Probabilistic Methodology for Terrorism Blast Risk Assessment

Paresh C. Poudel
PhD. Student, Dept. of Civil Engineering, Clemson University, Clemson, SC, USA

Weichiang Pang
Associate Professor, Dept. of Civil Engineering, Clemson University, Clemson, SC, USA

Saurabh Prabhu
Senior Catastrophe Research Analyst of CRS Product Development, AIG, Greenville, SC, USA.

Mohammad Javanbarg
Director of CRS Product Development, AIG, New York, NY, USA.

ABSTRACT: In this study, a probabilistic methodology has been developed to quantify terrorism blast risk for buildings. Concept of protection zones, which are zones in building with varying level of security, has been introduced based on the principle - as security increases the probable size of bomb should decrease. Probable bombs are uniformly placed at each protection zone to create many possible scenarios of terrorism event. Blast parameters (pressure and impulse) are estimated at many locations in 3D model of building for each scenario using a modified Kingery and Bulmash (KB) blast model called KB beta model. The United States Department of Defense's Pressure - Impulse damage curves are used to convert blast parameters to damage. The average damage to the building is estimated based on aggregation of damages to the building components. The methodology is applied to investigate the recent Brussel's airport attack incident and the results are compared with actual Brussel's Airport Attack. The terrorism-blast risk assessment shows that the attack could have been worse.

1. INTRODUCTION

Terrorism related activities pose great risk to life and property. As per database maintained by National Consortium for the Study of Terrorism and Responses to Terrorism (START), nearly half of terrorist attacks are due to bombing or explosion. Same database shows that Government and Commercial buildings are more vulnerable to such attacks. Therefore, terrorism risk quantification need has been long realized by researchers. Numerous empirical and CFD models are available to quantify blast. This study presents a probabilistic method to quantify blast load and terrorism risk.

Immediately after an explosion, an instantaneous rise from atmospheric pressure to a peak overpressure creates a bubble of air travelling at supersonic speed known as the shock wave. When the shock wave expands, pressure exponentially decays over time until it reaches the ambient pressure (Figure 1). After that, the negative phase begins, usually longer in duration than the positive phase. Impulse -the integrated area under curve of pressure time history is the measure of energy from an explosion. Maximum positive pressure and impulse values can be used to estimate damage to a structure. There is a common practice of normalizing blast parameters by its equivalent weight of TNT. The distance parameter is normalized as scaled distance $Z = \frac{R}{W^{1/3}}$, and impulse is normalized as scaled impulse $i = \frac{I}{W^{1/3}}$, where R is actual effective distance from explosive, W is equivalent weight of TNT and I is impulse. The pressure and impulse can be of two types – incident and reflected. Reflected values consider reflection of blast waves from surfaces making it higher than incident values.

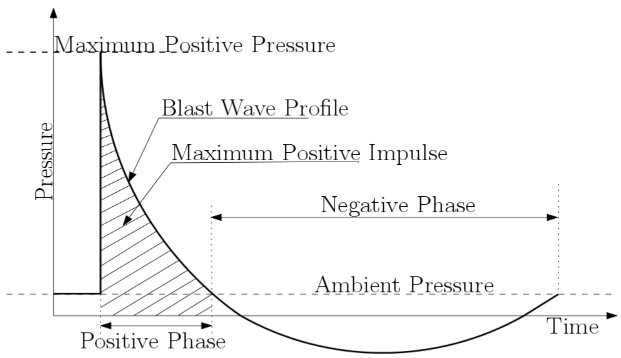

Figure 1: Typical Blast Pressure-Time history.

Kingery and Bulmash Blast model (KB model) is a popular blast model developed using data obtained from large-scale controlled TNT explosions. For a scaled distance, the KB model gives incident and reflected blast parameters. A modified probabilistic version of the KB model called the KB-β model is used in this study to get the blast parameters.

Department of Defense Explosives Safety Board (DDESB) has developed Pressure Impulse (PI) damage curves (referred as DOD-PI curves from here on) for different building and building components. DOD-PI curve (Figure 2) can be used for estimating damage ratio for corresponding values of pressure and impulse.

