The Science of Quantitative Risk Assessment for Explosives Safety

By
John Tatom (Manager, Explosives Safety Group, A-P-T Research, Inc.

Quantitative risk assessment (QRA) tools, as described in the QRA Corner article from SAFEX Newsletter 39, can only be considered valid if the real-world situation can be modeled accurately. For explosives safety, the model must be able to represent the effects produced by the detonation of the donor and the consequences on the target. The science that goes into such a model must be carefully thought-out and based on as much data as possible.

In a high-explosive (HE) event, the effects that must be considered are the blast wave, the debris, and the thermal environment created by the donor item (material, article, or weapon). The consequences to the target, which is normally a human but could also be other vulnerable assets, include not only the direct results of the HE effects, but also the response of the structure where the target is located. Glass hazard and building collapse are key facets of this structural response.

The algorithms that form a model of an HE event are based on physics, certainly, but are anchored whenever possible by test and/or accident data. Although a wealth of test data already exists, new test programs are underway that will supply important information for use in models, as described in the QRA Corner article from SAFEX Newsletter 40. The data from a test or accident can also be used to check the predictions of the model and point out areas for improvement.

There are generally three types of models: (1) physics-based, (2) empirical, and (3) semi-empirical. Although physics-based models can be developed to model explosives safety scenarios, they are, by necessity, quite complex and therefore expensive to develop. Empirical models, which report only data points available from tests and accidents, are by their nature limited in scope. Semi-empirical models, which use anchor points from available data but “fill in the gaps” with physics-based algorithms, may offer the best compromise between development cost, capabilities, and acceptance of results.

In a semi-empirical QRA model, conservatism is inversely related to the amount of available data. That is, if there are very few (or no) data points available to anchor an algorithm, the model must err on the side of caution. However, when an algorithm can be readily corroborated by test and/or accident data, the model does not need to include conservatism. This is important because the inclusion of conservatism would prevent model results from comparing well with the empirical data anchor points (i.e., reality).

This article intends to provide an overview of the explosives safety effects and consequences models that should be employed by QRA tools. Future articles will provide more detail (and references) on individual areas.

Effects and Consequences

To determine the effects and consequences of an explosive incident, the effective yield of the event must be determined. This is accomplished by adjusting the free-field results to account for

the explosive's immediate container (if present), the explosive type, and the attenuation of the blast wave caused by the presence of the donor structure (if applicable).

For modeling purposes, the effects of an explosive incident are the changes in the environment created by the blast outside the donor structure (if one is present). Such effects include overpressure and impulse, debris, and thermal. It should be noted that ground shock is not normally considered when concerned with fatality or injury.

The consequences of a blast are the results on the target structure (if one is present), including glass and structural failure.

These effects and consequences, as depicted in Figure 1, can then used to determine the target (usually a human) vulnerability. The target vulnerability should be considered separately for each applicable effect and consequence and then summed.

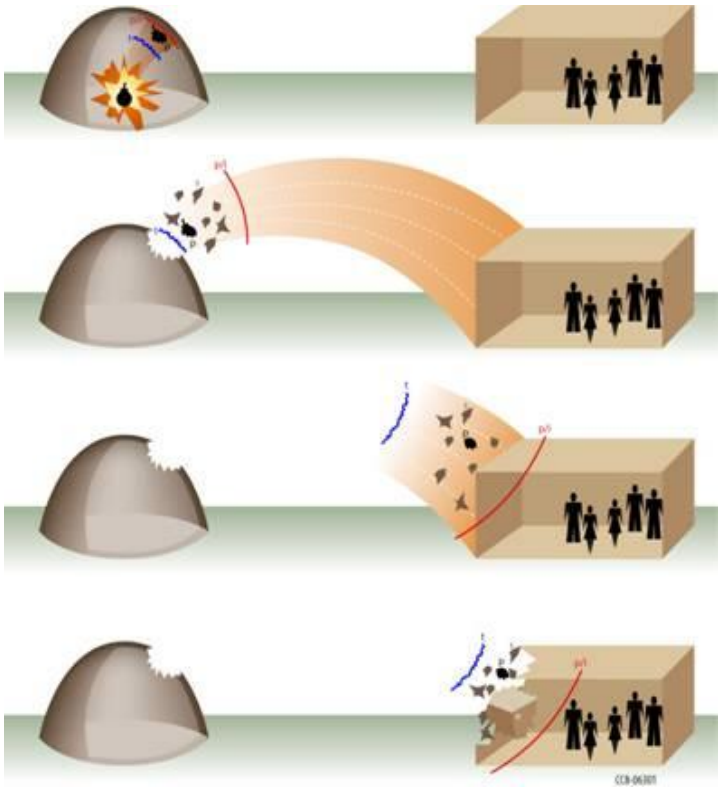

Figure 1. Blast Effects and Consequences

Yield

The explosive yield can be determined through the algorithms and procedures in the US Department of Defense Explosives Safety Board (DDESB) Blast Effects Computer, as documented in the DDESB Technical Paper 17. Equations for a hemispherical TNT surface burst are used as the "basic airblast engine" to generate the various airblast parameters. For situations other than a hemispherical TNT surface burst, including various types of charges in the open or detonations inside a donor structure, effective TNT yields are computed and used. These yields

are functions of the scaled distance (distance divided by the cube root of the explosive weight) from the center of the event and the type of donor item and/or structure selected. The calculated effective yields are used in conjunction with the hemispherical TNT surface burst curves to generate the appropriate airblast parameters.

