Engineering Structures 89 (2015) 191–203

Contents lists available at ScienceDirect

Engineering Structures

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

Experimental investigation on fatigue of concrete cantilever bridge deck slabs subjected to concentrated loads

Francisco Natário *, Miguel Fernández Ruiz, Aurelio Muttoni

Ecole Polytechnique Fédérale de Lausanne, ENAC, Station 18, CH-1015 Lausanne, Switzerland[1]

ARTICLE INFO

Article history:
Received 4 December 2014
Revised 27 January 2015
Accepted 10 February 2015
Available online 26 February 2015

Keywords:
Shear strength
Model Code 2010
Critical Shear Crack Theory
Bridge deck slabs
Concentrated load
Fatigue behavior

ABSTRACT

Shear has been observed to be often the governing failure mode of RC cantilever deck slabs of bridges without shear reinforcement subjected to concentrated loads when tested under a quasi-static application of the load. However, concentrated loads of heavy vehicles have a repetitive nature, causing loss of stiffness and potential strength reductions due to fatigue phenomena.

In this paper, the fatigue behavior of cantilever bridge deck slabs is investigated. A specific experimental programme consisting on eleven tests under concentrated fatigue loads and four static tests (reference specimens) is presented. The results show that cantilever bridge deck slabs are significantly less sensitive to shear-fatigue failures than beams without shear reinforcement. Some slabs failed due to rebar fractures. They presented significant remaining life after first rebar failure occurred and eventually failed due to shear. The test results are finally compared to the shear-fatigue provisions of the *fib*-Model Code 2010 and the Critical Shear Crack Theory to discuss their suitability.

1. Introduction

Design of reinforced concrete cantilever bridge deck slabs without shear reinforcement is generally governed by the action of concentrated loads of heavy vehicles (Fig. 1), which may cause shear, punching shear or flexural failures. Amongst these potential failure modes, shear is the most common governing failure mode under quasi-static application of concentrated loads [1–4]. The concentrated loads resulting from heavy vehicles have a repetitive nature and may cause potential stiffness and strength reductions due to fatigue effects [5]. Fatigue failure modes are the same as the static ones and can be due to rebar fracture and/or failure of concrete.

Investigation of fatigue behavior in shear has mainly focused in the past on three and four-point bending tests on reinforced concrete beams without shear reinforcement (Fig. 2a). An extensive summary on this topic can be found in Ref. [6]. Beams can fail in bending or shear in both static and fatigue tests (bending failures being associated to rebar fracture or concrete crushing). Shear-fatigue failures were first studied by Chang and Kesler [7,8]. They observed two potential failure modes: *diagonal-cracking* failures (where failure takes place by development of a diagonal shear crack) and the *shear-compression* failures (where failure takes place when the propagation of the shear crack reduces the depth of the compression zone to an extent such that it can no longer resist the acting compressive forces).

However, it should be noted that the results obtained for beams and one-way slabs are not directly applicable to cantilever slabs subjected to concentrated loads. This is justified as beams do not exhibit a two-way action and consequently cannot redistribute their internal forces due to bending and shear cracking [4]. Moreover, the ratio between the maximum acting moment m_{max} and the maximum acting shear force v_{max} in cantilever slabs at the support is lower than for cantilever beams with the same shear span [2].

With respect to fatigue testing of reinforced concrete slabs without shear reinforcement under concentrated loads, previous research has mainly focused on simply supported or inner slabs [9–19] supported on two or four edges, refer to Fig. 2b and c. Table 1 presents some geometric properties of available experimental evidence. With respect to typical deck slabs of concrete bridges, it can be observed that several specimens have relatively low thicknesses (< 100 mm) and others have low reinforcement ratios ρ ($\leqslant 0.2\%$, including specimens even with no flexural reinforcement) or fairly large ones ($> 1.5\%$).

To the author's knowledge no tests are available on cantilever deck slabs (Fig. 2d), whose mechanical behavior may significantly differ from simply supported slabs [4]. In order to provide such experimental evidence, an experimental programme has been performed at the Ecole Polytechnique Fédérale de Lausanne (Switzerland). The specimens are full-scale slabs (3.00 m × 3.00 m × 0.25 m) with a central line support and subjected to a single

---

[1] http://ibeton.epfl.ch.

* Corresponding author.

