Towards a rational design of timber structures with mechanical joints

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Towards a Rational Design of Timber Structures with Mechanical Joints

Projet rationnel de constructions en bois avec des articulations mécaniques

Rationelle Gestaltung für Holzbauten mit mechanischen Verbindungsstellen

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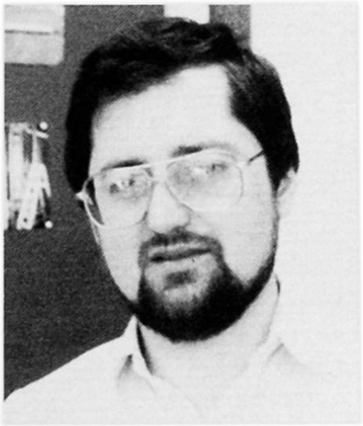
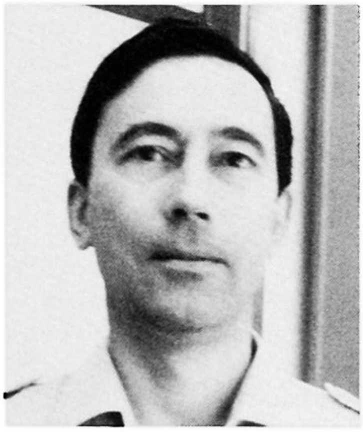




SUMMARY
The philosophy underlying a current investigation aimed at defining future research needs for mechanical joints in structural timberwork is outlined. An illustrative example shows the techniques being employed.

RESUME
L'article présente les conceptions de base qui ont inspiré de nouvelles recherches sur les articulations mécaniques dans les constructions en bois. Un exemple illustre les techniques employées.

ZUSAMMENFASSUNG
Das Denken, das hinter einer laufenden Untersuchung, die auf zukünftige Forschungsbedürfnisse an mechanischen Verbindungen bei Holzbauten gerichtet ist, wird erläutert. Ein Beispiel erklärt das angewandte Verfahren.

1. INTRODUCTION

Traditionally timber components are designed on an individual basis ignoring interactions and complex support conditions. There is now a general acceptance that the design of certain timber structures should follow more rational procedures, which take account of redundancies and partial fixities between components and which design to a target level of reliability. (It is important to note that rationality is in this context disassociated with discussions on formatting of design codes).

If more rational design procedures for structural timber components such as walls, floors, roof trusses and box beams are to be implemented it is necessary to know the load-deformation characteristics up to ultimate load of timber joints with mechanical fasteners. Inaccurate specification of joint characteristics in structural analysis for design of semi-rigidly connected components results in inaccurate predictions of deflected forms. This in turn leads to corruption of the design equations for strength and serviceability for all elements within a given structure. Unfortunately in most instances characteristic properties for timber joints are neither well defined nor accurately known. This lack of knowledge could severely inhibit transition to more rational procedures.

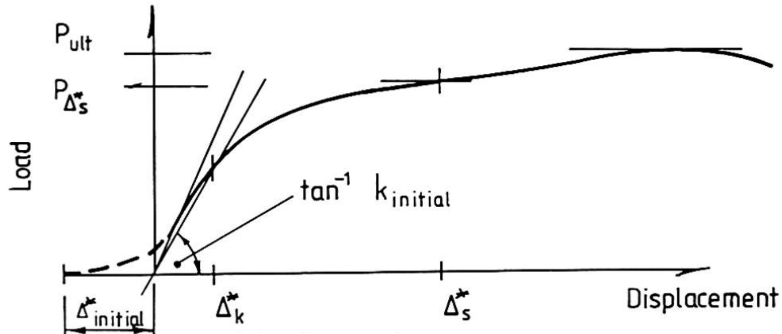
2. CHARACTERISATION OF JOINT PROPERTIES

Characteristic information on joint properties required in design can be divided into two categories: short term properties found in laboratory tests, having a duration in the order of 5 - 20 minutes; and modification factors used to adjust the short term properties. Application of these modification factors yields properties which can be used to predict the response of a structure to the combination of loadings and environmental conditions expected to be encountered during the design life. Fig.1 summarises characteristic short term properties that should be collected from experimental test programmes on nailed or bolted joints subject to lateral loadings. (Comparable characteristic properties should be collected for joints with other types of loadings or other types of fasteners or connectors).

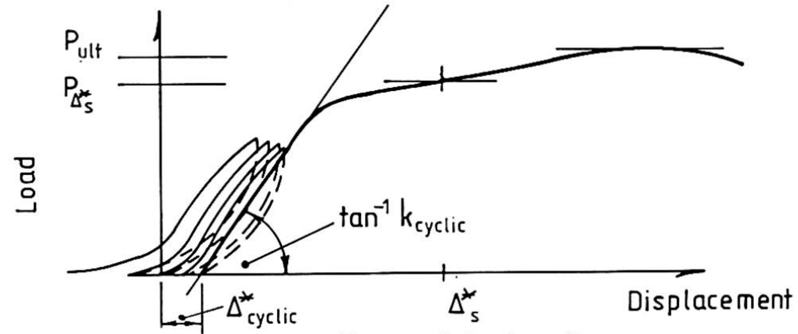
It will usually be adequate to use mean joint stiffness properties in calculations made to predict stress distributions in components, deformations and joint loads. Design against attainment of strength limit states in joints is likely to be based on 5% characteristic strength properties, i.e. it is necessary to know the distribution of each strength property. Whether characteristic strength properties based upon P_{Δ}'s or P_{ult} are more appropriate depends upon the type of structure and/or the types of loading.

