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INVESTIGATIONS OF ORTHOTROPIC DECKS

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Abstract: *The partial investigations of orthotropic decks carried out in the Institute of Theoretical and Applied Mechanics, v.v.i., in Prague for a project of the European Union „BRIFAG“ is described. The performance of orthotropic decks is studied under dynamic loads including the crack propagation, estimation of fatigue life of the bridge elements, etc. It was found that the most vulnerable detail appeared at the spatial connection of the deck with cross and longitudinal beams. The results are concentrated in a figure of stress ranges as a function of the number of stress cycles.*

Keywords: ***Orthotropic decks, fatigue, stress, Wöhler line.***

1. Introduction

The European Union approved the research of fatigue behaviour of orthotropic decks that are applied to highway as well as railway bridges and formed an international team see Fig. 1 whose main task is to study the fatigue of orthotropic decks on both the highway and railway bridges. The impact on economy and research is the most important.

Each of the participant team has its own research programme and, here, only the results achieved in ITAM (and not all) are shortly mentioned. The team can be seen in the Fig. 1 during its meeting in the laboratory of ITAM in Prague, (Lukić et al., 2009), (Akhlaghi et al., 2009).

ITAM tested the elements of orthotropic decks on fatigue in the testing machine up to the cracks. The evaluation of tests presented the relationship of stress ranges on the number of absorbed stress cycles (Wöhler line). It is supposed that the stress ranges are the main factor of fatigue cracks in structures. This function enables also to estimate the fatigue life of the investigated structural element.

Fig. 1: The BRIFAG meeting in the laboratory of ITAM, Prague, 2010.

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The orthotropic decks represent a popular structural element since the Second World War and it is counted now several thousands in structural engineering (civil, industrial, ship and space structures) all over the world. Their advantages are: light weight, low height and low first natural frequencies. On the other hand, as they are fully welded, they suffer from the secondary stresses that cause cracks and the initiation of fatigue cracks. Therefore, the orthotropic decks should be carefully studied and tested.

2. Specimens

The investigated model (see Fig. 2) represents a part (a cutout) of a railway bridge in the approximate scale 1 : 1. The strait ribs are preferred on railway bridges because they provide several advantages: no closed spaces, no corrosion, simple welding, easy maintenance and painting.

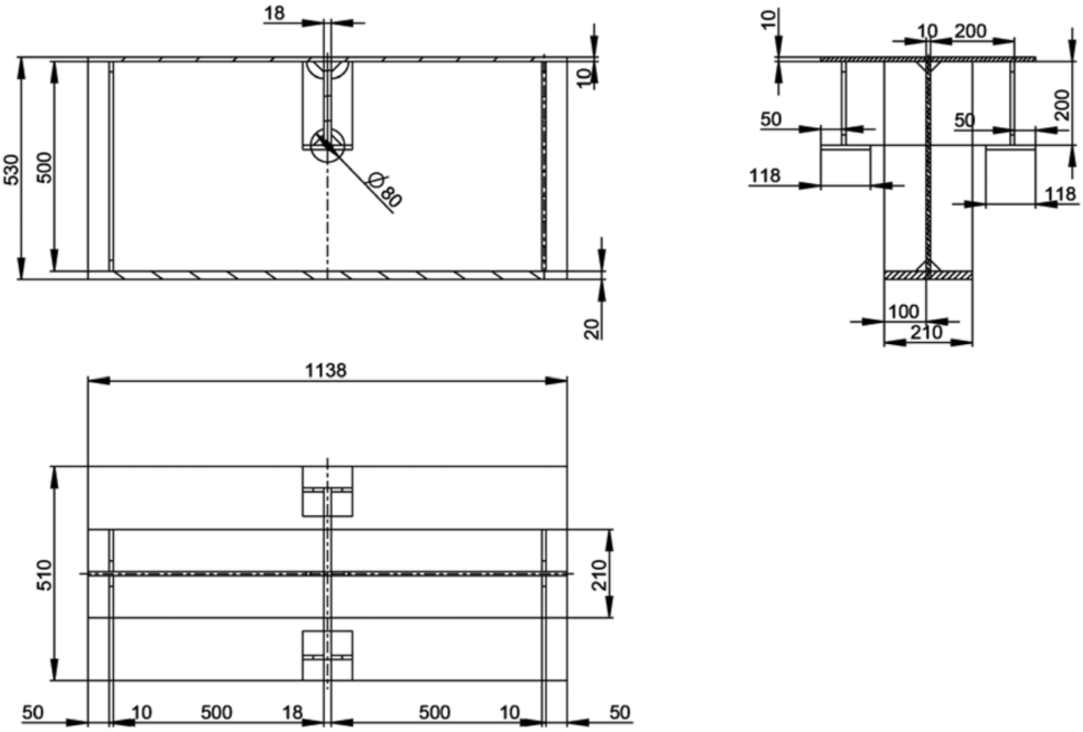

Fig. 2: The tested model of the orthotropic deck.

