MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

22nd Annual International Symposium
October 22-24, 2019 | College Station, Texas

Consideration of Non-Structural Internal Debris in Siting of Blast Resistant Modules

Jodi L. Kostecki, Thomas J. Mander*, and James Kelly Thomas
Baker Engineering and Risk Consultants
3330 Oakwell Court, Suite 100
San Antonio, TX 78218-3024
*Presenter E-mail: TMander@BakerRisk.com

Abstract

Blast resistant modules (BRMs) have become prevalent at petroleum refining and chemical processing facilities over the last decade. A primary rationale for utilizing a BRM is to allow a building housing essential personnel (e.g., operators) to be sited near the process units for which they are responsible. BRMs are selected based on a pressure-rating and response level (typically Low, Medium, or High). A common misconception is that a BRM will be undamaged and reusable for a specified blast overpressure rating, and such buildings are often incorrectly referred to as "blast-proof". In order to absorb blast energy, the walls and roof of a BRM are designed to undergo transient accelerations and displacements. The allowable displacements are dictated by the selected response level, and that stated response level does not directly communicate the hazard associated with wall deflection and non-structural debris.

Displacement and acceleration of a BRM wall can lead to significant non-structural internal debris hazards, as has been observed in testing programs and incident investigations. These hazards become more severe as the BRM blast rating and response level increases. Such hazards are sometimes overlooked when siting a BRM. A structural analysis of a BRM may be required to predict wall accelerations in order to quantify these hazards and properly site the BRM, rather than relying solely on a blast overpressure rating. This paper provides insight into the hazards associated with interior finish-out and wall-mounted items commonly observed in BRMs, and the means necessary to mitigate these hazards.

Keywords: Debris hazards, BRM, blast damage, facility siting study

1 Introduction

Occupied buildings in refining and processing facilities are required to be assessed for potential explosion, fire, and toxic hazards as documented in the Occupational Safety and Health Administration (OSHA) standard 29 CFR Part 1910. These assessments are performed as part of a facility siting study (FSS). FSSs often show that buildings not deliberately designed to withstand blast loads, and buildings located close to process units, have insufficient blast resistance to withstand the postulated worst-case blast loads. As a result, owners must then decide whether to strengthen the existing building in place or construct a new building that is designed for the required level of blast-resistance.

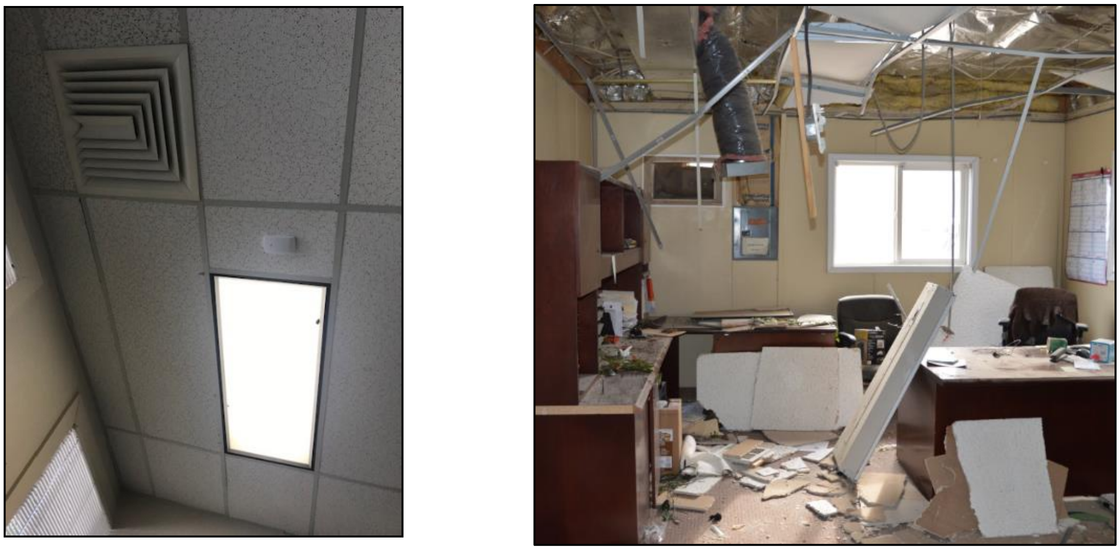
Safety requirements and inherent hazards at refining and processing facilities make on site construction more expensive than traditional commercial construction. Building upgrades can be intrusive to occupants and business interruption is therefore another owner consideration when deciding between building upgrades or complete building replacement. Modular buildings are viewed as an attractive option to owners to reduce the on-site construction time and disruptions to daily operations. These buildings are branded in the industry as blast resistant modules (BRMs).

BRMs are constructed similar to shipping containers, albeit with thicker corrugated wall panels and a heavier steel frame (beams and columns). While the construction is stronger than a shipping container, the structural members are still expected to sustain damage in a design-basis blast to absorb blast energy. This point is sometimes misunderstood, with owners and operators believing they are risk-free in a BRM, expecting little to no damage after a design-basis blast event. Depending on the allowable structural response, some BRMs may not be immediately habitable following a design-basis blast event.

