

Test and Numerical Simulation of Fixed Bollard and Removable Bollard Subjected to Vehicle Impact

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Abstract

Crash bollard system is a type of physical security measures used to prevent forced entry by vehicles, as well as to provide adequate standoff distance between the target and a Vehicle-Borne Improvised Explosive Device (VBIED). Thus, the design of crash bollard system will have to take into consideration against high-energy vehicle impact and minimizing the post-impacted penetration. In this paper, fixed bollard and removable bollard systems are developed as inelastic transient finite element models. Both systems are simulated against a vehicle crash impact using LS-DYNA analysis tool. Full-scale vehicle crash tests have been carried out to validate the design and analysis.

1. Introduction

Terrorism remains a threat for all nations including Singapore. Past events have shown that the use of vehicle bombs is a common mode of attack. Protection against explosive threats and vehicular impact threats has developed into a requirement. A combination of security measures could be employed to protect building. It would involve active measures covering access control, security screening and surveillance, as well as passive measures such as barriers and bollards.

Standoff distance is one of the most effective ways to reduce the blast effects of a vehicle borne improvised explosive devices (VBIED). This can be accomplished by designing blast blast-resistance structure and/or Vehicle Security Barriers (VSB) to provide a harden perimeter.

This paper attempted to demonstrates the use of LS-DYNA as a powerful design optimization tool. Two bollard designs were developed as part of the development work to counter possible attacks by vehicle-borne threats. For validation purposes, full-scale vehicle crash tests were conducted on two different bollard systems, termed as Fixed Bollard (FB151) and Removable Bollard (RB151), respectively.

2. Test Description

The bollards designed in this study were impacted in accordance to ASTM F2656-07 ‘Standard Test Method for Vehicle Crash Testing of Perimeter Barriers’; which nominates four types of vehicles and three test speeds as the impact conditions and assigns corresponding classification ratings to the tested VSB. For the purpose of this paper, we are focusing on one of the vehicular mass and speed combination.



Figure 1: 1998 Ford F700 medium duty truck

The test vehicle chosen for the comparative study is a commercially available 1998 Ford F700 medium duty truck with an inertial mass of 6,708kg. The test vehicle impacted onto the barrier at a velocity of 48.76 km/h on the middle bollard of a triple bollard assembly (Please refer Figure 2). Accelerometers were mounted on the test vehicle to record the vehicle deceleration profile during the vehicle impact. Real-time video cameras and high-speed cameras were also deployed in accordance with the requirements of the impact test standard, to capture the impact sequence, vehicle and bollard assembly response.



Figure 2: Pre and post impact images: FB151 (left) & RB151 (right)

3. Overview of Bollard Model in LS-DYNA

The crash impact simulation analysis is performed via LS-Dyna, which was developed by Livermore Software Technology Corp. (LSTC), is a non-linear, transient dynamic finite element code was used to model fixed bollard (FB151) and removable bollard (RB151).

The bollard tube, concrete and compacted soil boundary were modeled using 8-node constant stress solid hexahedron elements (ELFORM=1), with hourglass control IHQ=5. All steel frames, steel stiffeners and I-beam were modeled with 4-node shell elements (ELFORM=16), with hourglass control IHQ=8. Beam elements (ELFORM=1) were assigned for rebar reinforcement and the bolt connection.

The Release III of Karagozian & Case concrete model (*MAT72R3), which includes damage and strain rate effects, was used to model the concrete. The mass density, Poisson's ratio, and uniaxial compressive strength of concrete were set as 2400kg/m^3 , 0.18, and 40N/mm^2 , respectively. A piecewise linear plastic material model (*MAT24) with strain rate effect was used to present the material properties of steel tubes, steel frames, bolt and rebar reinforcement. The steel material properties are presented in Table-1.

Table 1: Steel material properties for *MAT24 Piecewise linear plastic material model

Items	Density (kg/m ³)	Poisson's ratio	Young's modulus (Gpa)	Yield stress (MPa)
Bollard tube	7830	0.3	210	355
Steel frame				355
Rebar reinforcement , Bolt				450

Drucker-Prager model (*MAT193) was used to simulate the compacted soil. The properties are illustrated in Table-2. The surrounding of compacted soil boundary were assumed as rigid body and the displacements and rotations were constraint.

