A-P-T RESEARCH, INC.
AN EMPLOYEE-OWNED COMPANY

HOW NOT TO SITE PLAN

Common Pitfalls and Mistakes in Hazards Analyses

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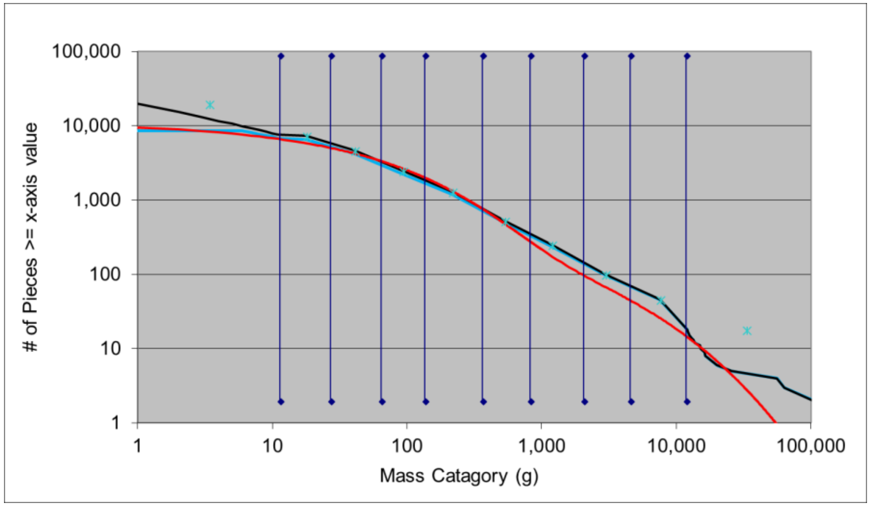
INTRODUCTION

- Explosives safety site planning often requires planners and engineers to provide protection from explosives hazards when standard Quantity Distance (QD) criteria cannot be met.
- Properly identifying and quantifying explosives hazards as well as selecting effective mitigation strategies is a challenge.
- Mischaracterizing hazards can lead to improper proposed solutions.

Identifying Hazards

USE OF EQUATIONS

- Most U.S. Department of Defense (DoD) safety references utilize empirical equations to calculate or estimate hazards.
- Empirical equations are based on test data, though data may be sparse.
- These equations have limitations in terms of range of applicability.
- Understanding the range of applicability, as well as any other constraint, for an empirical equation is critical to ensuring that unintended and incorrect extrapolation does not occur.