E-mail address: francisco.natario@epfl.ch (F. Natário).

http://dx.doi.org/10.1016/j.engstruct.2015.02.010
0141-0296/

Notation

β	load reduction factor
δ	vertical displacement
ε	strain
ε_{max}	maximum strain
ε_{min}	minimum strain
ρ	reinforcement ratio
ϕ_{rebar}	reinforcement bar diameter
E_c	Young's modulus of concrete
F	applied force
F_{max}	maximum applied force
F_{min}	minimum applied force
F_{Ref}	quasi-static strength
LL	level of load
N	endurance
R	fatigue loading ratio
R_l	linear reaction force
S	stress level
V_{CSCT}	quasi-static shear strength according to the CSCT
V_{max}	maximum applied shear force
V_{max}^{tot}	maximum applied total shear force
V_{MC2010}	quasi-static shear strength according to the *fib*-Model Code 2010
V_{Ref}	quasi-static shear strength
V_{tot}	total shear force
a	shear span (distance between the center of the support and the center of the loading plate)
a_v	free shear span (distance between the edge of the support and the edge of the loading plate)
b	subscript indice representing "bottom"
d	effective flexural depth
d_g	maximum aggregate size
f_c	compressive strength of concrete measured in cylinders
$f_{c,Ref}$	compressive strength of concrete in reference tests
$f_{c,fat}$	compressive strength of concrete measured in fatigue tests
f_u	ultimate stress of steel
f_y	yield stress of steel
m_{max}	maximum acting unitary bending moment
t	subscript indice representing "top"
x	x-axis and coordinate
w_{cr}	crack opening
$w_{cr,max}$	maximum crack opening
$w_{cr,min}$	minimum crack opening
v_{max}	maximum acting unitary shear force
y	y-axis and coordinate

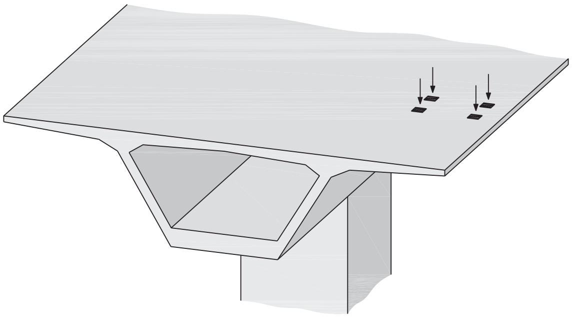

Fig. 1. Cantilever bridge deck slab subjected to concentrated loads.

concentrated load on both sides of the support. Four static tests were performed on two slabs (two tests per slab and load location) and eleven fatigue tests on eight slabs (four slabs per load location).

Other topics as the influence of moving loads [14,15,19] or the influence of impact loading on shear strength [20] are not investigated within this paper.

2. Test campaign

2.1. Test specimens

Ten slabs (FN1-FN10) were tested. The slabs had the dimensions of 3.00 m × 3.00 m × 0.25 m and contained only flexural reinforcement.

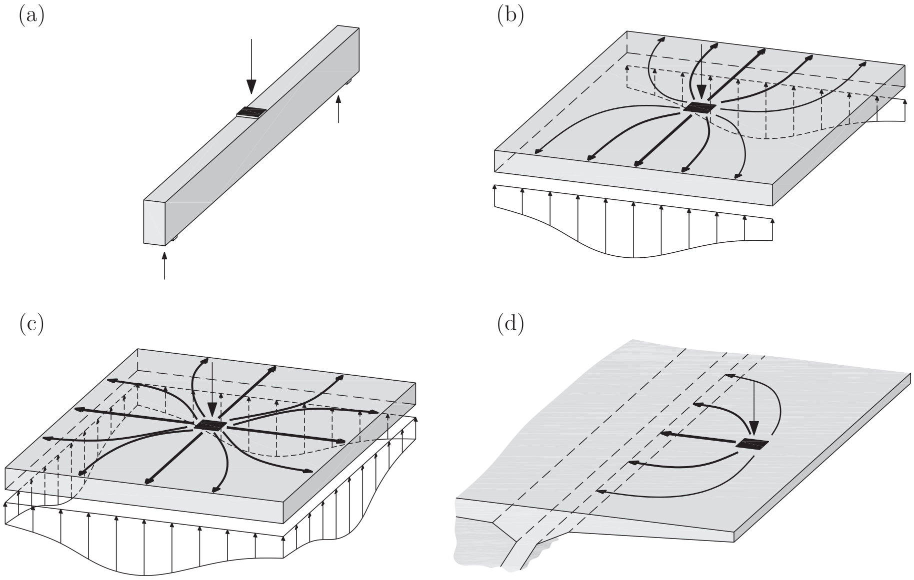

Fig. 2. Structural reinforced concrete members failing in fatigue shear loading: (a) simply supported beam; (b) slab supported on two edges; (c) slab supported on four edges; and (d) cantilever slab.