Design and Validation of a Crash Rated Bollard as per SD-STD-02.01 Rev. A (2003) Standard using LS-DYNA®

Saurabh R. Deshpande[1], Santosh E. Chopade[1],
Maj. Amitava Mittra[2], and N. V. Karanth[1]

[1]*Automotive Research Association of India, Pune, India*
[2]*Swaraj Secutech Pvt. Ltd., Ahmedabad, India*

Abstract

Use of vehicle barriers for traffic regulation is of utmost importance in a densely populated country like India. These barriers can be used effectively to divert vehicles during public events and emergency situations. Due to their periodic requirement at different locations, it is essential that the barriers provide visibility and security while remaining comparatively cheaper at the same time. Out of the different types of available barriers like solid walls, pillars, beams, gates, etc., a bollard (vertical pole protruding from the ground to a very less but visible height) is the most effective in terms of space occupied and absorption of impact energy. Multiple bollards used in series are effective towards withstanding large vehicle impacts, while allowing passage to pedestrians and bicycle riders with ease. The prevalent methodology of evaluating energy absorption capacity of bollard as per SD-STD-02.01 Rev. A (2003) standard includes physical impact of the designed bollard by designated vehicle type (M type of vehicles) for K-4, K-8 and K-12 types of crash ratings. A finite element (FE) model of the designed bollard was analyzed under similar impact conditions using crash analysis software (LS-DYNA v. 971). The FE results were validated with the results of the physical test conducted subsequently. Parametric optimization of the K-12 rated FE bollard was conducted and a new bollard design for K-8 rating was thus prepared and analyzed for vehicular impact. The use of Computer Aided Engineering (CAE) tools and FE analysis during design stage itself aimed at reducing the cost and time required to build and successfully test the bollard for crash rating.

1. Introduction

Efficient regulation of traffic in a densely populated country like India is always held at high priority for any transport planning authority. Some of the biggest metropolises in India rank amongst the top ten worst cities in the world with regards to traffic management according to recent survey by Numbeo, a global statistics collection website [1]. Due to the presence of large no. of vehicles, it is cumbersome to regulate such heavy traffic on comparatively smaller Indian roads. Use of vehicle safety barriers (VSBs) are widely seen during public events, rallies and emergency situations. At the same time, protection against explosive threats and vehicular impact threats has steadily increased post various attacks at various places in the world [2]. Exterior perimeter security requirements have increased which can also be fulfilled designing such VSBs capable of stopping malevolent vehicle load within the protection perimeter.

There are many potential barrier options to consider which need to be selected appropriately on case to case basis. One of them is a bollard, which is a vertical pole protruding from the ground to a very less but visible height. It can be commonly used for regulating traffic but can also be used for stopping suspicious vehicles from entering in a restricted area. The security bollards are rated with regards to their energy absorption capacity during such vehicular impact. Rating is dependent on the bollard performance and its effectiveness towards stopping the vehicle of certain weight moving at certain speed. There are different standards used across the globe to test these bollards and each standard has its own security rating designation. Many of the commonly used standards for evaluation are –

1) SD-STD-02.01 Rev. A (2003) [3]
2) ASTM F2656-07 (2007) [4]
3) BSI PAS 68 (2013) [5]
4) ISO IWA 14-1 (2013) [6]

Even though all standards depict bollard effectiveness in their own rating designation, it is ultimately based upon impact energy absorption capacity of the bollard. Table 1 below shows comparisons between rating designations of different standards which can be applicable to the same bollard.

