ABSTRACT
This article will briefly discuss the potential for industrial explosions. It will outline the steps in using one particular type of explosion modeling software called BREEZE® HEXDAM and VEXDAM that is used to predict the human and structural effects of explosions at a facility. Finally, the article will explain how to use this information to ensure workers’ safety and minimize facility damage resulting from explosions.

KEYWORDS:
Explosion modeling, damage assessment, software, process safety, injury, overpressure, dynamic pressure

INTRODUCTION
Industrial facilities run like well oiled machines, keeping the pulse of the nation’s economy moving at a steady clip. But on-site explosions slow this pulse, threatening workers’ safety and jeopardizing production. Industry leaders know all too well the devastating effects that explosions can have on a facility. In its 1999 Process Safety Performance Measurement report [1], the American Petroleum Institute (API) noted that respondents reported nearly 100 industrial incidents that resulted in significant injuries and even fatalities.

While many of these explosions may not be preventable, an industrial safety staff can predict their effects, enabling appropriate emergency response planning. Specialized explosion modeling software allows
facilities to input potential explosion scenarios based on the types of materials they use and store as well as the structural components of the buildings themselves, as depicted in Figure 1. These programs model structural damage as well as potential injury to workers within the facility. Facilities can benefit from explosion modeling in many different situations, including before constructing a new facility, when planning renovations to a facility, when changing the amount of a certain chemical stored on site, and before switching fuels. Equipped with this predicative tool, industrial personnel can help ensure the safety of their employees and the soundness of the structures in which they work.

This article will briefly discuss the potential for industrial explosions. It will outline the steps in using one particular type of explosion modeling software called BREEZE® HEXDAM and VEXDAM that is used to predict the human and structural effects of explosions at a facility. Finally, the article will explain how to use this information to ensure workers’ safety and minimize facility damage resulting from explosions.

**Susceptibility to Explosions**

Virtually any facility that handles, stores, or processes flammable gases, liquids, or solids has an explosion risk. Explosions can be produced either by high explosives such as TNT or dynamite, or by vapor clouds involving hydrocarbon fuels. All structures are classified as either overpressure or dynamic pressure sensitive. Blast waves resulting from an explosion will damage objects based on the object’s vulnerability to either type of pressure. Overpressure is the increase in pressure that results from the explosion, while dynamic pressure is the drag produced by the velocity of the wind behind the blast wave. Materials such as concrete are more susceptible to overpressure, and structures like towers, telephone poles, and bridges are affected more by dynamic pressure. In addition to overpressure or dynamic pressure, most structures are also sensitive, to some extent, to pulse duration. The integral of the overpressure or the dynamic pressure with respect to time, over the time interval corresponding to the pulse duration, represents the impulse. Dynamic pressure sensitive structures are more often sensitive to pulse duration and/or impulse than are overpressure sensitive structures.

Understanding the vulnerability of a facility’s structures is critical to predicting its ability to withstand a blast. Explosion models use pressure/impulse (P-I) characteristics to predict a material’s ability to
withstand conventional explosion or vapor cloud explosion blasts. For example, Trinity Consultants’
*BREEZE* VASDIP (Vulnerability Assessment of Structurally Damaging Impulses and Pressures) software
[2] generates P-I diagrams, as depicted in Figure 2, to produce vulnerability parameters, which allows
users to specify detailed properties of 24 different basic structural components and 19 human body parts.
The P-I diagram in Figure 2 pertains to a reinforced concrete beam. The vulnerability parameters
produced by VASDIP can be used as inputs to the *BREEZE* HEXDAM (High Explosive Damage
Assessment Model) [3-8] and/or VEXDAM (Vapor Cloud Explosion Damage Assessment Model) [9-13]
software.

**MODELING AN EXPLOSION SCENARIO**

The HEXDAM and VEXDAM explosion modeling software take into account the following considerations:

- Pressure effects
- Shielding effects
- Secondary explosions
- Pulse duration effects
- Damage/injury levels
- Subdivision of structures

The first step in modeling a potential explosion produced by a conventional high explosive is to specify a
primary explosion within or around a facility consisting of one or more structures and/or personnel. In
*BREEZE* HEXDAM software, the user can place an explosion within a layout diagram of the facility and
its grounds. The necessary information about the explosion includes X and Y coordinates for the
explosion’s location, the height above ground of the explosion, and the explosive yield. If the explosion is
produced by vapor clouds, in *BREEZE* VEXDAM the user must input the identity of the fuel, the number
and location of subclouds, the mass of fuel or volume of vapor-air mixture in each subcloud, and the
explosive strength of each subcloud.

After entering the explosion information, the user must input data about the structure or structures
potentially affected by the blast. Required data in this step includes the type of structure; the X, Y, and Z
coordinates of the structure; the dimensions of the structure including length, width and height; and the orientation; and the number of components, or subdivisions, comprising the structure. The structure type can be either a standard type or a special user-defined type.

Models have been pre-programmed into the HEXDAM and VEXDAM software for standard types of structural elements such as aluminum, brick, concrete, glass, and steel, and for standard types of composite structures, including buildings, hangars, underground structures, industrial equipment, and oil and gas storage tanks. Specific examples of such composite structures include:

- industrial building with a heavy steel frame and 25 to 50-ton crane capacity
- 100-pound liquid petroleum gas tank
- protected 7000-pound milling machine

The models automatically define the vulnerability parameters for these standard elements. For other (user-defined) types of elements/structures the vulnerability parameters can be generated by means of VASDIP.

