Vehicle Impact Bollards No Longer Required for Cylinder Storage and Exchange Cabinets

Research Project Leads to Change in International Fire Code

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Vehicle impact bollards are often required by building and fire-safety codes and standards to protect equipment located in or near traffic routes. However, these documents lack well-defined performance goals for vehicle impact protection, and the prescriptive regulations that are provided are not sufficiently detailed to achieve a consistent or known level of performance. This is true because important variables such as soil types, soil compaction and paving materials, all of which will affect bollard performance, are not addressed in the regulations.

Equipment requiring protection may include LP-gas cylinders in storage or exchange cabinets, and when such protection is required, bollard systems meeting the prescriptive design requirements in Section 312 of the International Fire Code (IFC) are typically used. The IFC is the most widely used fire code in the U.S., and along with National Fire Protection Association (NFPA) Standard 58 *Liquefied Petroleum Gas Code,* it provides a basis by which most jurisdictions regulate LP-gas safety.

Given that LP-gas cylinders are robust enough to withstand rough handling associated with transportation and use, and given that cylinder storage and exchange cabinets are likewise substantially constructed, members of the National Propane Gas Association (NPGA) Cylinder Exchange Council have long questioned whether bollards are truly needed to protect cylinders in cabinets. Nevertheless, without quantitative data or scientific research on the issue, NPGA lacked a sound basis for asking that model codes drop requirements for supplemental cabinet impact protection. To develop that basis, the Propane Education and Research Council funded a research and testing initiative from 2011 through 2013 that was contracted to International Code Consultants of Austin, Texas.

The initiative included three phases: 1) A literature review of research and regulations associated with vehicle impact resistance, 2) A full-scale testing program conducted at Southwest Research Institute in San Antonio, Texas, and 3) A code advocacy program that managed the process of changing the IFC. The remainder of this article discusses the results of each phase.

Phase 1 – Literature Review

Vehicle impact protection barriers may be provided for one or more purposes ranging from serving as a visual deterrent, to resisting low-speed automobile impacts, to resisting high-speed truck impacts that may be associated with a deliberate attack. A comprehensive review of the historic basis for the IFC's current impact protection requirements (below) found that the provisions were likely intended to resist accidental/low-speed automobile collisions. However, the literature review was unable to identify a specific performance objective for IFC-compliant impact protection. Likewise, the literature review found no documentation indicating that the performance capabilities of IFC compliant impact protection have ever been tested.

> ***IFC Section 312.2 Posts.*** *Guard posts shall comply with all of the following requirements:*
> 1. *Constructed of steel not less than 4 inches (102 mm) in diameter and concrete filled.*
> 2. *Spaced not more than 4 feet (1219 mm) between posts on center.*
> 3. *Set not less than 3 feet (914 mm) deep in a concrete footing of not less than a 15-inch (381 mm) diameter.*
> 4. *Set with the top of the posts not less than 3 feet (914 mm) above ground.*
> 5. *Located not less than 3 feet (914 mm) from the protected object.*
>
> ***312.3 Other barriers.*** *Physical barriers shall be a minimum of 36 inches (914 mm) in height and shall resist a force of 12,000 pounds (53 375 N) applied 36 inches (914 mm) above the adjacent ground surface.*

Although the IFC provisions are fairly detailed, they fail to address a number of important considerations that can greatly affect the performance of code-compliant barrier systems. For example, the bollard requirements in Section 312.2 do not consider soil compaction or paving, and the barrier requirements in Section 312.3 consider only static loading, which doesn't correlate well with resisting impacts from moving vehicles.

As a result of these code deficiencies, and lacking prior research or testing to demonstrate that additional vehicle impact protection is or is not needed for cylinder storage and exchange cabinets, it was determined that full-scale testing would be needed to answer a number of questions that were essential to the success of this project.

Phase 2 – Full-scale Collision Testing

The objectives of full-scale collision testing were as follows:

1) Evaluating the performance of vehicle impact protection bollards complying with the IFC, and
2) Relating the level of vehicle impact resistance provided by bollards with that of cabinets used to secure and protect LP-gas cylinders in storage or in an exchange program.

