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## Enclosed Process Bay Vented Blast Loads and Impacts on Occupied Buildings

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### Abstract

A typical approach to suppressing the effects of a vapor explosion inside an enclosed process building or bay is to use vent panels to relieve the confined blast pressures. This results in blast expanding outside the process building and reaching near-by buildings with potential hazardous consequences. Before the venting happens, blast also propagates within the process building itself and can load areas such as a control room. This paper examines blast wave characteristics (e.g., magnitude, shape, duration) of vented loads that are released after the vent panel is disposed of and the resulting blast loading on a near-by building assumed to be occupied. Blast propagation within the process building and loading on connected occupied areas (e.g., control room, break room) are also examined.

**Keywords:** CFD, Blast, Facility Siting, Structural Response, SDOF, Petrochemical

### Introduction

A vapor explosion inside a fictitious enclosed process building was modeled using the Computational Fluid Dynamic (CFD) code FLACS<sup>1</sup>. The example CFD simulation tracked blast propagation within the process building and tracked loads vented to the exterior that reach a near-by building. The results of the CFD simulation are compared to predictions made using traditional vapor cloud blast curves. Example Single Degree of Freedom (SDOF) structural response calculations are made for common building constructions and the hazards to occupants summarized.

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<sup>1</sup> Flame Acceleration Simulator (FLACS), Version 10.3r3, GexCon, Bergen, Norway, 2014.

## Overview of CFD Model:

Figure 1 illustrates the example enclosed process building with two hazardous process areas (A & B). The facility also includes occupied areas such as a laboratory, change rooms, and control room. The various spaces are connected by corridors. In addition, there is an administration building connected to the process building by a breezeway.

It is assumed that the process building was not designed with blast in mind and that the structure was sized for conventional loads (e.g., wind, snow). The construction of the process building includes exterior walls that are metal panels supported by cold-form girts. Interior walls are 8-inch unreinforced masonry block. The roof is concrete on metal decking supported by open web steel joists (OWSJs). Doors at the process areas are assumed to be lightweight panels such as in Figure 2, while doors to occupied areas (e.g., laboratory) are conventional hollow metal doors. It is important to point out that the internal explosion will load wall and ceiling surfaces, resulting in pushing those components from the inside out, which is the reverse direction of conventional loads.

The Administration Building was assumed to be exterior brick over masonry block. It has a built-up roof supported by OWSJs. The building has conventional insulated glass unit windows.

Two flammable cloud locations were investigated, one each in hazard areas A & B (Figure 3). Each vapor cloud explosion involved propane as the flammable material in a moderate congestion level

Figure 4 illustrates the propagation of blast internal of the building, plus that which is vented to the exterior, with blast reaching the Administration Building. The following comments apply:

- The blast propagates away from the source, interacting locally with walls and roof.
- The most intense loading is in the room with the explosion.
- Blast quickly leaks through doorways into adjoining rooms and adjoining corridors.
- As time progresses the blast makes its way through the building failing weak walls and upheaving the roof. (See Figure 5 where failed walls are shaded red)
- Blast is also leaked to the outside through exterior wall and roof failures. Leaked blast loads reach the administration building. Leaked blast can also wrap-around and load external wall and room surfaces of the main building.

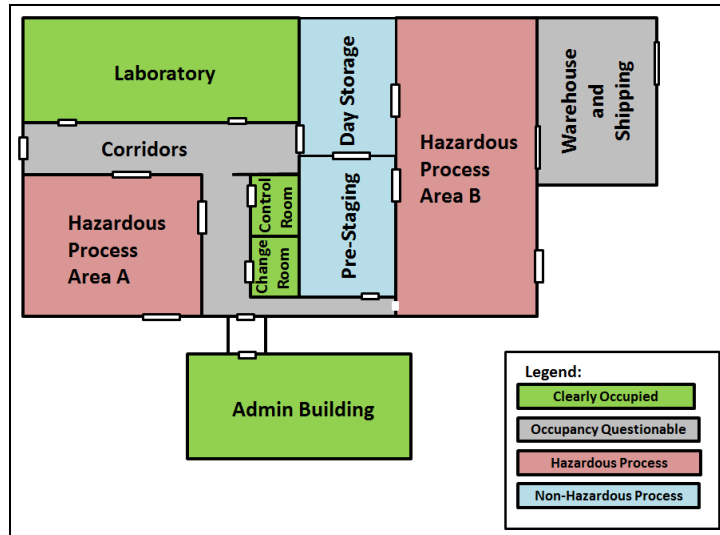
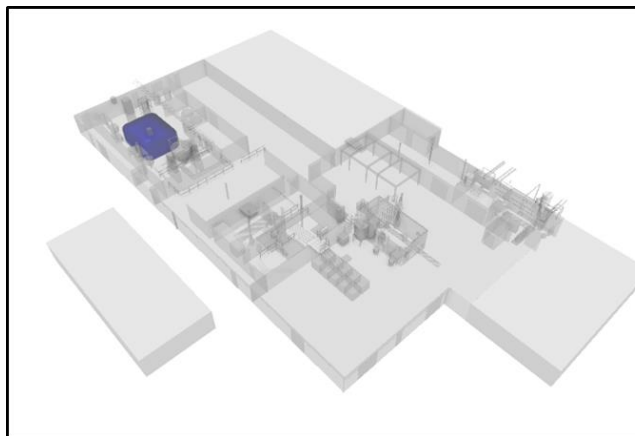