In order to get a complete picture of the damage an explosion can cause, industrial safety managers can also use explosion models to calculate human injury resulting from a blast. Modeling software [14,15], utilizing the HEXDAM Man concept as depicted in Figure 3, allows users to enter the description and location of every person in a facility with respect to the blast origin. Explosion models require the X, Y, and Z coordinates of each person, the orientation of each person in degrees from North, and the pose of each individual. A total of 44 different poses are available. The BREEZE HEXDAM and VEXDAM models can take into account the vulnerability to an explosion for each of twenty-eight different body components that comprise each person.

**Explosion Modeling Results**

With the explosion, structural, and personnel data entered into the software, the model can predict the pressures received by each structure and person in the facility based on the location of the structures and
people relative to the primary explosion. The effects of structures or people shielding one another may also be taken into account [16]. The models then calculate the damage and injury to each structure and person based on the magnitude of the pressure received and the ability to withstand the pressure. In addition, the user may superpose a grid, as shown in Figure 1, over the entire facility or any portion thereof to calculate pressures that occur at specific locations or analyze the distribution of damage or injury among the structures and workers.

The damage to each structure, as well as the injury to each personnel can be presented graphically using a color-coding scheme. For depicting damage, each structure can be subdivided into a number of components with the color-coded damage level for each component displayed, as shown in Figure 4. In this figure, structural damage is color-coded such that green corresponds to no damage, yellow to slight damage, orange to moderate damage and red to severe damage. In the case of injury to persons, the color-coded injury level for each of the twenty-eight body components can be depicted, as presented in Figure 5.

**HOW TO USE EXPLOSION MODELING DATA**

Armed with specific information about how explosions could affect their structures and employees, facilities can take preventative steps to ensure their safety. Engineers can consider explosion modeling data in plans for construction or renovation, improving their ability to build structures capable of withstanding blasts and to locate personnel in areas least at risk for sustaining explosion damage. Managers can also give their explosion modeling information to local fire and hazard authorities so that emergency personnel can respond appropriately if a blast occurs.

While the threat of industrial explosions may be inescapable, explosion modeling can help minimize the damage to structures and injury to workers. Explosion modeling provides companies with a valuable tool in their efforts to optimize productivity while maintaining the safest possible environment for their workers.
In the scenario depicted in Figure 1, involving an explosive manufacturing facility, one of four 8,000 gallon tank cars has overturned and developed a leak, as shown in more detail in Figure 6. This car, along with each of other three, is near-empty, containing only 480 gallons of propane, but the vapor clouds produced by such an amount of propane, as depicted in Figure 7, represent a significant hazard. In case of a detonation, with an explosive strength of 10, much of the facility would be exposed to overpressures in excess of 1 psi. Such pressure levels would result in significant damage to the various structures, which comprise the facility, as presented in Figure 8. As expected, structures nearest the vapor clouds would be severely damaged. Most of the other structures to the north and east would be partially protected by barricades and as a result would experience only slight or moderate damage. A plot of two-dimensional pressure contours ranging from 1 psi to 50 psi in the horizontal plane are provided in Figure 9. Likewise, a plot of three-dimensional pressures contours ranging from 1 psi to 50 psi are presented in Figure 10.

To further complicate the situation, secondary explosions in the building complex to the north could be triggered by the initial vapor cloud explosions, already described. Such secondary explosions would result in severe damage to most of the structures to the north of the rail cars, as presented in Figure 11. Structures to the east, behind the main barricade would remain only slightly to moderately damaged. A plot of the resulting two-dimensional pressure contours ranging from 1 psi to 50 psi in the horizontal plane are shown in Figure 12, while a plot of three-dimensional pressure contours over the same range are provided in Figure 13.

One of the structures to the east of the barricade, as indicated in Figure 14, is of special interest because six personnel are located within it. This structure includes three windows facing north, as indicated in the figure. Because of the special interest in this structure, it has been subdivided to provide greater detail regarding damage. The positions of the six persons within the structure are shown in Figure 15.

For the case involving multiple vapor cloud explosions with secondary explosions, the damage to the building containing personnel is shown in Figure 16. Likewise, the injury to personnel inside the building is depicted in Figure 17. Notice should be taken that the injuries indicated in this figure are produced by
blast and do not include broken glass fragments. Such glass fragment injuries can be computed by an associated software model, VEXFRAG that has been very recently developed.

CONCLUSION

Explosion modeling and damage assessment software has the ability to provide decision makers with information regarding the placement and protection of animate and inanimate objects alike. Shielding effects from structures or people are often an important consideration in evaluating explosion scenarios. By computing the damage and injury to structural components as a function of the magnitude of the pressure received and the ability to withstand the pressure, coupled with shielding effects, the software described in this article offer decision makers a cost-effective method of mitigating risk. By using simple data entry forms and graphical displays within BREEZE HEXDAM and VEXDAM, the process of setting up and modeling explosion scenario’s is streamlined and the presentation of the results is informative.

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