A series of 16 specimens was tested under the harmonic load in the laboratory of ITAM. The applied forces with various minimum $F_{\min}$ and the maximum $F_{\max}$ forces as well as the number of stress cycles up to the fracture were recorded. All tested specimens results are summarized in the Table 1.

Tab. 1: A survey of static and dynamic tests.

N. of specimens	type of testing machines	Fmin [kN]	Fmax [kN]	Number of cycles
A1 static force	ITAM GTM 500 kN	0	477	
	TZUS RK MFL PRUFSYSTEME	0	780	
A2 dynamic force	test machine MTS 250 kN, frequency 3 Hz	10	210	5 527 812
	test machine GTM 500 kN, frequency 2 Hz	10	410	1 543 930

A3 dynamic force	test machine GTM 500 kN, frequency 2 Hz	10	360	5 000 000
A4 static force	test machine GTM 500 kN,	0	200	
A4 dynamic force	test machine GTM 500 kN, frequency 2 Hz	10	380	2 236 037
A5 static force	test machine GTM 500 kN,	0	200	
A5 dynamic force	test machine GTM 500 kN, frequency 2 Hz	10	390	547 400
A6 dynamic force	test machine GTM 500 kN, frequency 2 Hz	10	390	576 000
A7 with CFRC	test machine GTM 500 kN, frequency 2 Hz	10	390	3 210 000
A8 with CFRC	test machine GTM 500 kN, frequency 2 Hz	10	390	2 320 000
A9 dynamic force	test machine GTM 500 kN, frequency 2 Hz	10	390	596 453
A10 dynamic force	test machine GTM 500 kN, frequency 2 Hz	10	400	371 000
A11 dynamic force	test machine GTM 500 kN, frequency 2 Hz	10	400	716 000
A12 dynamic force	test machine GTM 500 kN, frequency 2 Hz	20	380	1 350 000
A13 dynamic force	test machine GTM 500 kN, frequency 2 Hz	20	400	820 000
A14 dynamic force	test machine GTM 500 kN, frequency 2 Hz	10	370	2 600 000
A15 dynamic force	test machine GTM 500 kN, frequency 2 Hz	20	390	682 500
A16 dynamic force	test machine GTM 500 kN, frequency 2 Hz	20	370	1207000

It has approved that the stress range is the most important parameter affecting the fatigue of structures. The stress range is defined as the difference of the local maximum and minimum of stresses in the investigated point:

$$\Delta\sigma = \sigma_{\max} - \sigma_{\min} \tag{1}$$

It enables also to estimate the fatigue life of the investigated structural element.

The key results were concentrated in the Fig. 3 and evaluated by the last square method. It presented the mean value

