FOUNDATION BLAST LOADING ACCIDENT HISTORY, PAST USE, AND FUTURE CONSIDERATIONS

DDESB Summit

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US Army Corps of Engineers®

AGENDA

- Background & Overview
- Related DOD Criteria Documents
- Accident Data Analysis
- Cratering Analysis Tools vs. Accident Data
- Foundation Blast Loading Analysis and Design
- Examples of Use
- Conclusions and Questions

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BACKGROUND

- Protective construction (PC) criteria development has historically focused on components above the foundation due to their potential to rapidly fail and contribute to structural collapse and/or hazardous debris generation.
  - For example, allowable bearing pressure assumptions and appropriate load combinations are not addressed.
- The design and analyses of intentional detonation site (IDS) facilities have made it clear that improved understanding of analysis and design methods for blast loading on foundations would be beneficial.

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OVERVIEW

- This study compiles accident and testing data that led to exposures noted to have caused or not caused foundation damage to surrounding structures.
  - This information was used as an initial data point for a lower and upper bound of scaled standoff that could generate a risk to personnel from compromised foundations.
  - The data was also used to compare common approaches for crater diameter prediction to accident data.
- This study then examines some approaches previously used in designing or analyzing blast loading on foundations of intentional detonation sites.

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RELATED DOD CRITERIA DOCUMENTS

- **UFC 3-340-02 – Structures to Resist the Effects of Accidental Explosions**

  - Primarily focused on accidental detonations in Ammunition and Explosives (AE) facilities but includes a note that repeated intentional detonations require the structure to remain elastic. However, the design and analysis methodology for reinforced concrete is often useful for these conditions as well.

- **DESR 6055.09 – Defense Explosives Safety Regulation 6055.09**

  - Establishes explosives safety standards for the Department of Defense. These standards are designed to manage explosives-related risk associated with DoD operations and installations by providing protection criteria to minimize serious injury, loss of life, and damage to property.

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RELATED DOD CRITERIA DOCUMENTS

- **DA PAM 385-63 – Department of Army Pamphlet 385-63 – Range Safety**

  - Provides guidelines for Army Range safety protocols for many operations. For example, artillery and grenade live-fire training. This document references range standard designs for some operations. Such as, the artillery viewing bunker and grenade familiarization bunker.

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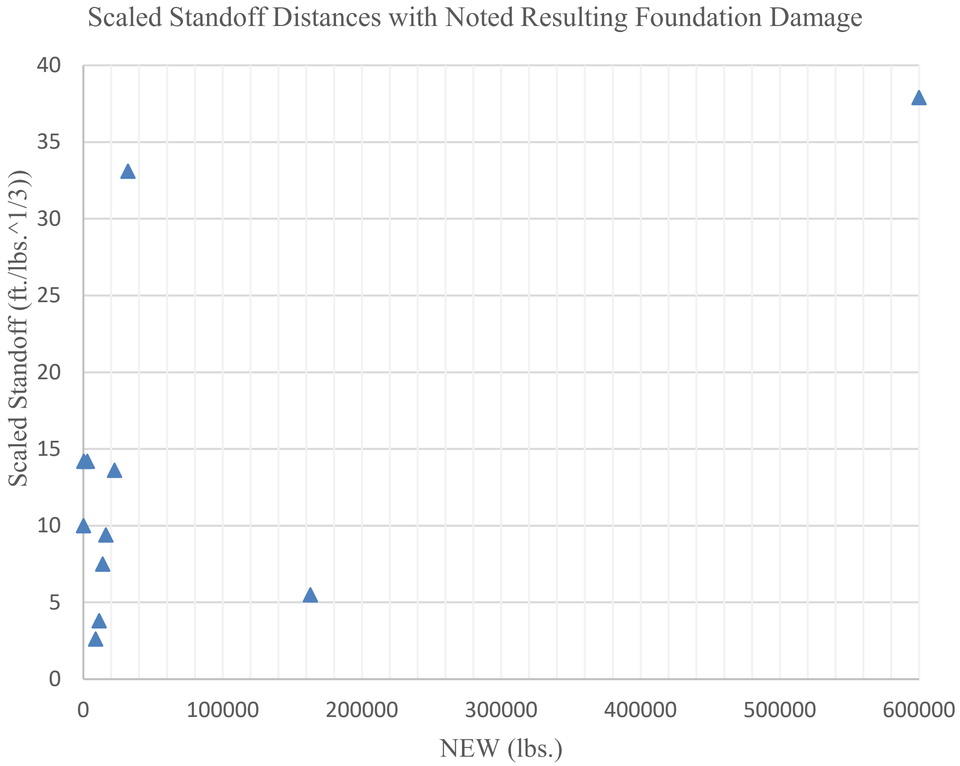
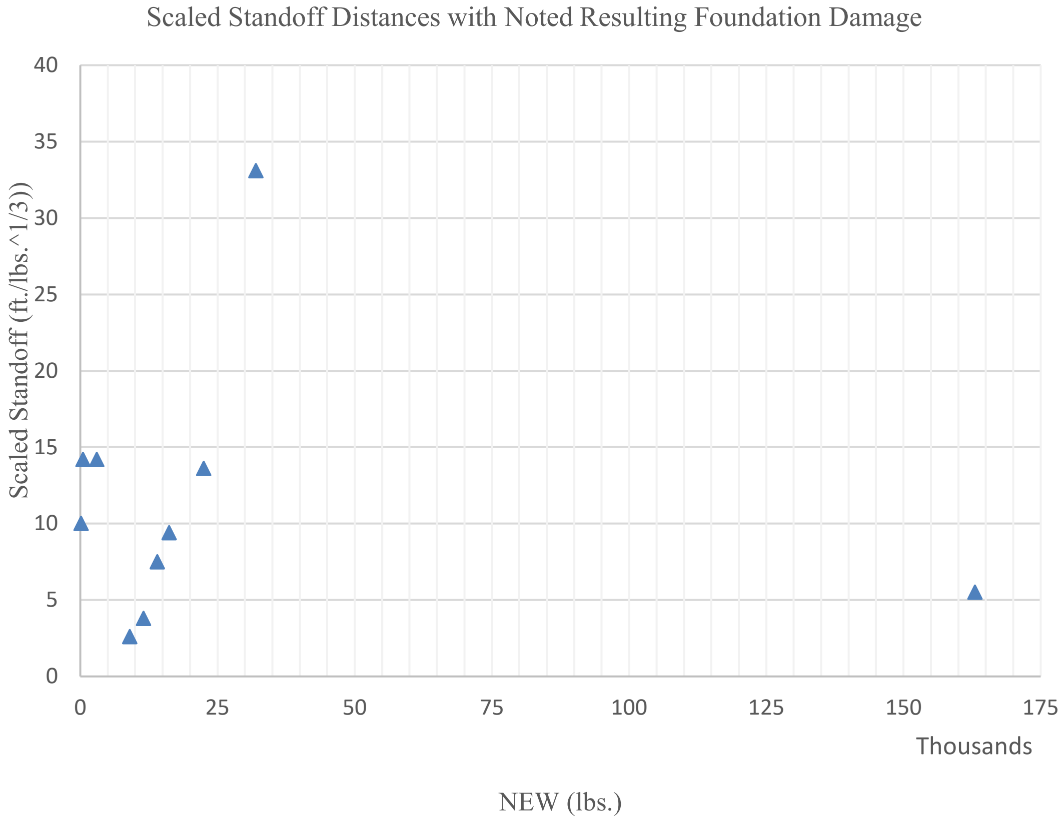
ACCIDENT DATA ANALYSIS

