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New Control Building Construction Feasibility Analysis

John N. Dyer*, Anay P. Raibagkar, Luca Magenes, Thomas Anderson

P.E. Baker Engineering and Risk Consultants, 11011 Richmond Av. Houston, Texas 77042
JDyer@BakerRisk.com

Blast load calculations are a central aspect to most Facility Siting Studies (FSS) and Quantitative Risk Assessments (QRA) for chemical processing facilities. The calculated blast loads can have important impacts on new buildings at an existing facility that need to be properly understood for them to become design basis loads.

This paper describes an efficient and cost effective method of selecting a building design that minimizes blast risk to the extent practical;

Firstly, by reviewing predicted blast loads and associated frequencies to select potential building types that can be used to achieve the required level of personnel protection, such as pre-engineered steel frames, masonry building with load-bearing walls, and precast concrete tilt-up construction.

Secondly, by developing structural models for each of the building types considered based on dynamic structural analyses of typical building components. The buildings’ blast load resistance can be graphically represented through pressure-impulse diagrams.

Thirdly, by investigating the sensitivity of a building’s blast capacity to changes for each building model by modifying structural properties such as roof components, exterior walls and other critical components of the building.

Fourthly, by determining a potential location for the building in the plant where a selected building construction type can be placed without exceeding a tolerable risk level.

Finally, by estimating the additional construction cost to locate the building at other locations where blast loads are more severe.

This paper assists in selecting cost-effective building design(s) to be considered in the planning and design stages by evaluating the material requirements of each building type to achieve acceptable performance. Sensitivity calculations can be performed to compare risk as a function of construction costs to allow a practical design to be selected.

Introduction

Traditionally, Facility Siting Studies (FSS) and Quantitative Risk Assessments (QRA) are used to model hazards such as jet and pool fires, toxic releases, and vapour cloud and other explosions in chemical and petrochemical processing plants. These hazards can have devastating consequences on buildings and other infrastructure and can cause serious injuries, infrastructure losses, or render large sections of the plant inoperative. The task of designing new buildings potentially subjected to these hazards requires careful consideration of the potential structural demands on the building and its performance requirements. Control buildings, in particular, would be expected to remain operational after accidents of a certain magnitude. Additionally, these buildings are frequently used to shelter-in-place in the event of an accidental release of flammable or toxic material. General guidelines and simplified methodologies described in this paper can be used to effectively model building blast damage in order to optimize the structural design of new control rooms which are critical to the operation of a facility. This paper emphasizes the impact of explosions on control rooms. However, the methodology can be extrapolated to other hazards and buildings.

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Building Damage Models

Building design can become a complicated and expensive endevour when explosion blast loads are considered. The blast-resistant requirements can be a significant driver in the cost when the building design is performed using ill-appropriate methods such as static structural analyses or elastic dynamic structural analyses. Furthermore, the use of computationally-expensive methods such as finite element analysis yield results that could be challenging to interpret or expensive to use in iterations inherent in the design process.

The process of designing a control building in a petrochemical facility ideally starts with a thorough understanding of the building requirements to resist the postulated hazards. The structural requirements to resist explosion blast should be based on restricting the building damage to a level that affords the maximum protection to the building occupants while mainting the construction cost as low as practicable. This process may require multiple iterations to achieve the optimal design. Therefore, efficiency and economy should be key features of the desing methodology.

In order to facilitate the design process, the structural analysis methodology ideally has the following characteristics:

1. The structural design is performed with dynamic structural analyses to account for the transient blast loading
2. The analysis is able to model plastic behaviour to allow estimating structural damage.
3. The building damage may be expressed as discrete building damage levels (BDL) with corresponding occupant vulnerability values (personnel injuries.)
4. The overall building damage is determined by quantifying damage of key structural components or component damage level (CDL) to allow optimization of construction material.
5. Potentially fatal injuries are associated with the building damage level, distribution of the interior population, amount of exterior windows, and relative weight of the building materials.

Blast Load Modelling

In general blast loading of structures is a well understood topic and is treated extensively in the literature [UFC 3-340]. The simplified blast modelling assumes that the pressure is instantaneously applied and to decay linearly to the atmospheric pressure over time t (duration of the blast). Integrating the pressure function over the duration yields the impulse of the blast. Therefore, a blast load (illustrated in Figure 1) can be defined by its pressure and impulse values.

