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Dynamics of modular expansion joints: The Martinus Nijhoff Bridge

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ABSTRACT

Modular expansion joints are structures that are submitted to severe fatigue load conditions. This may lead to unexpected premature damage of the structure which, besides the economic cost of repair, may limit the regular service of the bridge. To better understand the dynamic behaviour of modular expansion joints, different over rolling tests have been performed at the modular expansion joint of the Martinus Nijhoff Bridge in the Netherlands. The tests were part of a research program for developing an early warning monitoring system for expansion joints. Strain measurements were performed during the passage of a vehicle at different speeds, for two different scenarios regarding the fixations (sliding springs and sliding bearings) of the cross beams. At the same time, a numerical model was developed and validated by means of the experimental data. This article presents and discusses the measurements and the numerical analysis. The results highlight on the effect of the cross beam fixation, and the effect of the vehicle speed on the strain distribution along the centre beam, together with the changes in modal properties of the structure.

1. Introduction

Expansion joints in large span bridges are designed to accommodate the relative displacement due to temperature effects between bridge decks and abutments, ensuring the serviceability of bridges. Expansion joints are subjected to heavy traffic often leading to fatigue damage and subsequent repair and maintenance efforts for responsible bridge administration. In the Netherlands it is estimated that approximately €20 million are spent yearly in the maintenance of expansion joints [1], while in Europe the maintenance of expansion joints represent between 8% and 20% of the total maintenance costs for bridges [2].

Modular expansion joints are common for long span bridges. Modular expansion joints consist of centre beams welded to cross beams, allowing the total gap to be divided into smaller parts in between the centre beams, making it possible to accommodate significant bridge movements (above 100 mm [3]). Additionally, modular joints are designed to prevent the penetration of water and chemicals into the underlying structures, therefore reducing the corrosion of the structural elements [4–8]. Despite the general agreement on the good behaviour of modular joints, some premature failures due to fatigue have been reported in literature [4,5,9].

The Martinus Nijhoff Bridge, located in the Netherlands, opened to traffic in 1996 and contains three modular expansion joints that were designed for a 20 years life expectation. Due to more and heavier traffic than projected the joints were subjected to heavier traffic than anticipated in the design. Therefore fatigue damage was noticed much earlier than expected. Consequently the joints have been repaired several times. The experience in the Martinus Nijhoff Bridge has shown that the damage of the modular expansion joint was, in most cases, initiated by the lack of support of the cross beam, due to the movement of the sliding bearings.

Since joints directly affect the availability of the road network, possible failure of such expansion joints is of major concern for infrastructure managers. Because failure of the joints may lead to an unsafe situation, an early warning monitoring system (EWMS) was developed and implemented on the Martinus Nijhoff Bridge [10,11]. The goal of the system was to foresee possible failure of the joint in an early stage and take preventative measures according to plan, thus causing less hindrance for the traffic. As part of the early warning monitoring system, two over rolling tests were performed, aiming to increase the knowledge of the dynamic behaviour of modular expansion joints. In the second over rolling test the primary goal was to examine the possibility of damage detection on the cross beam fixations (sliding spring and sliding bearing) by monitoring the changes in strain magnitude and modal properties of the modular joint. This paper presents the results of this over rolling test. The effect of sliding bearing degradation was assessed together with the effect of speed and vehicle position. At the same time, a numerical model was developed and validated

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by comparison with the experimental data, which allowed the study of gradual degradation of the sliding bearings.

2. Description of the modular joint

The modular expansion joint chosen for the implementation of the early warning monitoring system is part of the Martinus Nijhoff Bridge. This bridge is located in the centre of the Netherlands, on the highway A2 that makes the connection between the cities of Utrecht and 's Hertogenbosch. The bridge consists of an approach section with ten spans and a main bridge with a span of 256 m and two approach spans of 152 m. The main bridge is a cable stay bridge with a reinforced concrete deck, supported by prestressed concrete cross beams, which are connected to two main girders that are supported by a multiple stay system. The approach bridge has a length of 492 m and consists of a concrete deck supported by longitudinal beams continuous over three spans. The width of the bridge is 34 m. The bridge road has three traffic lanes in each direction. On the western side of the bridge there is a bicycle lane [12]. Fig. 1 shows an overview of the bridge.