- 314 data points (mostly accidents, with some testing data) used to form an HD 1.1 matrix with Net Explosives Weight (NEW), scaled standoff, crater diameter, and foundation damage noted.

  - 12 occurrences of noted foundation damage, outside of crater diameter, with only two showing past K30 scaled standoff. One being a building noted as being two feet out-of-plumb, which was assumed to have occurred from rotation of the foundation and the other being differential settlement of a house at K33. Average scaled standoff of the 12 was K13.6.

ACCIDENT DATA ANALYSIS

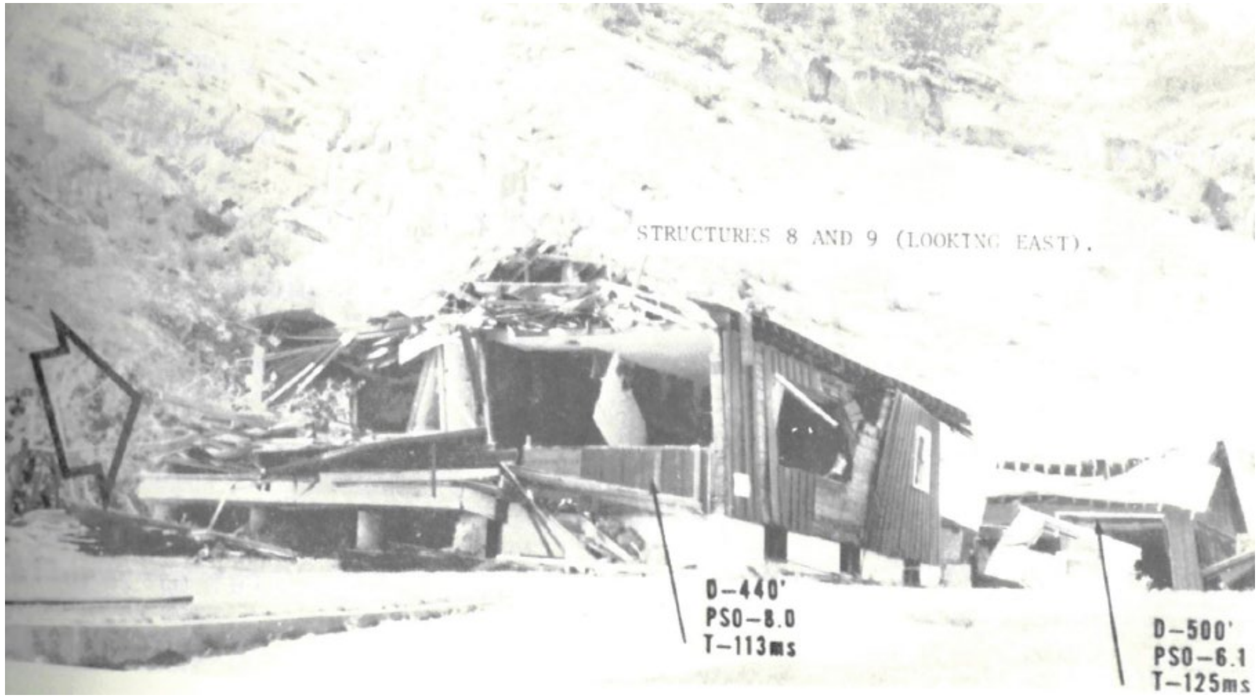




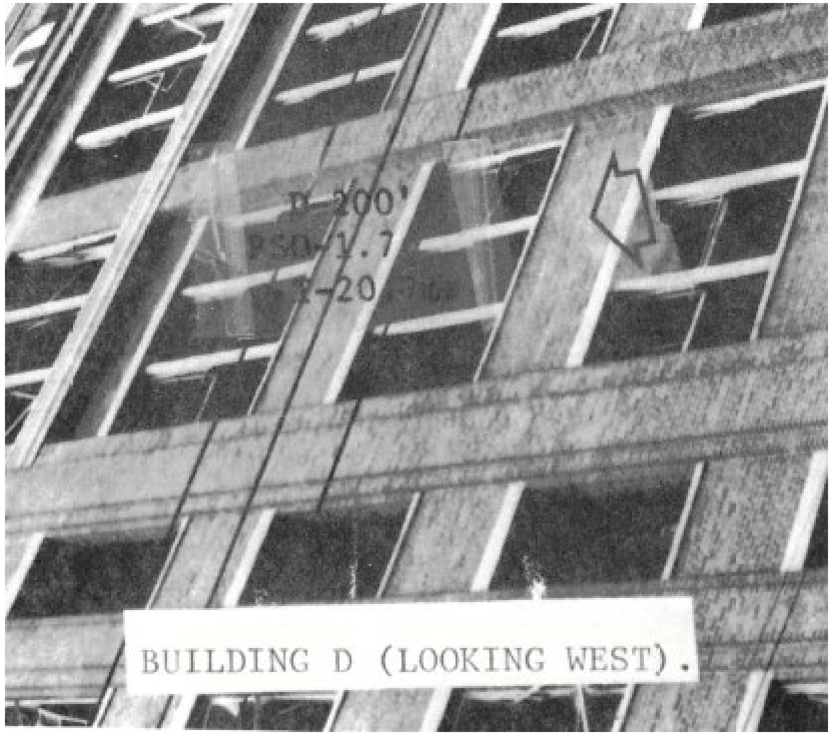
ACCIDENT DATA ANALYSIS

- In addition to examining noted occurrences of foundation damage, specifically stating scaled standoffs with no foundation damage were also recorded.
  - 11 occurrences of this were found, with an average scaled standoff of K19.55 (K20).
  - This data would suggest that K18 or K24 may be a reasonable arc for exclusion of the need for blast loading on foundation analysis.
  - However, the superstructure of the majority of these facilities was brick, wood, or CMU block. A couple of concrete and precast facilities did still fall below the K20 above. Only showing door and window damage at K12 and K14.

ACCIDENT DATA ANALYSIS



ACCIDENT DATA ANALYSIS



BUILDING D (LOOKING WEST).

