Risk-Based Approach to Building Designs and Decision Making

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Key Items

- The ‘Bunker Mentality’
- Concepts
  - Building Damage Levels
  - Occupant Vulnerability (OV)
  - Risk – Individual and Societal
- Risk Based Resource Allocation
  - Explosion Risk
  - Toxic Risk (Shelter-In-Place)
- Master Planning
- Optimal Building Location/Real Estate Cost
‘Bunker’ here refers to a very strong building

Bunkers are massive buildings that are typically orders of magnitude more robust than conventional buildings.

These are sometimes designed for the ‘Maximum Credible Event’ or MCE (API 752)
  - Feasible only if credible event is small enough

Likelihood of events is often ignored.
Credible Event?

cred·i·ble
/ˈkredəb(ə)l/

adjective

able to be believed; convincing.
"few people found his story credible"

synonyms: believable, plausible, tenable, able to hold water, conceivable, likely, probable, possible, feasible, reasonable, with a ring of truth, persuasive
"only one of the so-called witnesses could provide a credible story"

- capable of persuading people that something will happen or be successful.
"a credible threat"

synonyms: believable, plausible, tenable, able to hold water, conceivable, likely, probable, possible, feasible, reasonable, with a ring of truth, persuasive
"only one of the so-called witnesses could provide a credible story"
The ‘Bunker Mentality’

“Everything is cheap if you are not paying for it….,”
How can we avoid ‘Bunkers’ and still ensure safety?

Likelihood of events:
- Should a designer ignore events with low frequency?
- But what if multiple events have a low frequency?
- What if certain events have a Low Frequency but very high impact/consequence?

Larger Question: How do I determine my design basis?
Blast Loading of Buildings

Direction of blast

Direction of blast
Blast Structural Damage

Front

Side

Back
Understanding Building Damage Levels (BDL) and Occupant Vulnerability (OV)
Building Damage Levels

BDL 1 - Minor

BDL 2 - Moderate

BDL 2.5 - Heavy

BDL 3 Major

BDL 4 Collapse
What are Pressure-Impulse (P-i) Curves?

- A graphical way to assess Building Damage Level as a function of Pressure and Impulse of blast load
- P-i Curves are characteristic of building or structural component.
Blast Load is to the left or below the GREEN Curve – Means BDL = 1

OV = Occupant Vulnerability or Likelihood of Fatality
BDL 2 - $OV = 0.03\%$

$OV = \text{Occupant Vulnerability or Likelihood of Fatality}$
BDL 2.5 - \( OV = 3\% \)

\( OV = \) Occupant Vulnerability or Likelihood of Fatality
BDL 3 - OV = 30%
BDL 4 - OV = 90%
Building Individual Risk (BIR)

- **BIR (fatalities/year) = OV x Frequency**
  - **OV (Number of Fatalities per event)** – Based on Blast load, BDL, population distribution, type of structure, etc.
  - **Frequency (Events/year)** - Based on failure rate, wind direction, meteorological conditions, probability of ignition, etc.

- Societal Risk = OV x Occupancy x Frequency
Societal Explosion Risk = \[ \sum \text{Risk}_{\text{scenario}} \]
Design Explosion Cases

Sample P-i Diagram

Worst Case Event

Pressure (psi)

Impulse (psi-ms)
Design Explosion Cases

Sample P-i Diagram

All Credible Events

Pressure (psi) vs. Impulse (psi-ms)
Design Explosion Cases

Sample P-i Diagram

Higher Frequency Events

Pressure (psi)

Impulse (psi-ms)

BDL 1-2
BDL 2-2.5
BDL 2.5-3
BDL 3-4
Explosion Scenarios
### Cumulative Risk - Example