3. PRECISION TO WHICH JOINT PROPERTIES SHOULD BE ESTIMATED

As indicated above short term values for joint slip and joint strength will require modification before they are used in design. There is very little published upon which to base modification factors. As an illustration, Burgess [1] , who has reviewed the data on creep deformation of nailed joints, concluded that on the basis of available information it is only possible to distinguish two loading histories "short term" loading and "long term" loading. He recommended a global adjustment factor of "long term" deformation = 4.25 x "short term" deformation applicable to all nail types, all nail diameters and all environments for both solid-to-solid timber joints and plywood-to-solid timber joints. The available data for joints with other types of fasteners or connectors is even more scant than for nails. Furthermore it seems likely that any lack of precision in the estimation of the short term initial joint stiffness will be overshadowed by the lack of precision introduced in the subsequent adjustment to account for loadings other than short term.



1 Loading cycle



Effect of load cycling

Key:

$k_{initial}$ = initial joint stiffness = secant stiffness over the interval 0 to Δ_k^*

k_{cyclic} = within cycle joint stiffness following load cycling to produce coincidence of hysteresis loops

$P_{\Delta_s^*}$ = joint load at a displacement of Δ_s^*

P_{ult} = ultimate joint load

$\Delta^*_{initial}$ = initial slip due to take-up of tolerances and irregularities in contact surfaces

Δ^*_{cyclic} = take-up of tolerances following load cycling to produce coincidence of hysteresis loops

Fig. 1 Information on characteristic joint properties under short term lateral loadings required for rational design

3.1 Sensitivity studies

The lack of precision in the adjustment of short term values of initial joint stiffness so that they apply to other durations of loading (and other similar uncertainties) may have important implications for the design of structures or components. The influence on structure or component performance of variation in the stiffness of the joints may be established by means of sensitivity studies on components such as trussed rafters, built-up beams and columns, racking resistant panels and stressed skin panels.

3.1.1. Stressed skin panels

As an illustration of the kind of sensitivity study required, the typical nail jointed stressed skin panel shown in Fig.2 will be considered. The panel is subjected to a uniformly distributed load and simply supported over a span of 2.4m.

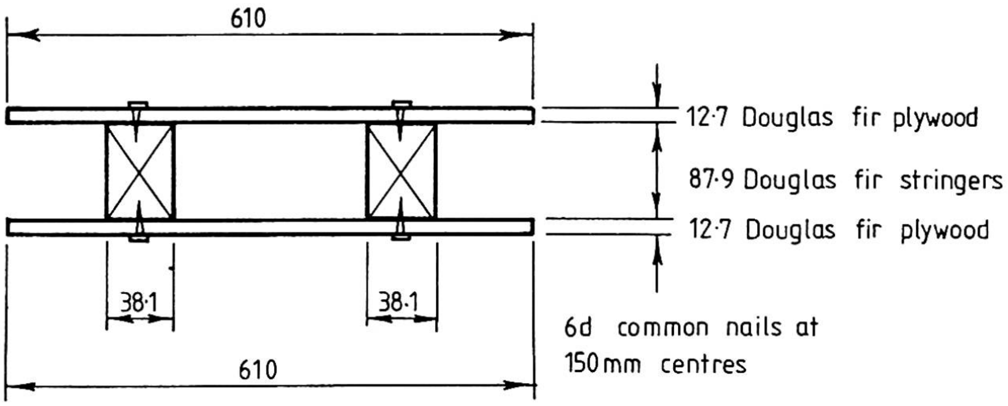


Fig.2 Stressed skin panel used in example of a sensitivity study

Let it be assumed for the purpose of demonstration that the design of the panel will always be deflection governed and that the sensitivity study may be restricted to consideration of panel deflection at mid-span. The initial joint stiffness for the nailed connections between the skins and the stringers is expressed in terms of a slip modulus per unit length, equal numerically to the mean initial tangent stiffness for a single nail loaded in single shear, k, divided by the nail spacing, s. For the linear elastic situation the panel deflection at mid-span can be calculated using expressions given by Smith [2]. Fig.3 shows the relationship between slip modulus per unit length and panel deflection at mid-span. Examination of Fig.3 shows that absolute panel deflection is more sensitive to variation in slip modulus at low values of slip modulus, i.e. in the region of values associated with "long term" loading where the curve is steeper. For the particular example an error of ± 20% in the estimation for "short term" slip modulus would yield an estimate of "short term" mid-span deflection to within approximately 10% of the true value.