While a properly-designed BRM will protect building occupants from structural failures during a blast, there are other secondary hazards that are often overlooked. Non-structural items that are necessary for the daily operating function of a BRM such as cabinets, shelves, desks, electrical equipment, ducting, lighting, etc. can become sources of hazardous debris to building occupants, even at blast loads below the BRM blast rating. This paper discusses current industry practice for addressing non-structural debris, the mechanisms that cause hazardous internal debris, and mitigation effectiveness in BRMs.

2 Examples of Non-structural Debris

Typical interior non-structural overhead debris consists of drop ceiling components, lights, mechanical ductwork and vents, as illustrated in Figure 1a. Drop ceiling lay-in panels generally create the largest volume of interior overhead debris, as observed in Figure 1b, because they “lay” between steel framing and are not physically anchored to supports. They are therefore prone to becoming dislodged with minor ceiling movement. Drop ceiling tiles weigh between 1 to 2 psf, equating to a weight of between 8 to 16 lbs for a standard 2 ft × 4 ft lay-in panel.



(a) Typical overhead items *(b) Post-blast event overhead debris*

Figure 1. Overhead Non-Structural Debris

Figure 1b also shows non-structural debris from overhead lights (troffers) and vents. These items can cause higher vulnerability to occupants upon impact than ceiling tiles due to their increased weight (10 to 20 lb troffers and 5 to 10 lb vents). Troffers and vents can either be built into a drop ceiling or stand-alone, typically connected to the structural roof members with vertical gauge wire. Failures of these elements include tension failure in the wire itself or unraveling of a poor tie connection of the wire. Mechanical ductwork tends to have the heavier connections consisting of steel straps or hangers, and failures in this components are less common, but have been observed in accidents.

Figure 2 shows common wall-mounted or near-wall architectural and electrical items such as cabinets, bookcases, TV/computer monitors, and electrical boxes that are potential sources of interior debris in a blast event. As shown in Figure 2a, occupants in single BRMs are inevitably located near exterior walls, which increases the vulnerability from non-structural debris compared to personnel located at the interior of a larger building. Electrical boxes (Figure 2b) are most typically anchored to the interior surface of exterior walls, and it is common for operator control panels (Figure 2c) to also be located at exterior walls to optimize the use of interior space.

(a) Single module layout *(b) Wall-mounted electrical boxes* *(c) Control monitors*

Figure 2. Example Wall-Mounted or Near-Wall Potential Debris Sources

Cabinets, bookcases and other items with an elevated center of gravity are generally placed directly adjacent to an exterior wall surface. These types of items are typically observed to topple over when placed near a blast-loaded exterior wall, as illustrated in Figure 3. Electrical boxes, picture frames, and wall mounted TVs and cabinets have been observed to fail and be thrown inward due to poor overall anchorage capacity to the structure, or failure of the element itself. In the first instance, the anchorage typically pulls out of the supporting wall component and creates a debris hazard. If the anchorage is sufficiently strong preventing this from occurring, failure can still occur in the non-structural component itself. This is observed in Figure 3, where the face of an electrical box has been dislodged but the box is still attached to the wall surface.

Figure 3. Wall mounted Non-Structural Building Debris

3 Industry State-of-the-Practice

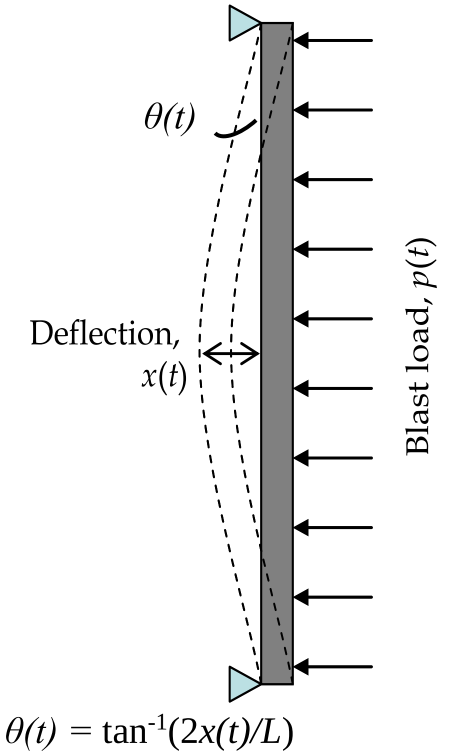
Typical BRM exterior dimensions are between 10 and 14 ft wide, up to 50 ft long, and between 8 and 12 ft tall. Single module units became popular replacements to wood trailers after the catastrophic 2005 Texas City refinery explosion and have become more prevalent as permanent structures in the past decade. Where larger footprints are desired, individual BRMs are field connected to one another. These multi-module BRMs are often classified as permanent structures but can also be temporary structures used for turnaround. BRMs can therefore be classified as either temporary or permanent structures. Figure 4 provides exemplar photographs of single and multi-module BRMs located near process units.