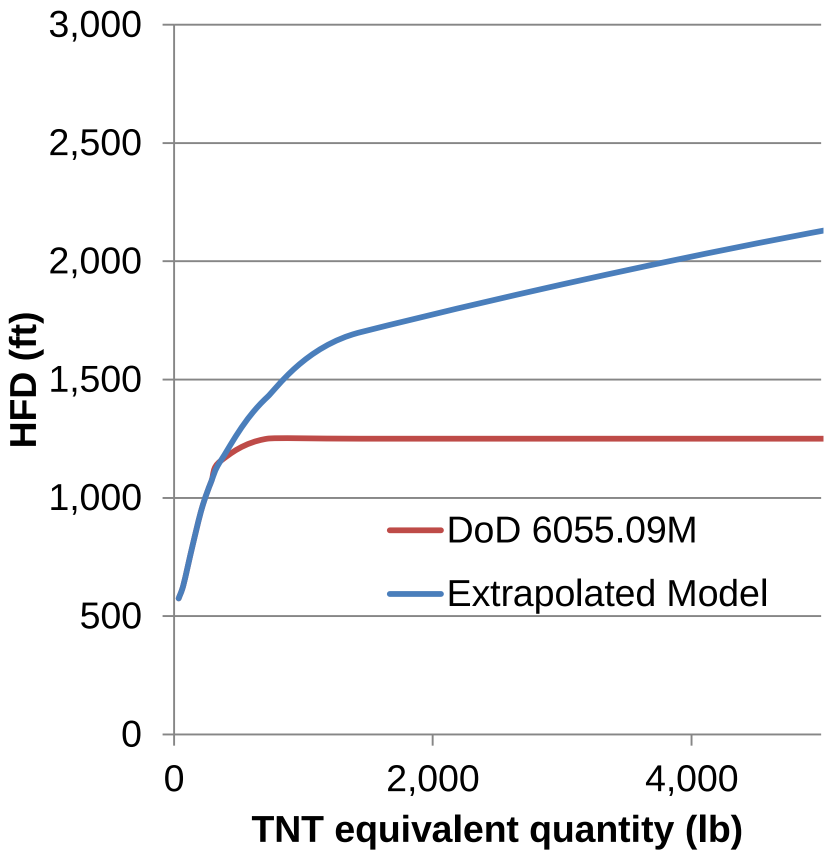
Empirical Equations

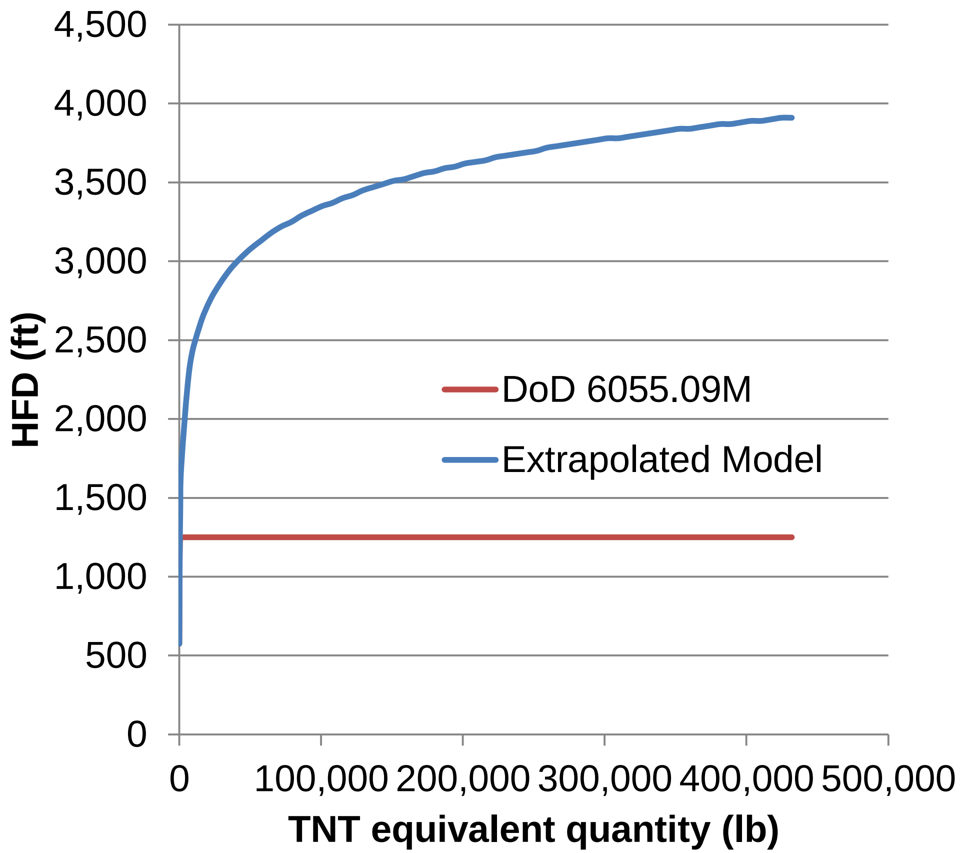
FRAG DISTANCE

- Hazardous Fragment Distance (HFD) is the prescribed standoff distance for persons unrelated to the explosives.
- For explosive weights less than 450 lb, the U.S. criteria manuals use an empirical equation to calculate the HFD.
- In 2014, APT was tasked to peer-review a hazard assessment model that was being sold to emergency responders throughout the U.S. as a fast-running model for explosives hazards.
- The software claimed to be using approved DoD methods.
- The model appeared to provide conservative HFD estimations for low explosive weights, and extremely conservative HFD estimations for large explosive weights.

Empirical Equations

FRAG DISTANCE





Empirical Equations

FRAG DISTANCE

- Upon review, it was discovered that the software designers extrapolated the U.S. DoD HFD equation beyond the intended limit of 450 lb.
- The resulting extrapolated HFD model appeared to be continuous and provide conservative results, and was, therefore, not questioned further by the software designers.
- However, this equation was never intended to be used beyond 450 lb of explosives.
- The results, though conservative, require extreme standoff distances.
- And the results were falsely promoted as being in accordance with accepted DoD methods.

Empirical Equations

FRAG PERFORATION

- Calculating estimated fragment perforation is a second common example of misrepresenting an empirical equation.
- Most DoD references for debris penetration and/or perforation of steel fragments into various types of metal, glass, or polycarbonate is based on a methodology known as Thor constants.
  - DDESB TP-16
  - UFC 3-340-01
  - ARBRL-TR-02561
- These empirical equations are based on test data and are widely accepted.
- The issue with these methodologies is that they are often presented without corresponding ranges of applicability for target thickness or impact velocity or mass.

