Engineering Explosive Safety – Development of the Pseudo-Underground Storage Structure (PUGSS)

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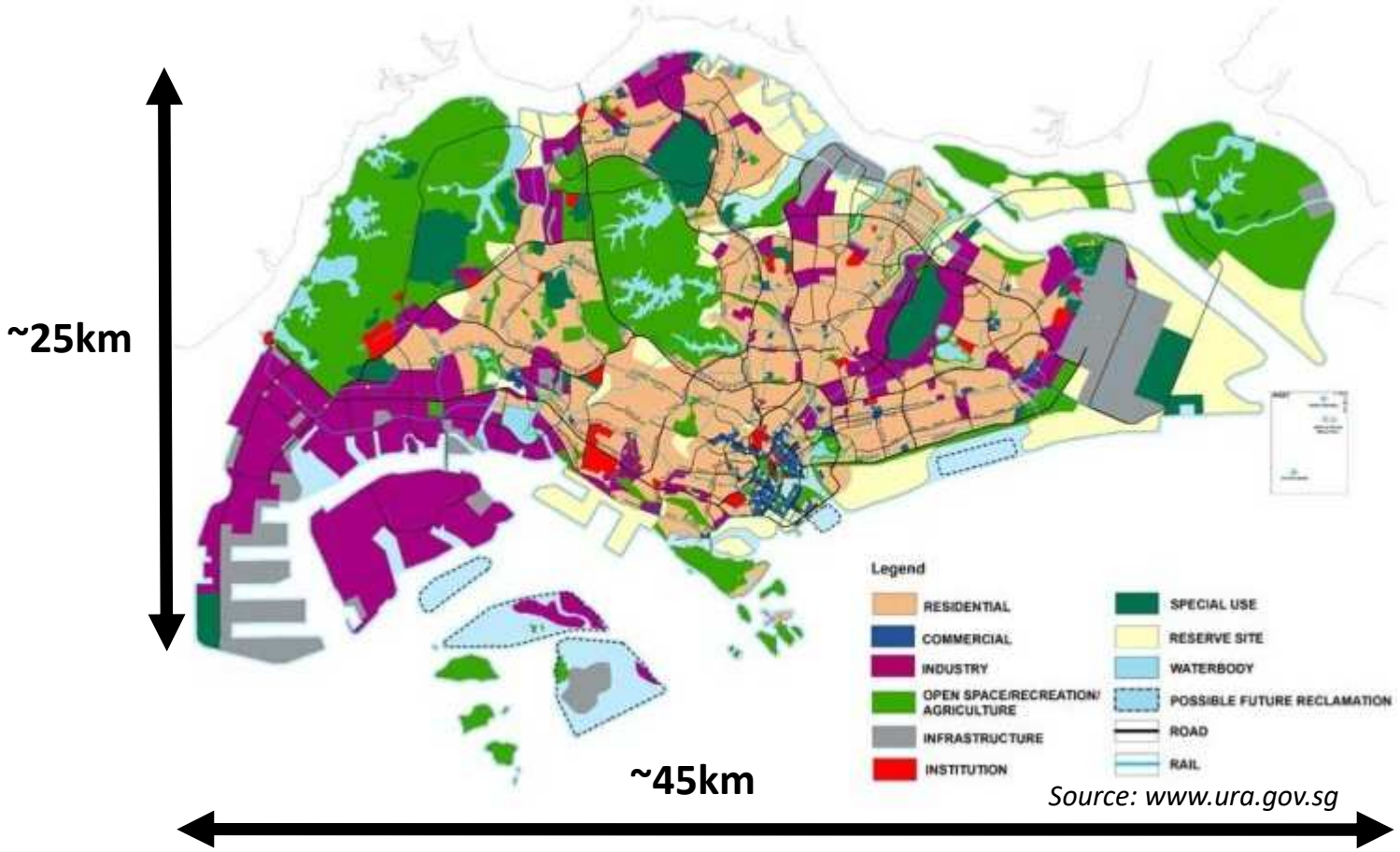
OUTLINE

- Introduction
- PUGSS and the Blast Resistance Wall (BRW) Technology
- Scaled Explosive Validation Test
- Results and Post Test Analysis
- Proposed Explosive Safety Siting
- Configurations of PUGSS
- Conclusion

LAND FACTS IN SINGAPORE

As of 2017,
Total Land area = 721.5km^2
Total population = 5.7 million
Population density = 8,100 p/km^2

LAND IS PRECIOUS!