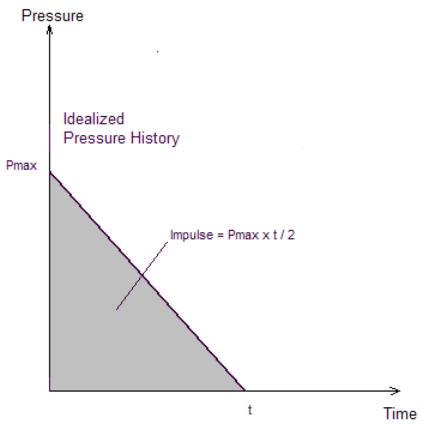

Figure 1: Idealized Blast Pressure Function

Dynamic Analysis and Blast Assessment

The response (damage) of a structural component can be estimated using simplified dynamic analyses based on the transient blast loads and the structural properties of the component. The Single-Degree-of-Freedom (SDOF) methodology can be effectively used to calculate deflections in the direction of interest only accounting for the strength and stiffness of the component and the overall mass of the system when loaded by the blast. The equation of motion (1) for such a system is [Biggs, 1964.]

$$F(t) = k(x) + C \cdot \left(\frac{dx}{dt}\right) + M \cdot \left(\frac{d^2x}{dt^2}\right) \qquad (1)$$

Where
x = horizontal deflection, length
K = stiffness, typically expressed as pressure/length
F(t) = load function in the horizontal direction, typically pressure vs. time
M = Mass of system

The equation of motion can be solved numerically using a spread sheet or other similar method. The component damage can be estimated by expressing the calculated dynamic deflections in terms of published response criteria [ASCE] that can be interpreted as component damage levels. The overall building damage can be estimated by observing component damage on the roof and sides of a building. The discrete building damage categories are summarized in **Table 1** and illustrated in
Figure ***2***.

Table 1. Building Damage Level Categories

BDL	Damage Description
1	Minor damage to roof and walls
2	Moderate or lower damage to roof and load-bearing components
2.5	Localized Major damage to roof or walls. Moderate damage to other components
3	Major damage to load-bearing elements or roof
4	Failure of load-bearing elements or roof collapse

Figure 2. Building Damage Level Categories (Examples)

When multiple explosion scenarios are considered, the blast assessment can become a cumbersome process, and a method that allows performing blast assessments under multiple loads becomes necessary.

Pressure-Impulse Diagrams

Pressure-impulse (P-i) diagrams are graphical blast assessment tools that allow considering multiple explosion blast loads simultaneously. The diagram consists of building damage curves that represent the blast loads (expressed as pressure and impulse combinations) that bound discrete building damage levels. The blast loads are represented by single points with specific pressure and impulse coordinates, as illustrated in Figure 3

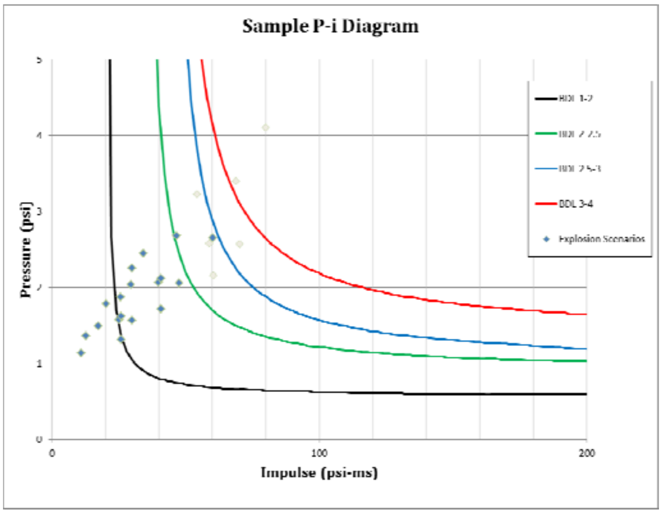

Figure 3. Example of P-i Diagram

The curves can be constructed using experimental data (obtained from testing); pseudo-empirical data (obtained from accident investigations, or can be constructed analytically using SDOF models of structural components.

