jointing technology, that was both structurally and economically viable, could be developed.

In fact a jointing technology that fulfils at least the first of the above 'viability' criterion has been developed in Canada. The associated joist product operates under the trade name 'Open Joist' and involves a unique system of finger-jointing the webs to the flanges, which is able to transmit the requisite forces around the triangulated structure of the joist. As described in reference 1, six 'Open Joists' air-freighted from Canada were subjected to a pilot test programme at Surrey University. Although the joists performed satisfactorily both in respect of bending strength and deflection, the real point of interest is the performance of the web-flange finger-joints. The excellent performance of these joints is best illustrated by the fact that none of the joists failed via these finger-joints [5 no. joists failed by top flange buckling in the central vierendeel bay with the remaining joist failing by tensile rupture of the bottom flange].

The development of this jointing system facilitates a joist product that is able to improve upon the weaker performance facets of steel open-web joists whilst maintaining the advantages implicit in an open structure for the joist. The performance facets of the steel open-web joists that are improved by this product are as follows:

1. The use of glued wood webs significantly increases the contribution towards fire resistance in respect of load-bearing capacity of the joists.
2. The 'materials' cost of the 38x38 timber webs is markedly less than that of steel webs. Although this is offset to some degree by the adhesive costs it still represents a substantial saving.

The glued wood webs also contribute to improved spanning capability by virtue of the fact that glued joints eliminate joint slip and thereby decrease joist deflection, which frequently is the limiting design requirement.

The only weakness of note in glued wood-web open joists is their lack of flexibility in respect of cutting a joist of any length. Although the existing glued wood-web open joist is detailed to readily accommodate changes in joist length brought about by incorrect site dimensions, like steel open-web joists, each joist length requires its own specific member configuration. This involves fabricators in having to maintain much larger inventories of joist stock than would be the case for other joist types. It also precludes glued wood-web open joists from being used as continuous joists, which therefore will not benefit from the attendant structural and constructional advantages of this step. However if glued wood-web open joists can be made as commercially viable as they appear to be in Canada, there is no reason why they should not also have a good future in the UK joist market.

## 5.0 CONCLUDING REMARKS

Builders and specifiers currently have a wider choice of generally better performing floor joists than ever before. The performance levels of wood-based joists, and maybe also the range of joist types available, are likely to improve further in the next decade. It will be interesting to see if any manufacturer can develop the Holy Grail for floor joists, being a joist which can be cut out of long stock lengths but contains holes for routing services.

## 6.0 REFERENCES

Reference 1 – TimberSolve report no. DETO1.05, dated July 2000, entitled 'Results and interpretation of structural tests undertaken on alternative wood-based floor joists'.

Reference 2 – TimberSolve report no. DETO1.06, dated March 2001, entitled 'Domestic intermediate floor site trials using alternative wood-based floor joists'.

*The above reports were produced as part of a research and development project supported by DLTR under the 'Partners in Innovation' programme (project ref. cc1522: CI 39/3/459). Copies of all reports produced during this project can be obtained by accessing TimberSolve's web site address:* **www.timbersolve.co.uk**

***NOTES FOR TABLES 3.1 & 4.1.***

*All joist systems are rated under each performance requirement into one of the following five categories:*

*Excellent / Good / OK / Poor / Very poor.*

*Those performance requirements under which the joist system is rated 'poor' or 'very poor' have been emboldened.*

| **'JOIST' FAMILY** | **PERFORMANCE REQUIREMENTS** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Post-installation shrinkage | Ease of installation | Joist Robust-ness | Common construction details | Vibration | Routing services | Fire resistance | UK joist depths? | Flexib-ility in length | Spanning capability | Tech-nical support | Cost |
| Solid timber joists (strength class C16) | **Very poor** | **Poor** | Good | With strutting **Poor** No strutting Good | **Poor** | **Poor** | Excellent | Good | OK | 400 centres Good 600 centres **Poor** | **Very poor** | Excellent |
| I-joists | LVL flanges Excellent Wood flanges Good | Good | **Poor** | OK | **Poor** | OK | OK | **Poor-**good | Excell-ent | OK (single-span) Good (continuous) | Good | OK |
| Steel open-web joists | Excellent | Good | OK | OK-Good | Good | Excellent | **Poor** | **Poor-**good | **Poor** | OK | Good | **Poor** |

Table 3.1 – Comparison of existing joists within the three 'joist' families across the twelve performance requirements

| **'JOIST' FAMILY** | **PERFORMANCE REQUIREMENTS** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Post-installation shrinkage | Ease of install-ation | Joist Robust-ness | Common construction details | Vibration | Routing services | Fire resistance | UK joist depths? | Flexib-ility in length | Spanning capability | Technical support | Cost |
| Top-notched TR26 joists | OK | OK | Good | Good | OK | Good | Excellent | Good | OK | 600 centres OK | Good | Excellent |
| High grade finger-jointed joists | OK | **Poor** | Good | OK | **Poor** | **Poor** | Excellent | Good | Excellent | 600 centres Good | Good | Good |
| Glued wood-web open joists | Good | Good | OK | OK-Good | Good | Excell-ent | Good | **Poor** | **Poor** | OK | Good | OK |

Table 4.1 –Assessment of prospective new joists (see section 4) across the twelve performance requirements

***NOTES FOR TABLE 4.1***

1. *For top-notched TR26 joists & high grade finger-jointed joists, it is assumed that the prerequisite requirements of section 4.1.1 are in place.*