To accomplish the first objective, it was necessary to "bracket" the performance capabilities of various bollard installations by evaluating combinations of soil and pavement conditions and various vehicle weights, impact speeds and impact heights to generate test results ranging from no damage to total failure. Once these performance brackets were quantified and maximum survivable impact scenarios were known for code compliant bollards, LP-gas cylinder exchange cabinets were then tested using similar impact scenarios to determine relative performance. For cabinets to qualify as equivalent to bollards for protection of LP-gas cylinders, cabinets were required to withstand to the maximum survivable impact scenarios identified by the bollard tests without failure of any LP-gas cylinders kept inside.

Given that the literature review in Phase 1 had identified that the apparent purpose of the IFC vehicle impact protection requirements is resisting accidental/low-speed automobile collisions, test scenarios involving mock passenger car (4,000 lbs. with an 18-in. bumper height) and SUV (6,000 lbs. with a 26-in. bumper height) impacts at speeds of five and ten miles per hour were established. The selected vehicle weights and bumper heights were based on a survey of Gross Vehicle Weight Ratings (GVWR) and state regulations governing permissible bumper heights.

Two code-compliant bollard installations were constructed for these tests. Each used the prescribed materials of construction, bollard diameter, bollard length, footing size, etc. set forth in the IFC, but soil and pavement conditions were varied because these parameters, while anticipated to have significant influence on performance, are not specified by the code. The two installation conditions tested were selected to represent opposite ends of the performance spectrum, ranging from "restrained" (strong) bollards embedded in compacted soil with concrete pavement to "unrestrained" (weak) bollards embedded in uncompacted soil with no pavement.

The "restrained" bollard, illustrated in Figures 1 and 2, was equated to the most robust performance level for a code-compliant installation.

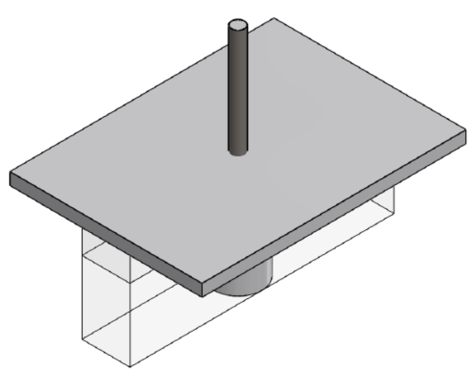

Figure1 Restrained Bollard Installation

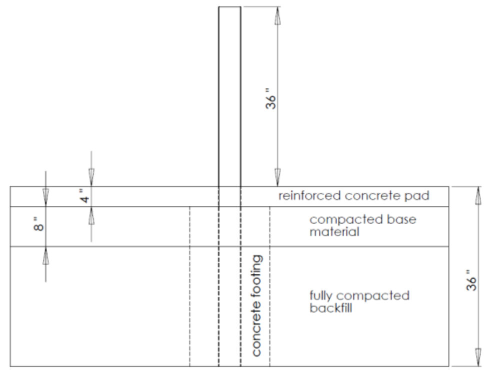

Figure2 Restrained Bollard Installation – Side View

The "unrestrained" bollard, illustrated in Figure 3, was equated to a least robust performance level for a code-compliant installation.

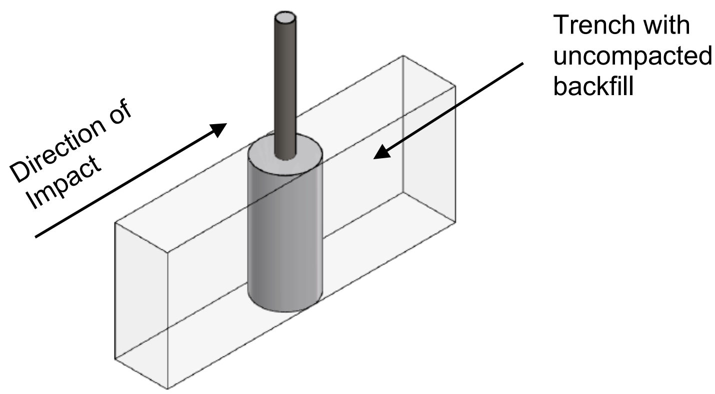

Figure3 Unrestrained Bollard Installation

In addition to impact testing, both installation types were tested using the 12,000 pound static load scenario specified by IFC Section 312.3. This additional testing provided a basis for determining whether a correlation exists between the performance of bollards installed per the prescriptive criteria in Section 312.2 versus the static load criteria in Section 312.3.