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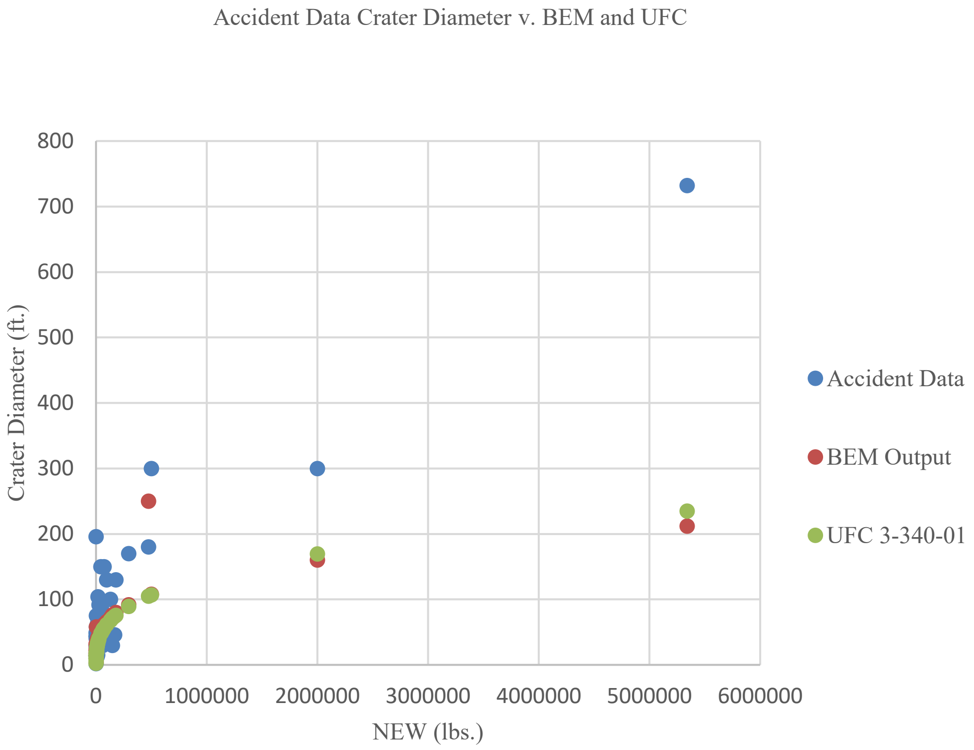
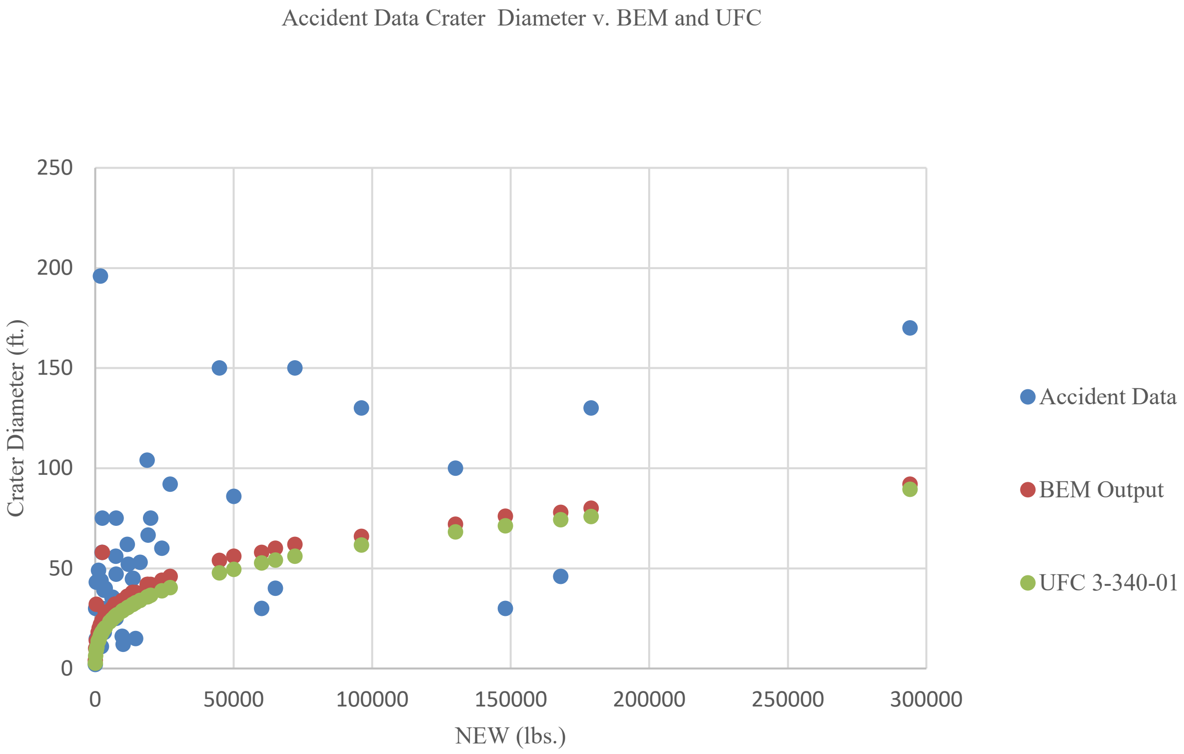
CRATERING ANALYSIS TOOL VS. ACCIDENT DATA

- Accident crater diameters were recorded and compared to UFC 3-340-01 and the Buried Explosion Module (BEM)

  - It should be noted that for this data a depth of burial of 0 ft. was assumed, which can lead to skewed data, due to the BEM and other software assuming a “buried” explosive.

CRATERING ANALYSIS TOOL VS. ACCIDENT DATA





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CRATERING ANALYSIS TOOL VS. ACCIDENT DATA

- Crater diameters underpredicted by on average 7% (BEM) and 24% (UFC 3-340-01), with maximum errors far exceeding that.
  - For this reason, BEM was used as a baseline for the matrix data.
  - It was assumed that some of the largest maximum errors may have been caused by soil liquefaction in a few cases.
  - Average radius of accident craters was K2.47, with only 2 of 57 exceeding K5.
  - Based on this data it was assumed that an appropriate range of analysis for blast loading on foundations of inhabited buildings may be K5-K18. With a recommendation to not place inhabited buildings inside of the expected crater radius.
  - Foundation blast loading analyses were performed using a scaled standoff range of K5-K40 to test this assumption.

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FOUNDATION BLAST LOADING ANALYSIS AND DESIGN

- **Analyses Assumptions:**

  - Facilities are between K5 and K40.

