Journal of Constructional Steel Research 138 (2017) 538–554

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Valencia bridge fire tests: Experimental study of a composite bridge under fire

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ARTICLE INFO

Article history:
Received 12 May 2017
Received in revised form 31 July 2017
Accepted 7 August 2017
Available online xxxx

Keywords:
Valencia bridge fire tests
Steel-concrete composite bridge
Mass loss rate
Bridge fire
Bridge resilience

ABSTRACT

The consequences of bridge fires and the lack of guidelines on the evaluation of the fire resistance of bridges have triggered a lot of recent research. Most of these studies are based on numerical models and thus need validation by experimental studies.

This paper aims to bridge this gap by describing a battery of open air fire tests carried out under an experimental bridge at the *Universitat Politècnica de València* in Valencia, Spain. The bridge, with a 6 m span and a composite deck with two steel I-girders supporting an RC slab, was submitted to four different fire scenarios similar to those of real bridge fires, although smaller in magnitude. Results show that: (a) maximum gas temperatures are reached in the region between the I-girders, (b) as gas and steel temperatures vary significantly along the longitudinal axis of the bridge, it is unrealistic to assume a longitudinally uniform gas or girder temperature (c) temperatures in the bottom flange and the web of the I-girders are very similar and significantly higher than top web temperatures, and (d) the magnitude of the fire load and its position are key factors in the bridge response. This study is of major importance as it enables the validation of the numerical models used in bridge fire engineering and is a crucial step towards the development of a performance-based approach for the design of bridges against fires. The information given will also be useful to those interested in carrying out open air experimental bridge fire tests.

1. Introduction

As bridges are a critical component of the road transport infrastructure, a lot of effort has been put into designing them to withstand accidental extreme load events, such as earthquakes, winds, scour, and ship collisions (e.g. Ghosn et al. [1]). Recent studies (Peris-Sayol et al. [2], Wright et al. [3] and Garlock et al. [4]) have shown that fire is also a major hazard for bridges and highlight the lack of guidelines in current codes on how to estimate a bridge fire resistance.

The serious consequences that can arise from a bridge fire can be illustrated by two fire events: an overturned tanker truck in the MacArthur Maze in Oakland, USA on April 29th 2007 caused the collapse of two spans of the Maze. This collapse resulted in repairs and rebuilding operations costing more than US $9 million [5] and indirect costs due to traffic detours of US $6 million per day [6]. The second example is the fire caused by a tanker truck that overturned when crossing the Mathilde Bridge in Rouen (France) on October 29th 2012, caught fire and spilled fuel that set fire to some trucks parked under the bridge. The bridge suffered severe damage and had to be closed until August 26th 2014, almost two years afterwards. The total cost associated with this event has been estimated at €18 million [7].

Traditionally, fire engineering has paid a lot of attention to mitigating the effects of fires in buildings and tunnels (see e.g. Fischer and Varma [8], Gernay et al. [9], Rodrigues and Laím [10], Rinaudo et al. [11]). However, as can be seen in Table 1, bridge fires have specific features that distinguish them from building and tunnel fires, which together with the gap in the current codes, have generated a lot of research on this topic in recent years. Garlock et al. [4] carried out a detailed review of incidents, case studies and assessment and repair strategies related to bridge fires. This study was complemented by Peris-Sayol et al. [2], who used statistical tools to collect and analyze data from 154 bridge fires and proposed a classification of bridge fire damage levels. The study showed that the bridge vertical clearance and deck material, the type of vehicle involved in the fire, the fuel carried by the vehicle and its position, were the main factors involved in the extent of bridge damage. Other researchers (Naser and Kodur [20], Gil et al. [21]) have proposed specific risk analysis methodologies, while others have used different approaches to study bridges fire response, including the use of fire curves (see e.g. the study on a steel girder bridge by Payá-Zaforteza and Garlock [12]), simplified methodologies based on the calculation of radiation heat fluxes applied to fires below

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http://dx.doi.org/10.1016/j.jcsr.2017.08.008
0143-974X/

Table 1
Differences among bridge, building and tunnel fires.