Standard	**Vehicle Weight**		**Nominal Vehicle Speed**		**Impact Energy**	**Rating Designation**
	lbm	**kg**	**mph**	**km/h**	**kJ**	
SD-STD-02.01 Rev. A (2003)	15000	6800	50	80	1695	K12 (L)**
ASTM F2656-07 (2007)	15000	6800	50	80	1680	M50 (P)**
BSI PAS 68 (2013)	16500	7500	50	80	1852	V/7500(N3)/80/90:XX/YY* D/7500(N3)/80/90/1852
ISO IWA 14-1 (2013)	15840	7200	50	80	1778	V/7200[N2B]/80/90:XX*
*** Note – XX denotes dynamic penetration distance and YY denotes vehicle debris distance (required as per relevant standard)** **** Note – L1 to L3 and P1 to P4 denotes dynamic penetration distance level (required as per relevant standard)**						

Table 1 – Comparison between Rating Designations of Standards for K12 Equivalent Bollard

Use of CAE tools in product development has increased over the past few years. CAE reduces the lead time and money involved in the product design to final prototype manufacturing process. Better understanding of the product and accelerated product development can occur during the concept stage itself. Various design iterations can be tried out virtually in order to obtain the optimized design. There is an overall decrease in the number of prototypes required to obtain the final product design.

In the present paper, Hyperworks by Altair, USA and LS-PREPOST® 4.2 were used to prepare the bollard FE model. LS-DYNA solver is widely used in the crashworthiness industry due to its robust nature and accurate results. Explicit analysis of the bollard was carried out for Design of Experiments (DoE) study until the bollard met the requirements of K-12 rating designation as per SD-STD-02.01 Rev. A (2003) standard.

A prototype of the final design was manufactured by Swaraj Secutech Pvt. Ltd., a VSB manufacturing company based in India. The bollard was sent to Motor Industry Research Association (MIRA), UK for physical testing. The bollard was physically tested and met the requirements of K-12 equivalent rating designation as per ISO IWA 14-1 (2013) standard. The FE simulation results were very well correlated to the physical test results with regards to bollard deformation and impact vehicle velocity recession.

2. Design and Development of K-12 Bollard

As per the target of meeting K-12 requirement, several design parameters were considered which affected the bollard performance. Figure 1 depicts some of the major design parameters used in the DoE study.