A summary of all bollard testing is provided in Table 1, and sample photos from the testing are provided in Figures 4 through 8.

Table 1

Summary of Bollard Tests

Test ID	Test Results			
	CONFIGURATION	IMPACTOR	ACTUAL IMPACT SPEED (mph)	DAMAGE/COMMENTS
URB-1	Unrestrained Bollard	6,000-lb Bogie	15.9	Bollard deflected nearly horizontal; bogie vehicle NOT stopped
URB-2	Unrestrained Bollard	6,000-lb Bogie	6.0	Bollard deflected approximately 45°; bogie vehicle stopped
URB-3	Unrestrained Bollard	4,000-lb Bogie	4.7	Bollard pushed back and deflected approximately 15°; bogie vehicle stopped
URB-4	Unrestrained Bollard	4,000-lb Bogie	9.8	Bollard deflected approximately 45°; bogie vehicle stopped on bollard
RB-1	Restrained Bollard	6,000-lb Bogie	11.5	Bollard sheared at base; bogie vehicle NOT stopped
RB-2	Restrained Bollard	6,000-lb Bogie	5.4	Bollard deflected approximately 15°; bogie vehicle stopped
RB-3	Restrained Bollard	4,000-lb Bogie	4.5	Minimal bollard deflection; bogie vehicle stopped
RB-4	Restrained Bollard	4,000-lb Bogie	10.1	Bollard sheared at base; bogie vehicle NOT stopped
URBS	Unrestrained Bollard	N/A – Static Test	N/A	At approximately 900 lbs. load; un-resisted movement began
RBS	Restrained Bollard	N/A – Static Test	N/A	At approximately 11,000 lbs. load; 3 inches permanent deflection

Figure 4 URB-1 Bollard Prior to Testing

Figure 5 URB-1 Bollard Following Testing

Figure 6 RB-2 Bollard Prior to Testing

Figure 7 RB-2 Bollard Following Testing

Figure 8 URBS Bollard Test

The second segment of impact testing evaluated the protection offered by cylinder exchange cabinets for LP-gas cylinders stored therein. This testing involved LP-gas cylinders that were partially filled with water and pressurized with low-pressure air. The cylinders were placed in industry-standard cabinets, and trials were varied among: 1) Steel versus aluminum materials of construction, 2) Anchored versus unanchored installations, and 3) With concrete backstops versus without (to simulate the presence or lack of a rigid exterior building wall behind the cabinet, which was thought to increase the potential for crushing). Impact scenarios, including vehicle weight, speed and bumper height, reflected those used in the bollard tests so that accurate performance comparisons could be made.

A summary of all cabinet testing is provided in Table 2, and sample photos from the testing are provided in Figures 9 through 12.

Table 2

Summary of Cabinet Tests

Test ID	Test Results			
	CONFIGURATION	IMPACTOR	ACTUAL IMPACT SPEED (mph)	DAMAGE/COMMENTS
SC-1	Steel Cabinet, Anchored, Backstop	6,000-lb Bogie	8.6	Majority of damage to center shelf; no damaged cylinders; bogie vehicle stopped
SC-2	Steel Cabinet, Anchored	6,000-lb Bogie	8.7	Front mounting tabs torn; cabinet knocked over; no damaged cylinders; bogie vehicle stopped
SC-3	Steel Cabinet, Anchored, Backstop	4,000-lb Bogie	8.5	Majority of damage to bottom shelf; no damaged cylinders; bogie vehicle stopped
SC-4	Steel Cabinet, Anchored, Backstop, Overloaded Shelves	4,000-lb Bogie	10.0	Overloaded with 20 cylinders to increase crush risk; majority of damage to bottom shelf; no damaged cylinders; bogie vehicle stopped
SC-5	Steel Cabinet, Anchored	4,000-lb Bogie	10.1	Front mounting tabs torn; cabinet pushed back; no damaged cylinders; bogie vehicle stopped
AC-1	Aluminum Cabinet, Backstop	6,000-lb Bogie	8.9	Significant crushing of center shelf; two damaged cylinders; bogie vehicle stopped
AC-2	Aluminum Cabinet, Backstop	4,000-lb Bogie	9.9	Significant crushing of bottom shelf; one damaged cylinder; bogie vehicle stopped