	Bridge fires	Building fires	Tunnel fires
Cause of the fire	Collisions (e.g. tanker truck accident). Ignition of construction materials (e.g. wooden formwork) during construction. Ignition of materials stored under the bridge. For further information see Garlock et al. [4] and Peris-Sayol et al. [2].	Ignition of the materials stored in the building	Collisions (e.g. tanker truck accident)
Type of fire and fire development	Hydrocarbon fire (in the most harmful case) with fast heating rates and high fire intensities (see Paya-Zaforteza and Garlock [12]). The fire is fuel controlled, there is no oxygen limitation. The heat feedback to the fuel surface in girder bridges depends mainly on the flame volume, the position of the fuel surface and the bridge geometry (see Peris-Sayol et al. [13]).	The typical building fire is cellulosic. This fire is less intense and results in lower temperatures than a hydrocarbon fire. The fire can be fuel or ventilation controlled. Flashover can happen. For further information see Buchanan and Abu [15].	Hydrocarbon fire (in the most harmful case). Tunnel fires can be fuel-controlled (then unreacted air by-passes the burning vehicles), or ventilation-controlled (with large amounts of toxic combustion products or toxic chemical species and incomplete combustion products). There is a heat feedback to the fuel surface from the surrounding environment which depends on parameters such as flame volume, tunnel lining, tunnel cross sectional area and tunnel ventilation For further information see Ingason et al. [17].
Fire curves	No specific fire curves available	Nominal fire curves such as the ISO-834 and the ASTM E119 available Parametric fire curves available. See e.g. EC-1 Part 1–2 [16]	Fire curves available, such as the modified hydrocarbon HCM, RWS, RABT ZTV. See ITA [18].
Structural engineering	As design codes do not specify any fire resistance for bridges, bridges are not designed against fires and do not typically have any type of fire protection. Bridge span lengths and design loads are usually much higher than in buildings. Therefore, bridge steel members are usually more slender and prone to failure modes not so critical in buildings, such as web buckling. (see Paya-Zaforteza and Garlock [12], Glassman and Garlock [14]).	Design codes specify the fire resistance required in buildings. Therefore, buildings are designed against fire hazards and can have passive and/or active fire protection.	Some guidelines (ITA [18], NFPA [19]) have proposed design criteria for the fire resistance of road tunnels. As fire hazards are commonly considered in tunnels, they can have passive and/or active fire protection.
Design objectives	Loss of life is not a major issue as fatalities are usually caused by the collision that started the fire, not by the bridge collapse or bridge damage. The major issue is to ensure the bridge can continue in operation and so avoid traffic problems.	Avoiding life loss is the major objective.	Avoiding life loss is the major objective.

steel and composite girder bridges (Quiel et al. [22]) or Computational Fluid Dynamics models of: (a) fire events below steel and composite bridges (Alós-Moya et al. [23], Peris-Sayol et al. [24,25], Wright et al. [3]), (b) a fire event in a long-span truss bridge (Gong and Agraval [26]) and (c) fires below and on the deck of cable supported bridges (Gong and Agraval [27]).

Experimental work on bridge fires is quite scarce due to the dimensions of bridge elements and the fire loads required, being noteworthy the work by Aziz et al. [28], who experimentally and numerically analyzed the fire performance of steel girders similar to those used in bridges. The girders spanned 3.658 m and were uniformly heated along their length in a furnace with the standard fire curve. The work by Aziz et al. [28] is an important contribution but it also has limitations that justify additional experimental research on bridge fires, including: (1) the standard fire curve is a cellulosic fire curve developed for building fires and is not representative of bridge fires, (2) bridge fires do not uniformly heat girders along their length and cross section, (3) bridge fires happen in the open air in conditions different to those in a furnace and (4) the bridge expansion joints should be considered in the experiments, since they can play a major role in the structural response, as has been shown by [12,23–25].

Within this general context, this paper details the procedures and results of a battery of fire tests conducted on an experimental bridge with a composite deck at the campus of the Universitat Politècnica de València in Valencia, Spain. The tests described here are of major importance, because, as far as the authors know, this is the first time that an entire bridge has been submitted to a number of different realistic fire scenarios, although of smaller fire load magnitude, and a complete set of thermal and structural results is provided. These results could subsequently be used to calibrate the numerical models used in bridge fire engineering. The experimental validation of these models is crucial to adequately predict the damage fires can cause on bridges and therefore to increase bridge resilience through the development of a performance-based approach to protect bridges from fires. The paper also provides interesting qualitative and quantitative information on bridge fire response, as well as detailed information that will be useful to those interested in carrying out open air experimental tests involving bridge fires.

2. Description of the experimental bridge

The experimental bridge (see Fig. 1) was divided into three parts:

1) Two abutments built on a leveling slab that placed the lower surface of the deck girders at a height of 1.9 m above the top face of the leveling slab. This top face was taken as the reference level (level 0 in Fig. 1a) in the project.
2) A composite steel-concrete deck formed by a 0.15 m thick concrete slab joined by shear studs to two IPE-160 steel girders. The deck was 6 m long and 2 m wide. The separation between the axes of the two IPE-160 girders was 1 m, with a 0.5 m overhang on each side. The girders were supported on the abutments by two unreinforced elastomeric bearings measuring 200 × 200 × 20 mm. A composite deck with I-girders was chosen because the analysis of bridge fire events by Peris-Sayol et al. [2] found this to be the most common structural system in bridges that had collapsed or suffered severe damage in fire events.
3) Two auxiliary steel frames used to fix the LVDT sensors used to record the vertical deflections of the deck during the tests.