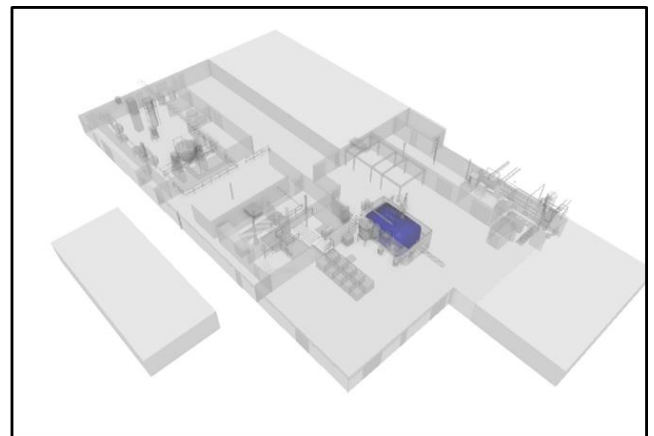
Figure 1. Example Building with Enclosed Process Areas



Figure 2. Typical Process Area Door



Explosion A



Explosion B

Figure 3. Explosion Locations in Hazard Areas A and B

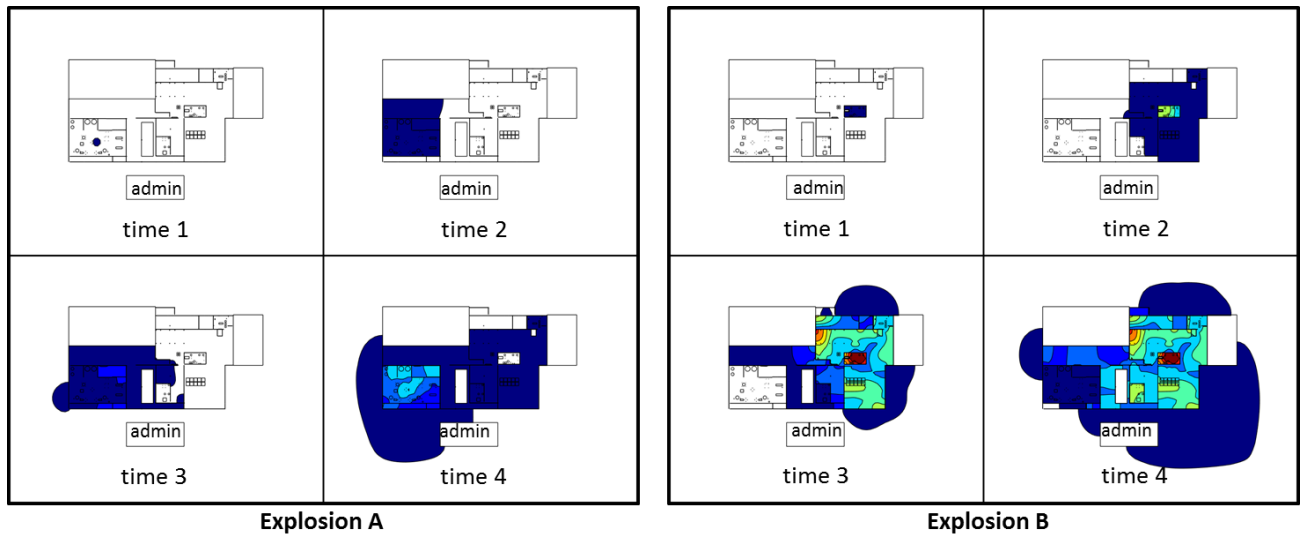


Figure 4. Blast Propagation Sequence

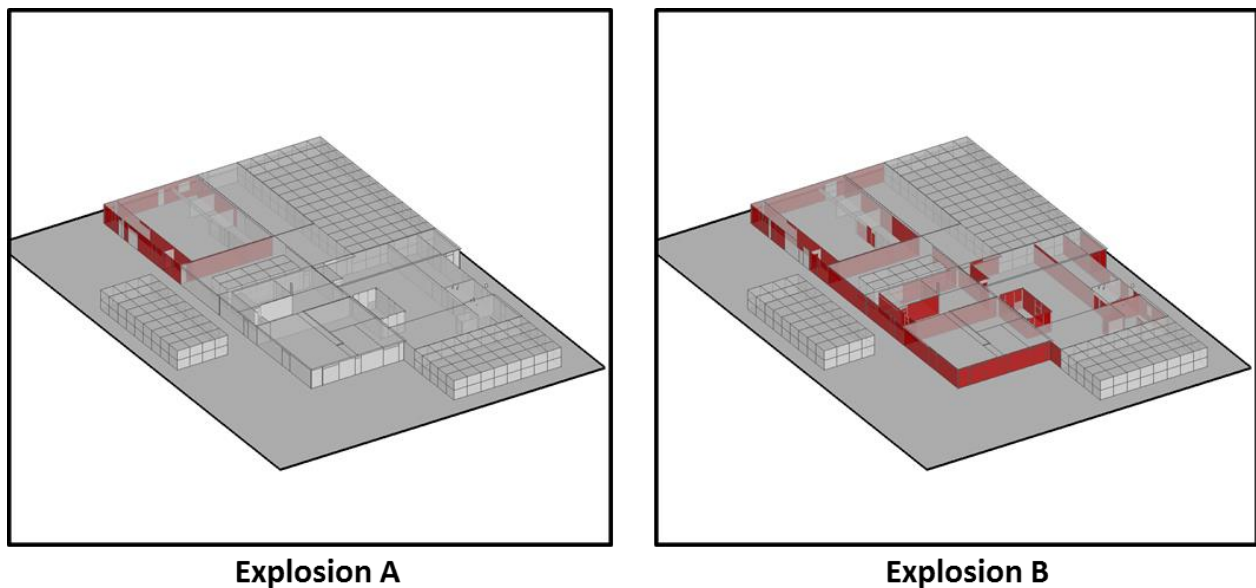


Figure 5. Wall Failures Patterns

### Representative Pressure Time-Histories:

The process of blast propagation within the building results in the pressure wave reflecting off walls and floors. This results in a reverberation pattern in the pressure time-history<sup>2</sup>. Figure 6 shows two sample blast-recordings from the CFD simulation. Explosion A recording was taken at the Admin Building wall facing the process building. Explosion B was taken inside the

<sup>2</sup> The pressure axis values were intentionally left blank as only relative magnitude is germane to the discussion.

process building, away from the explosion center. Both reveal several peaks and valleys in the pressure history. Explosion A at the Admin Building is lower pressure (due to the increased separation from the explosion) and demonstrates several pulses as blast reflections in the building leak out over time. Explosion B shows a similar pattern but at higher pressure, as it is within the enclosed process building.