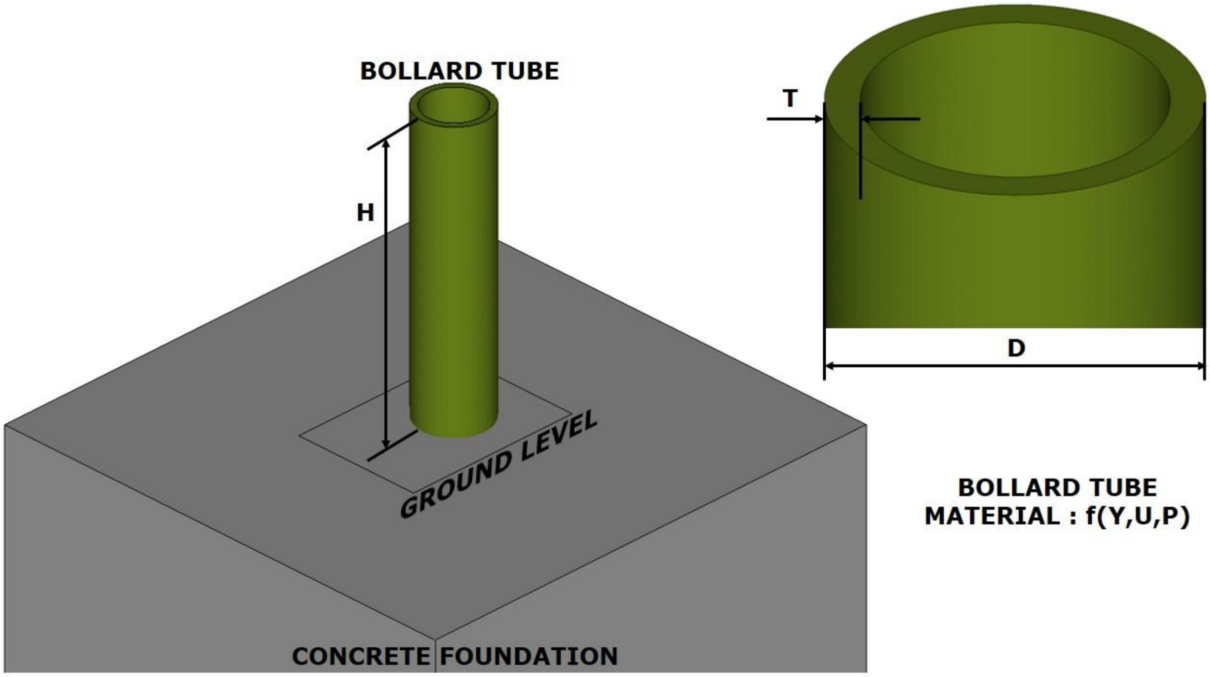


Figure 1 – Bollard Design Parameters

The design parameters were as follows –
1. Height of the bollard above ground level (H)
2. Bollard tube outer diameter (D)
3. Bollard tube thickness (T)
4. Bollard tube material (M) having
    4.1 Yield Strength (Y)
    4.2 Ultimate Strength (U)
    4.3 Plastic Strain (P)

The complete bollard installation consists of the bollard assembly erected within a concrete foundation at the required installation site. The bollard assembly includes the bollard tube inside a casing. A hydraulic or pneumatic system is used to raise the bollard tube above the ground and back inside. Steel rods are used to form a cage around the bollard casing inside the concrete foundation. This provides additional strength to the bollard foundation during vehicular impact. The bollard casing and other components were designed in such a way to create a load distribution on the entire assembly. Fins (circular rings) were provided at the base of the bollard tube as well as the bollard casing in order to transfer the impact load from the tube through the casing to the concrete foundation. Figure 2 shows a cut sectional view of the complete bollard installation.

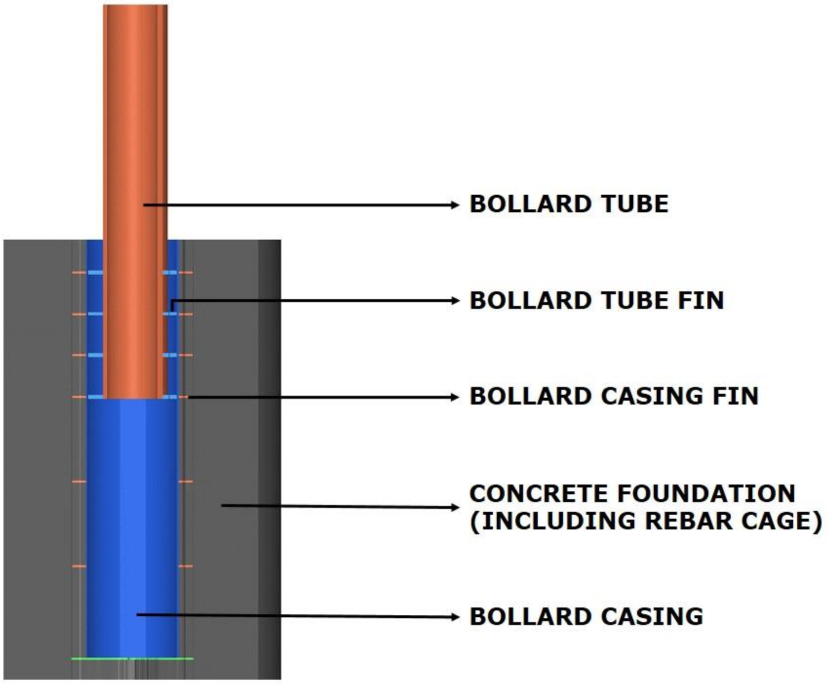


Figure 2 - Bollard Installation Cut Section

3. FE Simulation of K-12 Bollard

After the bollard design was finalized, 3D CAD model of the bollard assembly was created using Unigraphics NX by Siemens, Germany. The FE model was generated from this 3D CAD using Hyperworks and LS-PREPOST 4.2 simultaneously. The entire FE model was meshed using constant stress solid elements (*SECTION_SOLID) with ELFORM = 1 [7]. To reduce element distortion, hourglass card (*HOURGLASS) was used with hourglass parameter IHQ = 5. Bolts were modeled using 1D bar elements with circular cross-section as per different sizes (*SECTION_BEAM). Bolt connections with components were made using RBE2 type rigid elements.