  - Facilities are of reinforced concrete construction.

  - Shallow foundation systems, with continuous footings.

  - Footings bearing on sand foundation to minimize spring values.

  - Soil vertical and rotational springs modelled along wall perimeter for support conditions based on assumed footing size. Initial footing size developed from conventional loading.

  - International Building Code (IBC) minimum allowable bearing pressure for unknown soil conditions assumed (1,500 psf).

FOUNDATION BLAST LOADING ANALYSIS AND DESIGN

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- **Analyses Assumptions:**

  - A two times multiplier applied to allowable bearing pressure for blast loading combinations (3,000 psf), due to short duration. Similar to 33% increase allowed for seismic and wind, but higher due to milliseconds duration verse seconds duration.

  - Building 25 ft. x 50 ft. with a 15 ft. height.

  - Two double doors total, one on each 50 ft. length wall.

  - Lowest region for wind and seismic used for initial footing design to minimize strength and ACI 318-14 used.

  - Dead Load (DL) plus Blast Load (BL) used for blast loading scenario load combination. (1.0DL+1.0BL). No multiplier due to being an extreme loading event.

FOUNDATION BLAST LOADING ANALYSIS AND DESIGN

- **Analyses Assumptions:**

  - Following equation used to find bearing pressure.

$$\sigma = \frac{P}{A} \pm \frac{M}{S}$$

σ- Bearing Pressure

P – Axial load in kips

A – Area of footing

M- Moment in kip-ft

S- Section Modulus

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FOUNDATION BLAST LOADING ANALYSIS AND DESIGN

- **Analyses Assumptions:**

  - 2,000 lb. potential explosion site (PES) assumed for all cases to reduce variation in loading assumptions due to duration and impulse increasing with higher NEWs. Additional analyses recommended for cases with higher NEWs and other differing conditions.

  - DLF method used for analysis and compared to SDOF period response as sanity check.

FOUNDATION BLAST LOADING ANALYSIS AND DESIGN

- **Analyses Results:**

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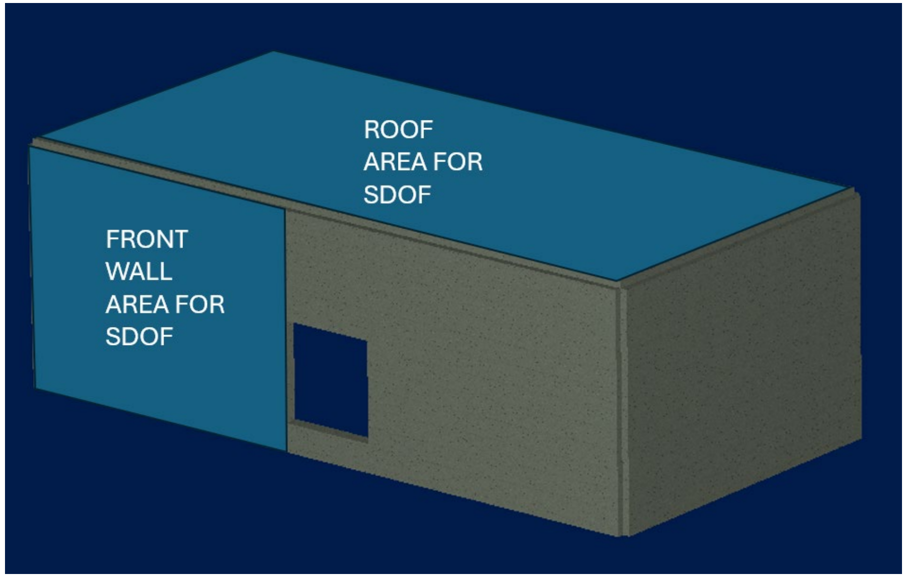

Component Period Comparison			
Method	**Component**	**Period T (ms)**	**Δ (%)**
DLF	Front Wall	44.37	-
SDOF	Front Wall	35.56	25%
DLF	Roof	82.93	-
SDOF	Roof	68.68	21%