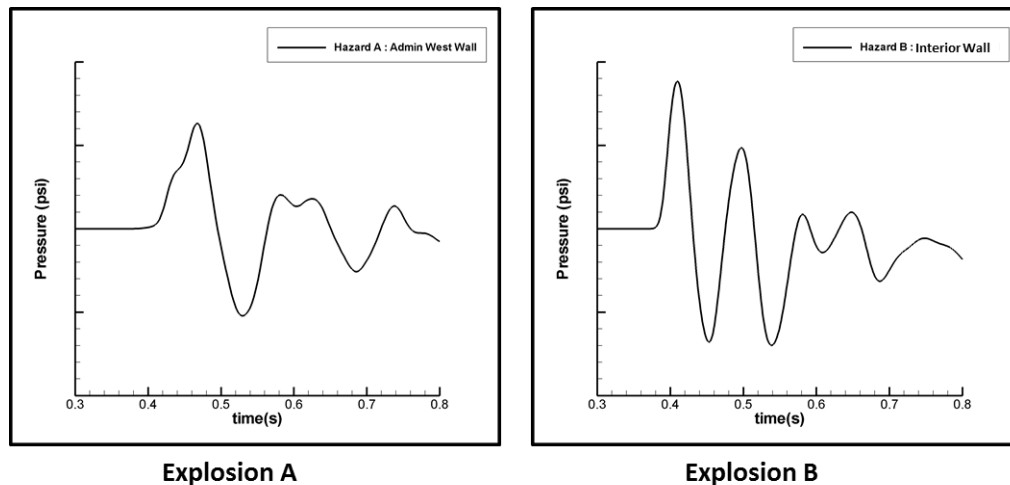


Figure 6. Pressure-Time Histories

Previous work investigated the structural response to blast histories comprised of multiple pulses. Previous work<sup>3,4</sup> examined the effect of multiple shock pulses on structural response. That work compared a traditional triangular single pulse load to that of a load comprised of three pulses that decay with time. Single Degree of Freedom (SDOF) analysis was used to calculate responses and results were plotted as non-dimension terms in Figure 7, with the X axis representing scaled time (relating structural frequency and load duration) and Y axis as scaled maximum deflection (related to static deflection from peak pressure). The shock time history (duration and arrival time) are scaled to the natural period of the SDOF element. A single solution for a shock arrival/shock duration equal to 2.5 is shown. The triple pulse in Figure 7 is similar to the blast profile shown in Figure 6, indicating that the overall structural response can be enhanced over that from the initial pulse alone. Later shock reverberations cannot be ignored.