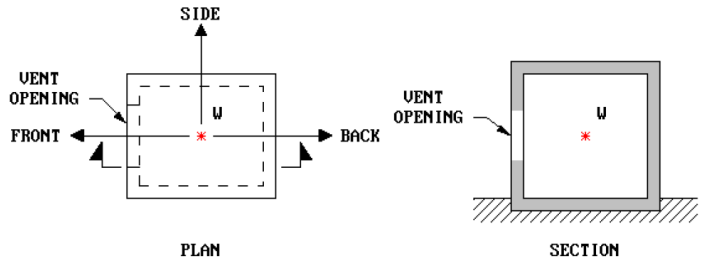


Source: www.ura.gov.sg

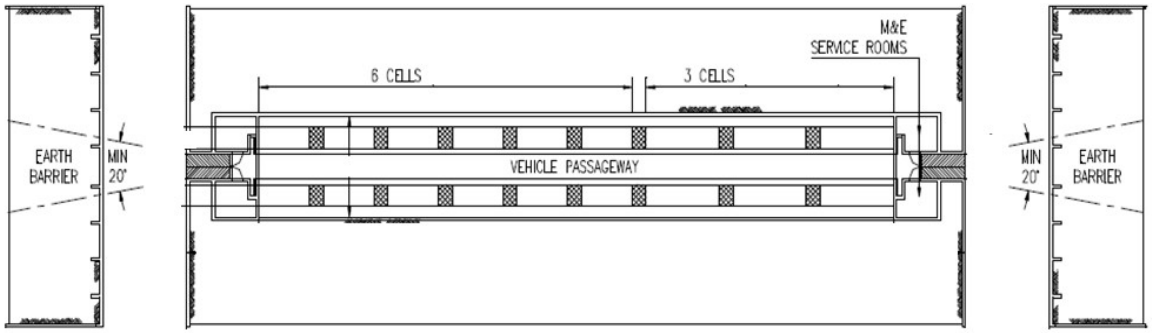
ENGINEERING EXPLOSIVES SAFETY

Underground Ammunition Facility

Figure 2-186 Four Wall Cubicle Vented Through a Wall and Direction of Blast Wave Propagation

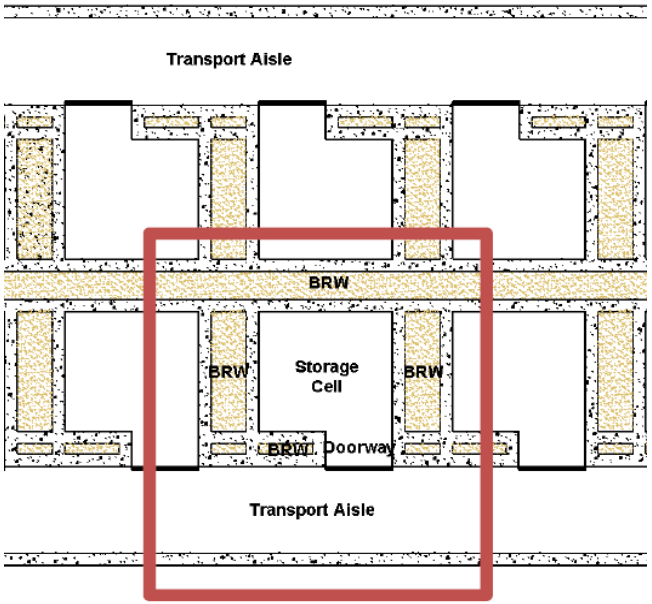


Containment Type Structures
(max. 2.4kg/m^3)
[UFC 3-340-02]