Table 2: Soil material properties for *MAT193 Drucker-Prager material model

Item	Density (kg/m ³)	Poisson's ratio	Shear modulus (MPa)	Angle of friction (radians)	Cohesion value (MPa)
soil	2100	0.3	35	0.581	0.069

3.1 FB151 Model (Fixed Bollard)

FB151 consists of a fixed three bollard array. Each bollard is spaced 1.4m apart centre-to-centre and stand 1.1m above ground. The length of the concrete foundation is 1.32m long with a width of 4.3m, as shown in Figure 3. The article consists of three identical bollards and base frames, eight universal I-beam columns, and rebar reinforcement.

Each bollard is composed of a 1.5m long steel pipe with a diameter of 220mm with a thickness of 22mm. The bollards are welded to their respective base frame and these welds were represented in the simulation model by merging nodes that coincided at the interfaces of the parts. The bollards were filled to capacity with concrete. The concrete has a compressive strength of 40N/mm².

The base frame consists of a top and bottom steel plate. A series of vertical steel stiffeners are located between the top and bottom plate. All steel frames and bollards are fillet welded for connection. Each side of universal I-beam column is bolted to the bollard base frame.

Figure 4 shows an overview of the bollard models. The end nodes of the beam element for bolt were merged with steel plate. The contact keyword *CONTACT_TIE_NODE_TO_SURFACE was used to join the steel plate to the base frame, and between bollard tube and concrete, and steel frame and concrete.

*CONTACT_ AUTOMATIC_SURFACE_TO_SURFACE was used to simulate the contact between concrete and soil, and vehicle and bollard tube.

*CONTACT_AUTOMATIC_NODE_TO_SURFACE was used between tire, soil and foundation surface. *CONSTRAINED_LAGRAGIAN_IN_SOLID with CTYPE=2 was used in coupling bolt and rebar reinforcement to concrete.

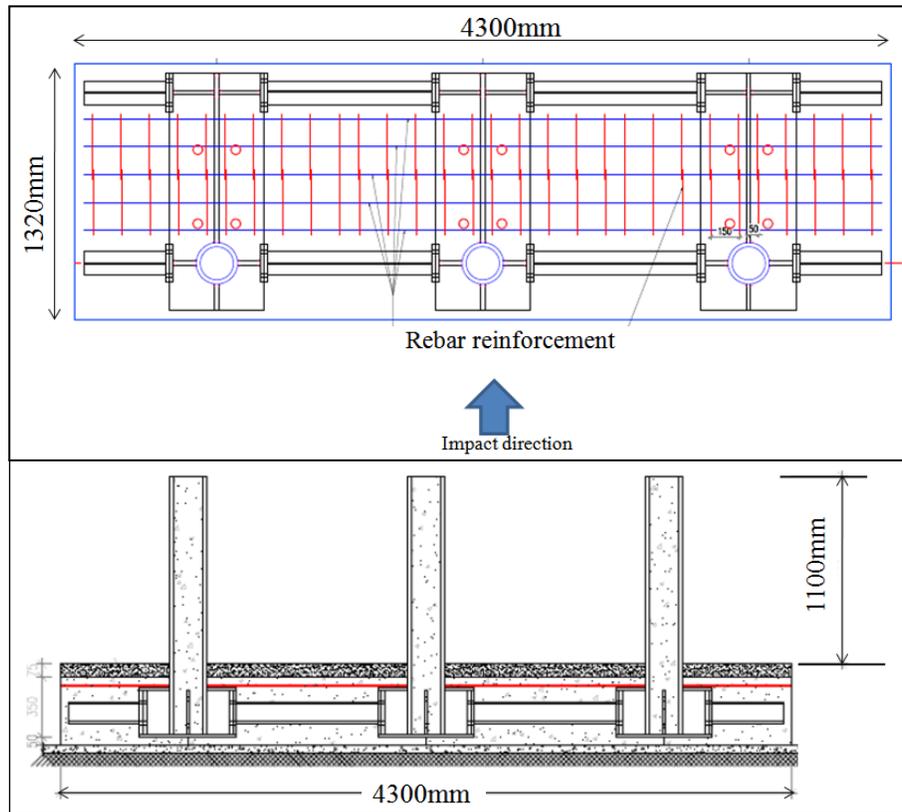


Figure 3: Configuration of fixed bollard system (FB151)