Empirical Equations

FRAG PERFORATION

- Review of the ranges of limitations for the equations shows that while many of the equations have wide ranges of applicability for striking velocity and target thickness, they are limited in the range of the mass of the steel fragment impactor.
- Other than steel targets, which are applicable for a steel fragment mass of up to approximately 2 ounces, all other target types are applicable for steel impactors only up to 0.5 ounces or less.
- The reasoning for this is likely that the models are intended for primary fragments (e.g., munitions casings), which are typically small.
- Application of these equations to larger secondary/structural debris is beyond their range of applicability.
- A more appropriate method for secondary fragments is to use UFC 3-340-02, which is intended for the response of structures.
- Equations in UFC 3-340-02 are not directly tied to Thor constants.

Identifying Hazards

OVERCONSERVATISM

- Conservatism is commonly required in hazard assessments to provide a factor of safety for unknowns ad other assumptions.
- Caution must be taken to ensure that unrealistic requirements are not imposed due the layering of multiple conservative assumptions.
- An example of this is illustrated by debris hazards, specifically flight range and impact energy.
  - Some representation of the fragment mass and velocity is required.
  - For both variables, a large value is generally more hazardous and is therefore assumed or required (i.e., a “worst-case”).
- Nearly all fragment perforation calculations are based in some way on kinetic energy (KE).

$$Kinetic\ Energy = \frac{1}{2} mass \times (velocity)^2$$

Identifying Hazards

OVERCONSERVATISM

A recent example illustrates the pitfall of automatically assuming the worst-case values for debris mass and velocity.

- A barricade was designed to mitigate a specific munition warhead.
- Arena test data was available in a technical report.
  - The largest recovered fragment was a front plate weighing 48.6 lb of steel.
  - The velocity for fragments was estimated to be 5,000 feet per second.
- A calculation of the KE resulted as 1.90E+07 ft-lb of energy.
- Without comparing this calculated value to other benchmark cases, it could be easy to progress with the design of the barricade.
- Upon further inspection, it can be seen that this value is incredibly large and wholly unrealistic.

Identifying Hazards

OVERCONSERVATISM

- The calculated KE for the potential design fragment can be compared to a common object - a fully loaded concrete truck (66,000 lb).

- The calculated KE for the warhead front plate would be equivalent to the concrete truck traveling at 92.5 miles per hour!
- This immense amount of KE cannot be imparted to a single plate in an open detonation by the energy contained within this warhead.
- For this scenario, the mass is known, and it can be shown that the launch velocity is unrealistic for the front plate.