Structural Design and Material Optimization

It is important to recognize that the overall blast resistance of any building depends on the combined resistance of the individual components. Furthermore, the overall capacity of the building is generally governed by the capacity of the weakest of its components. Therefore, increasing the capacity of any other components is not an effective approach to enhancing the capacity of a building. In other words, it is not reasonable to expect credit for overdesigning portions of the building while other portions remain relatively vulnerable to blast loading.
Therefore, optimization of structural materials is based on achieving a “balance design” in which a single structural component or a particular area a building does not significantly control the overall blast capacity. When the design is balanced, the process of enhancing the blast capacity of the building to meet the structural requirements consists of increasing the blast resistance of the components proportionately. When particular components are modified as part of design iterations, the revised building P-i diagram can be used to perform blast assessments and the cost-benefit relationship observed, as illustrated in Figure 4

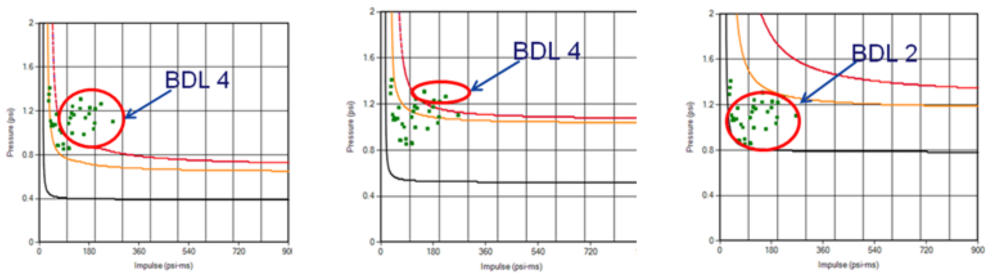

Figure 4: P-i Diagrams Corresponding to Design Iterations.

Design Methodology Outline

A general methodology to perform cost-effective building designs based on individual component analyses is outlined below:

1. Represent building capacity in terms of pressure, impulse, and building level of damage
2. Construct pressure-impulse (P-i) diagram for building concepts based on dynamic analyses of building components
3. Plot blast loads from all explosion scenarios considered
4. Calculate BDL for each blast load considered in the study
5. Determine occupant vulnerability for each construction type/BDL
6. Calculate risk for each building/concept combination by taking scenario frequency into account
7. Establish basis for risk/cost sensitivity analysis by modifying original building concept to increase its capacity, as illustrated in
8. Figure ***5***.
9. The process can be performed for different building construction types simultaneously to observe the sensitivity of different building materials or construction types to decrease risk with discrete cost increments, as illustrated in
10. Figure ***6***.

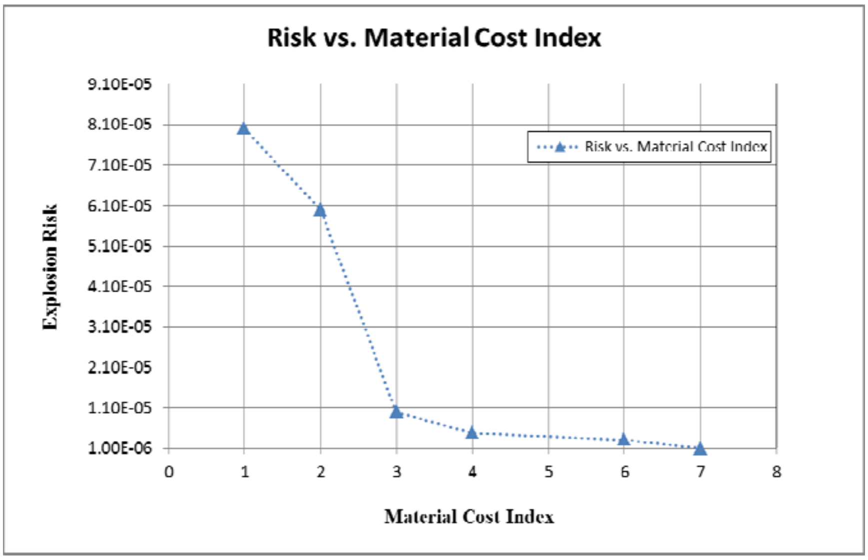

Figure 5. Risk vs. Material Cost Plot (Hypothetical Example)