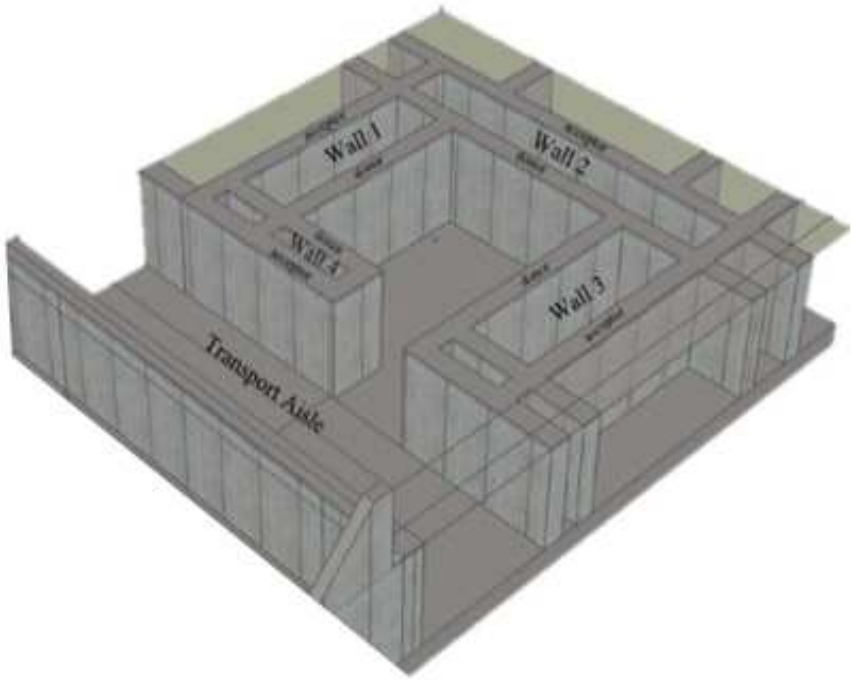


Singapore High Performance Magazine
(MCE = 1 ton/ storage cell)