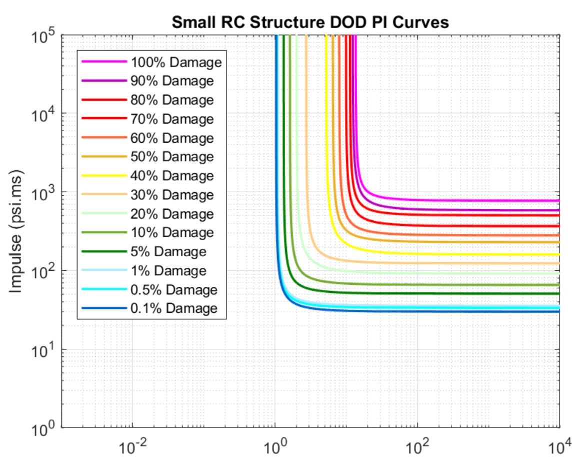

Figure 2 : DOD-PI damage curves for Small RC Structure.

FEMA 452 discusses about "layers of defense" which is a traditional approach used in security engineering by demarking regions for different security strategies against threat. A similar concept has been introduced in this study as protection zones, which are different zones in the building with varying security level. Probable bomb sizes are placed in different protection zones and damage ratio is evaluated using DOD-PI structures. Case study for Brussel's airport has been shown as an example for this method and results from terrorism risk assessment is compared with the actual Brussel's airport terrorist attack of 2016.

2. DEVELOPMENT OF PROBABILISTIC TERRORISM MODEL

2.1. KB β Model

Bogosian at el. (2002) had collected data for various blast experiments, which is used to modify the KB model to a probabilistic version to capture uncertainty. In generalized form the KB beta model is:

$$KB_{\beta}(Z) = KB(Z).\mu_1.\Phi \quad (1)$$

where KB_β is the KB beta model parameter, KB is corresponding KB model parameter, μ_1 is bias correction and Φ is random error ratio. μ_1 factor shifts the KB model values closer to experimental values. μ_1 is available for a range of scaled distance so it is fitted to power curve of the form: $ae^{bx} + c$ to make it applicable for all scaled distance. The parameters of the curve is given in Table 2. Φ factor captures the observed variability in the blast parameters and adds it to KB-β model as error ratio. The KB-β model was developed for four blast parameters – incident pressure, incident scaled impulse, reflected pressure and reflected scaled impulse. The KB beta model for incident pressure parameter is:

$$P_{i\beta}(z) = P_i(Z).\mu_{1\_ip}(Z).\Phi\,(0, \beta_{ip}) \quad (2)$$

where $P_{i\beta}$ is KB beta model incident pressure, P_i is KB model incident pressure, μ_{1_ip} is the bias correction and Φ is a random error ratio generated using lognormal distribution with lognormal mean of 0 and lognormal standard deviation β_{ip} (Table 1). KB-β can generate many random parameters within the uncertainty bound.

Table 1: Lognormal Standard Deviation for KB-β model parameters

KB Model parameters	Lognormal Standard Deviation (β)
Incident Pressure	0.1921
Incident Scaled Impulse	0.1840
Reflected Pressure	0.2062
Reflected Scaled Impulse	0.2137

Table 2: a, b and c values for μ_1 for different blast parameters

KB Model parameters	Scaled Distance	Fitted Parameters to equation: $ae^{bx}+c$		
		a	b	c
Incident Pressure	0-2.7	1.45	0	0
	2.7-100	0.81	-0.24	1.02
	>100	1.05	0	0
Incident Scaled Impulse	0 - ∞	0.98	0	0
Reflected Pressure	0 - ∞	1.07	0	0
Reflected Scaled Impulse	0-4.6	1.14	0	0
	4.6-40.8	1.24	-0.18	0.60
	>40.8	0.66	0	0

2.2. Protection Zones

When security increases, threat has to decrease or in this case, the size of bomb should decrease. Protection zones are different zones around a building with varying level of security. So, each protection zone is associated with a probable size of bomb. For example, for parking areas of the building the probable bomb would be a vehicle bomb, inside the building the probable bomb would be a suitcase bomb and in highly secure areas it could be a suicide bomb or no bomb at all. Using this concept, a methodology has been proposed for probabilistic quantification of terrorism blast risk.