Steel material of the bollard tube and other components of the assembly was defined using *MAT_024 (MAT_PIECEWISE_LINEAR_PLASTICITY) to account for strain rate effect on material [8]. The Young’s modulus, Poisson’s ratio, density and other material properties (yield strength, ultimate strength and plastic strain) were generated for the different materials from

physical test specimens and used as an input in the material cards. Concrete foundation was modeled using *MAT_159 (MAT_CSCM_CONCRETE) material model. Compressive strength, particle size and rebar strength parameters were defined in the model while other parameters were used from the Federal Highway Administration guide [9].
*CONTACT_AUTOMATIC_SINGLE_SURFACE was defined in between the different components of the bollard assembly with suitable coefficients of static and dynamic friction. Arbitrary-Lagrangian-Eulerian (ALE) coupling was used in between the bollard casing and concrete foundation using *CONSTRAINED_LAGRANGE_IN_SOLID card with default CTYPE = 2. The foundation block is constrained from five remaining sides by *MAT_RIGID panels.

The designated vehicle for K-12 rating as per SD-STD-02.01 Rev. A (2003) standard is a medium duty truck. For the same, FE model of a Ford medium duty truck was obtained from the National Crash Analysis Center (NCAC) website [10]. As the vehicle was already correlated for frontal impact as per available manual, the FE model could be used directly for the required impact. The mass of the vehicle was increased to match the required mass as per K-12 rating (6800 kg). This was done by adjusting the payload mass attached at the rear of the truck. Figure 3 shows the FE model of the medium duty truck used as the designated vehicle.