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FOUNDATION BLAST LOADING ANALYSIS AND DESIGN

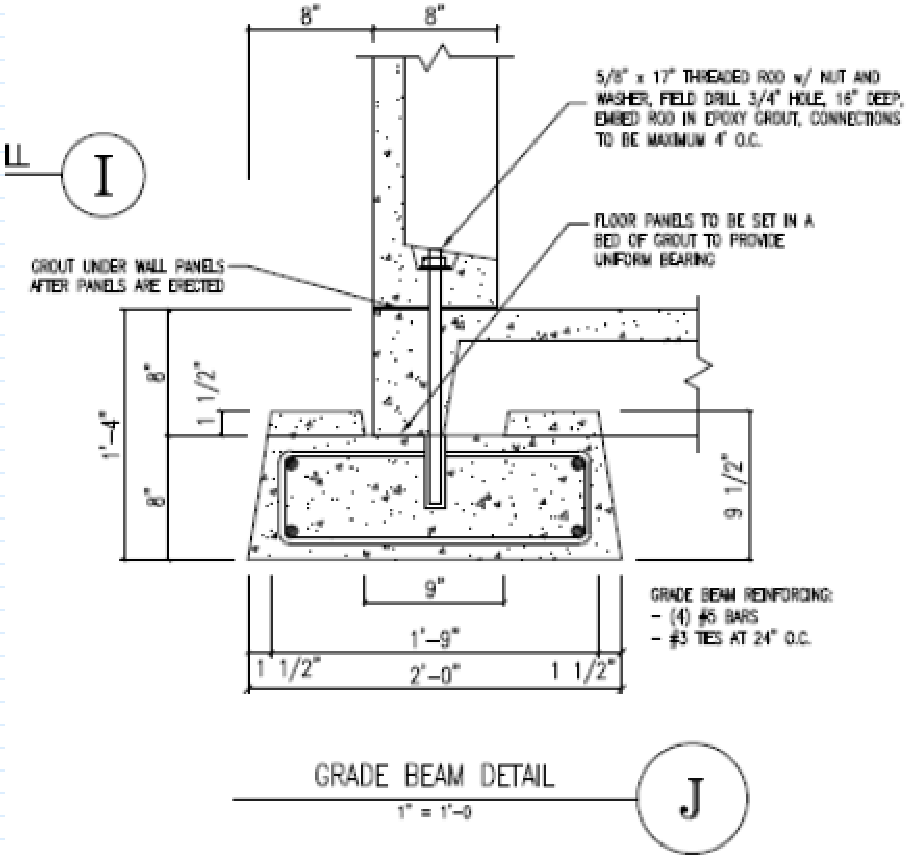
- **Analyses Results:**

  - It was found that demand did not fail residual footing capacity until scaled standoff distance was below K23, for a 2,000 lb. PES with a 12” thick concrete exposed site (ES).

  - This data agrees well with the K19.55 average of no foundation damage observed from accident data. Results may be even closer when PES is 20,000 lbs. instead of 2,000 lbs.