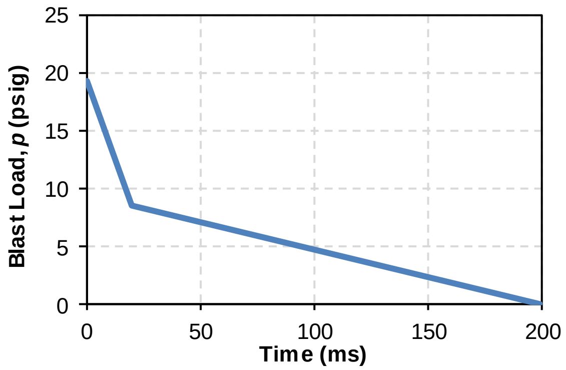
Figure 4. Single-module BRM (Left) and Multi-module BRM (Right)

While OSHA standard 29 CFR Part 1910 states that a FSS must be performed to assess potential hazards to occupants, it does not state the specific procedures for the assessment, or impose mandatory building design requirements. The principal documents for performing a FSS on permanent and temporary (portable) buildings are, respectively, API RP 752 *Management of Hazards Associated with Location of Process Plant Buildings* [1,2,3] and API RP 753 *Management of Hazards Associated with Location of Process Plant Portable Buildings* [4]. These recommended practice (RP) documents are non-mandatory guidelines but are considered as the industry standard for FSS. While intended for different building types, the RPs universally state that a detailed structural analysis is required for new buildings designed to resist blast loads and that non-structural debris should be evaluated. The state-of-practice for structural and non-structural design and evaluation is discussed in the following subsections.

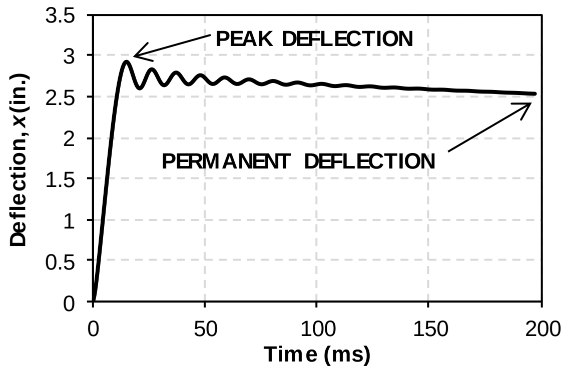
3.1 Structural Design Philosophy

It is important for the reader to understand the basic methodologies used for blast analysis of building structures. The structural elements such as columns, beams and wall panels that make up a BRM are typically analysed as individual components. Each component is analysed as an equivalent single-degree-of-freedom (SDOF) system, using the mid-span displacement as the point of interest. As shown in Figure 5, a SDOF component is loaded with a transient blast load, and the mid-span displacement is tracked. The magnitude of peak deflection is of primary interest, and this value is used to approximate the level of damage each component will undergo. Unless designed to remain elastic, which is rarely the case for any structural component, there will be a permanent deflection which may limit the reusability of a structure. Figure 6 further illustrates this with post-test photographs of an exemplar BRM panel that was blast tested using a shock tube.





Applied blast load history, p(t)



Mid-span displacement history, x(t)

Figure 5. Example SDOF Blast Analysis Methodology

API 752 and API 753 both recommend the use of the ASCE Petrochemical Guideline for the design and assessment of blast-loaded buildings. API 752 [3] also cites the PIP STC01018 manual and the USACE PDC Technical Report 06-08 [9], but neither of these documents specifically address the design of BRMs. The ASCE guideline provides deflection limits for the design of wall and roof components, such as the corrugated plate walls, columns and beams. These are known as response limits, which are intended to correlate the maximum predicted displacement to qualitative levels of *structural* damage, without consideration of non-structural debris.

