International Journal of Impact Engineering 75 (2015) 30–39

Contents lists available at ScienceDirect

International Journal of Impact Engineering

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

Test and numerical simulation of truck collision with anti-ram bollards

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ARTICLE INFO

Article history:
Received 2 March 2014
Received in revised form
15 July 2014
Accepted 20 July 2014
Available online 4 August 2014

Keywords:
Bollard
Concrete filled tubes
Truck collision
Finite element

ABSTRACT

Inelastic transient finite element simulations based on an actual truck collision test are used to investigate the demands imposed during collisions between medium-duty trucks and anti-ram bollards constructed with concrete-filled steel tubes (CFT). The medium-duty truck is considered for crashing into a bollard at speed 50, 65, and 80 km/h, respectively, based on performance demands of bollards of different grades. Numerical results show that both the impact force and the bollard deflection increase with increasing the truck impact speed. When the speed is relatively high (e.g. 80 km/h), there is a risk of the truck climbing over the bollard, even with little damage to the bollard. The analyses show that the impact force along the height of the bollard is not uniform and may change during the impact process. Considering the complexity and computation time consumption, a simplified analysis based on a two-degree-of-freedom mass-spring-damper system model is developed to simulate the collision process. In the analysis, a bilinear spring is used to characterize the truck considering its "soft front and hard rear" characteristics when impacting bollards. Results show that the simplified analytical model is in good agreement with the finite element model using a detailed truck model.

1. Introduction

The significant increase in terrorist activities, particularly the attack on World Trade Center Towers in New York on September 11, 2001, alarmed the international community for further enhancement of protection of important facilities and infrastructure against man made hazards. Among many forms of terrorist attacks, bombing is one of the most dangerous and frequently encountered threats to important civil infrastructures. According to the report of the U.S. National Counterterrorism Center [1], bombing contributed to the second largest number of terrorist attacks and caused the largest number of fatalities in 2010. Terrorist bombing attacks can take the form of vehicle bomb, human bomb, mail bomb, suitcase bomb, etc. As vehicles can carry a large amount of explosive charge, vehicular bombing poses the most serious threat, especially to important buildings. For example, on August 7, 1998, U.S. embassies in Kenya and Tanzania were attacked by vehicle bombs one after another, killing 243 people and leaving 5000 people injured. On August 25, 2003, two vehicle bombs exploded in Mumbai, killing 52 people and injuring more than 200 people. On December 8, 2009, government buildings in Baghdad were attacked by a chain of vehicle bombs, resulting in the death of at least 127 people and injuries to more than 513 people. Hence, it is very important to protect crucial (critical) buildings and other civil infrastructures from destructive effects of vehicular bombs. Engineering measures for the protection of crucial buildings against vehicle bombs can be divided into three categories. The first measure is to enlarge the distance between the possible point of explosion and crucial buildings by setting up roadblocks so as to reduce explosive hazards. The second is to block the air shock wave by setting the blast-resistant walls. The third measure is to strengthen key components of an important building to enhance their resistance to blast loads such that the collapse of the whole structure could be prevented. To date, there have been numerous reports on the component strengthening and anti-blast wall research. However, there are only few studies on the anti-blast roadblocks, especially anti-ram bollards [2–5]. Currently, there is no systematic design approach for this type of structure. This paper addresses this issue through a field test and detailed finite element simulations. While the finite

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http://dx.doi.org/10.1016/j.ijimpeng.2014.07.011
0734-743X/

element results can be used to better understand the collision process, a two-degree-of-freedom mass-spring-damper system model is also established to simplify the analysis and design of impact resistant bollards.

2. Field test

The field test was carried out by following the requirements of *SD-STD-02.01 Revision A* [6], which is the certification standard of perimeter barriers and gates in the United States of America.