The flowchart (Figure 3) shows the framework for evaluate terrorism blast risk using protection zones. First different protection zones is marked inside and outside the building. For a zone, probable bombs are uniformly placed around the zone. Each bomb location acts as a terrorist attack scenario and for each scenario the blast parameters (pressure and impulse) are calculated using KB-β model for various points in the building. The generated blast parameters is then converted to appropriate damage percentage with DOD PI damage curves. As shown in flowchart this is repeated for all protection zones. Finally, the compiled damaged ratio will help us understand risk posed by different scenarios in each protection zones.

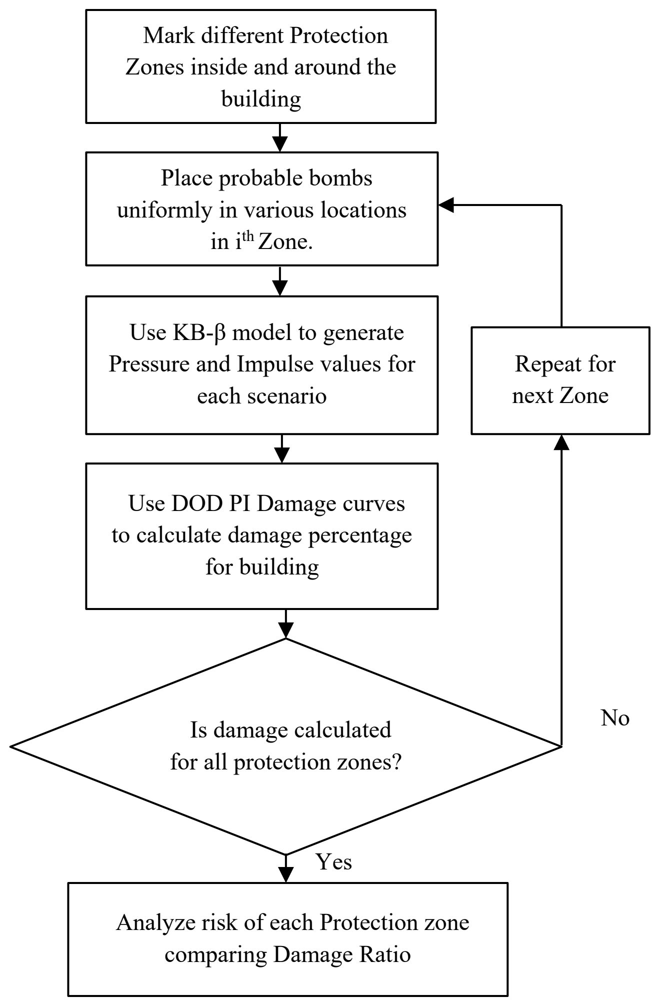

Figure 3: Flowchart showing framework to evaluate terrorism risk using protection zones

3. CASE STUDY: BRUSSEL'S AIRPORT

On 22nd March 2016, two suicide bombers detonated about 44 pounds of TATP (Triacetone Triperoxide aka Peroxyacetone) each in a suitcase with metal nails and bolts. The two bombs were exploded in the North Terminal in checking row 11 and 2 respectively. Damage percentage for the actual TNT explosion is also calculated treating the two explosions as two separate events and is compared with simulated damage percentage.

In this study, three protection zones for Brussel's airport is assigned as shown in Figure 4. Protection Zone 1 and 2 are assumed as the marked areas outside the building whereas protection zone 3 is the building volume. Table 3 shows the blast parameters associated with each protection zone. The standard bomb sizes were acquired from data published by National Counterterrorism Center (NCTC). Protection zone 1 is assumed as least secure parking area with largest probable bomb size of 4000lb (cargo van bomb). Zone 2 is closer to the building with higher security with probable 500lb bomb (compact car bomb). Zone 3 being inside the building has highest level with probable 35 lbs. bomb (suitcase bomb). Each bomb is also given a variation of 10% to account for uncertainty in size. For Zone 1 and 2 bombs will uniformly distributed in ground level, whereas for Zone 3 they will be uniformly distributed in each floor.