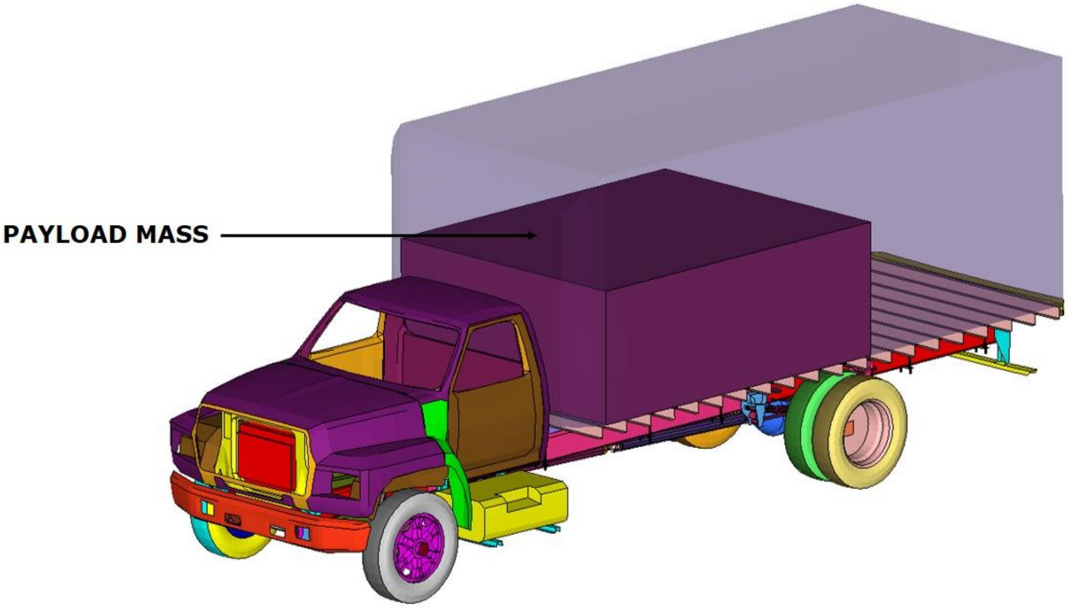


Figure 3 – FE Model of Designated Vehicle for Impact as per K-12 rating

LS-PREPOST 4.2 was used to include both the bollard and impact vehicle FE models in the same environment. *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE was defined in between the bollard and impact vehicle. The impact vehicle was placed as close to the bollard as possible in order to reduce the total run time. Initial velocity was prescribed to the entire vehicle using *INITIAL_VELOCITY_GENERATION card. Simulation setup at t = 0 ms is shown in Figure 4.

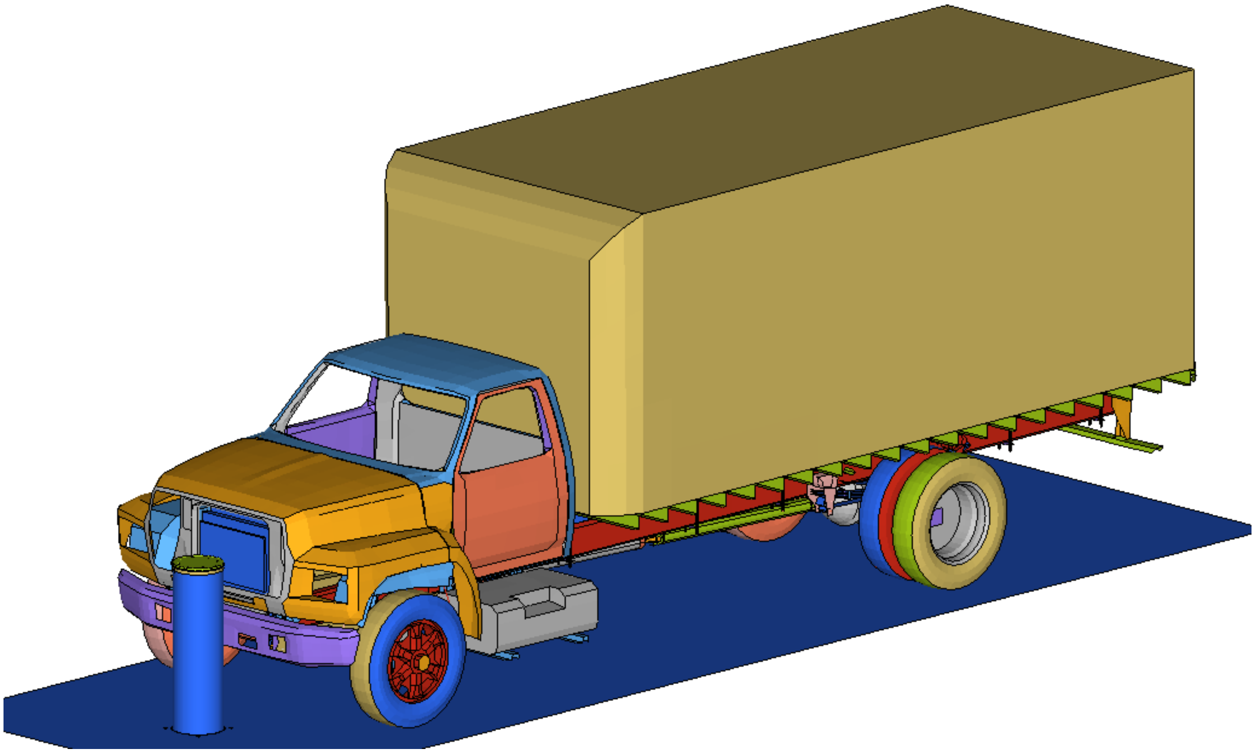
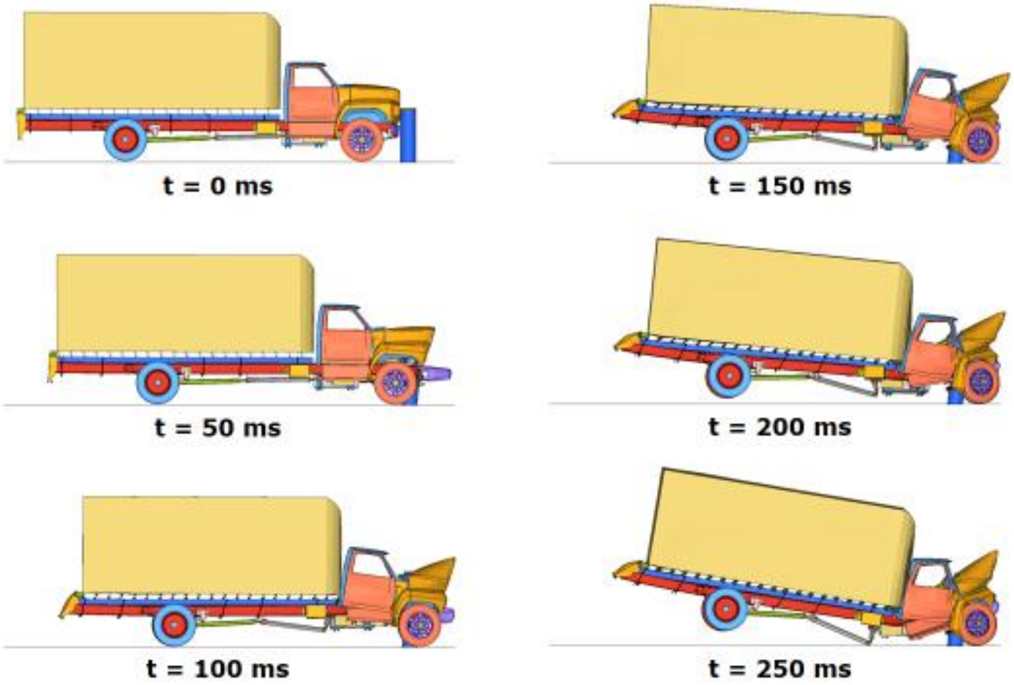