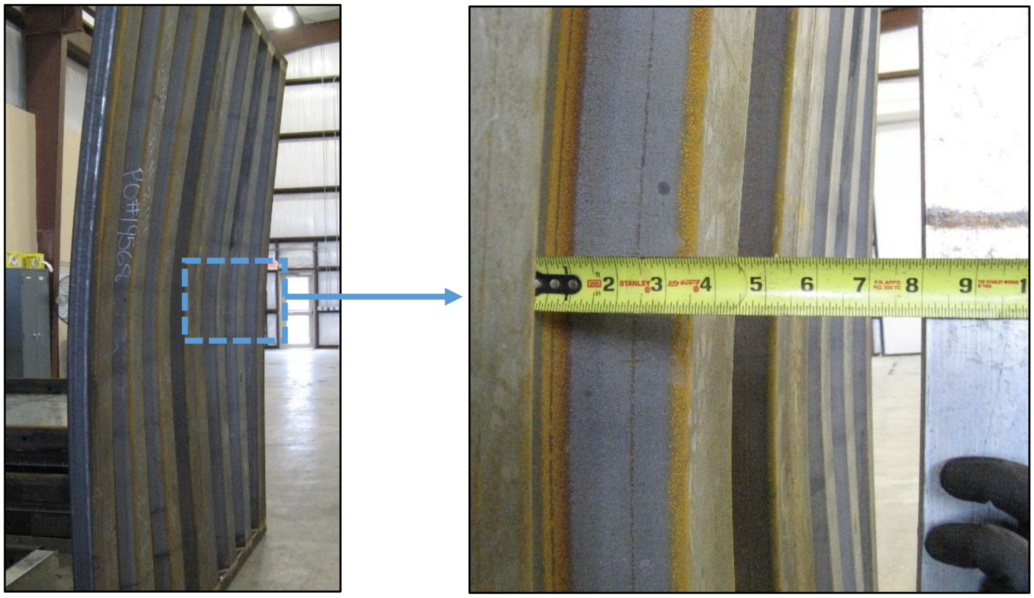


Figure 6. Example Permanent Deflection of a Tested BRM Wall Panel

There are three damage thresholds specified in the ASCE Petrochemical Guideline [5,6]; Low, Medium, and High. The qualitative damage descriptions for each of these states are listed in Table 1. Note that the damage descriptions are only indicative of structural damage and do not consider non-structural debris. Qualitative descriptions are correlated to quantitative response limits, which dictate allowable structural component deflections caused by blast loading. Quantitative limits have historically been developed using scaled- and full-scale high-explosive (HE) and shock tube test data and accident investigation observations.

Limited test and accident data are available for the crimped wall panels used on BRMs, and consequently there is not a prescribed response criterion for this type of structural component. The ASCE Petrochemical Guideline recommends that this type of crimped wall panel is designed for a response between a light-gauge corrugated panels (typical on metal warehouse-type buildings) and flat steel plate. Table 2 lists the quantitative limits for these component types. The table also includes the ductility factor, μ, which is the ratio of maximum displacement to yield displacement. Hence a value exceeding unity implies the component has yielded and there will be permanent deflection. The qualitative and quantitative limits in the PIP STC01018 [7,8] manual are replicates of the ASCE Petrochemical Guideline.

Based on the ASCE Guideline [6], it is customary practice for an average of the two limits to be used for the design of crimped plates for BRMs. Light-gauge panels have a propensity to buckle, which is why their limits are much less than that of flat steel plates. If buckling is explicitly accounted for in the analysis, the response limits of flat steel plates can be adopted, allowing larger displacements in the wall and/or roof panels. Note that the original ASCE Guideline [5] had no considerations for the design of BRMs, and guidance was first provided in the 2010 2nd Edition.

As previously mentioned, the overall dimensions of a BRM can vary significantly. The roof eave height is typically the most consistent across modules, ranging between 8 ft and 12 ft. Table 3 is provided as an example of the magnitude of allowable structural component deflections in a typical

BRM design. Most BRM structural components are designed to sustain Medium damage, which corresponds to an allowable peak mid-span deflection of 5 inches for a 12 ft span. Because typical BRM crimped wall panels are stiff, the permanent displacement would be expected to at least 80% of the peak deflection.

Table 1. Qualitative Damage States for Component Blast Design [6]

Damage Level	Component Response
Low	Component has none to slight visible permanent damage.
Medium	Component has some permanent deflection. It is generally repairable, if necessary, although replacement may be more economical and aesthetic.
High	Component has not failed, but it has significant permanent deflections causing it to be unrepairable.

Table 2. Quantitative Criteria for Steel Panels and Plates [6]

Element Type	Low		Medium		High	
	μ_a	θ_a	μ_a	θ_a	μ_a	θ_a
Secured cold-formed panels	1.75	1.25°	3	2°	6	4°
Flat steel plates	5	3°	10	6°	20	12°
Average (used for BRM crimped panels)	**3.4**	**2.1°**	**6.5**	**4°**	**13**	**8°**

Table 3. Allowable Panel Deflections for Different Wall/Roof Panel Spans

Damage Level	θ_a	Maximum Mid-span Deflection			
		Span = 8 ft	Span = 10 ft	Span = 12 ft	Span = 14 ft
Low	2°	1.7″	2.1″	2.5″	2.9″
Medium	4°	3.4″	4.2″	5.0″	5.9″
High	8°	6.7″	8.4″	10.1″	11.8″

3.2 Non-structural Design Guidance

The recommendations and methodologies in the blast guidelines and recommended practices are discussed herein. Non-structural design guidance is most commonly qualitative, and limited quantitative measures are provided. Table 4 provides a summary of these for the most common U.S. guidelines used for blast assessment of buildings in refineries and processing facilities.