Figure 9 SC-1 Cabinet Prior to Testing

Figure 10 SC-1 Cabinet Following Testing

Figure 11 AC-1 Cabinet Prior to Testing

Figure 12   AC-1 Cabinet Following Testing

The cylinder exchange cabinet tests were followed up by a series of direct impact tests on individual cylinders to validate cylinder survivability at higher pressures with comparable impacts. This subsequent testing was considered necessary because cylinders in the cabinet tests were only slightly pressurized, and some cylinders were dented during testing. To gain confidence that cylinders at full (approximately 225 psi) service pressure would not fail, cylinders at full service pressure were individually tested using a weighted pendulum apparatus with a customized tip that reproduced the dent profiles resulting from the cabinet tests.

A summary of all cylinder testing is provided in Table 3, and sample photos from the testing are provided in Figures 13 through 15.

Table 3

Summary of Cylinder Tests

Test ID	Test Results			
	CONFIGURATION	IMPACTOR	ACTUAL IMPACT SPEED (mph)	DAMAGE/COMMENTS
CYL-1	Center Impact (At Seam)	4,000-lb Pendulum	2.7	Baseline to duplicate damage from cabinet tests; no rupture or leak; PRV not activated
CYL-2	High Impact (Above Seam)	4,000-lb Pendulum	2.7	Baseline to duplicate damage from cabinet tests; no rupture or leak; PRV not activated
CYL-3	Center Impact (At Seam)	4,000-lb Pendulum	5	No rupture or leak; PRV not activated
CYL-4	Low Impact (Below Seam)	4,000-lb Pendulum	2.7	Baseline to duplicate damage from cabinet tests; no rupture or leak; PRV not activated
CYL-5	High Impact (Above Seam)	4,000-lb Pendulum	5	No rupture or leak; PRV not activated
CYL-6	Low Impact (Below Seam)	4,000-lb Pendulum	5	No rupture or leak; PRV not activated
CYL-7	Center Impact (At Seam)	4,000-lb Pendulum	10	Cylinder ruptured; activation of PRV
CYL-8	Low Impact (Below Seam)	4,000-lb Pendulum	10	No rupture or leak; activation of PRV
CYL-9	High Impact (Above Seam)	4,000-lb Pendulum	10	Cylinder ruptured; activation of PRV

Figure 13 CYL-1 Cylinder Prior to Testing.
(Concrete weighted pendulum with steel impactor tip at right)

Figure 14 CYL-1 Cylinder Following Testing

Figure 15 CYL-7 Cylinder Following Testing

In summary, the results of Phase 2 were as follows:

1) The level of protection offered by IFC-compliant bollards generally correlates with passenger or sport utility vehicles traveling at speeds in the 5- to 10-mph range. At vehicle speeds in the 5 mph range, both restrained and unrestrained bollards were found to be reasonably effective in stopping passenger vehicles and SUVs. However, as vehicle speeds approach 10 mph, confidence in the effectiveness of a single bollard of either type severely diminishes. The level of protection offered by IFC-compliant bollards will vary greatly depending on soil and pavement conditions surrounding each bollard. Testing of static loads on bollards showed no correlation with kinetic load test results.

2) Typical cylinder exchange cabinets constructed of either aluminum or steel, anchored or unanchored, and against a building wall or not, are capable of providing comparable or better impact protection for LP-gas cylinders than bollards alone. These cabinets, and the cylinders therein, survived both passenger vehicle and SUV impacts at speeds up to 10 mph. Although cylinders were damaged in some cases, the level of damage was always well below that which would be required to rupture a 20-pound LP-gas cylinder.

