Journal of Building Engineering 18 (2018) 130–141

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Review of design methods for round notched timber sections subjected to flexure and shear

Justin Dewey, Rabin Tuladhar*, Nagaratnam Sivakugan*

College of Science and Engineering, JCU, Townsville, Australia

ARTICLE INFO

Keywords:
Snipe
Notch
Round
Timber
Girder

ABSTRACT

Timber is an extremely versatile and relatively inexpensive natural material. It is widely used in the construction of timber structures in Australia. An interesting feature is that girders used in these structures are often round in profile. Round timber girders are usually notched at both ends. Notching (or sniping) of the timber girders at the end support areas is required for seating purposes and to create levelness in the top of the structure. Notching reduces the strength of the girder in the vicinity of the connection due to a concentration of high shear and cross-grain tensile stress at the re-entrant corner. Extensive literature has been published on the design and behaviour of notched rectangular sections, but there is a dearth regarding round sections. Very little research has been undertaken with regard to the behaviour of, and design procedures for, notched round timber sections. The techniques available for design rely on research relating to rectangular sections with area properties from truncated round sections substituted into the equation. Another common assumption in design is that the profile of shear stress parallel to the grain is parabolic. This is not the case, as finite element analysis simulations show high concentrations of both tension perpendicular to the grain and shear stress parallel to the grain occur at the notch corner. Currently asset managers and engineers must rely on patchy and often anecdotal assumptions when considering sniped timber girders. Due to the current lack of knowledge and the state of liability laws, some timber girders are removed from service long before any issues arise. This deficiency in understanding leads to unnecessary and expensive intervention that should not be occurring as timber, if maintained, should last hundreds of years.

1. Introduction

Round timber girders are a common sight in Australia's vast infrastructure network, particularly in bridges. These round girders are notched/sniped at both ends. Notching of the end support areas of girders is required for seating purposes and to create levelness on the top of the structure (Fig. 1). However, notching at the end supports reduces the strength of the girder in the vicinity of the notch. The concentration of high shear and cross-grain tensile stresses at the re-entrant corner can cause cracks to propagate along the grain leading to catastrophic brittle failure of the girders. This behaviour is difficult to represent using traditional linear elastic theory for beams [1].

Round timber girders are often used for aesthetic reasons or the inability to get sawn timber of the appropriate dimensions. In its round form timber is less susceptible to the strength reducing effects of sloping grain and exposed juvenile wood. It has also been shown that the coefficient of variation of timber due to defects reduces significantly when round sections are used. This is because of the fibres continuity around defects not being interrupted resulting in a fewer stress concentrations at defects [2,3]. Round timber girders used in structures are processed to some degree often in the form of shaving to a smooth cylindrical shape to remove sapwood. This practice removes the natural taper of the log and reduces strength by exposing knots and other defects.

The behaviour of notched round timber girders is not very well understood in either flexure or shear. Very little research has been undertaken in terms of the derivation of design equations for these unusual sections. A comprehensive review of the literature shows that most methods used are just extensions of the design equations used for rectangular beams [4–8]. This ignores the fact that the grain profile in natural round timbers is completely different. Research related to the capacity and behaviour of notched circular girders is also extremely limited. The Department of Transport and Main Roads, Queensland, Australia has found that the majority of investigation undertaken on notching of timber beams has been on rectangular shaped softwoods used in regions other than Australia [9]. The assumptions used in the design of notches in round timber have never been experimentally verified and as such may be too conservative due to a dissimilar loss of

* Corresponding authors.

https://doi.org/10.1016/j.jobe.2018.03.002
Received 28 June 2017; Received in revised form 11 March 2018; Accepted 11 March 2018
Available online 15 March 2018

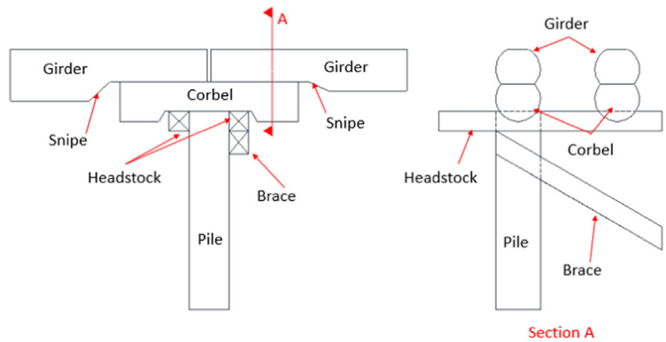

Fig. 1. Typical notched round timber girders and support system.

shape profile compared to the rectangular beams.

1.1. Failure mechanisms of notched timber girders

The principal actions that a timber girder must resist are bending moment and shear [10]. For simply supported sections, bending moments are greatest at the middle of the span due to the dead and live loads acting on the structure. Bending moment creates tensile stresses in the fibres below the neutral axis and compression stresses in the fibres above the neutral axis. However, for the notched timber girders, shear failures are more likely to occur in girders with short effective lengths. For notches applied on the tension side of the timber, the concentration of shear and tensile stresses perpendicular to the grain can lead to a catastrophic brittle failure which tends to split girders into top and bottom sections parallel to a fault along the grain (Fig. 2) [11,12].

