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Racking performance of Platform timber framed walls assessed by rigid body relaxation technique

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HIGHLIGHTS

- An iterative method to trace the racking load–displacement curve of timber framed walls.
- The method is based on the assumption of rigid-body behaviour for the timber members and sheathings.
- Only two DoFs are needed to model the kinematics of the timber frame.
- The numerical model is validated against laboratory test results.

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ABSTRACT

A new method to assess the raking performance of Platform timber framed walls, is provided in this study: each component of the unit wall assembly is assumed as rigid, hence allowing to drastically reduce the overall number of DoFs involved within the model. The timber frame in particular, is modelled as a mechanism, having only two DoFs (regardless of the number of studs) corresponding to the horizontal and rotational displacements of the header beam. For a given imposed horizontal displacement Δ_h, the corresponding racking load $P(\Delta_h)$ is computed by numerical relaxation, allowing to consider a continuous function to represent the load-slip curves of the connections. A comparison of the numerical analysis against laboratory test results is provided, showing the method's capability in predicting the raking strength of the wall, despite the assumed reduced number of DoFs.

1. Introduction

First introduced in North America, the Platform timber frame is a widespread construction method for both single and low to mid-rise multi-storey buildings [1]. The method lends itself to the use of prefabricated elements manufactured off-site under quality controlled conditions and benefits from improved quality, reduced construction time and costs [2,3]. In the Platform construction method, walls are formed on site by side-joining single story unit wall panels that have been prefabricated off-site in a factory environment. The floor structure is then fixed to the top of the walls and that forms a Platform from which the prefabricated walls for the next storey can be erected. The prefabricated wall panels are formed by assembling a timber frame composed of vertical and horizontal members (commonly referred to as studs and beams respectively) with a sheathing material, such as Oriented Strand Board (OSB), Particleboard or Plywood. The sheathing is fixed to one or both faces of the frame by mechanical fastening, e.g. nails, staples or screws. A schematic representation of the unit wall and its components is shown in Fig. 1. From a structural point of view, the function of the studs is to provide vertical support for loading coming from the above floor/walls, as well as provide means of connecting adjacent wall panels in each storey to form wall diaphragms. The beam elements provide a solid base onto which the wall diaphragms (and floor structures) can be secured to provide vertical and horizontal anchorage. The structural function of the sheathing panels is essentially to work as a system with the timber frame, in order to provide in-plane racking stiffness and strength to the wall diaphragms against horizontal loading arising from lateral actions such as wind and/or earthquake. The aim of this paper is to present a numerical method for assessing the racking stiffness and strength of such walls through the application of a rigid body relaxation technique.

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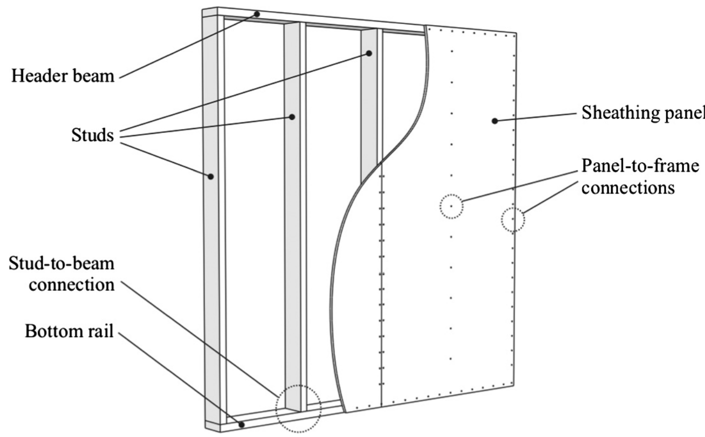

Fig. 1. Schematic representation of a unit timber framed wall and its components.

