AN EXECUTIVE SUMMARY OF INVESTIGATIONS INTO THE VIBRATIONAL SERVICEABILITY OF DOMESTIC TIMBER FLOORS

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Written by: ______________
J.P.Marcroft

Reviewed by: ______________
L.R.J.Whale

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1.0 INTRODUCTION

Domestic floor joists have to meet the following design requirements in order to ensure satisfactory performance in service:

Strength requirements...............bending
...............shear
.............bearing

Serviceability requirements......deflection
.....vibration

The strength and deflection design requirements are laid down in BS5268: Part 2 are used in the case of proprietary joists, in conjunction with design data given in the associated BBA Certificates. In the case of vibration, BS5268: Part 2 contains no guidance other than indirectly limiting vibrations through capping deflections under full dead and imposed floor loading to 14mm. As floor vibrations result from the movement of a person(s) on the floor it is clear that any vibration criterion related to uniformly distributed rather than point loading must be of limited accuracy. In the national Codes of several other countries, including Norway, Sweden, Canada and Australia, as well as in Eurocode 5, the more logical approach for controlling vibrations of limiting deflection under a 1kN point load has been adopted.

However, limiting deflection under a 1kN point load introduces the problem for design engineers of actually calculating a realistic (ie. embracing floor decking/ceiling contributions) deflection of the floor under point loads. A design engineer's current recourse to evaluating the deflection of a floor under a point load is to evaluate the deflection based only on the properties of the underlying joist alone. For all types of joist, whether solid timber or engineered, when under standard domestic loading [0.5kN/m^2 dead, 1.5kN/m^2 imposed] and being used at their maximum permissible span based on a deflection limit of 0.003 times span, this approach gives deflections under a 1kN point load of just over 4mm for joist centres of 600mm and just over 6mm for joist centres of 400mm. As these deflections are well in excess of those accepted by any of the aforementioned National Codes, a less conservative method of calculation, incorporating a knowledge of the contribution from the floor's attendant secondary construction, is required. The results of a test investigation designed to furnish this knowledge, by determining the magnitude of actual deflections occurring in timber floors under 1kN point loads, are summarised in section 2, based on tests carried out at Surrey University.

2.0 RESULTS OF INVESTIGATION INTO DEFLECTIONS OCCURRING IN TIMBER FLOORS UNDER 1kN POINT LOADS

The tests carried out to determine the behaviour of timber floors under 1kN point loads investigated two different structural mechanisms as summarised in sections 2.1 and 2.2.

2.1 The degree by which the stiffness of the floor in the direction of the joists (longitudinal stiffness) exceeds the stiffness of the joists alone as a result of composite action between the joists and floor decking/ceiling

The findings of this part of the study were as follows:
1. For floors where the floor decking and ceiling are fixed using standard nailing specifications, the increases in floor longitudinal stiffness due to composite action are modest, being in the range 13-17% for all the commonly used permutations of chipboard and plasterboard thickness. Dense nailing specifications for the floor decking (three-fold increase over standard specifications) only brought about a further 5% increase in stiffness.
2. For floors where the floor decking was glued to the joists, although full composite action was not achieved, much more substantial increases in floor longitudinal stiffness were measured in the range 50-70%.

2.2 The ability of the floor decking, ceiling and any other transverse members present to distribute the point load perpendicularly to adjacent joists.

The findings of this part of the study were as follows:
1. Existing timber floor constructions were able to make a substantial contribution in transferring the effects of the point load to adjacent joists as shown in Table 1.

Joist details	Chipboard thickness(mm)	Plasterboard thickness(mm)	Deflection under 1kN point load
44x195 C16 joists @ 600$^c/_c$	22	12.5 or 15	1.8mm, being 41% of the deflection of the joist acting alone
44x195 C16 joists @ 400$^c/_c$	18	12.5	2.0mm, being 32% of the deflection of the joist acting alone

Table 1 - Deflections occurring under 1kN point loads in existing floor constructions

2. Extensive tests were carried out on the effects of threading timbers of various sizes (from 22x60 up to 44x110) through the joists to form a grillage system. It was found that relatively large grillage members were required to effect a significant reduction to the point load deflection, over and above that automatically provided by the floor decking and ceiling. Broadly a 30% such reduction would require the use of a single 44 x 110mm member at mid-span, or alternatively 3 no. 44 x 84mm timbers positioned at mid-span and the quarter-points. For any grillage specification the lowest mid-span deflection measured under a 1kN point load was 1.33mm.

3. As the formation of grillage systems clearly causes constructional difficulties for many types of joists, the use of thicker decking materials were also investigated by using 22mm chipboard in conjunction with joists at 400mm centres. However it was found that this step also had a modest effect - reducing the point load deflection by just 10% compared with that occurring with 18mm chipboard.