Figure 4 – FE Simulation Setup

Figure 5 depicts the entire impact simulation through a series of screenshots. From the entire simulation, it was observed that the impact vehicle was brought to a complete stop by the bollard assembly.



t = 0 ms

t = 150 ms

t = 50 ms

t = 200 ms

t = 100 ms

t = 250 ms

Figure 5 – Impact Simulation Screenshots

The velocity of the impact vehicle was measured till the vehicle came to a complete standstill (front axle velocity = 0). Angular deformation of the bollard was also measured in order to assess bollard movement during the impact. Many different iterations were carried out to complete the DoE study and the optimized design parameters of the bollard were obtained.

4. Physical Test of K-12 Bollard

The physical prototype of the bollard assembly was built as per the finalized design and shipped to MIRA, UK for the physical test due to unavailability of the suitable test setup and infrastructure in India. A pit was dug in which the bollard assembly was installed and later filled with concrete. The concrete was cured for predetermined time in order to achieve the designated compressive strength. The designated impact vehicle was selected as per the requirements of ISO IWA 14-1 (2013) standard. The physical test was performed for the impact energy equivalent to the K-12 rating as per SD-STD-02.01 Rev. A (2003) standard. Figure 6 shows pre-test bollard and impact vehicle details.

[redacted] [redacted] [redacted] [redacted] [redacted]

Figure 6 – Pre-Test Bollard and Vehicle © Swaraj Secutech Pvt. Ltd.

The impact vehicle was brought to a complete standstill by the bollard. Decrease in the vehicle velocity and angular deformation of the bollard post impact were measured for correlation purpose. Figure 7 depicts the complete physical test through screenshots.