Table 3 Blast Parameters for each protection zone

Zone		Probable TNT (lbs.)	Description	CoV in TNT size
1	(yellow)	4000	Cargo Van	10%
2	(green)	500	Compact Sedan	10%
3	(blue)	35	Suitcase	10%

A simplified five-story 3D- model of the Brussel airport North terminal was created by dividing the building into wall and floor points as shown in Figure 5. For each scenario of bombs in protection zones, reflected pressure and impulse on floor points and wall points is determined using KB-β model. The floor point's blast parameters are converted to damage percentage using DOD PI curves for RC structure and wall point's blast parameters are converted to damage percentage using DOD PI curves for annealed type glazing. The damage percentage for all the points are summed up to get total damage percentage of the building. The damage ratio for each protection zone is plotted as cdf (Figure 6). The actual TNT explosions separately gave damage of 7.8% (Figure 6).

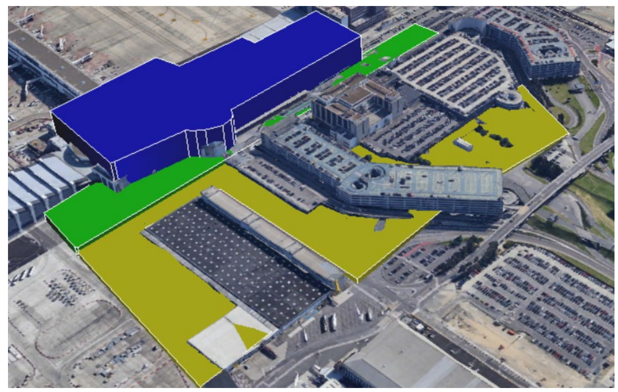

Figure 4: Three Protection zones

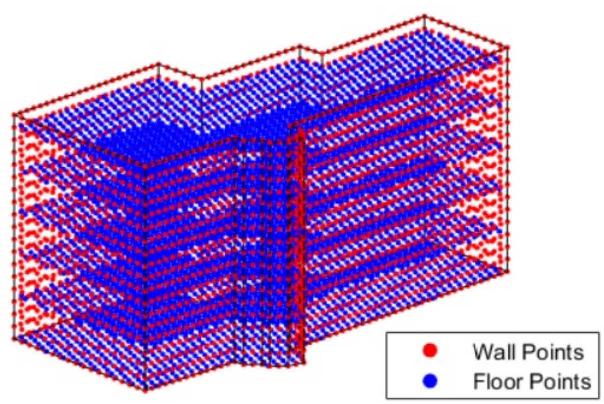

Figure 5: 3D model of the building showing wall and floor points

4. CONCLUSIONS

Using the cdf plot, range of average damage for the scenarios and the worst-case scenario can be determined. The damage for protection zone 3 ranges from 5 % to 10%. The actual damage was 7.5% could have been worse. In addition,

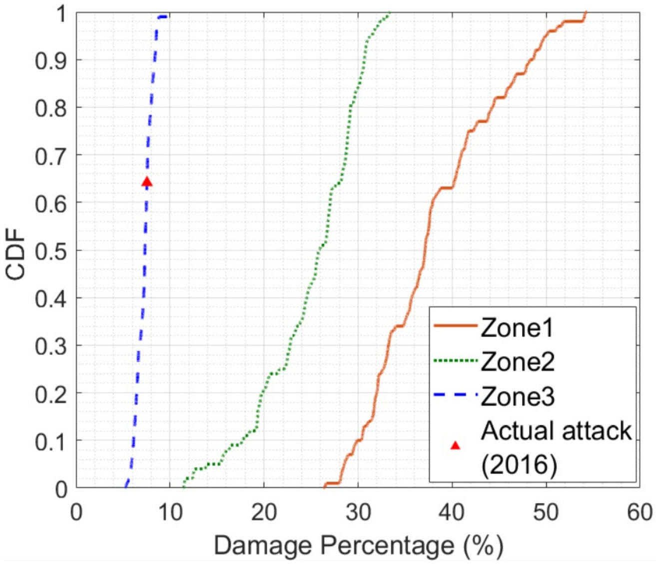

Figure 6: CDF of Damage for different protection zones and location of actual attack

there is a possibility of higher damages from scenarios in other protection zones. The damage range of protection zone one shows that the damage was as high as 55%.

Using this result, decision makers can understand the various consequence of terrorist attack and plan accordingly to avoid the worst case. For this case since the majority of damage occurs due to bombs in protection zone 1, security can be improved in that area to limit the bomb size and reduce the risk.

The damage calculation process using floor and wall points is crude. The employed method does not consider the possibility of progressive collapse. A comprehensive damage model will give results that are more realistic.

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