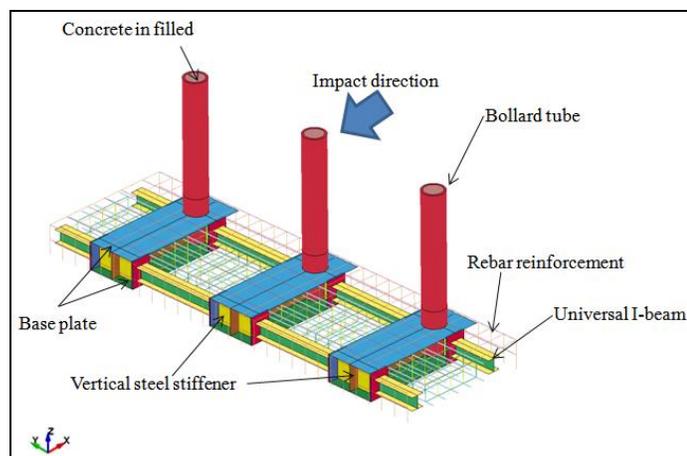


Figure 4: Model of FB151

3.2 RB151 Model (Removable Bollard)

As shown in Figure 5 and Figure 6, RB151 consists of a bollard array composed of three removable bollards. RB151 is similar to FB151 model, except the bollards are inserted into the base frame sleeve and bolted together with a M10 bolt. *CONTACT_AUTOMATIC_SINGLE_SURFACE was used to simulate the contact between the removable bollards which inserted into the base frame sleeve.

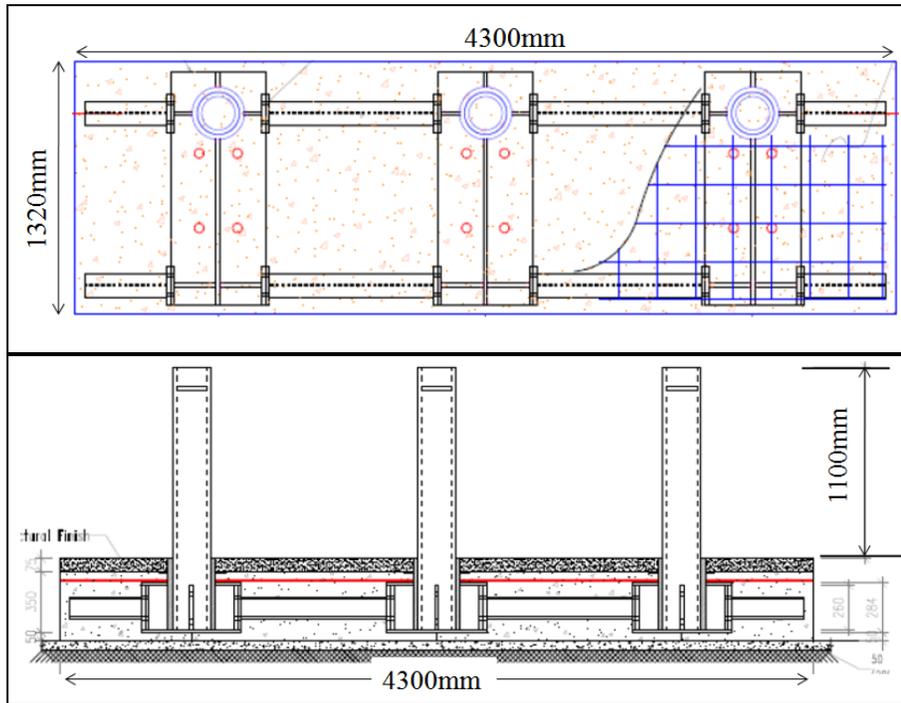


Figure 5: Configuration of removable bollard system (RB151)