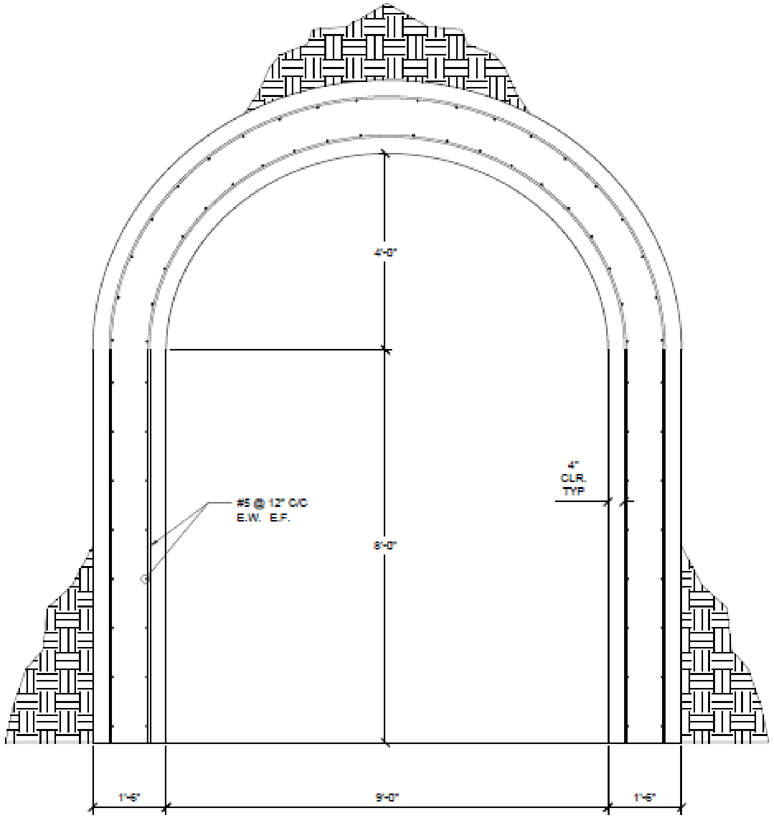
EXAMPLES OF PAST USE

- **Precast Training Structures:**



EXAMPLES OF PAST USE

- **Internal Detonations in Buried Structures:**



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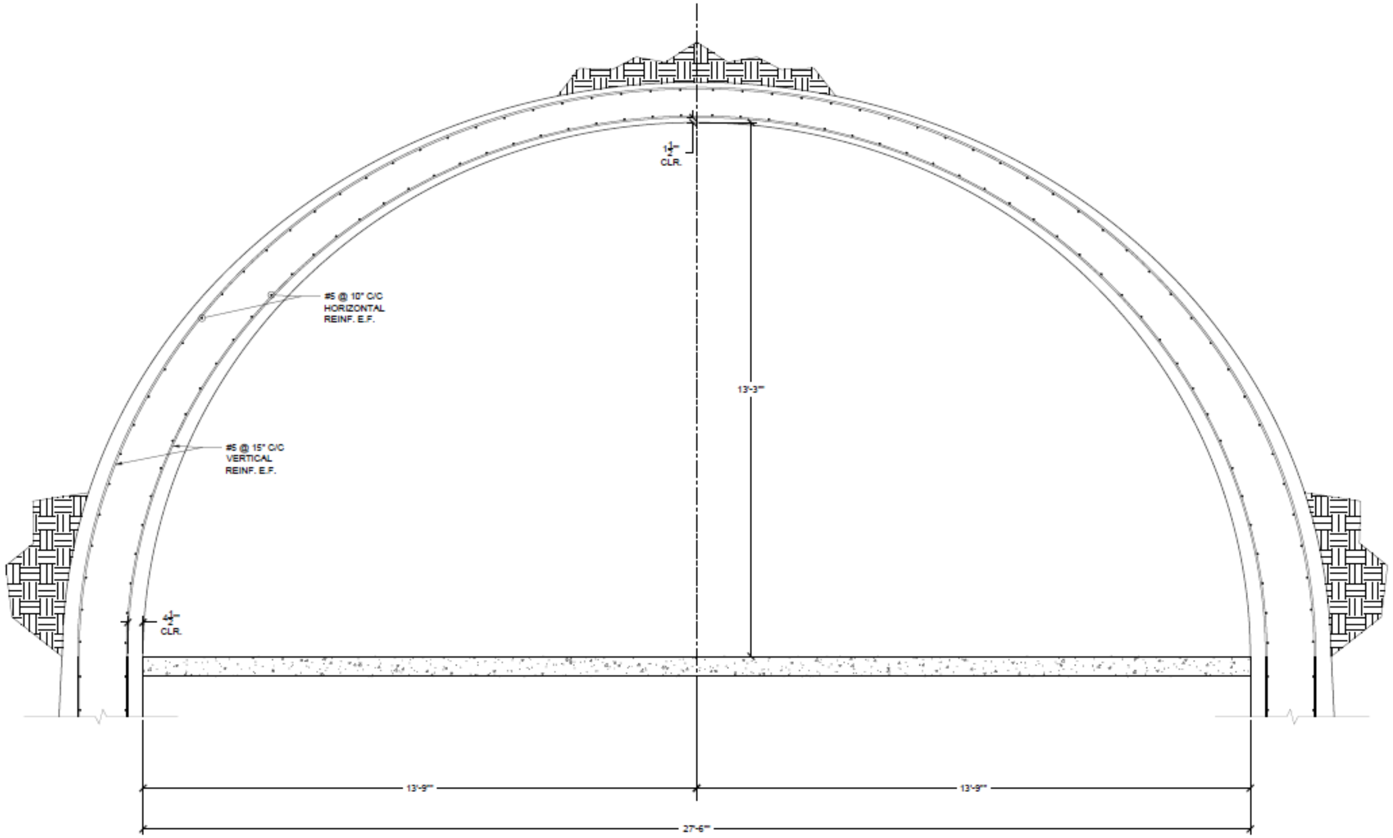

CW ARCH SECTION
SCALE: 3/4" = 1'-0"