The bridge comprises three expansion joints, one between the north abutment and the approach section, one between the approach section and the main bridge and one between the main bridge and the south abutment. All three joints are modular joints manufactured by Maurer Söhne in Germany. The early warning monitoring system was implemented in the modular joint located on the south side.

The modular joint consists of three centre beams supported on cross beams. Each centre beam is welded to a corresponding cross beam, and the cross beams are supported at the joist boxes by sliding bearings and prestressed elements (sliding springs and sliding bearings), to allow the expansion and contraction of the structure.

Fig. 1. Martinus Nijhoff Bridge.

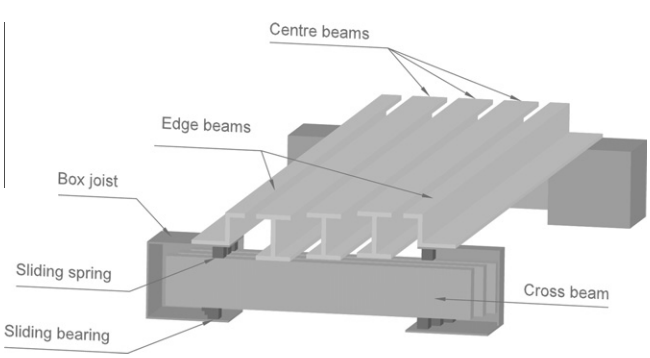

Fig. 2. Modular expansion joint.

The gap between the different centre beams are kept constant by means of control springs. A rubber membrane is placed between each pair of centre beams and edge beams to seal the joint system, and avoid the passage of water and other remains. Fig. 2 shows a schematic view of the modular expansion joint.

3. Experimental program – over rolling test

3.1. Overview

The over rolling test was performed as part of the early warning monitoring system that was applied at the Martinus Nijhoff Bridge for continuously evaluating the performance of the modular joint [11]. The goal of the early warning system is to detect damage in the modular expansion joint by monitoring changes in the dynamic behaviour. As a result, it is expected an extension of the service life of the joint, together with the reduction of traffic hindrance, since maintenance can be planned due to the timely warning.

The over rolling test was performed according to the ETAG recommendations [13].

3.2. Instrumentation

The instrumentation consisted of strain gauges placed along the modular expansion joint. An overview of the device position is presented in Fig. 3. Two distinct areas with sensors can be distinguished, on the west and east sides. These areas are related to the early warning monitoring system. The over rolling test was performed on the west side, at which a total of 27 strain gauges were installed, 16 on the cross beams and 11 on the centre beams (Fig. 3). Centre beams L1 and L3 have 2 strain gauges, one between joist 5 and 6 and another between joist 7 and 8. Centre beam L2 contains eight strain gauges: four at each midspan between joist 4 and 8 and adjacent to the supports between joist 5 and 7.

The goal was to accurately characterise the strain variation along the length of the centre beam. On five joists (joist 4–8), all the cross beams (3 per joist) were instrumented with one strain gauge. All the over rolling test was performed with an sampling frequency of 2000 Hz.

3.3. Tests

The main objective of the research is to determine whether it is possible to detect failure of the sliding bearings by monitoring the strain level. This is related to the past experience of the maintenance manager, where it was found that the degradation of the modular joints is related to the lack of support of the cross beams, due to the movement of the sliding bearings. Therefore, two different test scenarios were performed:

- test 1, which corresponds to the state of serviceability;
- test 2, where one sliding bearing on joist 6 cross beam T2 (see Fig. 3) is manually removed, corresponding to a damaged situation.

For each test, the vehicle crossed the joint at different speeds, and at two different positions (Table 1). Test A corresponds to the vehicle passage with the right wheel crossing the centre beam at the midspan (crossing devices 1/3/5 – see Fig. 3), whereas test B corresponds to the vehicle passage with the right wheel crossing the centre of joist 6 (crossing devices 24/25/26 – see Fig. 3). Test A focused on the behaviour of the centre beams, whereas test B focussed on the cross beam behaviour.