Table 4. Non-Structural Debris Design Recommendations from Different Blast Documents

Title	Guidance	Recommendation
API RP 752 (3rd Ed.)	Qualitative	Assessment must address non-structural components (roofs, walls, ceilings and mechanical services) that may present debris hazards to occupants.
API RP753 (1st Ed.)	Qualitative	Design should limit dislodgement of internal features. Secure internal furniture, office equipment and fixtures
ASCE Petrochem (2nd Ed.)	Qualitative	Permanent fixtures and equipment should be designed to withstand local building motions. Seismic anchorage techniques are valid for blast. Functional or decorative objects should not be mounted on the interior surface of an exterior wall.
	Quantitative	Place file cabinets and other furnishings off the interior surface of an exterior wall greater than the maximum predicted displacement of the wall.
PIP STC01018 (2nd Ed.)	Quantitative	**Suspended items:** Anchorage for a statically applied force equal to the mass of the item times the maximum acceleration of the roof, or five times the weight of the item, whichever is less. Items weighing more than 10 pounds should be independently anchored. **Equipment and Internally Mounted Items:** Instrumentation or electrical equipment shall not be mounted on the interior face of walls subjected to blast loads without owner's approval. All fixed floor-supported items (e.g. lockers, electrical cabinets, racks) shall have a minimum clearance from exterior walls equal to the maximum calculated lateral blast load deflection. The maximum deflection shall be the sum of both the overall building sidesway and the deflection of and wall component(s), calculated based on the maximum blast loads. Supports and anchorage for equipment shall be designed to resist a lateral force equal to 20% of the equipment weight.

The API 752 and API 753 RPs recognize the need to assess non-structural debris hazards in different qualitative ways, depending on the edition. Appendix D in the 1st and 2nd editions of API 752 include an example building checklist for assessing risk-reduction measures in occupied buildings. The questions include looking at whether large office equipment, stacks of materials, lighting fixtures, ceilings, or wall-mounted equipment are "well-supported" or "adequately secured". Quantitative recommendations for determining what type of connection is adequate are not provided in the document. This checklist was removed from the 3rd Edition of API 752 and readers were instead made aware of non-structural debris as a cause of occupant vulnerability with the following statement:

> "*The primary hazards to personnel located indoors are building collapse and debris. Debris may include building materials thrown from exterior walls or dropped from ceilings/roof. Building contents located on, against, or near external walls may also become debris.*"

API 752 (3rd Edition) states that the evaluation of existing buildings (Section 6.6) and new buildings (Section 6.8) address non-structural components that may present debris hazards from roofs, walls, ceilings and mechanical services. However, like the 1st and 2nd editions of API 752, there is no recommendation on how to perform this assessment, or correctly design the anchorage. API 753 also acknowledges non-structural debris in portable buildings can cause injuries to occupants and requires blast assessments address internal non-structural features. Further recommended risk reduction practices include securing internal furniture, office equipment, and fixtures, but without specific examples or guidance on how to do so.

Non-structural debris is discussed in the ASCE Petrochemical and PIP STC01018 guidelines that are referenced by API 752. ASCE Petrochemical states that "*permanent fixtures and equipment should be designed to withstand the calculated local building motions as a results of blast loads.*" This guideline stops short of providing quantitative guidelines for designing restraints and direct the user to seismic guidelines that provide anchorage methods for non-structural items in earthquake prone buildings. As stated in ASCE, "*all non-structural upgrades recommended for buildings subject to earthquake loads are also applicable for blast resistant design.*"

The ASCE manual covers architectural items in more detail, albeit somewhat contradictory to the aforementioned statements. Architectural items fall under the discipline of the architect, who is not often knowledgeable of expected building damage. Quantitative guidance is given that file cabinets and furnishings should be placed off the interior surface of the wall at least the distance of the maximum predicted wall displacement. ASCE also states that functional or decorative architectural objects should not be placed on the interior surface of an exterior wall.

PIP STC01018 provides the most quantitative guidance minimum structural and non-structural design criteria requirements for permanent blast resistant buildings. Any item weighing more than 10 pounds (5 kg) and suspended from the roof, should be anchored to structural framing members. The anchorage should be designed to resist a static force that is the lesser of 5 times the weight of the object, or the mass of the object multiplied by the peak predicted acceleration. Hence if a roof member has a blast acceleration that exceeds 5***g*** (***g*** = acceleration of gravity), then the anchorage would only be designed for 5 times the weight of the object. Other clauses are similar to ASCE, where interior items should not be wall mounted, and fixed-floor items should be spaced a distance equal to the total wall deflection.

4 Reasons for Non-structural Debris

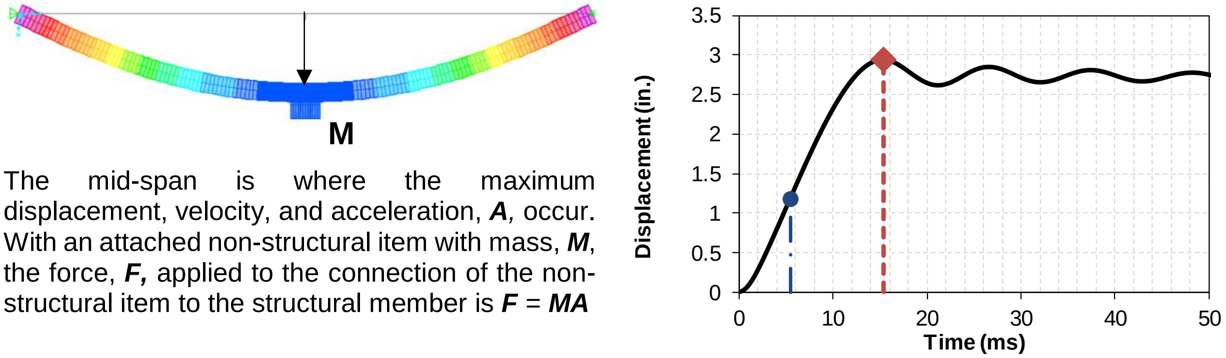
Non-structural debris generated during an explosion are primarily caused by wall or roof displacement. BRMs differ from permanent buildings, as they are not always integral with a foundation, and they can slide during a blast event. Both of these phenomena cause large decelerations to occur to objects within a BRM. This is analogous to rapid deceleration in an automobile, where occupants are thrust forward in their seat as a car is traveling forward and brakes suddenly. Accelerations can be significant from both local (wall or roof) and global (sliding) movement during a blast event in BRMs, and both of these are discussed in more detail herein.