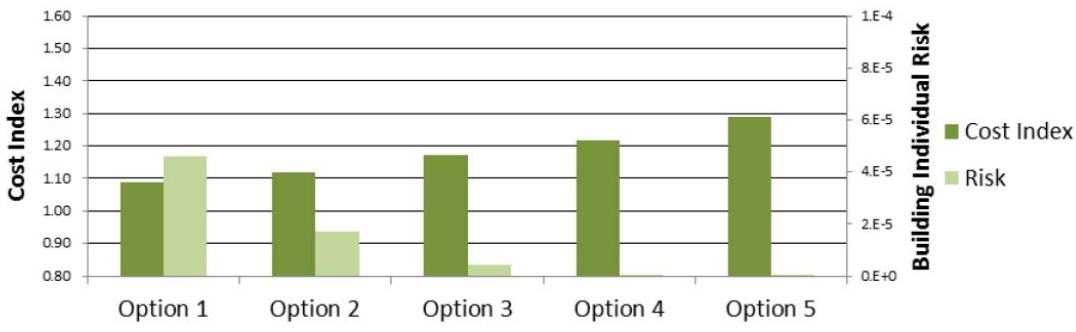

Figure 6. Risk vs. Material Cost Plot for Multiple Building Options (Hypothetical Example)

Additional Considerations

The feasibility phase of a new building design should consider potential alternative locations for the new building. In addition to less severe explosion blast loads, the alternative locations may be considered on the basis of providing better access for employees, having better access to power, sewer, or other utilities, improving facility efficiency, future plant expansion, or other. The potential siting of the new control room can be assisted by the use of contours such as the ones shown in
Figure ***7***, where the contours illustrate the potential locations achieved by increasing the cost of the building material in increments expressed in terms of the least expensive of the options. Contours similar to these can be constructed analytically using the results of a typical FSS or QRA and P-i diagrams for various building models.

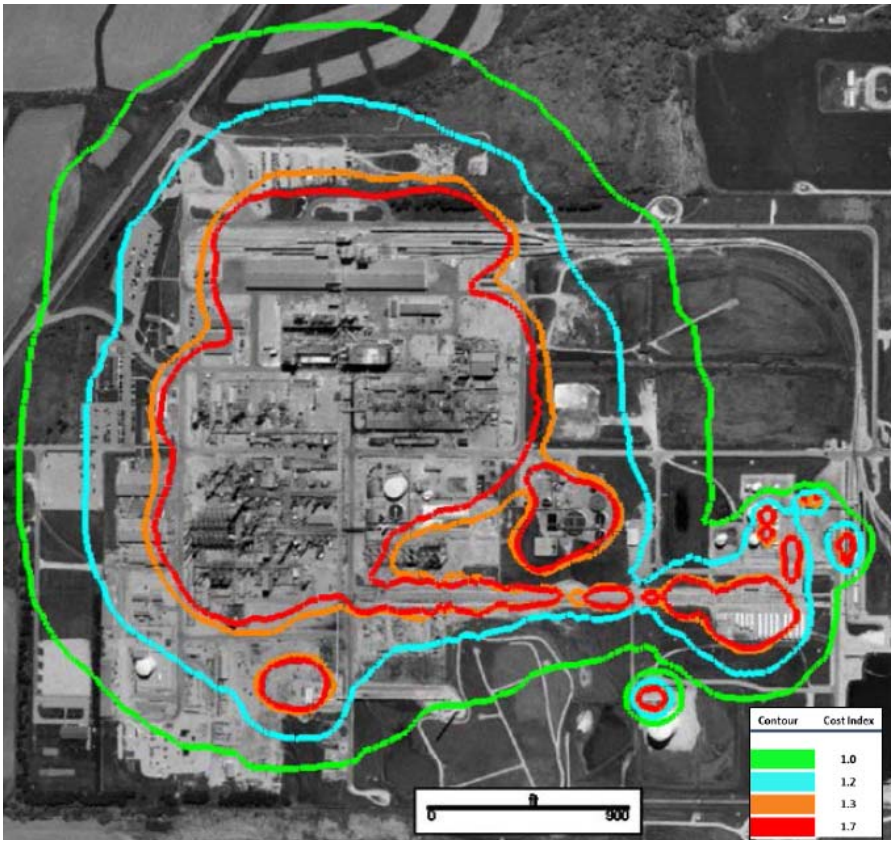

Figure 7. Material Efficiency Contours (Example)

Conclusions

Considering explosion hazards calculated in Facility Siting Studies is essential in determining building requirements for new control buildings in petrochemical and chemical processing plants. The feasibility phase of the design is important to understand the cost-benefit relationship of different building construction options. Simplified structural analyses can be used to construct building damage models that allow performing blast assessments under multiple explosion scenarios and performing necessary design iterations without incurring in expensive building designs. The general methodology outlined in this paper can be used to consider alternative locations within a plant that may constitute preferable options.

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