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Fatigue resistance of the deck plate in steel orthotropic deck structures

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ABSTRACT

Steel orthotropic decks in bridges and ferries have shown to be prone to fatigue cracking. A typical fatigue crack observed in these structures initiates at the root of the weld between the deck plate and stringer and grows into the deck plate. Due to limited fatigue test data available and the deviating characteristics of this type of crack as compared to other types of fatigue cracks, the fatigue strength is uncertain. In this study, a linear elastic fracture mechanics model has been developed for this type of crack, providing insight into its fatigue performance. The model predicts a relatively high fatigue resistance which is close to the results of fatigue tests. The model further predicts a relatively long residual fatigue life after crack detection, providing large inspection intervals.

1. Introduction

Steel orthotropic decks are applied in bridges and ferries. They consist of a deck plate stiffened by stringers and supported by crossbeams. In many cases the stringers are of trapezoidal shape and are running through openings in the crossbeam web. Steel orthotropic decks are prone to fatigue cracking due to passing wheels of heavy vehicles, [1]. In such a deck, a typical type of fatigue crack can initiate in the deck plate from the root of the weld between the stringer and deck plate, Fig. 1. This type of crack is reported for bridges in Japan [2], France [3], Belgium and The Netherlands [4]. Decks with a thin deck plate and a thin road pavement are especially sensitive to this type of crack.

Fatigue test data are available for deck plate cracks. Test results for the deck plate in between crossbeams, Fig. 1a, are reported in [5–8]. In case of continuous stringers with crossbeams welded around, deck plate cracks are predominantly observed at the junction with the crossbeam, Fig. 1b, caused by the high stress concentration at that location. This crack location – which is the focus of this paper – has been tested in [9,10] and with slightly different geometry in [11]. Kolstein [10] combined the results of [9,10] and provided the fatigue reference strength at $2 \cdot 10^6$ cycles in MPa, which is further in this paper referred to as FAT class, with as subscript the survival probability. The FAT classes are provided in Table 1. These FAT classes are high when compared to other types of welded details for which fatigue test data are available. As a reference, standards and guidelines such as [12] and [13] provide $FAT_{95\%} = 90$ or 100 for weld toe cracks assessed with the hot-spot stress, whereas root cracks usually have a lower fatigue strength. The differences in FAT class may be due to important differences in geometry and loading between the deck plate geometry and more common types of fatigue prone details, Table 2. The main difference is that the crack initiates from the root of the weld between the stringer and the deck plate and grows into the deck plate, whereas usual fatigue cracks starting from the weld root grow through the weld. Another distinct characteristic of this deck plate crack is that the deck plate is loaded in bending with the initiation point

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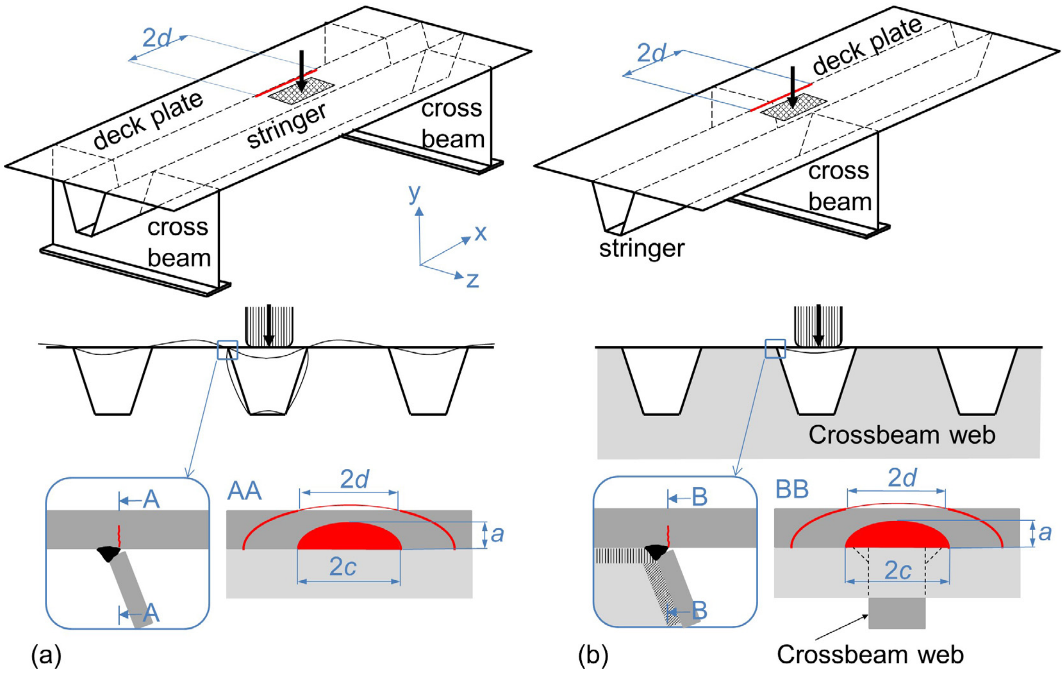

Fig. 1. Geometry of the deck plate crack: (a) Deck plate crack between crossbeams; (b) Deck plate crack at crossbeam.

Table 1
Fatigue reference strength in MPa (FAT class) of the deck plate as determined in tests [10].

Location	No. of specimen	Stress parameter	$FAT_{50\%}$	$FAT_{95\%}$	$FAT_{97.7\%}$
Between crossbeams	21 (two series, [6,7])	Nominal	183	146	140
At crossbeam	21 (two series, [9,10])	Hot-spot	214	167	158

Table 2
Comparison of deck plate detail and usual fatigue sensitive weld details for which test data are available.

Aspect	Usual weld details tested in fatigue	Deck plate crack
Crack location	-Weld toe: through base plate -Weld root: through weld	Weld root, through base plate
Type of load	Tension (in fatigue tests). Sometimes bending with tension at the initiation location	Bending (in fatigue tests) with compression at the initiation location
Stress	Simple geometries – straightforward stress analysis	Complex geometry at the junction with the crossbeam – direct stress decreases with distance to crossbeam
No. cycles between through-thickness crack and failure	Limited	Significant
Inspection	Weld toe: possible Weld root: difficult unless the crack is large	Difficult; no access from above (road pavement), no access from below (stringer wall and crossbeam)

experiencing compression due to wheel loading. The cracks experienced in fatigue tests are believed to be influenced by residual welding stresses, which result into internal tension at the crack initiation point. In practice, yielding of the deck plate due to loading by extremely heavy axles, may further contribute to residual tensile stresses or reduce residual compression stresses. Accurate stress determination is performed for the deck plate at the weld toe and weld root in [14], indicating a relatively high effective notch stress at the weld root. The FAT class of this detail is relatively uncertain due to limited test data available and the deviating characteristics of this type of fatigue crack, as compared to other types. In addition, the fatigue tests are a simplified representation of reality because, deck plate road pavement was not applied, a fixed load position was applied, and the crossbeam was vertically supported over the entire length.

A lack of access to the crack location makes fatigue inspection of the deck plates difficult. Practical experience indicates that small cracks can best be detected from above the deck with the time of flight diffraction (TOFD) technique, but only after removal of the road pavement. Consequently, an inspection is best planned when the road pavement is to be replaced. The question is, if the