Engineering Structures 150 (2017) 231–241

Contents lists available at ScienceDirect

Engineering Structures

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

Review article

State-of-the-art on load testing of concrete bridges

Eva O.L. Lantsoght [a,b,c,*], Cor van der Veen [b], Ane de Boer [d], Dick A. Hordijk [b]

[a] Universidad San Francisco de Quito, Politecnico, Diego de Robles y Vía Interoceánica, Quito, Ecuador
[b] Delft University of Technology, Concrete Structures, Stevinweg 1, 2628 CN Delft, The Netherlands
[c] Adstren, Plaza del Rancho, Of. 203, Via Tanda, Cumbaya, Quito, Ecuador
[d] Ministry of Infrastructure and the Environment, Griffioenlaan 2, 3526 LA Utrecht, The Netherlands

ARTICLE INFO

Article history:
Received 13 March 2017
Revised 25 May 2017
Accepted 17 July 2017

Keywords:
Concrete bridges
Existing bridges
Instrumentation
Load testing
Proof load testing
State-of-the-art

ABSTRACT

Load testing of bridges is a practice that is as old as their construction. In the past, load testing gave the traveling public a feeling that a newly opened bridge is safe. Nowadays, the bridge stock in many countries is aging, and load testing is used for the assessment of existing bridges. This paper aims at giving an overview of the current state-of-the-art with regard to load testing of concrete bridges. The work is based on an extensive literature review, dealing with diagnostic and proof load testing, and looking at the current areas of research. Additional available information about load testing of steel, timber, and masonry bridges, buildings, and collapse testing is briefly cited. For the implementation of load testing to the aging bridge stock on a large scale, efficiency in procedures is required. The areas requiring future research are identified, based on the available body of knowledge.

Published by Elsevier Ltd.

Contents

* Corresponding author at: Universidad San Francisco de Quito, Politecnico, Diego de Robles y Vía Interoceánica, Quito, Ecuador.
E-mail addresses: E.O.L.Lantsoght@tudelft.nl (E.O.L. Lantsoght), C.vanderveen@tudelft.nl (C. van der Veen), ane.de.boer@rws.nl (A. de Boer), D.A.Hordijk@tudelft.nl (D.A. Hordijk).

http://dx.doi.org/10.1016/j.engstruct.2017.07.050
0141-0296/Published by Elsevier Ltd.

Nomenclature

The following symbols are used in this paper:

effR_u	capacity of the structure
extF_{lim}	additional load that can be applied to reach onset of nonlinear behavior
extF_{target}	additional load to achieve the target proof load
f_R	probability density function of the resistance
f_R^*	probability density function of resistance, updated with information of proof load test
f_s	probability density function of the load
f_{ym}	average yield strength of steel on the tension side of the cross-section
$f_{0.01m}$	average yield strength based on a strain of 0.01% (elastic zone)
l_t	span length
s_p	magnitude of proof load
$\tan(\alpha_i)$	the secant stiffness at any point i on the increasing loading portion of the load-deflection envelope
$\tan(\alpha_{ref})$	the slope of the reference secant line for the load-deflection envelope
w	crack width
D_d	factored dead load
D_s	superimposed dead load
D_w	self-weight of concrete
E_s	modulus of elasticity of reinforcement steel
F_{lim}	onset of nonlinear behavior
F_R	cumulative distribution function of the resistance
F_s	cumulative distribution function of the load
F_{target}	target proof load
G_1	load caused by permanent loads
G_{di}	additional permanent loads, not acting on the bridge at time of testing
I	impact allowance
I_{DL}	deviation from linearity index
I_{pi}	permanency index for the i-th load cycle
$I_{p(i+1)}$	permanency index for the (i+1)-th load cycle
I_{pr}	permanency ratio
L	live load
L_d	factored live load
L_r	live load on the roof
L_R	comparable live load due to the rating vehicle for the lanes loaded
L_T	target proof load according to the Manual for Bridge Rating through Load Testing
P	load
P_{fa}	probability of failure after proof load test
P_{fb}	probability of failure before proof load test
P_{fd}	probability of failure during proof load test
P_i	load in i-th load cycle
PL	target proof load
$P_{\max}$	maximum load in load test
$P_{\min}$	baseline load
P_{ref}	load in first load cycle
Q_d	transient loads
SL	snow load
R	resistance
RL	rain load
R_n	load effect
TLM	test load magnitude
X_{PA}	target live load factor
$_{c}$	strain measured during proof loading
$_{c,lim}$	limit value of the concrete strain : 0.6‰, and for concrete with a compressive strength larger than 25 MPa this can be increased up to maximum 0.8‰.
$_{c0}$	analytically determined short-term strain in the concrete caused by the permanent loads that are acting on the structure before the application of the proof load
$_{s2}$	steel strain during experiment: directly measured or derived from other measurements
$_{s02}$	analytically determined strain (assuming cracked conditions) in the reinforcement steel caused by the permanent loads that are acting on the structure before the application of the proof load.
$\Delta^i{}_{\max}$	maximum deformation occurring in i-th cycle, measured between beginning and peak of the i-th cycle
Δ_r^i	residual deformation occurring between i-th and (i-1)-th cycle
Δ_l	maximum deflection
Δ_r	residual deflection
Δ_{ref}	deflection in first load cycle
Δw	increase in crack width of an existing crack

1. Introduction

Load testing of bridges is a practice as old as building bridges [1]. In the early days, when analytical methods for determining bridge response were not well-developed yet, load tests were carried out prior to opening bridges to the traveling public, as a way to show that the bridge is safe. Sometimes, the load test resulted in the collapse of the new bridge [1]. In some countries, such as Switzerland [2] and Italy [3], such load tests are still required prior to opening.

Since the early days, load testing has also been used to evaluate the performance of existing bridges. While nowadays the analytical methods for predicting bridge responses are much more refined, and the need for convincing the traveling public that a bridge is safe has diminished, the uncertainties on the bridge's behavior increase over time due to the effect of deterioration mechanisms. Moreover, the design methods prescribed in the codes aim at providing a conservative method, suitable for design. Upon assessment, the goal is to have an estimate of the bridge behavior that is as precise as possible. Therefore, additional mechanisms, which are traditionally not considered in the codes, can be counted on, such as transverse load distribution for shear in reinforced concrete slabs [4,5]. In bridge types where the additional mechanisms are not well-known, load tests can be used to have a better understanding of the bridge behavior. This understanding can be in terms of response, in order to calibrate analytical models,