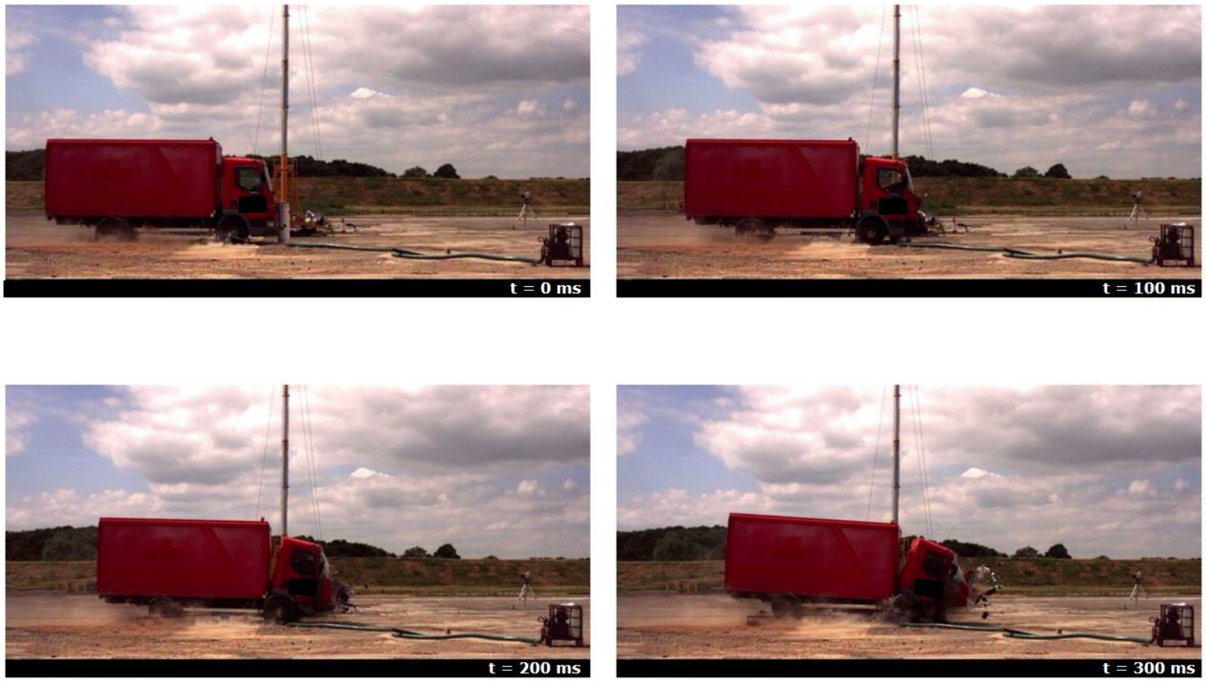


Figure 7 – Physical Test Screenshots © Swaraj Secutech Pvt. Ltd.

5. Correlation Exercise of K-12 Bollard

From the results obtained from the FE simulation and physical test, comparison was done between the decrease in velocity of impact vehicle and angular deformation values of the bollard post impact. Figure 8 shows the comparison between the angular deformation of the bollard post impact in the physical test (left) and the FE simulation (right).

Figure 8 – Comparison of Bollard Angular Deformation between Physical Test (L) and FE Simulation (R)

Figure 9 shows the comparison between decrease in the impact vehicle velocity in the physical test and FE simulation.

