Construction and Building Materials 111 (2016) 22–29

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Fatigue performance of steel–concrete composite slabs with a cementitious adhesive subjected to water leakage

Isamu Yoshitake [a,*], Yusuke Kuroda [a], Yasuo Watada [b], Yail J. Kim [c]

[a] Department of Civil and Environmental Engineering, Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi 755-8611, Japan
[b] Ube Machinery Co., Ltd., 1980 Okinoyama Kogushi, Ube, Yamaguchi 755-8633, Japan
[c] Department of Civil Engineering, University of Colorado Denver, Denver, CO 80217, USA

HIGHLIGHTS

- Fatigue behavior of composite slabs with water leakage is examined.
- The effect of water leakage is significant on decreasing the fatigue life of the composite slabs.
- Water weakens the bond of the cementitious adhesive when associated with fatigue loading.

ARTICLE INFO

Article history:
Received 12 September 2015
Received in revised form 12 December 2015
Accepted 17 February 2016

Keywords:
Adhesives
Bridge decks
Composite structures
Fatigue
Slabs
Water

ABSTRACT

A steel–concrete composite slab using a cementitious adhesive has been developed to simplify the design of shear connectors between concrete and a steel bottom plate. Fatigue is one of the critical issues for constructed bridge decks, so a moving-wheel fatigue test was performed using the composite slab in a previous study. The test showed the superior fatigue behavior of the proposed composite slab system, while the needs for follow-up research emerged because existing bridge deck slabs frequently suffer from water leakage. The study deals with testing thirteen composite slabs having the cementitious adhesive subjected to water leakage in static and cyclic loadings. Test results show that the fatigue life of the composite slabs in water leakage is significantly lower than that of the slab tested in a dry condition. To further understand the effect of water on reducing the efficacy of the adhesive, supplementary tests are conducted with an emphasis on water-absorption and shear capacity in a wet environment.

1. Introduction

It is well known that steel–concrete composite bridge deck systems have many advantages such as effective use of materials (i.e., steel in tension and concrete in compression), a reduced member size compared with non-composite sections, and an enhanced load-carrying mechanism. Most composite slab systems employ mechanical shear connectors to facilitate the composite action between a concrete deck and supporting steel. Shear connectors positioned in between the deck and steel may cause some technical concerns such as premature cracking at an early age. A new composite bridge deck system with a cementitious adhesive was developed by the authors to preclude potential problems associated with shear connectors [1]. Fatigue is one of the major technical challenges facing the bridge engineering community. A moving-wheel load test was conducted to examine the fatigue behavior of the composite slab [2] and confirmed that the cementitious adhesive had potential for replacing conventional steel shear connectors, including a post-fatigue test dedicated to evaluating the flexural capacity of the slab system. A flexural fatigue test using composite beams was conducted to study a failure mode along with fatigue life [3]. It was confirmed that the bond failure of the adhesive did not occur until concrete crushing.

The fatigue performance of a concrete deck may be influenced by water leakage. Matsushita [4] reported the compressive fatigue life of concrete in water was significantly lower than the fatigue life of dry concrete. Onoue and Matsushita [5] investigated the reduction mechanism of fatigue-concrete subjected to various liquids. The study reported that interfacial energy between the concrete and liquid caused a decrease in fatigue strength. Nishibayashi [6] and Inoue et al. [7] performed a flexural fatigue test using reinforced concrete beams in water. It was observed that the beams under water failed by shear, whereas those tested in a dry condition failed by flexure. Matsui [8] studied the moving-wheel fatigue behavior of reinforced concrete slabs covered with water (wet-cloth). The study reported that the presence of water decreased the fatigue life of the slabs. As such, waterproofing is

* Corresponding author.
E-mail address: yositake@yamaguchi-u.ac.jp (I. Yoshitake).

http://dx.doi.org/10.1016/j.conbuildmat.2016.02.048
0950-0618/

Table 1
Composition of the adhesive.

	Component	Composition (%)
Compound powder	White cement	36
	Quartz sand	54
	Carbon fiber	3
	Additive	7
Liquid emulsion	Water	73
	Acrylic ester	27
	Additive	<1

Manufacturer (Mighty-kagaku).

recommended in Japanese design code [9,10] to enhance the durability of bridge deck slabs.

Most investigations dealing with fatigue performance subjected to water focus on concrete or reinforced concrete members. Although the fatigue behavior of steel–concrete composite slabs may be affected by water leakage [11,12], limited research has been conducted to study the effect of water on the fatigue of a composite structure. Provided that flexural cracks are frequently observed in a concrete deck, water leakage appears to be a concern for constructed composite bridge slabs. This study aims at examining the fatigue behavior of steel–concrete composite slabs with the aforementioned cementitious adhesive, including a groove representing water leakage.