<sup>3</sup> DOE/TIC-11268, "A Manual for the Prediction of Blast and Fragment Loadings on Structures," Prepared for United States Department of Energy, Albuquerque Operations Office, by Southwest Research Institute and Wilfred Baker Engineering, Inc., under Contract with Mason & Hanger, and Battelle Pantex, July 1992.

<sup>4</sup> "Structural Response to Multiple Pulse Blast Loading," Whitney, Mark; Barker, Darrell; Wacławczyk, Jr., Johnny; Proceedings on the Sixth International Symposium on the interaction of Non-Nuclear Munitions with Structures; pages 122-127, May 1993

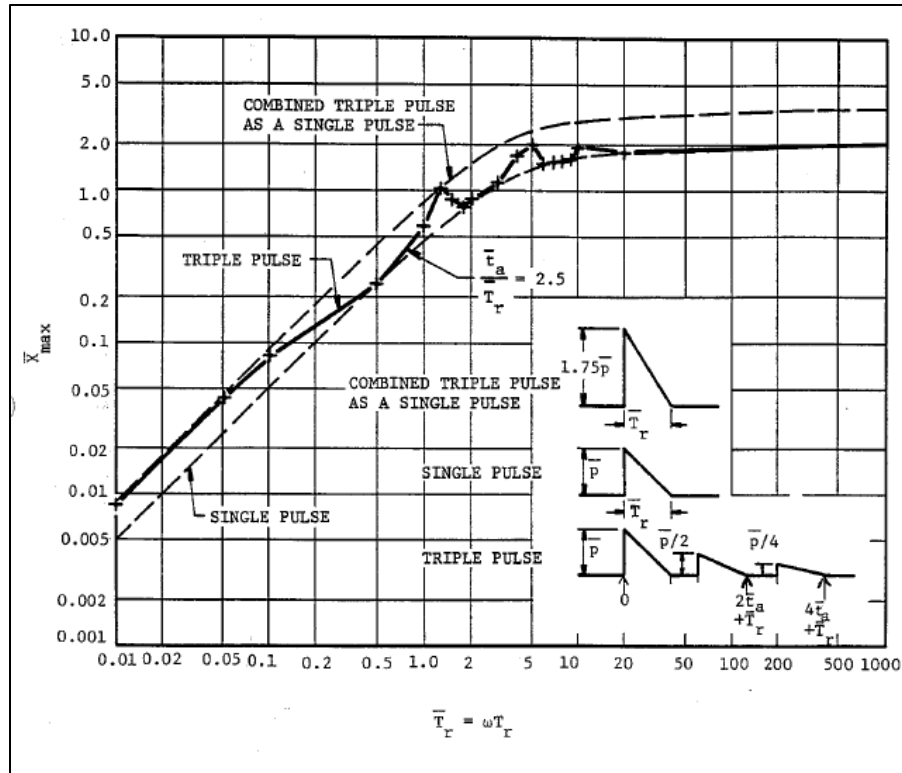


Figure 7. Triple Pulse Analysis (Taken from 3)

## Construction Considerations

The following comments apply to conventionally constructed buildings:

- Provision of vent panels reduces blast load in the interior of the process building, but can increase blast loading on buildings near the vent location.
- Provision of vent panels does not eliminate blast loading on interior walls and ceilings and localized failures may occur unless design is provided to resist the loading.
- Brittle elements such as unreinforced masonry walls are unforgiving and can be driven to collapse. This is particularly troubling if the wall is load bearing.
- Brittle elements can be sensitive to pressure time histories with multiple shock reverberations such as those in Figure 6. In some cases, the element may not fail from the initial pulse but is driven to failure by the cyclic loading.
- Roof elements are designed to principally resist gravity loads. Some capacity is provided to resist uplift from wind loading; however, this is overcome by even modest blast loads. Roofs uplifted by blast result in a falling debris hazard after the blast load is relieved through venting.
- Some reinforced concrete cast-in-place slabs have greater reinforcement at the bottom to provide a tension component for gravity load. Interior blast loading can uplift the slab and 'crack the back' of the slab.

- Precast elements, such as double-Ts, typically have relatively weak connections to their supports. Also, double-Ts often have bottom pre-stressed tendons and relatively light top reinforcement. These are vulnerable to reverse loading.

## **Conclusions**

This paper investigated explosions in enclosed process areas and how that affected blast propagation within the process building and vented blast that reached near-by buildings. A structural response should address the full pressure time-history of the loading. Examples are given to identify potential weaknesses in conventional construction to blast loading.