Mitigation

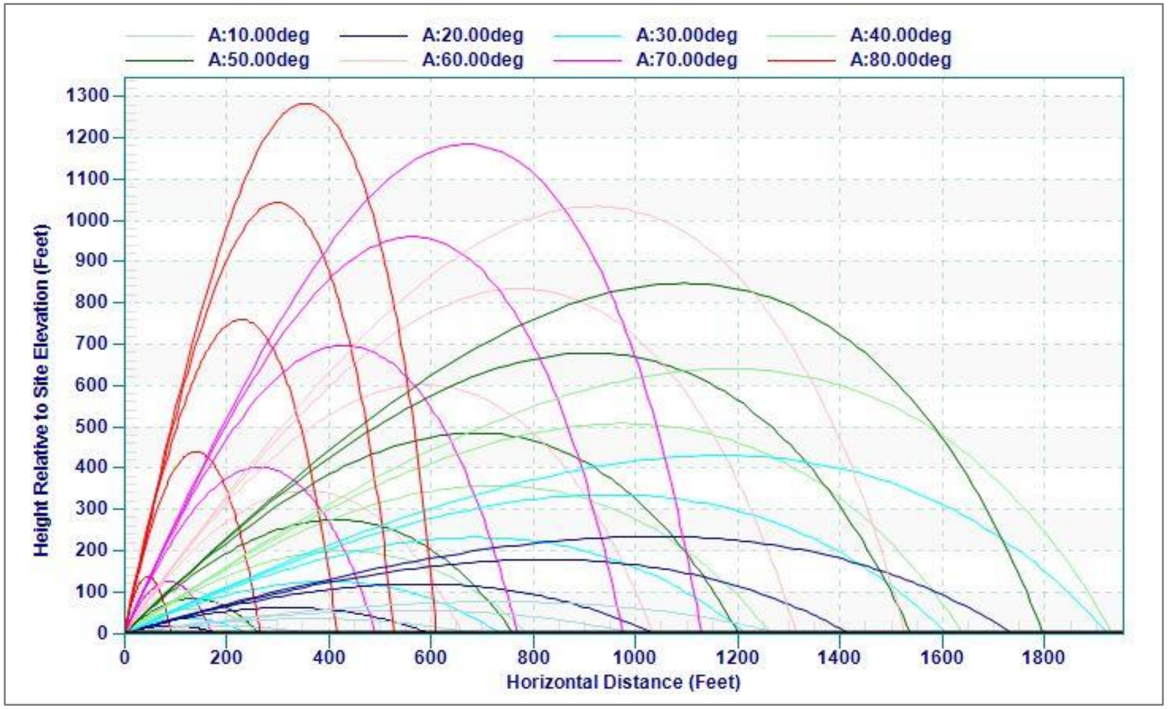
BARRICADES

- Barricades or berms are common blast hazard mitigation strategies.
- They have significant advantages in terms of cost and constructability, but also have limitations that are not always recognized.
- DoD criteria recognize that barricades can be used for fragment mitigation as well as blast overpressure attenuation but establish limitations on the applicability of these protective features.
- By DoD criteria, fragment mitigation from the barricade is only applicable to low-angle debris for intermagazine distance (IMD) and intraline distance (ILD).
  - No credit or reduction is given to inhabited building distance (IBD) and public traffic route distance (PTRD) for barricades.
  - Similar criteria are found in NATO manuals.
- The fragments that reach IBD or PTRD ranges are not low-angle fragments that would be intercepted by barricades.
- The debris that overwhelmingly control the HFD for both IBD and PTRD are fragments that are launched at angles of at least 5 to 10 degrees.

Mitigation

BARRICADES

- TrajCan simulation of typical ranges for debris variables.
  - Debris mass: 1, 5, 10 and 25 lb
  - Launch velocity: 100-500 fps
  - Launch angle: 10-80 degrees



Mitigation

BARRICADES

- APT has inspected multiple contractor-owned contractor-operated (COCO) sites that have been required by review and approval authorities to build large barricades with the intent of reducing the IBD.
- In two scenarios, the exposure in question was a highway located approximately 1,100 feet from the donor structure; each donor structure had a sited explosive limit of less than 30,000 lb.
  - Case 1: a 600 ft long, 25 ft tall earthen berm was constructed.
  - Case 2: a multi-million-dollar concrete wall 400 ft long and 25 ft tall was required.
- Enormous, expensive barricades are not likely mitigating the hazard that is driving the requirement, thus requiring such barricades is not in keeping with DoD criteria manuals that dictate the site planning.
- Barricades are versatile and cost-effective in mitigating some blast and fragment hazards. However, they should not be required or utilized in scenarios in which they do not effectively reduce the hazard being analyzed.

Mitigation
SUBSTANTIAL DIVIDING WALL

- Substantial dividing walls (SDW) are pre-approved blast mitigation features that can be incorporated into site plans if all applicable criteria are met.
- SDWs are intended primarily to prevent prompt propagation of explosives between adjacent bays but can also be designed in select circumstances to provide personnel protection.
- An SDW is a robust concrete wall (minimum of 12 inches thickness) with proper steel reinforcement, support constraints, and venting.
- The usefulness of this type of pre-approved mitigation feature has led to wide application.
- Due to the implementation of the criteria at so many locations, many people have been exposed to the benefits of these criteria.

Mitigation

SUBSTANTIAL DIVIDING WALL

- However, widespread implementation does not ensure widespread understanding of the criteria and their limitations.
- Unfortunately, it is common for almost any concrete wall with a robust appearance to be labeled as an SDW.
- Many existing structures include robust walls with significant capacity for explosives hazard mitigation, yet they do not meet all SDW criteria.
- Common structural deficiencies that prevent legacy structures from utilizing the SDW criteria are:
  - Lack of proper shear reinforcement.
  - Lack of sufficient venting for detonation scenarios.
  - Confinement of deflagration effects within a common structure.