1.1. Reasons for the use of a rigid body approach

Limiting the content of the paper to the case of timber framed walls subjected to a monotonic, static loading regime; two main subsets of analysis methods can be found within literature:

- Analytical models
- Iterative (numerical) methods

Analytical models enable to predict the raking behaviour of the wall by simple hand calculations, which are suitable for design purposes and usually only provide strength results. Indeed, modelling the complex mechanics of the behaviour of a wall with a closed-form equation is only possible if simplifications of the behaviour of the wall are made. Such simplifications may relate to the stud-to-frame connections which, for example, can be modelled as perfect hinges [4,5] or assumed to have a linear elastic stiffness behaviour against uplift reaction forces [6,7]. Design solutions to nearly match such theoretical models can be achieved by anchoring the studs to the wall's substructure e.g. by means of holding-down brackets. However, where such a measure is not to be used in the construction process, the uplifting forces arising in the non-anchored, or partially anchored frame, will trigger a mechanism of separation at the bottom stud-to-beam connections (most pronounced on the windward side of the wall) which must be taken into account to be able to predict the wall's racking strength with an acceptable degree of accuracy. In regard to this, Källsner and Girhammar [8,9] developed closed form solutions suitable for hand calculations that are loosely based on the theory of plasticity [10] to provide a conservative result (i.e. lower bond values). For instance, the current design method in UK for timber raking walls, as given in the PD 6693–1 document [11,12], is partially based on their plastic model [13].

Unlike analytical models, iterative methods are able to achieve a great level of accuracy in reproducing the mechanical behaviour of the wall since material and geometric non-linearities can be fully accounted for, especially with regard to the non-linear behaviour of the connections. Mainly compiled using Finite Element (FE) methods, the primary use of such models falls within the context of research and product development, e.g. to carry out simulation testing and parametric analyses. Recent developments on the modelling of racking timber framed walls using the FE method can be found in [14,15].

Although such FE methods are readily available for commercial use, the benefit of proposing an alternative rigid body relaxation technique relies on the assumption of rigid behaviour for the timber frame wall components, which underpins most of the analytical design models. Such a widely accepted assumption is based on the understanding that because of the stiffness/strength properties of the wall panel connections, the deformations of the various members making up the unit wall assembly (i.e. studs, beams and sheathing panels) only plays a marginal role in determining the overall horizontal displacement of the wall, which is in fact greatly influenced by the stiffness/strength properties of its connections. On this basis, it is reasonable to model the wall assembly as a set of rigid bodies connected to each other by means of springs reproducing the system of fasteners holding the assembly together. Furthermore, whilst it is understood that nothing prevents the use of rigid body simulation within a FE framework, the underlying functioning of the FE analysis is often not transparent and readily understood by the analyst (the so called 'black-box syndrome' [16]). The benefit of the rigid body relaxation method which is addressed in this paper, is that it uses simple vector algebra operations, e.g. to describe the torque/lever-arm relationship, and by doing so, it provides a direct and more intuitive link between concepts a Platform design engineer is more familiar with, (e.g. stabilising/overturning moments) and the underlying functioning of the method itself.

The theoretical basis of the rigid body relaxation method is described in detail within the following section, whilst in Section 3 there is a comparison between the strength and stiffness behaviour of racking walls based on the application of this method and the results of three walls subjected to racking test.

2. Theory

The rigid body relaxation method described is this section is an extension to rigid bodies of the Dynamic Relaxation technique, which is a numerical method introduced by Day [17]. The method is particularly suitable for solving structural engineering problems involving a high degree of non-linearity, such as the form-finding/analysis of tension structures [18] and grid-shells [19,20], and it is particularly suited for parallel computing schemes [21].

2.1. Fully hinged timber frame

As already pointed out in the Introduction, for a fully anchored[1] timber framed wall the stud-to-beam connections can be assumed to behave as hinged joints. Where that is the case – and using the

[1] The term 'fully anchored' is referred in this paper to the timber frame only. There can be situations in which the timber frame, as well as the sheathing panels, will be anchored to the underlying floor/foundation but the behaviour of such walls will not comply with the modelling assumptions presented in this paper.