The maximum recommended loss of depth in round girders due to notching is 15% of residual depth (i.e. after top seating is formed) and an absolute maximum loss of 30% provided bolted strengthening is applied [4]. Some methods to reduce these stress consentrations are to predill the notch corner creating a stop point for cuts. This creates a curve surface at the notch which reduces the effects of stress concentration [13]. Another option is to create a taper or slope from the reentrant corner. A gradual tapering of the notch reduces stress concentration at the notch corners [14]. AS 1720.1—2010 states that increasing the angle of the notched slope reduces the stresses encountered [15]. Eurocode 5 [16] states that tapered notches with slopes greater than 1:10 have very little effect on strength and thus the stress concentrations at the notch can be ignored. Keeping the distance between the face of the support and the internal notch corner small will also help to reduce any effects caused by bending [6].

Notch failures can be classified into three distinct modes. Mode 1 failure (Fig. 3) occurs due to the tensile stress perpendicular to the timber grain, Mode 2 failure relates to shearing parallel to grain and the less common Mode 3 where failure occurs due to torsion or rolling shear [12]. In AS1720.1–2010, Mode 1 and Mode 2 are represented as characteristic tensile strength perpendicular to the grain, and characteristic strength in shear parallel to the grain, respectively. Mode 3 which relates to the stability of the section is not a concern in round sections due to their inherent stability [15]. Mode 1 initially occurs at the centre of the width of the notch before propagating laterally

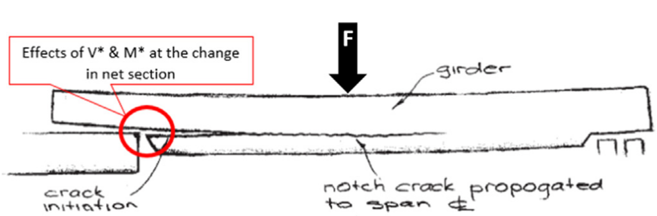

Fig. 2. Typical failure at the notch in a timber girder [10].

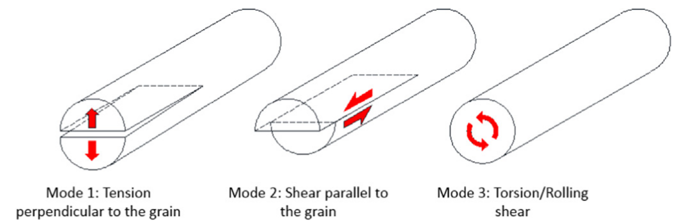

Fig. 3. Timber notch failure modes.

towards the surface. Ultimate failure at the notch occurs due to Mode 2, at which point the member could be considered two beams stacked on top of each other.

Literature shows that initial crack opening at the notch cannot be stopped. It will occur whether by loading, drying or ageing. It, however, is not in itself fatal but an initial contributing factor. As such, design provisions should be focused towards accounting for Mode 2 shear failure while maintenance schedules should be particularly focused on identifying large notch depths especially with stepped notch profiles.

2. Round timber

Notching is commonly created in round girders for seating purposes. However, there is very limited information regarding the design of notched rounds sections [4]. A review of the literature shows that design equations are based on rectangular sections with the assumption that cross sectional shape and grain profile has no effect on the load capacity of notched timber girders [17].

2.1. Bending

AS1720.1–2010 [15] treats round timber girders the same as rectangular beams using the shear plane area of the net section, various reduction factors and the characteristic strength of the particular species to determine design limits. With regard to design bending capacity of fully circular cross sections, AS1720.1–2010 uses Eq. (1) for girders less than 300 mm deep. Where k factors relate to reduction factors for timber and the elastic section modulus (Z) is determined using Eq. (2) using the diameter d_p of the girder at the relevant section [15]. If sections are larger than 300 mm, the characteristic strength value is multiplied by $(300/d)^{0.167}$ which further reduces the strength. In Eq. (1) below, $\varnothing$ is a strength reduction factor, k_1 a duration of load factor, k_4 moisture content factor, k_6 a temperature effect factor, k_{12} stability factor, k_{20} an immaturity factor, k_{21} a factor for shaving of round sections and k_{22} a processing factor only applied if the sections have been steamed.

$$M_d = \varnothing\ k_1 k_4 k_6 k_{12} k_{20} k_{21} k_{22} f'_b Z \tag{1}$$

$$Z = \frac{\pi d_p^3}{32} \tag{2}$$

AS/NZS 4676:2000 Structural design requirements for utility services poles [18], uses a similar method to determine the design bending capacity of round timber poles (Eq. (3)) where the section modulus is determined using Eq. (2) where k_d is a degradation factor for service environment.

$$\varnothing M = \varnothing\, k_1 k_{20} k_{21} k_{22} k_d \quad [f'_b Z] \tag{3}$$

The design procedure described in AS1720.1–2010 is purely for notched rectangular sections. The code contains no recommendations for notched or truncated round sections.

2.2. Shear

AS1720.1–2010 [15] defines the design shear capacity of round