Pressure and Impulse

Once an effective yield has been calculated, the airblast algorithms from the Blast Effects Computer can be used to generate the pressure and impulse at the target structure. The pressures and impulses computed in this manner have been compared to all available test data and have been found to be in good agreement.

Structural Response

When the target building is "hit" by the blast wave, the structure may provide its occupants with some protection. However, as the building breaks up – the worst case being total collapse – the occupants are exposed to the additional hazards produced by the building itself.

Glass

Extensive research has been conducted, especially by the physical security community, on glazing targets to determine their response to blast loading. A "broader brush" program can use the output of these more detailed models in combination with accident data to generate results suitable for a QRA. It is important to note that while glass is a serious hazard to personnel in a building with windows, anecdotal evidence suggests that it is rare that fatalities are caused by glass in an explosives event.

Ongoing testing efforts will eventually supply enough data to expand the list of input options for QRA purposes. Safety retrofitting of existing windows is now a relatively common occurrence; consequently, more work must be done on the glass models to allow such modifications to be taken into account.

Building Failure

A great deal of testing has been conducted on the blast response of structures. However, actually determining the hazard to the building occupants is another matter. The results of accidental (or terrorist) events can be studied, but it is not always easy to reconstruct the scenario, i.e., the exact location and amount of explosives and the precise position of the people within the building.

Clearly, the first step is to understand the response of the target building to the blast load. This allows for the development of pressure-impulse (P-I) diagrams, which are then used to predict damage to a specific structure (or structural component) based on the blast load. Given the damage, the hazard to the occupants can then be predicted. These types of predictions have been compared between models and to the limited real-world data available, with encouraging results.

Debris

The debris created by the blast can be divided into three categories: primary fragments (the casing and/or immediate packaging of the donor item), secondary debris (the pieces of the donor structure), and crater ejecta (the debris from the crater formed in the ground and/or foundation of a donor structure).

Primary Fragments

The primary fragment characteristics that should be modeled (initial velocity, number of fragments, size distribution, and maximum range) are consistent with information and procedures contained in DoD literature, such as DDESB Technical Paper 16, Methodologies for Calculating Primary Fragment Characteristics. However, commercial explosives normally do not have a dominant primary fragment hazard.

Secondary Debris

Predicting the size, shape, initial velocity and angle, and maximum throw range of debris coming from the donor building is a particularly challenging task. Even if a given model can accurately predict the debris characteristics of a single event, it is still quite possible that the same model will be inaccurate for other events. This is the reason why it is highly desirable to have multiple data points (usually at different loading densities) for the same building type.

Crater Ejecta

Characterization of crater ejecta should be based on the type of soil around the donor structure; crater ejecta prediction algorithms can be based on available models and data.

Thermal

For QRA, thermal effects are usually only considered for Hazard Division (HD) 1.3 materials (mass fire). It is assumed that thermal effects from a high-explosives event would be insignificant (compared to other effects) if 1.3 items were not present. This assumption is based on the fact that, compared to other blast effects, thermal effects are extremely short ranged; i.e, the hazardous consequences from blast and fragmentation extend to significantly greater distances than do thermal effects.

Thermal models have not been developed to the level of maturity of the other algorithms discussed. However, the models are based on available data and literature, and have been compared to each other within NATO.

Vulnerability

Predictions involving the probability of fatality (or injury) for a person exposed to a given hazard are always difficult to corroborate, but some good work has been done in this area. For the human response to direct blast loading (skull fracture, lung rupture, and whole-body displacement), American and European research led to the development of probit functions to estimate the conditions required for lethality. This type of probit function has been expanded and extended for inclusion in QRA models and is widely accepted.

The range (missile launch) safety community has developed and issued standards for determining the vulnerability of people to debris impacts. This standard provides a series of "S-Curves" relating the probability of fatality to the kinetic energy of the fragment.

<u>Models</u>

Each scenario that can be considered by software tools must have a model for the elements that will affect the results. These elements are the donor item type, the donor structure (or PES, the

Potential Explosives Site), the target structure (or ES, the Exposed Site), and any natural or man-made barricades. To the extent possible, these models are based on test data. These models will be described in a future QRA Corner article.