3.0 IMPLICATIONS OF THIS INVESTIGATION FOR CODE-WRITERS

The investigations undertaken within this project could substantially assist UK Code-writers in interpreting both Eurocode 1 and Eurocode 5 for the benefit of the UK timber industry and design community as outlined below:

<u>Eurocode 1 - ‘Actions on Structures’</u>

Magnitudes of imposed loads on floors are defined in table 6.2 of section 6.3.1.2 of Eurocode 1, in which domestic floors are described as Category A floors. For Category A floors table 6.2 stipulates an imposed load of 1.5kN/m^2 except for floors ‘without sufficient lateral distribution’, for which an imposed load of 2kN/m^2 is recommended. As existing UK floor construction has been widely considered as having only limited transverse stiffness, Eurocode 1 could easily be construed as advocating increasing the imposed load to be applied to UK domestic floors from the traditional 1.5kN/m^2 to 2kN/m^2. However the tests carried out at Surrey University have clearly demonstrated that even floors where the transverse construction only comprises a chipboard floor decking and a plasterboard ceiling, were capable of substantial lateral distribution of load. This is apparent from Table 1, which showed that, for joists at 600 and 400 centres, 59% and 68% respectively of a 1kN point load was transferred away from the directly underlying joist. It is considered, in view of this evidence, that existing UK timber floors possess ‘sufficient lateral distribution’ to justify the continued use of an imposed load of 1.5kN/m^2.

Eurocode 5 - 'Design of Timber Structures'

Unlike BS5268, Eurocode 5 has always contained design criteria for the control of vibrations, including limiting the deflection under a point load. Until recently this limit has been set at 1.5mm for a 1kN point load. However the latest draft of Eurocode 5 defines three performance levels for vibration - high, medium and low -the criteria for which in respect of deflection under a 1kN point load are given below:

High - 1mm, Medium - 2mm, Low - 4mm.

In the absence of knowledge on the contributions of the floor decking and ceiling, calculations based on the properties of the underlying joist alone indicate that UK floors do not even meet the 'low' performance level. However from the knowledge gained about these contributions, as summarised in section 2, the following conclusions can be drawn about the vibration performance levels of UK floors:

1. Existing UK floors, where the transverse construction only comprises a chipboard floor decking and a plasterboard ceiling, just fall within the medium' performance level.
2. Although the previous Eurocode 5 threshold of 1.5mm is achievable, it is unlikely that UK floors, designed to a 0.003 times span deflection limit, would be able to attain the current 'high' performance level even with the addition of grillage members.

From the perspective of the next draft of the UK National Application Document to Eurocode 5, it is recommended that designers are no longer relieved of having to apply Eurocode 5's recommendations on vibrational serviceability, but instead be required to specify floors meeting the 'medium' performance level as stipulated in the current draft of Eurocode 5 using the redistribution factors derived in this research.

4.0 RECOMMENDATIONS ON THE USE OF GRILLAGE SYSTEMS WITH THE TYPES OF ENGINEERED JOIST CURRENTLY AVAILABLE

From the test programme carried out at Surrey University, it was found that relatively large grillage members (sizes of 44x84 upwards) were required to effect a worthwhile decrease in point load deflection, and that increasing the size of a mid-span grillage member is a more effective strategy than the insertion of additional grillage members at other locations in the joist span.

The costs of inserting grillage members into a timber floor are two-fold. Firstly the material costs which, for a single mid-span grillage member, are likely to be acceptable for all types of engineered joist. Secondly the labour costs for the three operations below:

1. Forming the hole near mid-span of the joist.
2. Threading the grillage member through in-situ joists.
3. onnecting the grillage member to each joist through which it passes.

These labour costs will vary considerably depending on the type of joist being used and this is appraised below by considering the joists currently available under three families:

Solid timber joists. Although the test programme utilised solid timber joists to appraise the benefits of grillage members, it is doubtful whether their use is a viable proposition in view of the following:

- concerns about the effect of a large hole at mid-span on the joist's structural capability, particularly the possibility that the sawcuts to the hole might over-run their intended positions. Although a factory operation would alleviate the above concerns, it would introduce problems aligning the holes on site.
- as, for solid timber joists, the hole can only be slightly larger than the grillage member, there will be difficulties in threading the grillage member through the joists - a situation that can become untenable if the joists are sprung or otherwise distorted.
- the labour costs for cutting the holes and inserting the grillage members.

I-joists. I-joists can accommodate significantly larger holes than solid joists with only small reductions in their structural capabilities. This factor in conjunction with their much improved dimensional stability should enable the grillage members to be inserted much more easily. However the labour costs for cutting the holes remain high and fixing the grillage member to the relatively thin web member of the I-joists would present considerable difficulties.

Open-web joists. Although open-web joists are basically triangulated structures, in order to accommodate joist lengths that are not an exact fit to their web module, they are most commonly detailed with a vierendeel bay at mid-span. As shown in Figure 1, this rectangular void facilitates the ready insertion of the grillage member. As the grillage member-to-joist connection can be achieved by simply nailing the grillage member to one of the verticals of the vierendeel bay, it is believed that grillage members can be used with open-web joists at minimal labour costs.

In view of the above cost considerations, as well as the fact that the use of grillage members is unlikely to improve the floor's performance level from 'medium' to 'high' as defined in Eurocode 5, it is considered that the use of grillage members to improve vibrational performance would only be a worthwhile strategy for open-web joists.