$$\Delta\sigma = -10^{-6} N + 81{,}126 \tag{2}$$

where is $\Delta\sigma$ in N/mm^2 and N is the number of absorbed stress cycles

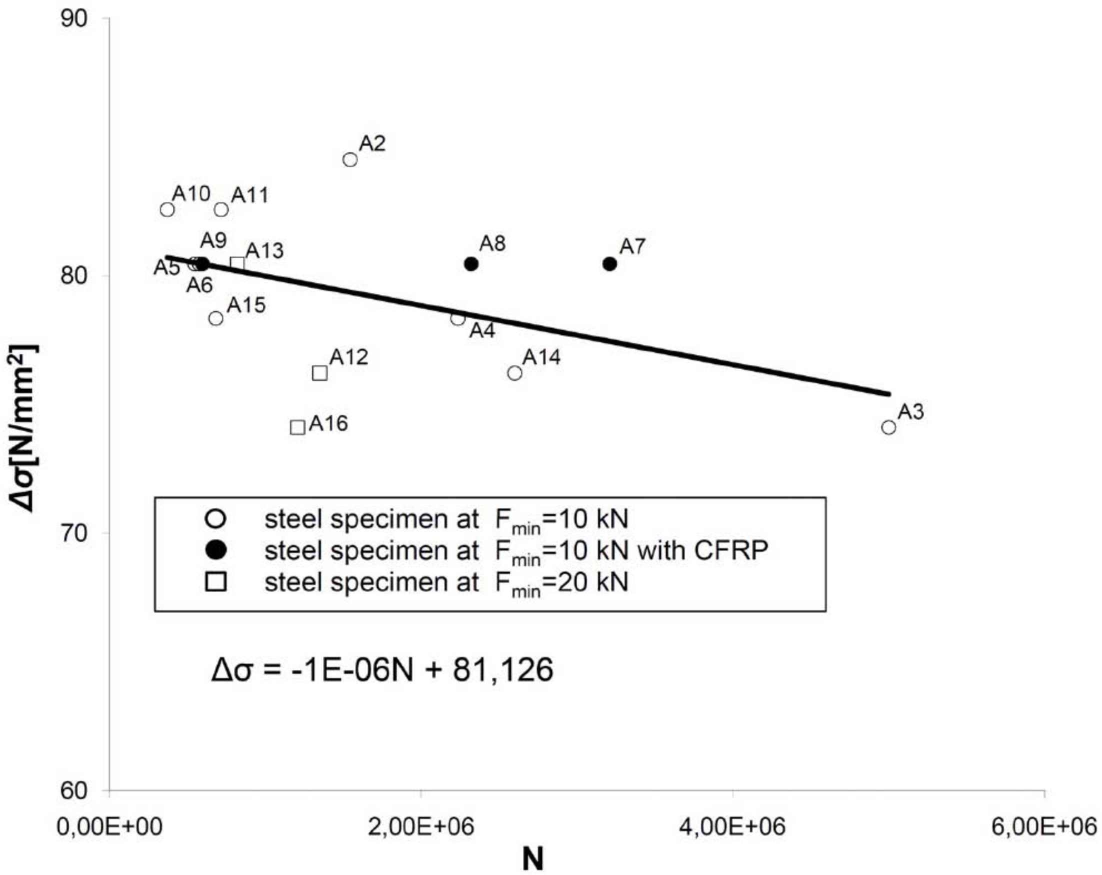

Fig. 3: Stress ranges as a function of absorbed cycles.

The other involved teams tried to raise the fatigue life with the glued carbon fibre elements (Prof. Pirner et al.) and to study the breathing of webs (Prof. Škaloud et al.). Together with the other international teams, the programme has presented a picture on the problem from various sites.

3. Arising of cracks

The arised cracks have at the beginning an unimportant significance. The traffic can continue in most cases. However, the regular (or irregular) inspections signalize that the inspections should be more often. In the mean time, the bridge authorities may prepare the suitable precautions: design a new structure or its repair, etc.

The typical cracs in the cross girder web can be seen in the on the Fig. 4 (specimen A 2) and on the Fig. 5 (specimen A 3).

Fig. 4: Fatigue cracks on the specimen A2.

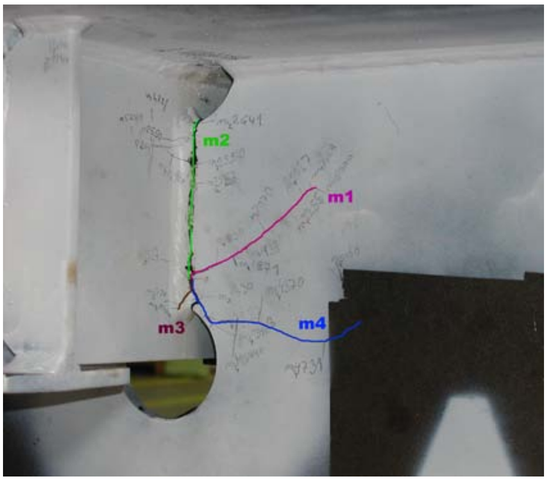

Fig. 5: The fatigue cracks of the element A 3.

The propagation of fatigue cracks on the element A 3 can be seen in the Fig. 6.

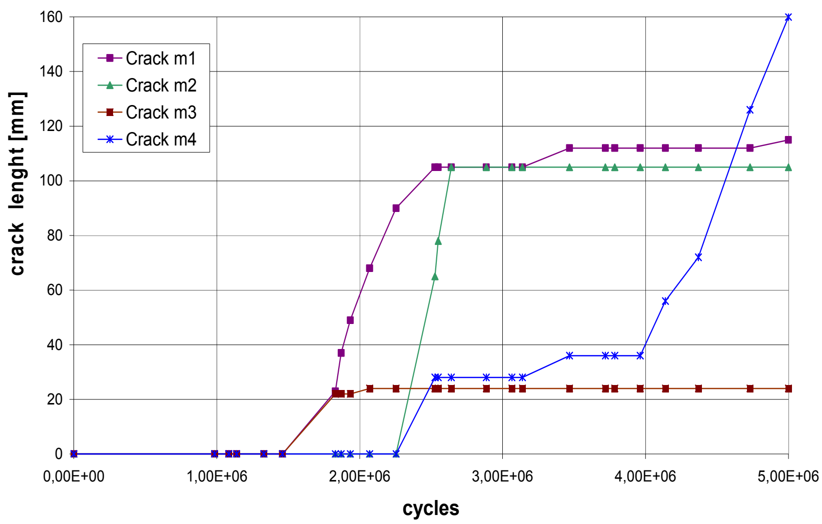

Fig. 6: Propagation of fatigue cracks on the specimen A 3.

