Engineering Failure Analysis 36 (2014) 353–361

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Analysis of a bridge collapsed by an accidental blast loads

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ARTICLE INFO

Article history:
Received 16 September 2013
Received in revised form 22 October 2013
Accepted 30 October 2013
Available online 9 November 2013

Keywords:
Bridge collapse
Fireworks explosion
Engineering algorithms
Numerical simulation

ABSTRACT

Analysis of the structural failure of a bridge caused by an accidental fireworks explosion is presented in this paper. The equivalent mass of TNT due to the fireworks explosion and the structural response of the bridge due to the dynamic load imposed by the explosion are modeled by engineering algorithms and numerical simulations. Analysis confirmed that bridge failure occurred due to the blast load and there was no inherent design defect. The results of this investigation are relevant towards understanding future events wherein a dynamic load might be accidentally applied to fixed structures.

1. Introduction

Military assaults, terrorist attacks and accidental explosions may cause serious damage to buildings and other infrastructures [1–4]. Bridges are the most common infrastructures in a national highway system. As a result of terrorist threats and attacks, engineers and transportation office workers are becoming more active in physically protecting bridges from potential blast attacks [5,6]. Damage effect analyses and assessments of bridges under blast loading are very important in the area of explosion accident analyses, blast-resistant design and anti-terrorist and military weapon design [7].

With the rapid development of computer hardware over the last decades, detailed numerical simulations of explosive events in personal computers have become possible and significantly increased the availability of such methods. New developments in integrated computer hydrocodes, such as the AUTODYN software [8] used in this paper, complete the tools necessary to conduct a numerical analysis successfully.

Although efforts have been exerted to model blast effects on civilian structures, mainly on building structures, relatively less attention has been directed toward bridge structures under blast loads. Two simulations of bridge structure responses to blast loads were conducted by Winget et al. [9] and Islam and Yazdani [5], who separately investigated the response of an AASHTO concrete girder bridge under blast impact using an uncoupled SDOF system and the commercial software STAAD.Pro, respectively. Both researchers considered various detonation positions to obtain a better perspective of bridge performance against blast loadings. Results indicate that the studied bridge type is highly vulnerable to failure under the impact of a conventional truck bomb. Winget et al. [9] concluded that bridge response under blast loads is highly dependent on bridge geometry, such as clearance of the bridge deck from the ground and the confinement effect resulting from the deep girder; these factors can significantly enhance the magnitude of the blast pressure acting on the structure.

Unintentional explosions are highly undesirable. In process industries, steps are frequently taken to minimize the causes and consequences of accidental explosions [10]. When an explosion occurs, attention shifts from prevention to attribution from the perspective of both cause and effect. A forensic engineer seeks to understand whether any resulting harm to

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http://dx.doi.org/10.1016/j.engfailanal.2013.10.022

persons or property can be attributed to negligence on the part of those responsible for the design, construction, maintenance or operation of the damaged structural system.

In this study, the aftermath of an accidental explosion on a bridge is reported. Observed structural damages are explained in detail. The determination of accident causes and bridge design defects is the main issue addressed when dealing with the accident. The equivalent TNT mass of the fireworks explosion and the structural response of the bridge attributed to the dynamic load imposed by the explosion are modelled by engineering algorithms and numerical simulations. The analysis confirms that bridge failure occurred because of the blast load without any inherent design defect. Thus, we can determine whether the power of the fireworks explosion can damage a well-designed bridge.

2. Incident

A truck loaded with fireworks exploded on a bridge in China in early 2013. This accident caused part of the bridge to collapse, and the local deck of the bridge was marred. Fig. 1 shows the ruptured configuration of the cross section of the bridge.

From the accident report, the explosion occurred on the third span of the bridge, as shown in Fig. 2. The length of one span of the bridge is 40 m, the width of the deck is 11 m, the least thickness of the deck is 17.7 cm and the largest thickness of the deck is 31 cm. This bridge consists of five girders: two are side girders and three are middle girders. The width of each girder is 240 cm, as shown in Figs. 3 and 4.

3. Distinguishing the accident causes

3.1. Analysis of the equivalent mass of TNT in the accident by numerical simulation

Using numerical simulation [8,11], three typical damage spots were reproduced. The least equivalent TNT mass to achieve the damage effects was affirmed.

The first damage spot was a car engine and its accessories weighing 380 kg and thrown 75 m away. The initial velocity of the car engine was calculated to be 35 m/s based on the height of the deck from the ground and the distance by which the engine was thrown away. By simplifying the engine and its accessory, a fluid–solid couple model with the explosive, air and engine was created to simulate the action of the engine while being thrown away. When the TNT mass was greater than or equal to 500 kg, the velocity of the thrown engine was the same as the request velocity, as shown in Fig. 5.

The second damage spot is the glass in building structures with distances of 500 m, 800 m and 2000 m away from the explosion center broke up in different levels. In accordance with the critical overpressure of shock wave to break up the glass (2–12 KPa), the least mass of TNT equivalence can be ascertained. The multi-material Euler method is used to compute the air shock wave profiles with different mass of TNT and different distance, as shown in Fig. 6. From Fig. 6, the least mass of TNT of the explosion is 800 kg.

The third damage spot was the balustrade of the other bridge near the blast center, which had a 7 m breach as shown in Fig. 7. A large part of the bridge deck under the accident truck was also crushed.

A finite element model was built to compute for the damage modes of the bridge under different TNT masses. From the numerical simulation results, the length of the balustrade breach and the crushed deck were in accordance with the accident spot when the TNT mass was 800 kg, as shown in Fig. 8. From this phenomenon, the TNT mass of the explosion was calculated to be 800 kg.

Moreover, based on the analysis of the conditions of the reproduced typical damage spots in the accident, the TNT mass of the explosion was calculated to be 800 kg.

Another analysis of bridge damage under blast load with a TNT mass of 3650 kg was conducted by numerical simulation. When the TNT mass was 3650 kg, the lengths of the balustrade breach and the crushed deck are shown in Fig. 9. The balustrade of the other bridge had a 9 m breach, and the area of the crushed deck was approximately 14 m^2 larger than the damage spot. From this phenomenon, the TNT mass of the explosion was calculated to be less than 3650 kg.

Fig. 1. The ruptured configuration of the cross section of the bridge.