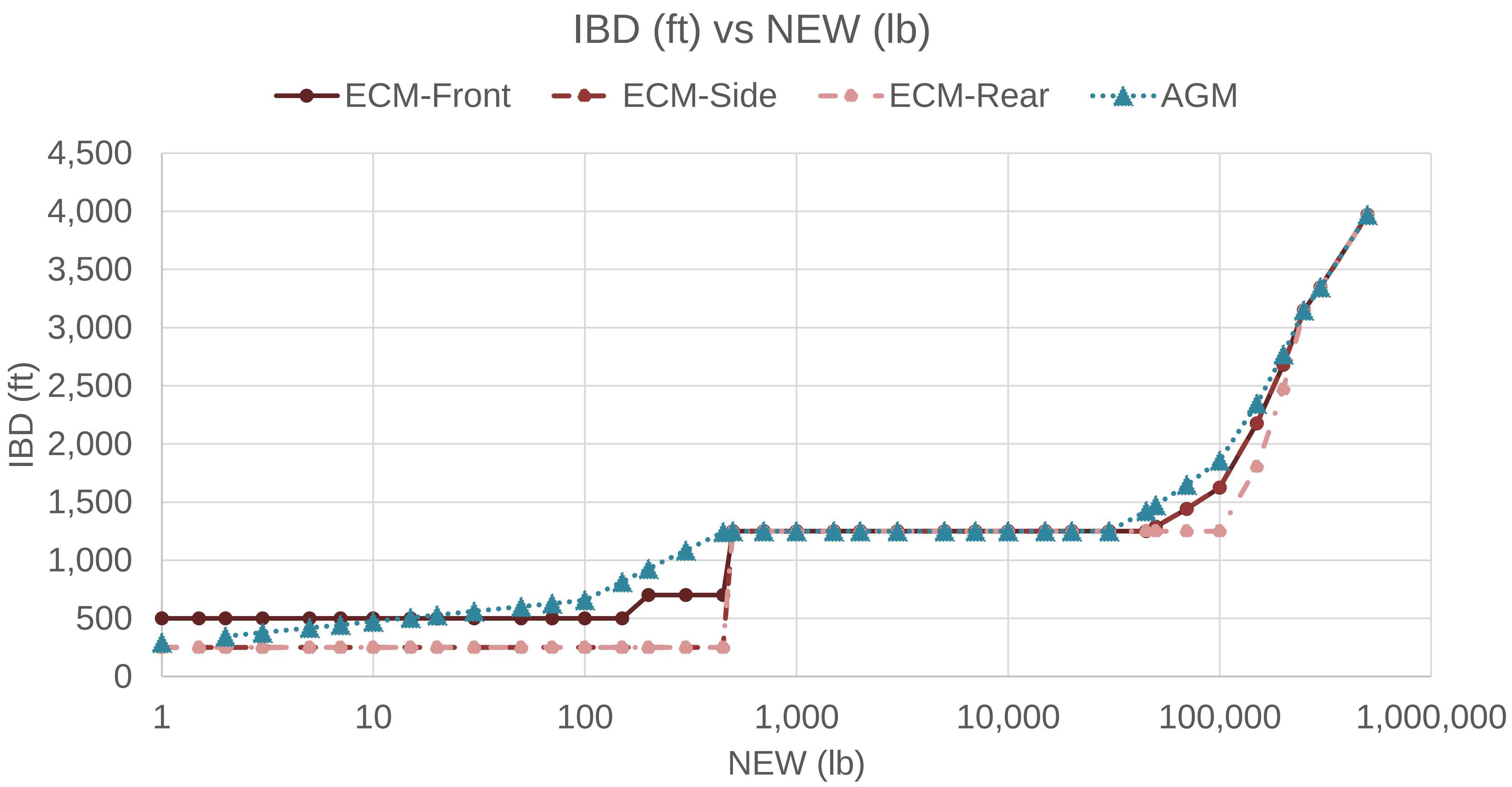
Mitigation

EARTH-COVERED MAGAZINE

- The earth-covered magazine (ECM) is another example of a widely implemented hazard mitigation option that can be misunderstood.
- These common structures are effective at reducing the IMD required between storage facilities, and therefore can provide significant reductions in required land when used in large quantities.
- A surprisingly common misconception is that ECMs are preferred and add safety because the magazines (are believed to) actually contain the explosives effects.
  - ECMs are designed to protect the contents from external loads such as the detonation of an adjacent magazine.
  - Test series Navajo and Hastings showed that explosives quantities as little as 20 lb can destroy the roof of an ECM.
- Another misconception of ECMs is that the site planning criteria is always preferable over equivalent above-ground magazine (AGM) criteria.
  - ECM criteria do provide reduced IMD and ILD criteria and should be considered if many storage magazines are required, high explosives quantities are required, and space is restricted.
  - However, if few magazines are required and moderate explosives quantities are requested, the significant additional cost for ECMs may not be justified.
  - This is particularly true if IBD is the controlling factor in the site plan.

Mitigation

EARTH-COVERED MAGAZINE



CONCLUSION

- Properly identifying explosives hazards and properly designing mitigation strategies can ensure that excessive cost is not incurred for impractical considerations.
- This can also help ensure that impractical or unnecessary structures are not designed and implemented.
- Understanding the intents and limitations of various explosives safety criteria can aid in selecting effective mitigation strategies.

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