Mechanics of timber – to - timber shear connections with metal fasteners considering perfect plasticity and large deformations: The rope effect

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The ultimate load bearing capacity of timber - to - timber shear connections with metal fasteners depends on two quantities, firstly, the fully plastic embedment capacity of timber, parallel to the fibre (plastic limit line load, force per length), and secondly, the fully plastic bending moment capacity of the metal fastener (plastic limit bending moment, force times length). The underlying theoretical mechanical model represents perfect rigid plasticity from the material point of view combined with the small deformation setting from the kinematics point of view. This requires perfect ductility of the timber embedment mechanism as well as perfect ductility of the metal fastener bending mechanism, over relevant ranges of deformation. Based on these assumptions the spectrum of practically relevant shear connection configurations can be analyzed and the related perfectly plastic shear connection capacities can be analytically determined. The latter quantities have a typical formal appearance since they result as solutions of quadratic equations [1].

There are several striking model features which come into play as consequence of the chosen perfectly plastic model framework, as follows: 1. The metal fasteners act as statically determinate initially straight beams, 2. these beams are continuously loaded in transverse direction by field - wisely constant, oppositely directed embedment limit line loads, 3. these beams have no explicit fixed support conditions and 4. they are governed by equilibrium conditions only, 5. the bending moments are piecewisely quadratic, according to the loading, with smooth transitions, since there are no concentrated transverse loads in the interior of the beams, 6. the bending moments are limited by the plastic limit condition, which demands vanishing shear force at these distinct locations, i.e. the extremal property of the limit bending moment. These ideas are well known today and go back to the pioneering works of Johansen and others [1 to 4].

Increased load - carrying capacity can be achieved when the fasteners (bolts, self - tapping screws) are built - in at initial angles $\alpha_0 > 0$ against the normal to the timber - to - timber shear plane [6]. In this case an additional load - carrying mechanism is activated. Relative tangential displacements occur between the inclined fastener axis and the surrounding timber, based on elementary geometrical considerations. This leads to the build - up of a fastener - normal - force - based force - transmission - system between the timber components, where the effectivity of force transmission is clearly controlled by the actual force transmission capacity between fastener and surrounding timber (bolt friction, bolt head pullthrough, screw pullout etc). The Johansen load - carrying mechanism which is exclusively based on fastener - transverse - forces remains unaffected by this additional normal - force - based mechanism. The inclination of the fastener axis is accounted for by introducing the geometrical and material quantities related to this inclined fastener axis into the otherwise unaltered Johansen expressions. Finally, both of these statically determinate load -carrying mechanisms join together additively in global force equilibrium of the shear - connected timber components.

At this very point, now the large deformation effect is brought into play. In the present context geometric nonlinearity manifests itself in a uniform finite rotation ϕ of the central segment of the continuous fastener, i.e. which crosses the shear plane and extends between neighbouring plastic hinges [2, 3, 5]. Thereby the shape of the fastener axis changes from an initially straight line (with $\alpha_0 = 0$ or $\alpha_0 > 0$) to a zag- zig- zag line with two finite kinks at the locations of the plastic hinges. The consequences of occurrence of this finite deformation mechanism are elaborated upon in detail in this paper, on the general background of perfect rigid plasticity, leading to the genuine "rope effect" as will be shown. The formal framework, established for the geometrically linear situation before, remains completely unchanged. The angle α_0 has simply to be replaced by $\alpha = \alpha_0 + \phi$ for the central segment of the fastener, other things staying equal. The result presented in [7] is incorrect; it contradicts the requirements of the basic perfect plasticity model assumption.

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