4.1 Wall or Roof Deflection

As previously discussed, wall and roof members of BRMs are allowed to undergo large displacements. Guidance for placing items off the walls is not always followed, particularly in single module BRMs to maximize the useable floor area. As previously shown in Table 3, an interior partition wall would need to be spaced between 4 to 6 inches off the interior surface of the exterior wall to not be directly impacted by the wall. This is not possible with interior ceiling items, which by necessity must be connected to a structural member to be suspended. Hence this section focuses on items rigidly attached to a wall or roof surface to demonstrate connection the magnitude of connection forces.

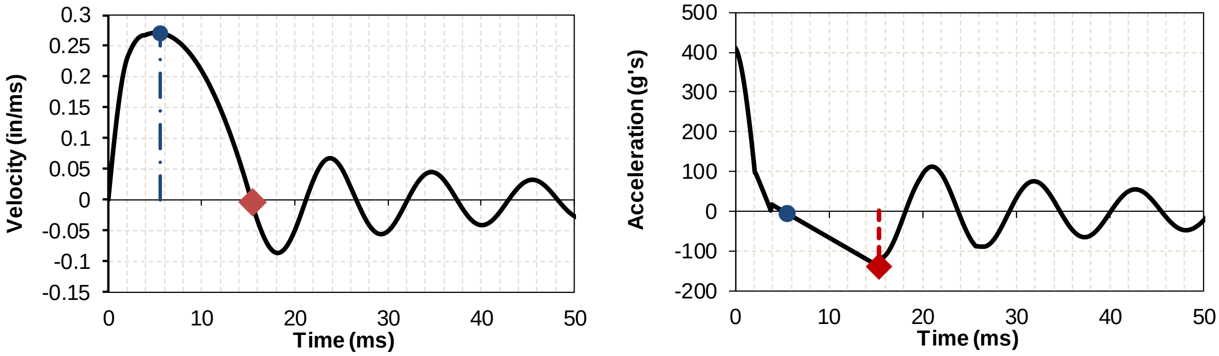
As plotted in Figure 7a, peak displacements, and therefore velocities and accelerations, will occur at the mid-span of a member responding in flexure. When a member reaches peak displacement, indicated with the dotted-line and diamond marker in Figure 7b, the velocity of the wall is nil (Figure 7c), and the wall deceleration is maximum (Figure 7d).

In the case of non-structural wall or roof debris rigidly attached to the structural wall, the peak deceleration coincides with the maximum force that will be experienced in the connection of the non-structural item to the structural member. The connection force, ***F***, is equal to the product of the maximum deceleration, ***A***, of the structural member and the mass, ***M***, of the non-structural item. Hence for the example in Figure 7, the peak deceleration of the structural member is around 140***g*** which means any non-structural item would need to be anchored for 140 times its own mass.



The mid-span is where the maximum displacement, velocity, and acceleration, ***A***, occur. With an attached non-structural item with mass, ***M***, the force, ***F,*** applied to the connection of the non-structural item to the structural member is ***F*** = ***MA***

(a) Deflected shape at arbitrary time *(b) Mid-span displacement*



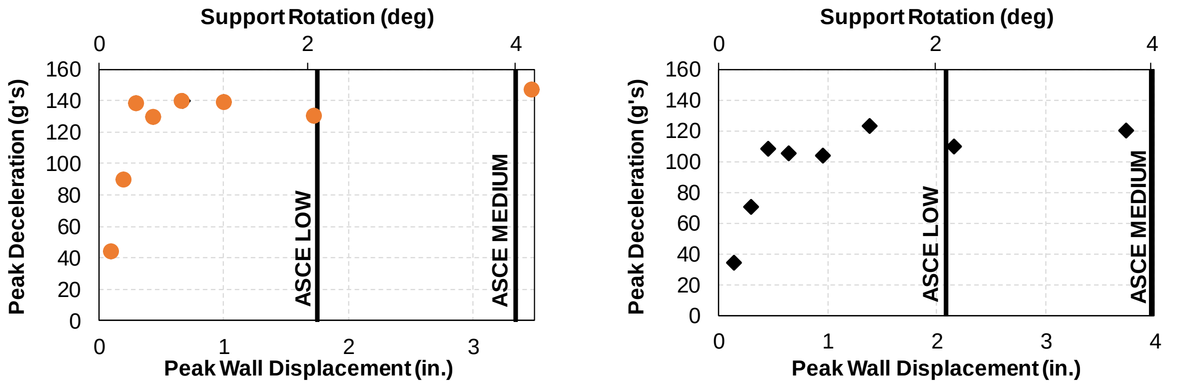
(c) Mid-span velocity *(d) Mid-span acceleration*

