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Full-scale fatigue tests of precast reinforced concrete slabs for railway tracks

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ABSTRACT

This paper describes the experimental part of a research project on the fatigue behavior of precast reinforced concrete slabs for high-speed railway slab track systems, based on the Japanese Shinkansen system. First, characterization tests on the materials and the fastening system were performed, including compressive fatigue tests over cubic specimens carried out in order to get the fatigue parameters involved in probabilistic models of fatigue. Second, three-point bend fatigue tests on the full-scale slabs were conducted. The slabs were placed on two rubber supports, the cyclic sine wave load was applied on its middle section through two rails. The loading frequency was 1.5 Hz, the maximum and the minimum load were 220 kN and 22 kN, respectively. The number of cycles was set 10^6. Third, the loss of stiffness of the slabs was presented before and after the fatigue tests, and its evolution monitored throughout them. The displacement development of the middle section of the slabs under the maximum load was also stored and plotted in order to calculate the secondary displacement rates. These data enabled us to predict the number of cycles to failure of any concrete slab with only knowing its secondary displacement rate. Furthermore, the damage (cracks) was marked in the slab to show the failure pattern. The testing procedure leads to the mechanical deterioration of the slabs with only 10^6 fatigue cycles, while reproducing the actual loads would result in longer and more expensive tests. The results allow us to check resistance of the slab design and could be employed to validate numerical models with fatigue failure criteria.

1. Introduction

Slab railway tracks, also called ballastless tracks, have been used successfully around the world for high-speed lines, heavy rail, light rail and tram systems, see [1–23]. This development is due to the fact that slab track systems have several advantages over ballasted tracks. Especially, concrete slab track systems offer a greater degree of trackbed stability and, therefore, higher running speeds are achievable. Another advantage is that the buckling of rails is avoided altogether, which also makes of these systems good candidates for high-speed lines.

In particular, the Japanese Shinkansen slab track system, mounted for the first time in the line between Tokio and Osaka in 1964, has been fairly used, especially in Japan and Germany. Tayabji and Billow [2] classified it as a two-slab layer system, and Esveld [3] described this system as composed of a sub-layer stabilized with cement, cylindrical bollards or dowels to prevent lateral and longitudinal movement, and reinforced or prestressed precast concrete slabs that are adjusted on top of an in-situ concrete slab by means of spindles and bolts. Between the in-situ slab and the precast elements a gap is left to be filled with a thin layer of cement-asphalt mortar afterwards, see Fig. 1. Such layer conveys to the system the desired degree of vertical flexibility. This system has been selected by the Spanish company OHL S.A. to develop a new type of high-speed railway track that accommodates the two gauges that are in use within Spain, that are the Iberian gauge (1668 mm) and the International Union of Railways (UIC) gauge (1435 mm). This new design is in need of validation, in particular the behavior of the full-scale reinforced concrete slab under the repeated loads of high-speed trains, which constitutes the main objective of the experimental research presented in this paper.

Nevertheless, little research has been published on this topic so far. Some authors tested precast concrete slabs on real track installations, such as Crail et al. [4], who took measurements on a real German slab track system ("Feste Fahrbahn" FF, system Boegl) and on a full-scale test sample, attaching different optic fiber sensors in order to discuss aspects with regard to design and prefabrication of sensors and sensor frames. Their work shows that in-situ tests are very expensive and rarely lead to obtaining sufficient number of cycles to represent the life span of the track.

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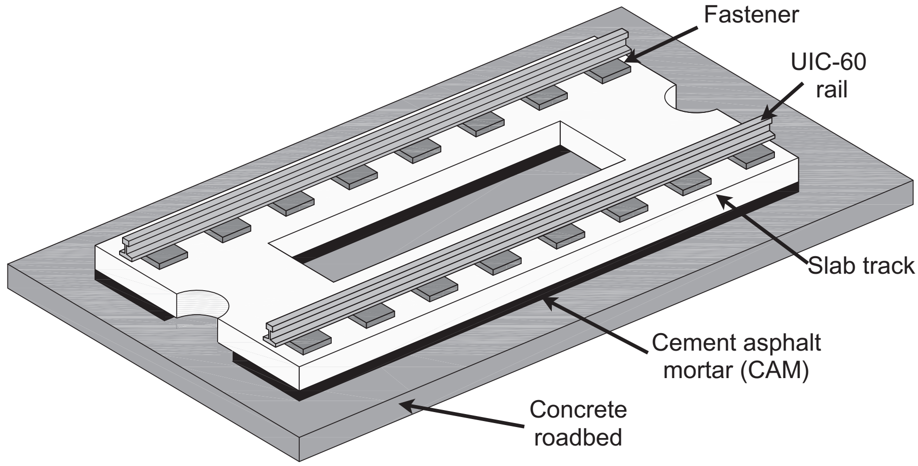

Fig. 1. Slab track system components.