2. Materials

2.1. Cementitious adhesive

A carbon-fiber-blended cementitious adhesive was used for the present experimental investigation. Although the details of the adhesive such as chemical composition and blended carbon fibers (0.5 micrometer dia. × 2–3 mm long) cannot be released because of a contractual obligation to the manufacturer, the constituents and typical engineering properties of the adhesive are provided in Tables 1 and 2, respectively. The adhesive made with the compound powder and liquid emulsion shown in Fig. 1(a) has rust-preventive and waterproof functions [13]. The adhesive components were blended with a portable mixer at a weight ratio of 2.3:1 for the powder and liquid as per the recommendation of the manufacturer. The cementitious adhesive is sprayable as shown in Fig. 1(b). The adhesive sprayed to a steel substrate was cured for 14 days (Fig. 1(c)). Upon complete drying (curing) of the adhesive (Fig. 1(d)), its thickness was measured using a film thickness gage (0.5 mm on average) and concrete was cast. It is worth noting that the amount of moisture supplied from the fresh concrete was not sufficient to affect the bond performance of the dried adhesive, as evidenced by previous study [1–3].

2.2. Steel plate welded with rib stiffeners and reinforcing bar

Fig. 2(a) exhibits a schematic of the proposed composite deck system. Two transverse rib stiffeners, dimensions of 1800 mm long × 70 mm high × 9 mm think, were welded to the steel plate. The stiffeners were periodically perforated at a spacing of 250 mm (semicircular hole with a diameter of 40 mm) to enhance bond

Table 2
Properties of fresh and hardened adhesive.

Fluidity	>250 mm
Air permeability	476 cm^3/m^2 (24 h)
	1455 cm^3/m^2 (72 h)
Flexural strength	5.8 MPa (7 days)
	6.9 MPa (28 days)
Compressive strength	21.0 MPa (7 days)
	36.8 MPa (28 days)
Tensile strength	3.1 MPa (7 days)
	4.0 MPa (28 days)
Tens. bond strength	1.9 MPa (7 days)
	2.2 MPa (28 days)
Strain capacity	0.4% (7 days)
	0.4% (28 days)
Drying shrinkage	0.08% (7 days)
	0.13% (28 days)
Water permeability	0.4% (water pressure: 0.1 MPa)

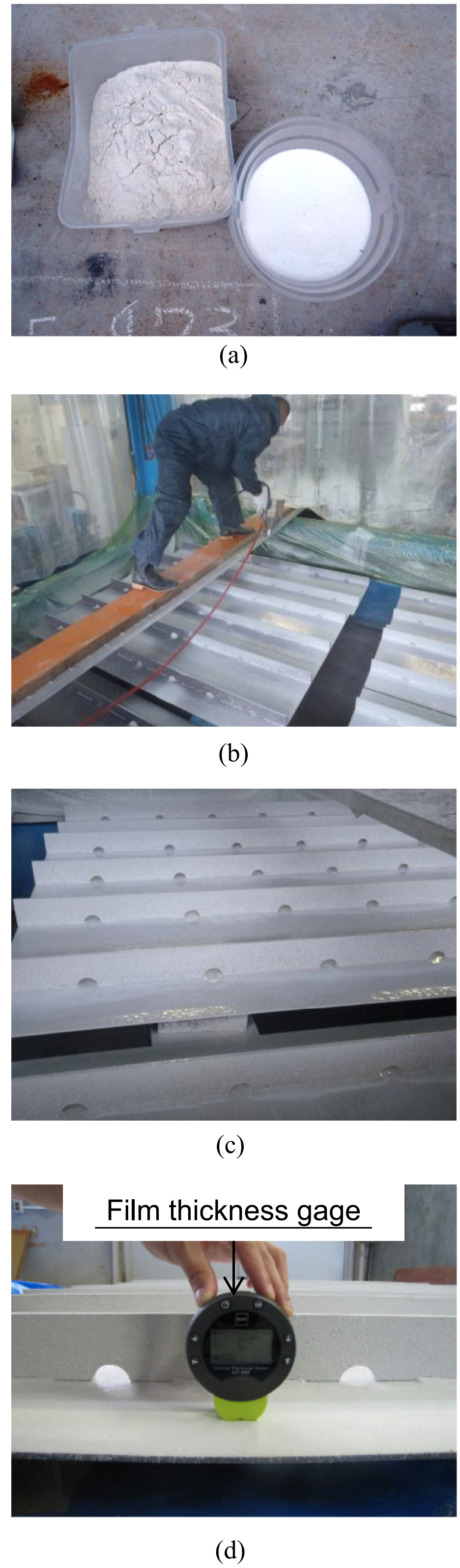

Fig. 1. Application of cementitious adhesive; (a) cementitious powder and liquid emulsion; (b) sprayable adhesive; (c) curing of adhesive sprayed to steel plate; (d) dried adhesive after curing.

between the steel and the concrete. For comparison, Perfobond rib-stiffener (circular hole with a diameter of 30 mm) shown in Fig. 2(b) was also prepared. The nominal yield strength of the steel plate was 245 MPa with an elastic modulus of 200 GPa, while the yield strength of the reinforcing steel bar (13 mm in diameter) had 345 MPa