Figure 7. Example SDOF Analysis to Predict Connection Forces and Debris Velocities

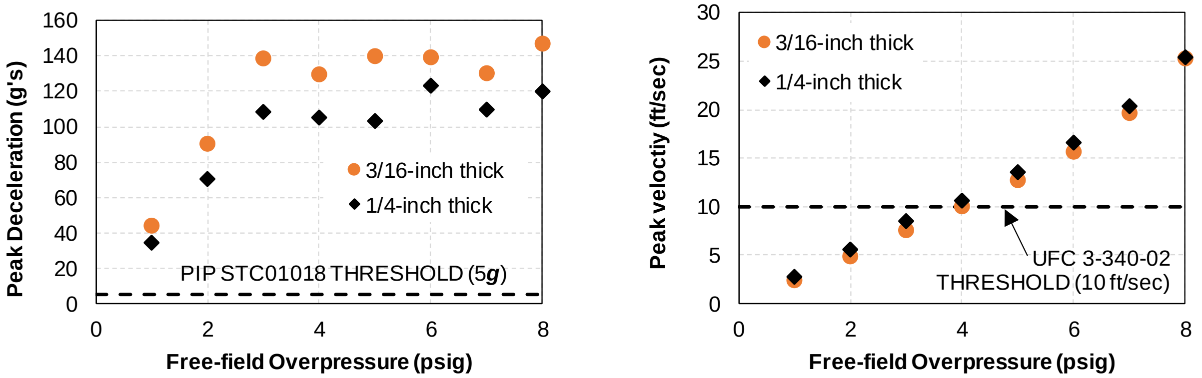
It is evident that for this arbitrary wall panel, the guidance by PIP STC01018 (5 times the member weight) would significantly under-predict the required anchorage force. Figure 7 plots a dash-dotted line with a circular marker to represent this case. It can be observed that the non-structural item would detach prior to the structural wall or roof element reaching peak displacement. A non-structural item would therefore detach and be launched with an initial velocity (Figure 7c) near the peak wall velocity. This phenomenon is what causes wall or roof mounted debris to be launched into occupied areas of BRMs.

Individual 3-inch deep crimped walls, one with 3/16-inch thick plate spanning 8 ft, and the other with ¼-inch thick plate spanning 9.5 ft are selected for demonstration purposes. The profiles selected are representative of BRM construction and satisfy an ASCE Medium response for an 8 psig free-field overpressure. SDOF analyses were completed from which the peak decelerations and velocities were computed to examine the predicted differences in rigid non-structural element connections.

Figure 8a and Figure 8b plots the peak decelerations for the 3/16-inch thick and ¼-inch thick plate, respectively. These graphs demonstrate that the wall accelerations are independent of the wall deflection, provided the wall deflection exceeds the yield point, which is usually on the order of ½-inch. Hence a BRM will still experience the same deceleration at a wall displacement that is less than the allowable displacement. Comparison of these two graphs also demonstrates the concept that heavier wall panels will have lower decelerations than lighter panels. Figure 8c further demonstrates these concepts with respect to free-field overpressure.



(a) Decelerations for 3/16-inch thick crimped wall plate *(b) Decelerations for 1/4-inch thick crimped wall plate*



(c) Deceleration for different wall panels *(d) Peak velocities for different wall panels*

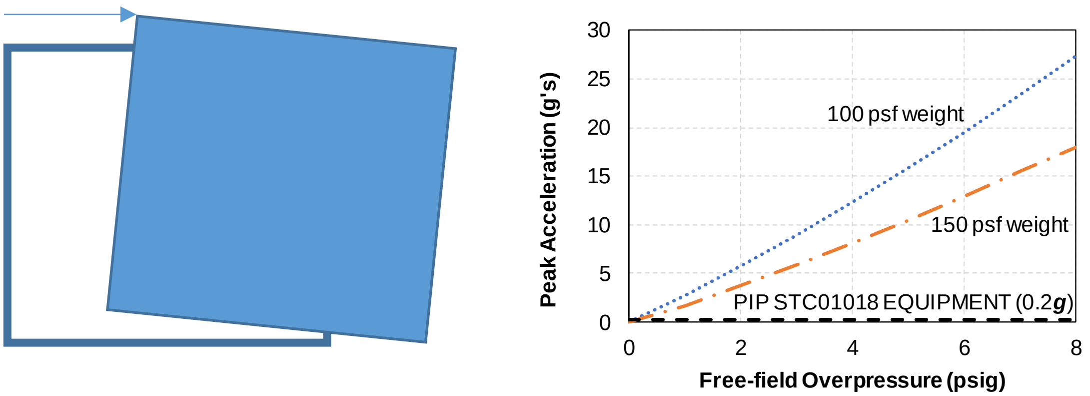
Figure 8. Peak Wall Decelerations and Velocities for Representative BRM Wall Panels