Other researchers tried to reproduce the distributed train loads in a laboratory by using several actuators at different points of the slab, like Ball [9], who described fatigue tests, which lasted for 3 million cycles, conducted over a full-scale direct-fixation slab track (DFST) and independent dual block track (IDBT), with the aim to simulate the train load conditions. Bian et al. [19,20] designed a scaled test on ballastless track for high-speed railways, according to practical engineering design. The wheel loads were simulated by several actuators spaced along the scaled track and that followed a definite sequence mimicking a train passing. Sensors, such as dynamic soil pressure cells, layered settlement transducers and accelerometers, were installed in the ballastless track in order to monitor dynamic response of subgrade and track structure under traffic loadings. Similarly, Hongguang et al. [22] established a dynamic test apparatus for testing slab tracks in Zhejiang University. They simulated the high-speed train traffic loadings using a distributed loading system to represent the movement of wheel axle loads of trains. Thus, they studied the dynamic response of slab structures under different train speeds and the subgrade settlement. Later, Chapeleau et al. [23] demonstrated the applicability of fiber-optic-distributed strain sensing technique to monitor ballastless track structures. They simulated a two axle bogie by applying the loads with two independent groups of four 200 kN hydraulic jacks, with a duration of 10 million cycles. Likewise, Cox et al. [10] designed a test rig to investigate slab track structures for controlling the ground vibration. This rig allowed them to measure dynamic properties of different track systems. They also studied the effects of the changes in track configuration and the distribution of applied loads on the deflection of track component parts. These researchers were aware of the limitations of this procedure as they expressed that the test rig did not aim to replicate a section of slab track, but was a relatively simple system into which real track components could be introduced and evaluated. Thus, the reproduction of distributed traffic loading in a laboratory leads to long and expensive tests, and anyway it does not faithfully reproduce reality.

So, a new, simple and relatively inexpensive laboratory test procedure on precast reinforced concrete slabs for high-speed slab track systems is proposed in this paper, consisting in three-point bend fatigue tests on full-scale slabs. It is inexpensive compared to tests like the ones described above, which imply costly means like the reproduction of the roadbed, the use of multiple actuators, testing several connected slabs, etc. This set-up was adopted in order to get measurable fatigue damage in full-size precast slabs without using several actuators nor complex settings and reaching only 10^6 cycles, so that one whole test on a single slab can take only one week. Our test procedure follows Ball experiments [9] regarding the slab visual inspection and the basic determination of the damage caused to the slab by comparing the static mechanical performance of the slab before an after a repeated load test. Nevertheless, our test procedure includes a novel way for detecting critical damage on the slabs consisting on the analysis of the displacement history of the slab throughout the loading process. Such analysis gives plenty of information regarding the fatigue life of the slab, including the critical displacement that produces failure and a relation between the rate of displacement and the fatigue life that can be used to predict the number of cycles that a definite slab will resist. This analysis has been employed before in structures as concrete bridge deck slabs [24] or in fatigue tests over concrete specimens [25]. Besides, this procedure is considerably cheaper than building experimental tracks in-situ or than reproducing the train loads in a laboratory. The test results obtained with this testing procedure can be employed to validate numerical analyses to study the track behavior, since the procedure also includes a thorough mechanical characterization of the materials used to fabricate the slabs. The characterization includes compressive fatigue tests on cubic specimens, made of concrete from the slabs, in order to get the fatigue parameters relevant to probabilistic models of fatigue.

The rest of the paper is structured as follows: The experimental procedure is presented in Section 2, the results of the tests are described and discussed in Section 3; and finally the conclusions are drawn in Section 4.

2. Experimental procedure

Characterization tests on the materials and the fasteners were performed, besides three-point bend fatigue tests on five of the seven full-scale slabs (S7, S8, S9, S10, S11, S12 and S13). One of the slabs (S7) was discarded during the manufacturing process and another (S8) was employed to adjust the testing procedure.

2.1. Materials

A single conventional plant concrete was used throughout the experiments, made with a siliceous aggregate of 12 mm maximum size and ASTM type I cement, 52.5R. Filler and super plasticizer (BASF Glenium ACE 425) were used in the concrete composition. The mixing proportions by weight were