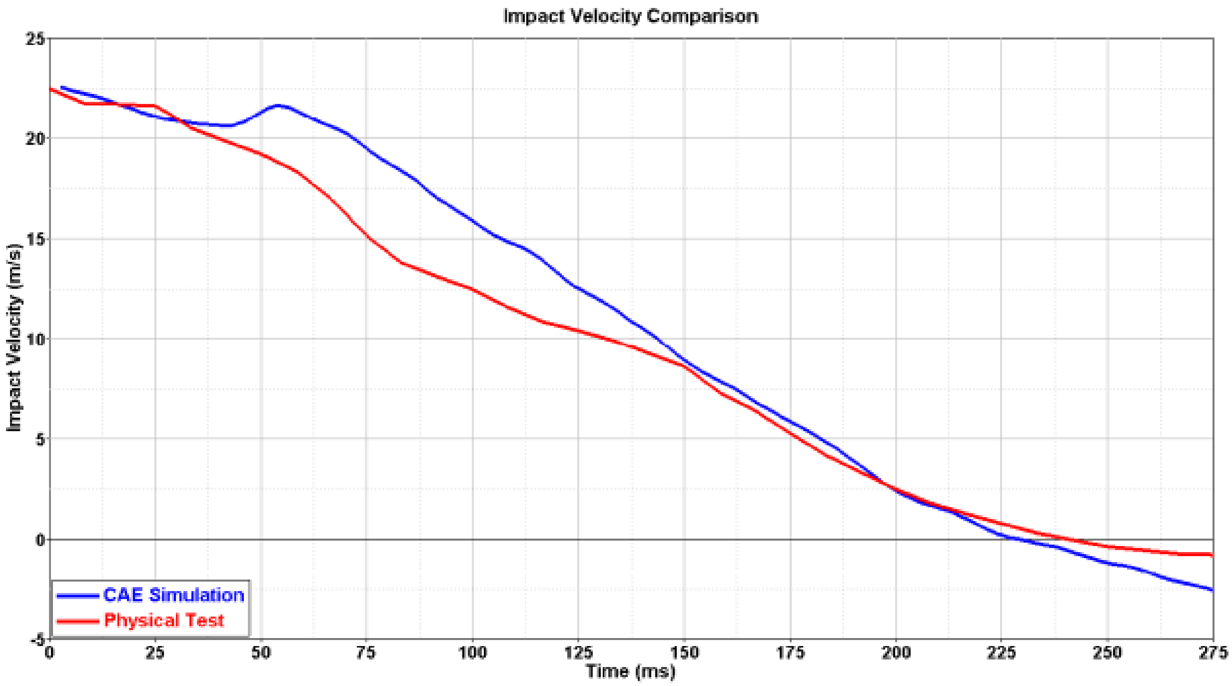


Figure 9 – Comparison between Reduction in Impact Velocity during Physical Test and FE Simulation

From the comparison study, it could be seen that the velocity and angular deformation results of the FE simulation correlated very well with those obtained from the physical test. Further, a methodology was set in order to assess different bollard designs for other ratings.

6. Parametric Design of K-8 Bollard

Using the FE simulation methodology developed after correlating FE simulation of K-12 bollard with the physical test, design parameters for a K-8 bollard were developed and finalized using parameterization. High confidence was achieved in using FE simulation as the first step in bollard design rather than performing physical tests on different prototypes until a final optimized design could be achieved. Use of CAE tools and FE simulation reduced the overall design to prototype lead time by more than 60 percent.

The final design prototype was kept slightly on the conservative side in order to account for manufacturing defects, side-effects of different joining processes, procurement of bollard tube and other components with correct grade, etc. With increased number of physical tests for bollards with different ratings and their subsequent correlation with the FE simulations, this conservatism can be brought down to an absolute minimum and provide the bollard end user with a high quality and cost effective VSB.

7. Conclusion & Future Scope

Using a DoE study, an optimized bollard design for K-12 rating was obtained using a series of FE simulation iterations. Prototype of the final design was prepared and tested physically. The FE simulation results correlated very well with those obtained in the physical test, leading to increase in confidence of using FE simulations at the design stage to reduce prototype costs. The simulation methodology thus defined was used to finalize the design parameters of a K-8 bollard. Physical test of this bollard design is a part of the future scope of this work.

FE simulations help decrease overall cost and lead time associated with bringing a product from the concept stage to final prototype stage. Use of LS-DYNA as a robust structural analysis solver could be determined by the degree of correlation obtained in this exercise.

8. References

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