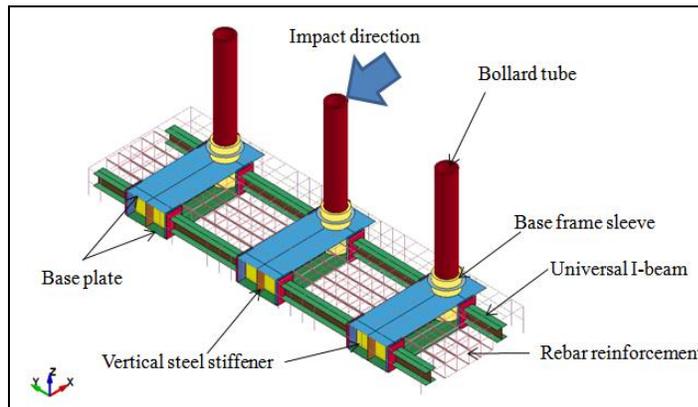


Figure 6: Model of RB151

4. LS-DYNA Vehicle Model

A publicly available finite element truck model of Ford F800 truck was downloaded from National Crash Analysis Center (NCAC) and shown in Figure 7. The F800 truck has a net weight of 5230kg, which is comparable to that of the test vehicle (5318kg). With the ballast load of 1390kg, the total weight of the test vehicle is about 6708kg. In order to compare with the results from the field test and also comply with the requirements of ASTM F2656-07 to the M30 level, the density of the ballast was change to make the total weight of F800 truck equal to 6800kg.

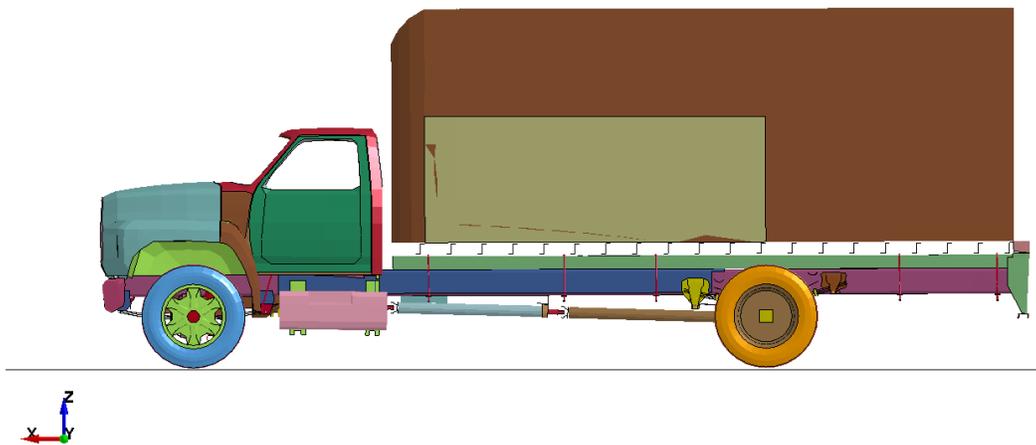


Figure 7: NCAC Finite Element Model of F800 Truck

5. Results

Figure 8 and Figure 9 compares the sequential snapshots taken at distinct times for the numerical simulation and crash test, for both FB151 and RB151 bollard systems. The vehicle was stopped by the bollard in both simulations. No penetration was recorded from the leading lower edge of the cargo bed on the medium duty truck to the rear face of bollard.

