Crack growth prediction of deck plate-stiffener joints in orthotropic steel bridge decks

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Summary

Orthotropic deck structures are used in many steel bridges. Due to the typical detailing applied as around 1970, a significant number of deck structures constructed in that period suffer from fatigue damage. In many countries cracks have been detected, in particular in the weld between the deck plate and the trapezoidal stiffener. These cracks tend to grow relatively slowly, but are difficult to detect in an early stage because they initiate from inside of the trapezoidal stiffener.

This paper presents a model with which the growth of these cracks can be predicted. The model is aimed at the growth rate prediction of through-thickness cracks that can be detected by visual inspection. Stresses are extracted from a detailed finite element model of the entire deck. A second, local finite element model including the crack is used as the basis of a fracture mechanics model. The growth rate determined with the model is calibrated and validated with measured cracks in various bridges.

Keywords: orthotropic deck, fatigue assessment, fracture mechanics, crack growth rate, finite element analysis, trapezoidal stiffener, fillet weld.

1. Introduction

Early onset fatigue is affecting the orthotropic steel decks on several major bridges. A frequently observed type of fatigue crack occurs in the joint between the deck plate and the stiffeners, Fig. 1. Around 1970, these joints were made by fillet welding. The cracks in these fillet welds predominantly initiate from the root and grow through the weld, caused by bending and membrane stress ranges in the stiffener wall. Subsequently the crack grows along the length of the weld, in between the crossbeams.

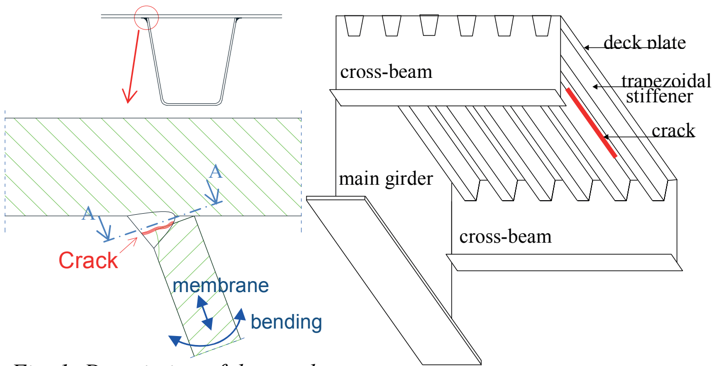

Fig. 1: Description of the crack

The joints are visually inspected for cracks. Only cracks that already have grown through the weld thickness and that

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have a certain length can be detected. A crack with length of appr. 100 mm can be detected with sufficient probability of detection (POD).

2. Summary of the model

Stress ranges in the trapezoidal stiffener are determined using an accurate load model for lorries passing over the bridge, and an accurate Finite Element (FE) model representing the bridge deck.

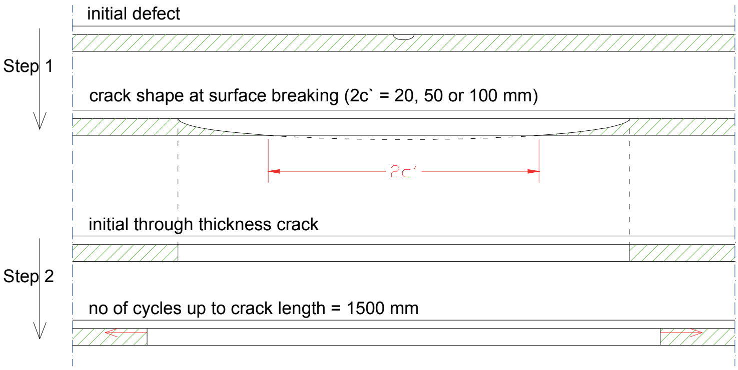

Fig. 4: Two crack growth models (cross-section AA in Fig. 1)

Subsequently, two fracture mechanics models have been developed, one for a small crack, growing from an initial size to a surface breaking crack, and one for a large crack, growing from surface breaking to a length of 1500 mm. The aim of the first model is to determine the crack dimensions in case of a visual length 2c', Fig. 4. This visual length is the crack length at the outside of the trapezoidal stiffener. The crack size at the inside of the stiffener is larger because the crack grows from the inside. The crack of the second model is approximated with a straight crack front. The length of this crack is conservatively assumed as the largest crack size of the first model, in agreement with the standard BS 7910:2005. The aim of the second model is to determine the fatigue life, starting from a visual crack and ending with a critical crack.

FE models are used to determine the stress intensity factors (SIF) for cracks in the considered joint. The models indicate that the SIF remains constant at cracks with a length of approximately 750 mm and longer. A numerical procedure based on fracture mechanics is developed that makes use of the SIF. This numerical procedure forms the prediction model. The model is calibrated by comparison with cracks detected in the Muiderbridge. These cracks are very suited for model calibration, because the joints were inspected in 1999 and 2009, and the cracks were not repaired in between. Crack growth predictions with the model are then compared with measured cracks in various bridges in The Netherlands. The predictions agree well with the measurements.

The model can be used to: a) set inspection intervals, so that potential cracks are detected before they reach a critical size; b) determine the moment in time at which repair or strengthening needs to be applied; c) determine the crack sizes that do or do not grow once the bridge deck is strengthened by a HSC layer. The model is successfully applied to provide the fatigue life of the bridge decks of 6 large existing bridges in The Netherlands.

Conclusions

This paper presents a crack growth model for the trough to deck plate joints in orthotropic decks of existing bridges. The model is based on fracture mechanics principles and it is calibrated and validated by comparison with extensive inspection results on various bridges in The Netherlands. The paper shows that the crack growth rate of this type of crack remains constant from crack lengths of 750 mm onwards. The cracks as observed in various bridges are in agreement with the theoretic models.