The specimen A 4 was statically tested for the hot spot method. The static forces were: 20, 40, ..., 200 kN with steps 20 kN. The static stresses were measured and the results delivered to the Chalmers University for further evaluation using the hot spot method, see the Figs. 7 and 8.

The dynamic forces subjected to the specimen A 4 were 10 kN and 380 kN, respectively, and absorbed 2 236 037 times. The cracks can be seen in the Fig. 8 and their propagation on the Fig. 9.

Fig. 7: The static tests on the specimen A 4 (arrangement for the hot spot method).

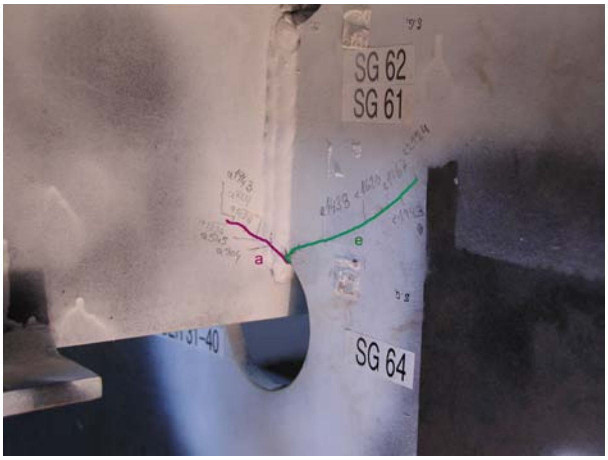

Fig. 8: The cracks on the specimen A4.

The specimen A 5 absorbed first of all the static forces 0 to 200 kN and then the dynamic forces 10 to 390 kN repeated 547 400 times. Analogous results were obtained on the specimen A6. with the forces 10 to 390 and with 576 00 repetitions.

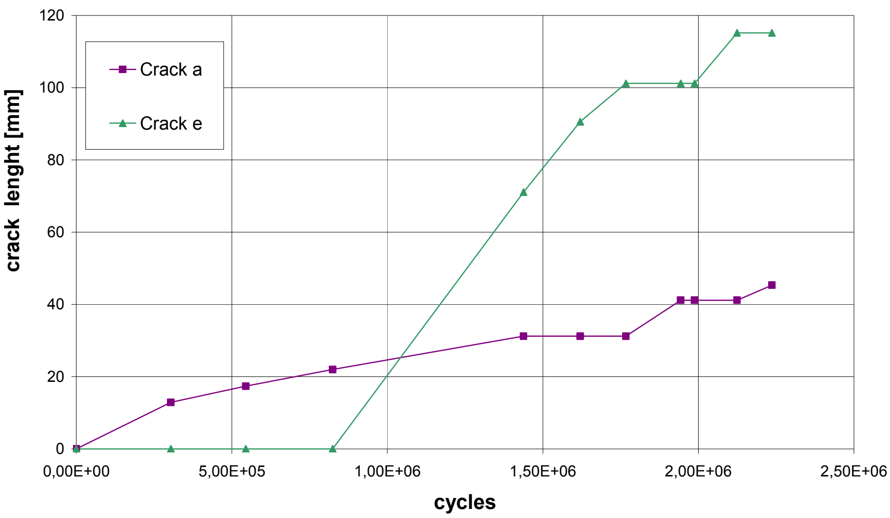

Fig. 9: Propagation of the fatigue cracks on the specimen A4.

The critical places on the specimen A7 were covered with the Carbon Fibre Reinforcement Composites (CFRC) whose statical properties were investigated in details earlier (see the report BRIFAG.ITAM.2009.1). The view of the specimen together with the CFRC is in the Fig. 10. The specimen was loaded by the same forces as that ones on the specimens A 5 and A6 (10 and 390 kN, respectively). To our surprise, the number of cycles was N = 3 500 000. Therefore, the investigation will be repeated on the specimen A 8.

Fig. 10: The specimen A7 covered by the CFRC.

4. Conclusions

The international project "BRIFAG" has presented the fatigue data of orthotropic decks on both the railway and highway bridges. The fatigue cracks appear in the places (in most cases) where the stress concentration arise and form the initiation of fatigue cracks. It happens usually in spatial crossing the deck with cross and longitudinal beams.

The function on N enables to estimate the fatigue life of structural elements. It is the most important result of investigations, Frýba, & Urushadze (2011), Urushadze et al., (2011).

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