It is important to note that the bogie vehicle bumpers and cylinder impactors used in this test series were comprised of heavy-gauge steel, directly affixed to a steel vehicle frame with no mechanism to absorb shock. This inelastic bumper/impactor arrangement provided very conservative test results versus what would be expected in "real world" collisions since automobile manufacturers design production bumpers and vehicle frames to absorb a significant portion of collision impact force.

Phase 3 – Code Advocacy

The results of Phase 2 testing gave NPGA the technical basis needed to advocate changes to IFC Chapter 61, which regulates LP-gas. NPGA's recommendations focused on: 1) Better correlation between the IFC and NFPA 58, and 2) Recognizing cylinder storage and exchange cabinets as a permissible alternative to generic vehicle impact protection methods described in IFC Section 312. Additionally, NPGA's research provided a basis for the International Code Council's Fire Code Action Committee (ICC-FCAC) to propose an update to the generic methods in IFC Section 312. The ICC-FCAC is an official ICC committee charged with developing code change recommendations on behalf of ICC's fire service members.

NPGA's proposal was processed as Item F331-13, and the ICC-FCAC proposal processed as Item F15-13. Both of these proposals, shown below, were accepted by the ICC membership, and the recommended changes will be included in the 2015 edition of the IFC, which has been completed and should be available by late-2014. Note that text shown as underlined in the proposals is text that will be added to the code, and text shown as "strike through" will be deleted.

F331-13

6107.4 Protecting containers from vehicles. Where exposed to vehicular damage due to proximity to alleys, driveways or parking areas, LP-gas containers, regulators and piping shall be protected in accordance with NFPA 58.~~Section 312~~.

6109.13 Protection of containers. LP-gas containers shall be stored within a suitable enclosure or otherwise protected against tampering~~. Vehicular~~ Vehicle impact protection shall be provided as required by Section 6107.4. ~~the fire code official~~.

Exception: Vehicle impact protection shall not be required for protection of LP-gas containers where the containers are kept in lockable, ventilated cabinets of metal construction.

F15-13

312.1 General. Vehicle impact protection required by this code shall be provided by posts that comply with Section 312.2 or by other ~~*approved* physical~~ barriers that comply with Section 312.3.

312.2 Posts. Guard posts shall comply with all of the following requirements:

1. Constructed of steel not less than 4 inches (102 mm) in diameter and concrete filled.
2. Spaced not more than 4 feet (1219 mm) between posts on center.
3. Set not less than 3 feet (914 mm) deep in a concrete footing of not less than a 15-inch (381 mm) diameter.
4. Set with the top of the posts not less than 3 feet (914 mm) above ground.
5. Located not less than 3 feet (914 mm) from the protected object.

312.3 Other barriers. ~~Physical barriers shall be a minimum of 36 inches (914 mm) in height and shall resist a force of 12,000 pounds (53 375 N) applied 36 inches (914 mm) above the adjacent ground surface.~~ Barriers other than posts specified in Section 312.2 that are designed to resist, deflect or visually deter vehicular impact commensurate with an anticipated impact scenario shall be permitted when *approved*.

The revisions to Section 312.3 were made because NPGA's research revealed that, contrary to what one might assume by reading the code, the current text of Section 312.3 is not a performance-based alternative design basis for the prescriptive provisions in Section 312.2. Instead, the two sections contain redundant and unrelated approaches to impact protection that came from different IFC source documents. NPGA's testing demonstrated that there is no performance consistency between the two design approaches, and with bollards specified by Section 312.2 having become the well-established norm for compliance in the past 15+ years, Section 312.3 was updated to become a truly flexible performance option to Section 312.2.

Conclusion

Developing the comprehensive foundation necessary to substantiate a change to the IFC's longstanding vehicle impact protection requirements took three years of research and advocacy work. The project was eventually successful in eliminating the IFC bollard requirements for the protection of cylinder storage and exchange cabinets, after demonstrating that cabinets and cylinders are able to withstand vehicle impacts that equal or exceed the capabilities of code-compliant bollards. As a result of this project, the installation of cylinder storage and exchange cabinets will be simplified, and the appearance and accessibility of installations will be improved.