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Determination of residual weld stresses with the incremental hole-drilling method in tubular steel bridge joints

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Abstract

Tubular arch bridges are susceptible to fatigue problems due to stress concentrations, welding imperfections and tensile residual weld stresses. These bridges are composed of circular hollow section profiles welded together in tubular joints. This paper describes the determination of residual weld stresses in T-joints with the incremental hole-drilling method. The residual stress distribution can be used to determine fatigue crack behavior and fatigue lifetime more precisely.

The incremental hole-drilling method is used to measure residual welding stresses on two similar T-joints. Experimental residual stress measurements were performed with the aid of the RS-200 milling guide. Strain gauge rosettes are attached to the test surface and with the milling guide, a small hole is drilled through the center of the strain gauge rosette. Strains at incremental depths are measured and the residual stresses are calculated according to ASTM E837-13a.

A comparison is made between residual stress distributions obtained with finite element simulation and the experimental measurements. The distributions from finite element simulation show tensile yield stresses close to the weld while the experimental measurements indicate tensile yield stresses only in the axial direction of the primary tube. In all other cases, the residual stresses are tensile within 50% of yield stress or even compressional. However, more measurements on similar test specimens are necessary for a reliable residual stress distribution.

Knowledge of the residual stress distribution is essential to accurately estimate the crack development under fatigue loads. In future research, the residual stresses can be used to study the influence of residual weld stresses on the fatigue lifetime and improve the design of steel tubular joints in arch bridges.

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Keywords: Residual weld stresses; Incremental hole-drilling; Tubular T-joints

1. Introduction

Tubular steel arch bridges are highly appreciated for their aesthetic value. The use of hollow tubes with circular sections and the connections in the nodes where several tubes meet, ensures a smooth shape [1]. These structures are composed of several steel bridge joints where larger primary tubes are welded together with smaller secondary tubes. The fatigue strength is important

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because the numerous welded joints introduce high stresses near the weld toe of the joints. These high stresses are the result of the welding process and the influence of geometric discontinuities on the flow of the stresses, resulting in possible fatigue failure [2].

The welding process introduces residual welding stresses near the welded tubular joints. Residual stress distributions can have large stress gradients due to their non-uniform behavior [3]. These stress gradients make it necessary to perform residual stress measurements in order to estimate the influence on the fatigue strength of the welded joints in tubular arch bridges. The fatigue strength can be increased by the presence of compressive residual stresses [4]. Tensile yield stresses tend to open cracks and have a detrimental influence on the fatigue crack propagating under cyclic traffic loadings on the bridge. Residual stress can make the difference between a fatigue micro crack to grow or not. Moreover, residual stresses can also influence the rate of crack propagation, since the tensile residual stress field is often associated with a shorter fatigue life [5]. Therefore, accurate fatigue design of fatigue-sensitive bridge components requires knowledge of the distribution of the residual welding stresses.

In this paper, the residual stress distribution of tubular T-node joints are experimentally determined with the incremental hole-drilling method. Therefore, a small hole is drilled through a strain gauge rosette which is attached to the primary and secondary tubes of the joint. During the drilling, strains are recorded and these are used to calculate the residual stresses [6]. Several measuring points are chosen on the bridge joint and a residual stress distribution is established. Then, these results are compared with results available in literature.

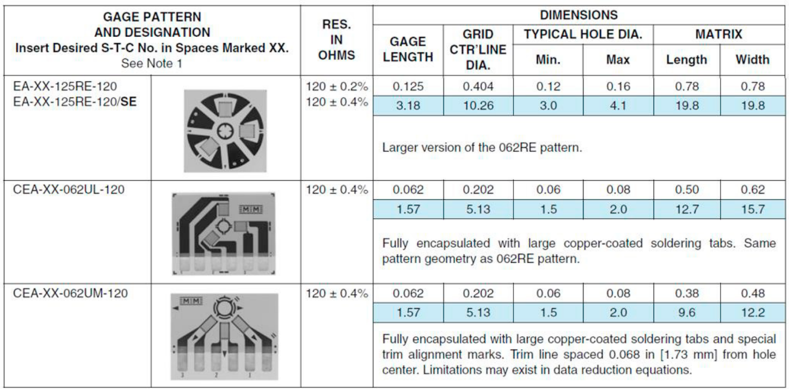
Nomenclature

D	diameter of primary tube
d	diameter of secondary tube
L	length of primary tube
l	length of secondary tube
T	thickness of primary tube
t	thickness of secondary tube
FEA	finite element analysis

2. Incremental hole-drilling method

The incremental hole-drilling method is a semi-destructive measuring method where a small hole is drilled into the test material through the center of a strain gauge rosette. These strain gauge rosettes are used to measure the relieved surface strains caused by the introduction of a hole that is formed by drilling in a series of small steps. The measured strains are used to calculate the residual stresses according to the principles specified in ASTM E837-13a and this test method only applies assuming linear-elastic material behavior [7].

In order to obtain reliable measurements, a certain sequence of actions must be respected. First, the surface has to be prepared. The surface is prepared using silicon carbide abrasive paper to ensure adequate microscopic roughness to promote secure gauge bonding (Ra 1.6 to 3.2 μm). Before attaching the strain gauge rosette, the surface has to be neutralized and degreased [8]. For the residual stress measurement on the tubular bridge joints, three different types of strain gauge rosette configurations were used. Strain gauge rosette type EA-06-125RE-120 is used to drill a hole with an approximate diameter of 4mm up to a depth of 2mm. Measurements for a hole with an approximate diameter of 2mm with a depth of 1mm are performed with strain gauge rosette types CEA-06-062UL-120 and CEA-06-062UM-120 for measurements close to a weld or edge [9]. The different types of strain gauge rosettes and their dimensions are shown in Fig. 1.



GAGE PATTERN AND DESIGNATION Insert Desired S-T-C No. in Spaces Marked XX. See Note 1		RES. IN OHMS	DIMENSIONS					
			GAGE LENGTH	GRID CTR'LINE DIA.	TYPICAL HOLE DIA.		MATRIX	
					Min.	Max	Length	Width
EA-XX-125RE-120 EA-XX-125RE-120/**SE**		120 ± 0.2% 120 ± 0.4%	0.125	0.404	0.12	0.16	0.78	0.78
			3.18	10.26	3.0	4.1	19.8	19.8
			Larger version of the 062RE pattern.					
CEA-XX-062UL-120		120 ± 0.4%	0.062	0.202	0.06	0.08	0.50	0.62
			1.57	5.13	1.5	2.0	12.7	15.7
			Fully encapsulated with large copper-coated soldering tabs. Same pattern geometry as 062RE pattern.					
CEA-XX-062UM-120		120 ± 0.4%	0.062	0.202	0.06	0.08	0.38	0.48
			1.57	5.13	1.5	2.0	9.6	12.2
			Fully encapsulated with large copper-coated soldering tabs and special trim alignment marks. Trim line spaced 0.068 in [1.73 mm] from hole center. Limitations may exist in data reduction equations.					

Fig. 1. Strain gauge rosette types [8].