2.1. Bollard design

The test bollard system, as shown in Fig. 1, was designed by KCPT, Singapore. The upper structure comprised of five identical concrete filled steel tubular (CFT) columns placed at equal spacing. Cross-sectional properties of each of the columns are: diameter = 219 mm; thickness of the circular steel tube = 20 mm and length of the circular tube above ground = 1265 mm. The average yield and ultimate strengths of the steel tubes are 346.6 and 546.0 MPa, respectively. The average cylindrical compressive strength of the concrete filled in the tubes at the time of testing was 20.7 MPa. The footing of the columns consisted of steel plates, reinforcements and concrete and had dimensions of 7400 mm in length, 2200 mm in width, and 385 mm in height (including a 35 mm-thick concrete cover). The steel plates with 10 and 16 mm in thickness and nominal yield strength of 235 MPa were used. The reinforcements had nominal yield strength of 335 MPa and a diameter of 25 mm. The average compressive strength of the concrete in the footing at the time of testing was 25.3 MPa.

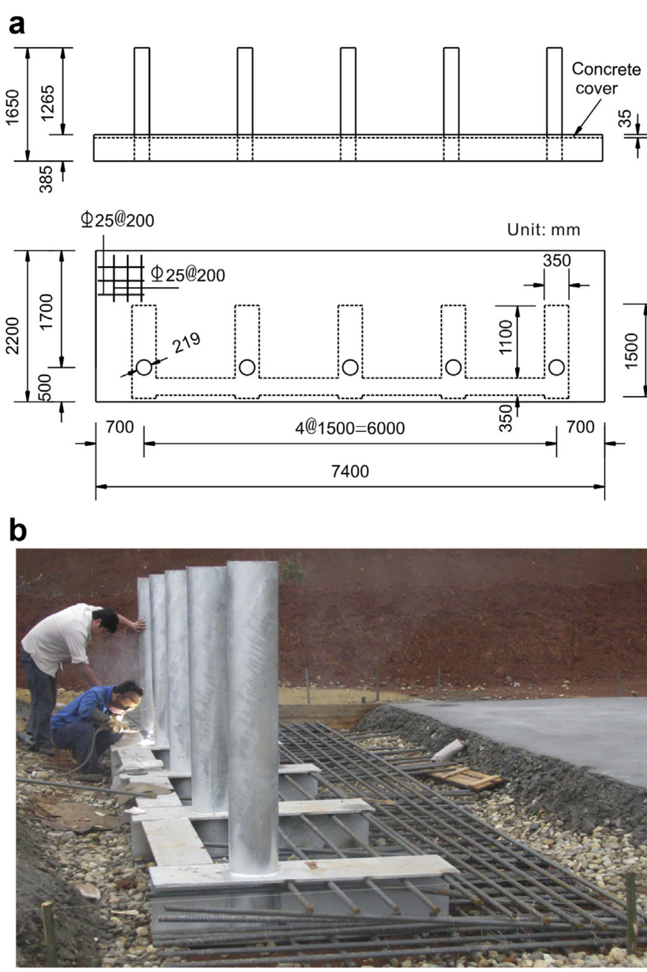

Fig. 1. Bollard system: (a) design details; (b) footing.

2.2. Collision truck

As shown in Fig. 2a, a Dongfeng-EQ140 medium-duty truck, which is widely used in China, was selected as the collision truck for the field test. The truck was diesel engine rear wheel drive vehicle, with a net weight of 5170 kg. The truck was retired from duty, but fully equipped with the entire engine and other parts and was able to move if hauled or pushed. Before testing, the truck was loaded with six petrol barrels filled with soil to reach the required total weight of 6800 kg [6]. The collision truck was set to neutral gear and was pulled by another truck through a wire and pulley system to reach the required impact speed. Immediately before the collision, the pulling wire and the truck were separated by a trigger device [7].

2.3. Test results

The collision truck was crashed almost straight into the middle bollard, as shown in Fig. 2b. The speed of the truck just before the impact was recorded as 43.2 km/h. The truck was damaged severely after the collision, with the bumper bent and fractured in the middle, the driver's cabin severely compressed with the doors jammed and the steering wheel touching the seatback of the driver's seat. The front right and left wheels went beyond the other edge of the bollard by 33 and 23 mm, respectively. As shown in Fig. 2b, the front edge of the truck bed was still away from the other edge of the bollard, implying that the bollard successfully stopped the truck at the desired location. On the other hand, the bollard deformed slightly and no buckling was identified on the steel tube.

Fig. 2. Truck in the field test: (a) before collision; (b) after collision.