Figure 8d plots the peak velocity of the different wall panels with respect to free-field overpressure. Also included in this plot is the 10 ft/sec threshold specified by UFC 3-340-02 [10] as a critical velocity for serious injury to personnel due to fragment impact. Serious injury is expected if a fragment is traveling faster than 10 ft/sec and exceeds 2.5 lbs (impacting the thorax), 6 lbs (impacting the abdomen), or 8 lbs (hitting the head). For the representative BRM wall panels analyzed, this threshold would be exceeded at approximately 4 psig, or half the design-basis blast load of 8 psig.

4.2 Sliding Acceleration

BRMs that are not anchored to a foundation, or only anchored for conventional wind loads, are susceptible to sliding during a blast event, as illustrated in Figure 9a. This causes global accelerations to be imparted to non-structural items, even if they are anchored off a wall surface. The magnitude of the horizontal accelerations incurred depends on the BRM weight, dimensions, blast load and coefficient of friction between the BRM and foundation (or soil) beneath it.

An example case is created for a 12 ft tall, 12 ft wide BRM with an assumed coefficient of friction of 0.3, representative of steel on concrete. Representative weights per floor area, 100 psf and 150 psf, were selected. Figure 9b plots peak horizontal accelerations as a function of free-field overpressure. While increased weight reduces the horizontal acceleration, pressures less than a typical 8 psig design pressure exceed the PIP STC01018 recommended design acceleration of 0.2***g*** for equipment. Hence debris can credibly be produced even if interior items are spaced off the interior walls and anchored for a notional force equivalent to 20% the item weight.



(a) Schematic of rigid body sliding　　*(b) Global acceleration using friction coefficient of 0.3*

Figure 9. Sliding Acceleration in BRMs

5 Conclusions and Recommendations

Non-structural debris is recognized as a credible hazard in blast documents that are used to site and design temporary and permanent buildings at chemical processing and refining facilities. This paper summarized the limited quantitative guidance available intended to mitigate against these hazards. Simplified modeling of crimped wall panels representative of BRMs demonstrated that anchorage forces for wall-mounted non-structural items are significant and may be impractical to develop in some structural substrates. This conclusion also applies to architectural and mechanical equipment attached to the interior roof structure of a BRM.

While some guidance documents instruct designers to place non-structural items off the interior face of exterior walls, this is not possible to do with ceiling items which must be attached to the superstructure to remain suspended. Even if this guidance is followed for walls, global sliding accelerations are applied to all interior non-structural items in unanchored BRMs. This paper demonstrated that these sliding accelerations can be significantly higher than the recommended design forces in blast guidelines, therefore increasing the likelihood of debris generation. BRMs should be designed with these factors as a consideration. Design forces should be based on detailed computational models, where the non-structural elements are accounted for in the model. Alternatively, representative wall or roof assemblies can be blast tested to determine if non-structural connections are sufficiently strong to prevent non-structural items from becoming debris hazards.

6 References

1. American Petroleum Institute (API), *Management of Hazards Associated with Location of Process Plant Buildings, API Recommended Practice 752*, First Edition, Washington, D.C., May 1995, 34 pp.
2. API, *Management of Hazards Associated with Location of Process Plant Buildings*, *API Recommended Practice 752*, Second Edition, Washington, D.C., November 2003, 34 pp.
3. API, *Management of Hazards Associated with Location of Process Plant Buildings*, *API Recommended Practice 752*, Third Edition, Washington, D.C., December 2009, 27 pp.
4. API, *Management of Hazards Associated with Location of Process Plant Portable Buildings, API Recommended Practice 753*, First Edition, Washington, D.C., June 2007.
5. American Society of Civil Engineers (ASCE) Task Committee on Blast-Resistant Design, *Design of Blast-Resistant Buildings in Petrochemical Facilities*, First Edition, Reston, VA, 1997.
6. ASCE Task Committee on Blast-Resistant Design, *Design of Blast-Resistant Buildings in Petrochemical Facilities*, Second Edition, Reston, VA, 2010.
7. Process Industry Practices (PIP), Construction Industry Institute, (2006). *PIP STC01018: Blast Resistant Building Design Criteria*, The University of Texas at Austin, Complete Revision, Oct. 2006.
8. Process Industry Practices (PIP), Construction Industry Institute, (2014). *PIP STC01018: Blast Resistant Building Design Criteria*, The University of Texas at Austin, Complete Revision, Oct. 2014.
9. PDC TR-06-08, "Single Degree of Freedom Response Limits for Antiterrorism Design," USACE PDC *Technical Report 06-08*, Jan. 2008.
10. U.S. Department of Defense (DoD). "Structures to Resist the Effects of Accidental Explosions," *Unified Facilities Criteria (UFC) 3-340-02*, Dec. 2008.