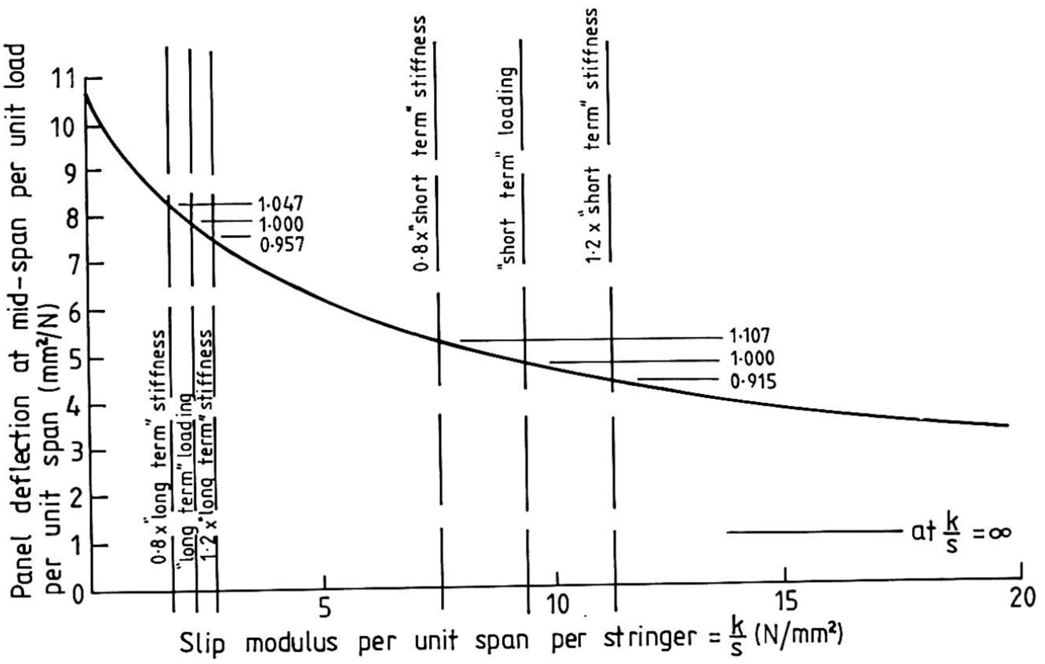


Fig.3 Relationship between slip modulus per unit span and mid-span deflection

Looking at the "longer term" loading region of the graph however, and assuming a "long term" loading modification factor for slip modulus of 4.25^{-1} [1], an error of ± 20% in the estimation of "short term" slip modulus would yield an estimate of "long term" mid-span deflection to within approximately 5% of the true value. Deflection of the component is sensitive to the factor chosen to transform the slip modulus, although the influence of error in the initial estimate of slip modulus diminishes when the transformation is made. Hence it can be seen that it is the choice of an appropriate value for the duration of loading modification factor which is potentially most critical. Error in the estimate for the "short term" slip modulus is relatively unimportant provided that it is constrained to some reasonable level such as ± 20%.

3.1.2 Other Components

Sensitivity studies on the effect of the load deformation characteristics of fasteners in racking panels have been started. Initially, components being examined consist of 2.4m square light wall frames, of a type similar to that used in timber frame housing. These have plywood or other sheathing attached to the wood framing with nails or similar fasteners; plywood with nails having been selected to commence the work.

Initial conclusions suggest that for higher fastener stiffnesses, which tend to correspond to "shorter term" properties, the overall component stiffness is relatively insensitive to alterations in the property of the fastener. This can be explained by redistribution of shear forces along the framing members. As the fastner stiffness is assumed to decrease, through effects such as those associated with "longer term" performance, the apparent behaviour of the component becomes increasingly sensitive. In a similar way to the study on the stressed skin panel described above, this work appears to be confirming the importance of assigning reliable values to the load duration modification factors.

4. CURRENT RESEARCH

A wide range of sensitivity studies are being conducted by the authors for various structural components. These encompass the influence of variation in joint stiffness on the deflection characteristics and the distribution of stresses within structures or components. This work is being used to determine:

- Precision to which short term strength and stiffness properties should be estimated.
- Precision to which modification factors accounting for other service conditions and the intended design life should be estimated.
- Level of information on joint properties that should be included in codes of practice.

Following from these, rational decisions can be made concerning the adequacy of existing test data, the number of replicates required in new test programmes and priorities for new research.

5. CONCLUSIONS

In order that rational design procedures for timber components with mechanical fasteners can be used with confidence, it is necessary to know how load-slip characteristics of the joints should be modelled. Unfortunately there is relatively little reliable information on which to base characterisations of properties for various types of connection. A systematic investigation based on sensitivity studies of the type described in this paper is needed to assess the adequacy of existing test data, allocate priorities for new research and to identify the minimum level of codified data on joints which will produce an acceptable precision in design calculations.

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