Parametric study on effects of load position on the stress distribution in network arch timber bridges with light timber decks on transverse crossbeams

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ABSTRACT

Hanger arrangements suitable for timber network arch bridges with light timber decks on transverse crossbeams have been studied. The focus was on radial hanger patterns for glulam arches with circular shapes. The premise for the patterns are that the hangers always are attached in pairs to the transverse crossbeams, which are evenly distributed along the deck. The arrangement of hangers in network arch bridges is crucial for the structural performance of the bridges, as well as the stress distribution among the hangers. In the paper the performance of network bridges with classical radial patterns as well as introduced modified patterns under various load positions are compared. The underlying research is based on two-dimensional parametric numerical models of the network outlines. The parameters which have been varied are arch rise, hanger spread angle and location of a focal point for hanger creation. A comparison of stress ranges in hangers as well as bending moments in the arch for the considered patterns have been emphasized. The paper shows how the introduced pattern modifications influence the network arch performance. The intention is to provide a rational basis for better material utilization and design. In general it is recommended to apply a design modification leading to separate centres for the arch and the focal point for the hanger creation.

1. Introduction

Per Tveit introduced the concept of network arch bridges [1] in the early nineteen-sixties, as bowstring arches with hangers crossing each other multiple times. An important advantage of such type of bridges is that a fairly homogenous stress distribution can be achieved in the structure. It leads to a significant decrease of internal forces, and thus the cross sections of the bridge elements (arch, hangers) can be reduced compared to classical bridges with vertical hangers. The decisive features affecting force distribution in these bridges are primarily the number of hangers and the pattern type.

Several researchers have studied the most popular patterns like radial, fan, or pattern with constant inclination of hangers, or with constant change of hanger inclination, see Fig. 1. Tveit studied [1], among others, hanger inclination and hanger relaxation dependent on load location on the deck for network arches with variable hanger inclination. Schanack and Brunn [2] introduced the radial hanger arrangement, and presented a comparison between patterns with vertical hangers and radial network patterns, showing that bending moments can be highly reduced in the latter. De Zotti et al. [3] studied performance of various types of network arches, as well as arches with vertical hangers or fan arrangement, comparing bending moment distribution and axial force in the arch. Studies on stress and force distribution in the hangers were also performed by Pellegrino et al. [4] who studied patterns with vertical, fan, radial pattern and pattern with constant change of hanger inclination. Teich [5] compared five different network patterns showing that radial pattern is one of the most efficient. Also De Backer et al. [6] studied stresses in hangers in network and Nielsen-Lohse bridge types, using numerical models with nonlinear material behaviour of hangers.

However, the studies presented in the literature consider mainly heavy bridges made of steel and concrete. Such bridges are suitable for all types of traffic: pedestrian, car and train. The common feature of their construction is equidistant hanger distribution along the arch, while ignoring the locations of hanger fastening points on the deck. However, an equidistant location of hangers on the deck level is a premise for the present analyses.

The studies of hanger patterns presented in this paper are based on timber bridges with light timber deck. It is intended that both the arch and the deck are made of glulam. The deck is resting on evenly spaced...
transverse crossbeams, which constitute the natural fastening points for the hangers. The arch has circular shape and variants of the radial pattern are used in all the analysed network outlines.

In network arch bridges with a standard heavy deck, the self-weight of the deck prestress hangers in the network. When the bridge is exposed to a moving load, additional positive or negative forces appear in the hangers, depending on load position. The negative force reduces hanger prestress, and in some cases, can cause compression in a hanger. In the optimal network arrangement, forces in hangers from the self-weight prestress, and in some cases, can cause compression in a hanger. Therefore, the network pattern arrangement is important. Note, that hanger relaxation also leads to bigger bending moments in the arch.

The study focuses on stress distribution in hangers and bending moments in the arch, for different radial patterns. Classical (reference) radial patterns, which have coinciding centres for the arch and the focal point for hanger creation, are studied and compared to modified radial patterns, introduced by the authors.

2. Methodology

2.1. Classical radial pattern

In radial patterns the relation between a radial ray and a hanger is precisely defined. The ray goes from the centre of the circular arch, denoted as $C_a$, towards and through a transverse crossbeam. The ray defines an average direction of a pair of hangers. Next, at the fastening point on the crossbeam, for a pair of hangers, one hanger rotates left with angle $\alpha$, and the other rotates right with the same angle $\alpha$, called the spread angle. Consequently, each hanger is created between the crossbeam and the point of intersection of the rotated hangers with the arch; confer Fig. 2. It is assumed that the centre of the arch $C_a$ is also the origin of the Cartesian xy-coordinate system ($X = Y = 0$). The origin point for radial rays is called a focal point. For radial patterns the focal point coincides with the centre of the arch $C_a$; confer Fig. 2. By building the network outline in the presented way, the fastening points of hangers on the arch become unevenly distributed. The locations of these points depends on configuration parameters such as: deck length $l$, arch rise $f$, number of crossbeams $n$ and spread angle $\alpha$.

2.2. Radial pattern with modifications

In radial patterns with modifications, the location of the focal point, denoted as $C_a$, does not coincide with the centre of the arch $C_a$. An offset of centre $C_a$ from centre $C_a$ is a parameter of the modification procedure. In total three modifications of the patterns were investigated. First, only horizontal offset was applied along $x$-axis and patterns based on that premise were studied. Next, vertical offset along $y$-axis was

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**Nomenclature**

- $f$: arch rise [m; % of bridge length $l = 100$ m]
- $l$: particular hanger
- $l$: deck length [m]
- $n$: number of transverse crossbeams [-]
- $p$: particular pattern
- $P_{r,a}^i$: reference pattern
- $r$: arch radius [m]
- $x, y$: coordinate system
- $C_a$: arch centre origin
- $C_{a,L}, C_{a,R}$: centre of hanger ray (focal point); $C_{a,L}$ - left; $C_{a,R}$ - right
- $H$: maximum number of relaxed hangers in a pattern; in [%]
- $M_{max}$: maximum value of the in-plane bending moment in the arch; [kN m]
- $P_{r,a}^{i,XY}$: set of modified patterns
- $P_{r,a}^{i,XY}(M)$: best modified pattern chosen after bending moment criteria
- $S_{i}^{max}, S_{p}^{max}$ maximum stress; $S_{i}^{max}$ - in one hanger; $S_{p}^{max}$ - in a pattern; [MPa]
- $S_{i}^{min}, S_{p}^{min}$ minimum stress; $S_{i}^{min}$ - in one hanger; $S_{p}^{min}$ - in a pattern; [MPa]
- $dS_i, dS_{p}^{max}, dS_{p}^{min}$ stress range; difference between a maximum and a minimum stress; $dS_i$ - in one hanger; $dS_{p}^{max}, dS_{p}^{min}$ - in a pattern; [MPa]
- $X, Y$: particular coordinate
- $X, Y$: set of coordinates $X, Y$
- $\alpha$: hanger spread angle in radial pattern; [°]

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**Fig. 1.** Different hanger patterns: (a) fan; (b) radial; (c) constant hanger inclination; (d) constant change of hanger inclination.

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**Fig. 2.** Radial pattern for bridge with equidistant crossbeams.
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