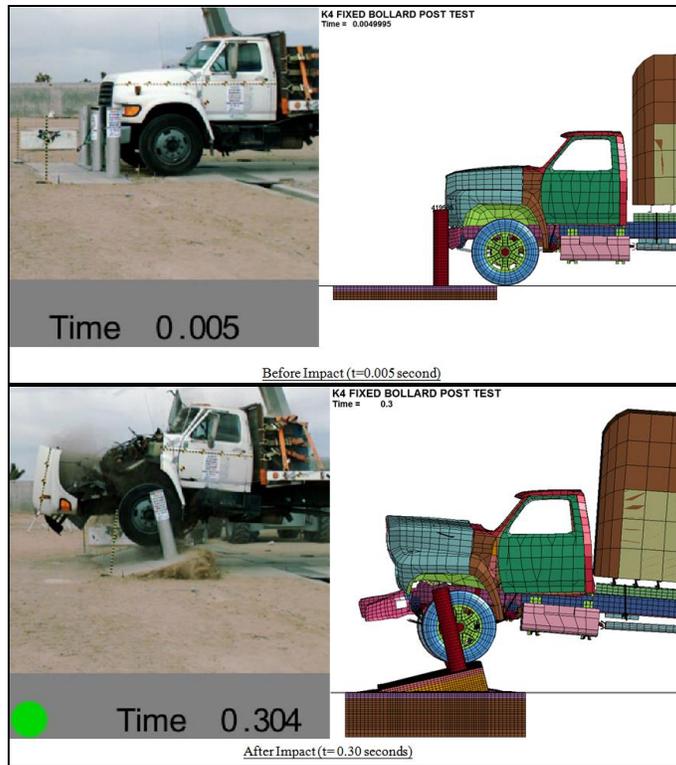


Figure 8: Comparison of vehicle model impacting FB151 Model

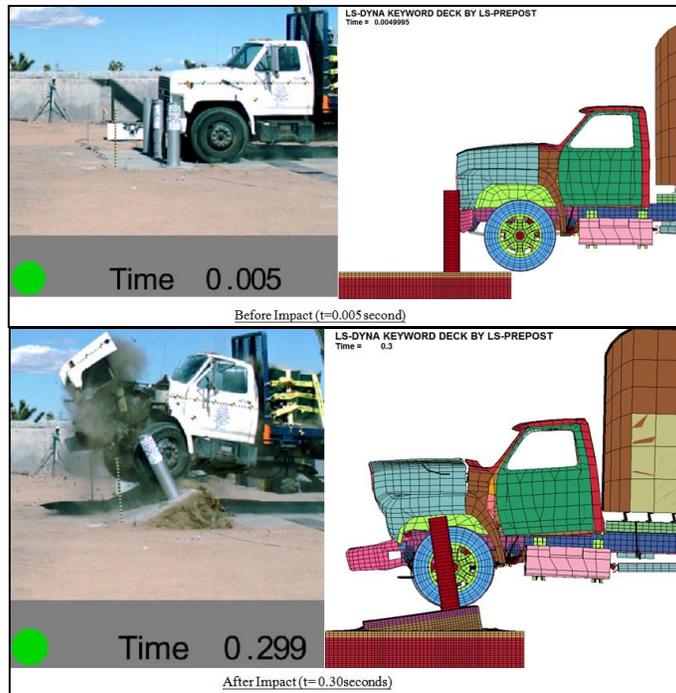


Figure 9: Comparison of vehicle model impacting RB151 Model

Figure 10 and Figure 11 compares the velocity-time plot from the crash test results with the numerical simulation. The field test results exhibited a linear decrement behavior from initial impact speed to zero as predicated by the numerical simulation. Based on the qualitative and quantitative comparisons, a reasonable match between the actual field test data and the outputs from the finite element vehicle model, it can be concluded that simulation accurately predicted the bollard response behavior.

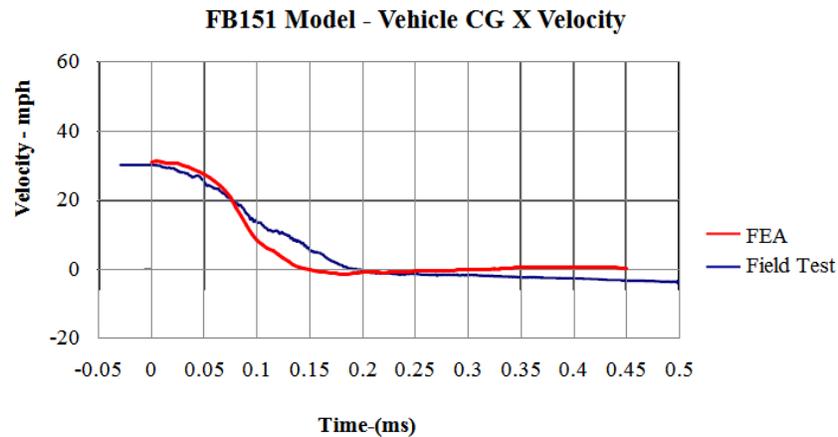


Figure 10: Comparison of vehicle truck velocity histories (FB151 Model)

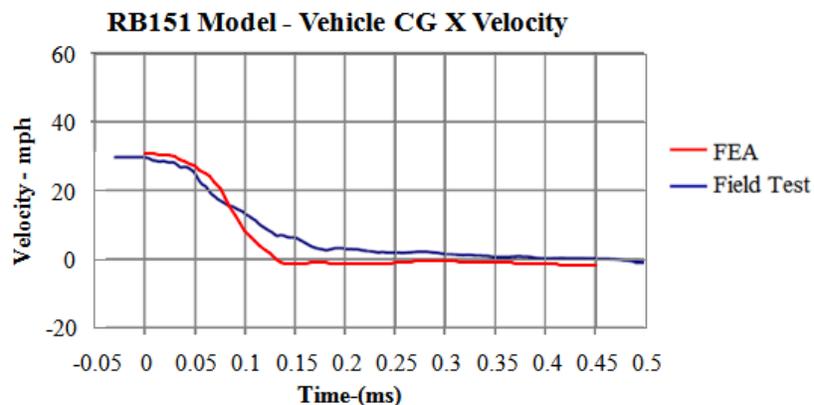


Figure 11: Comparison of vehicle truck velocity histories (RB151 Model)