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EXAMPLES OF PAST USE

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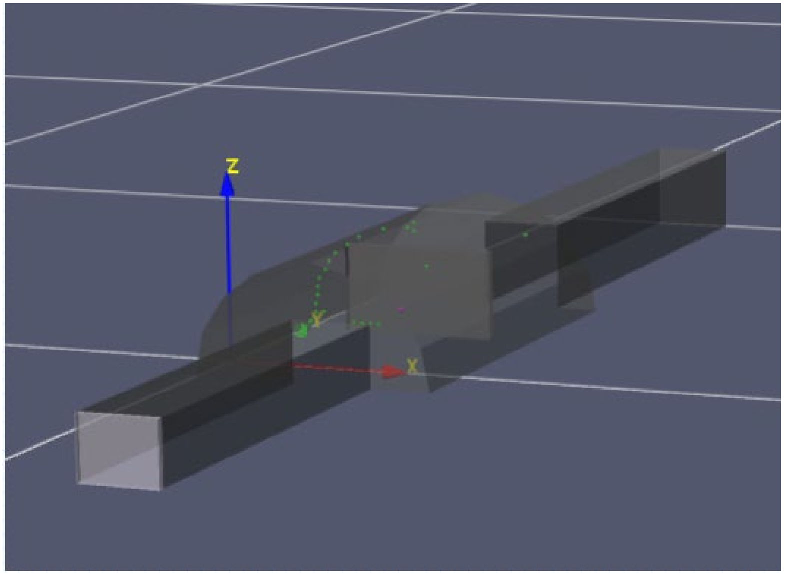
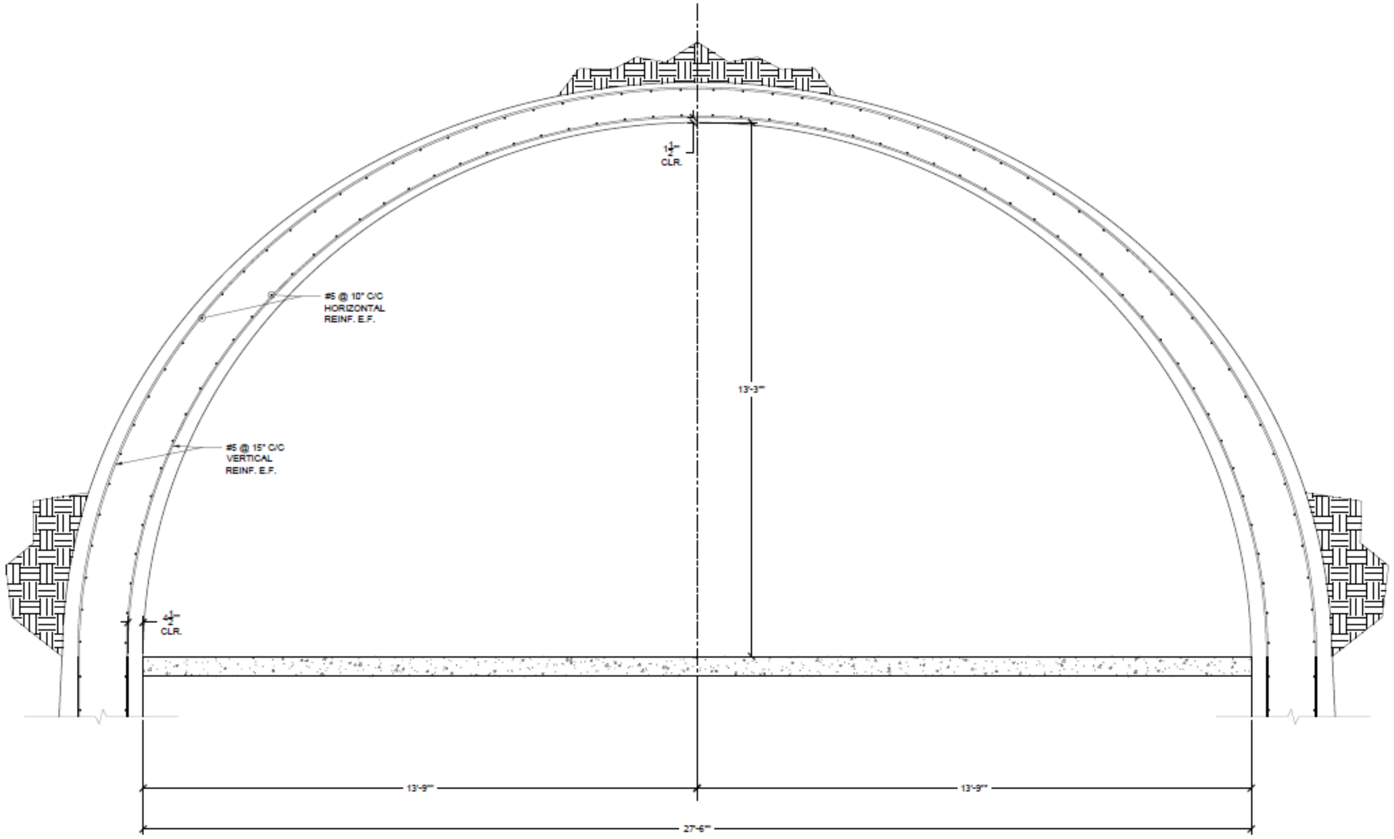
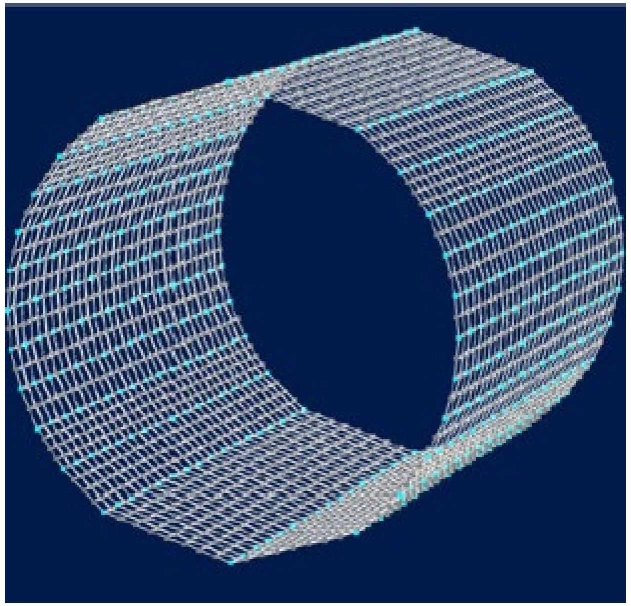




CW ARCH SECTION
SCALE: 3/4" = 1'-0"

EXAMPLES OF PAST USE

- Analysis of Buried Bunkers



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CONCLUSIONS

- Conclusions:
- Expected crater radius to K18 or K24 may be a reasonable range for recommending consideration of additional research on foundation blast loading.
- Intentional detonation site (IDS) operations should come with analyzing surrounding foundation components to ensure they remain elastic.
- Simplified methods for analyzing reinforced concrete foundations agree with accident data observations.

QUESTIONS?