<table>
<thead>
<tr>
<th>Explosion Scenario</th>
<th>BDL</th>
<th>OV</th>
<th>Frequency</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.00035</td>
<td>1.50E-06</td>
<td>5.25E-10</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>0.78</td>
<td>2.00E-09</td>
<td>1.56E-09</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0.00035</td>
<td>3.00E-05</td>
<td>1.05E-08</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0.0001</td>
<td>1.00E-04</td>
<td>1.00E-08</td>
</tr>
<tr>
<td>n</td>
<td>2.5</td>
<td>0.005</td>
<td>6.00E-08</td>
<td>3.00E-10</td>
</tr>
</tbody>
</table>

**Σ Risk**

- **2.29E-08 Fatalities/year**
- **Or**
- **23 fatalities in a billion years**

*Note: It is not uncommon to have n > 5,000*
Evaluate Building Options

**Tolerable Risk**

- Original: 1.08E-03
- BRM: 7.37E-04
- Annex 1: 2.18E-04
- Annex 2: 6.07E-05

**Delta Cost**

- Original: 0.00
- BRM: 360,000.00
- Annex 1: 370,000.00
- Annex 2: 450,000.00

**HSE/PSM Teams Involved**

**Project Team**
Example

Risk Distribution
Reasonably practicable is a narrower term than ‘physically possible’ and implies that a computation must be made... in which the quantum of risk is placed in one scale and the sacrifice involved in the measures necessary for averting the risk (whether in time, trouble or money) is placed in the other and that, if it be shown that there is a great disproportion between them – the risk being insignificant in relation to the sacrifice – the person upon whom the obligation is imposed discharges the onus which is upon him.
Risk vs Cost: Various Building Types

In this region, more money is not reducing risk.
<table>
<thead>
<tr>
<th>Building</th>
<th>Explosion Risk</th>
<th>Building Risk/Total Risk</th>
<th>Unit Cost/Building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration Building</td>
<td>4.0E-07</td>
<td>0.3%</td>
<td>29%</td>
</tr>
<tr>
<td>Control Room</td>
<td>5.0E-06</td>
<td>3.7%</td>
<td>20%</td>
</tr>
<tr>
<td>Laboratory</td>
<td>2.0E-05</td>
<td>14.8%</td>
<td>15%</td>
</tr>
<tr>
<td>MCC 1</td>
<td>3.0E-05</td>
<td>22.2%</td>
<td>10%</td>
</tr>
<tr>
<td>MCC 2</td>
<td>6.0E-05</td>
<td>44.3%</td>
<td>10%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>2.0E-05</td>
<td>14.8%</td>
<td>16%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.4E-04</strong></td>
<td><strong>100.0%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
New Staff Office Building
Cost Contour for 1E-6 BIR
Toxic SIP – Risk Approach

- Multiple toxic release locations (one or more types of toxics)
- Several possible wind directions with different probabilities
- Angle of Release: Several Possibilities
- Building has different leakage characteristics at different wind speeds

Toxic Release 1

Toxic Release 2

Toxic Release 3

Building: Shelter In Place
For Each Release...

- Estimate Toxic Concentration Outside the building for each scenario
- Estimate Air Change Rate (ACH) for the scenario (Based on Tracer Gas Test/Blower Door Test for buildings)
- Based on ACH for the scenario, estimate inside concentration for the building
- Based on toxic concentration, estimate OV using Probits. That’s your consequence!
- Estimate Risk = Frequency x Consequence
- If the risk is acceptable, the building may be an acceptable SIP
Decision Process

- Determine if alternative designs effectively reduce risk
- Estimate cost/\(\Delta_{\text{risk}}\) for each alternative
- Choose lowest cost/\(\Delta_{\text{risk}}\) within budget
- Proceed with design
Conclusions

- Expensive building designs can be avoided without compromising on safety
- When thousands of scenarios are postulated, a Risk Based Approach can be effectively used to optimize resources and maximize safety
- A Risk Based Approach can be used in:
  - Designing a building or
  - Determining the most optimal location on the facility
- This conceptual framework can be used for various types of hazards – Explosion, Toxic, Fire etc.
Questions?

Thank You