Change in the bollard displacement versus time is plotted in Figure 12 and Figure 13. The general trend of the displacement time-history of the bollard from numerical simulation is similar to the field test. Both exhibited linear increment behavior during the initial stage before a maximum displacement value is achieved. However, the maximum displacement of the bollard from the numerical simulation is higher than that from the field test. The reason that might cause the difference is the difference in the center of gravity (CG) of the field test vehicle F700 and simulation vehicle F800 due to ballast load applied condition.

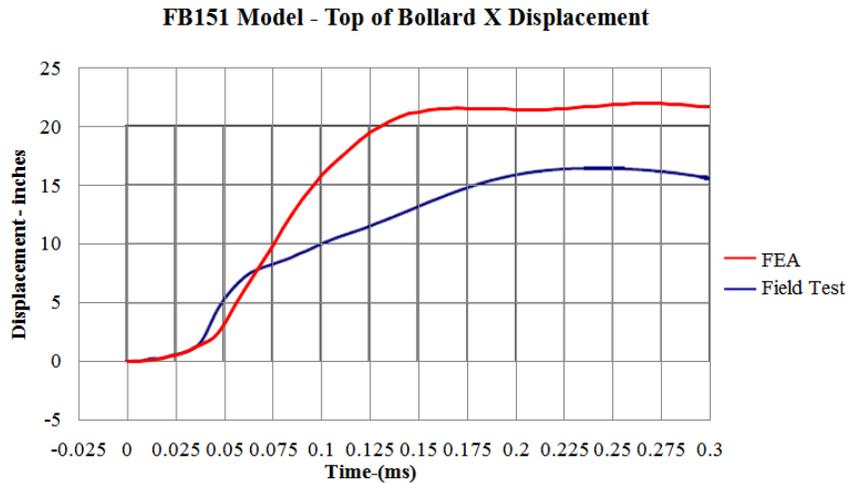


Figure 12: Comparison of top of bollard displacement histories (FB151 Model)

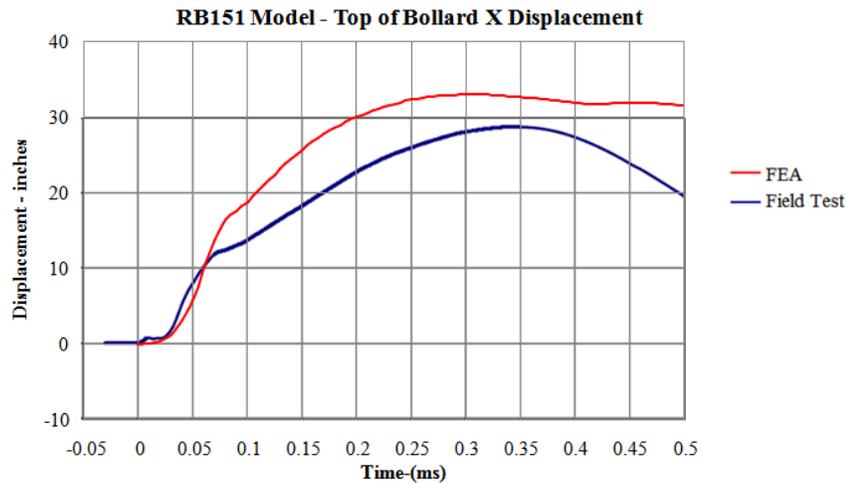


Figure 13: Comparison of top of bollard displacement histories (RB151 Model)

6. Conclusion

In this paper, two different bollard systems were developed to simulate crash impact against a medium duty truck. The results of the numerical model were validated though comparing with the field test results. Based on the qualitative and quantitative comparisons of the results such as event timings, bollard deflections and vehicle histories, it can be concluded that the simulation accurately predicted the crash test response behavior and thus validate the accuracy of the developed finite-element model.

7. References

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