PUGSS AND BRW TECHNOLOGY



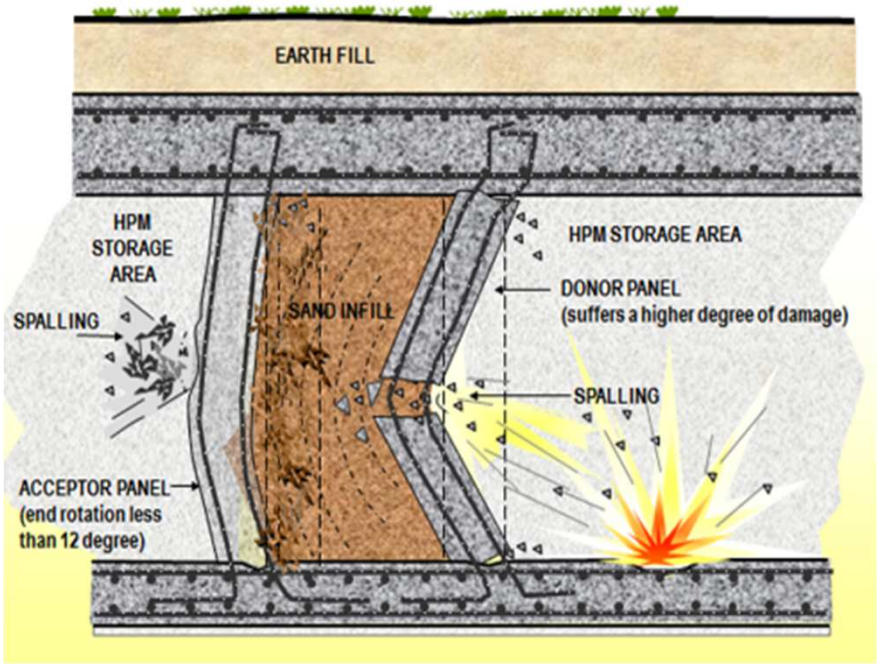
Conceptual Design of PUGSS

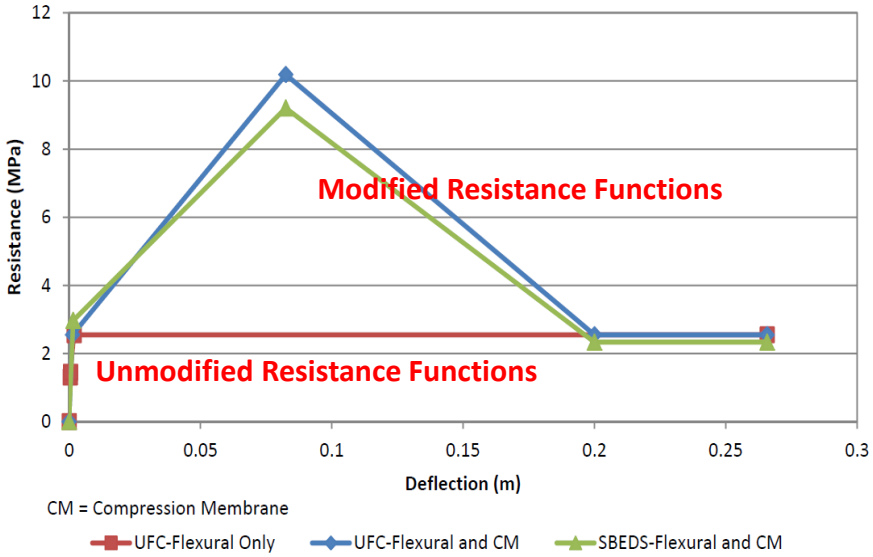


Typical PUGSS Storage Cell

PUGSS AND BRW TECHNOLOGY

Blast Resistant Wall (BRW) Technology (Design limit: support rotation < 12 degrees)





Design with consideration of Compression Membrane effects using UFC 3-340-01 and SBEDS -> better representation of the strain absorption capability of the BRW RC panels

SCALED EXPLOSIVE VALIDATION TEST

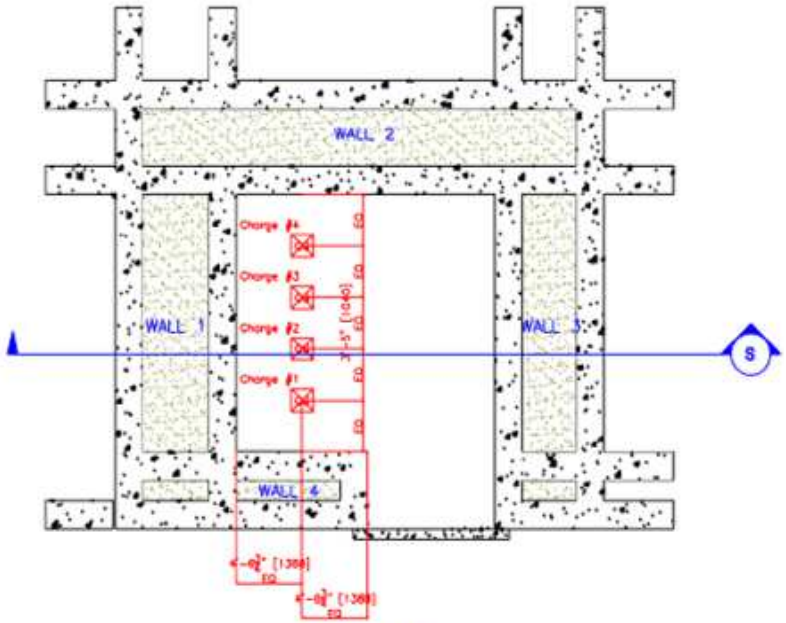
Half-Scale Test Structure:

Blast Resistance Wall No.	Thickness of Blast Resistance Wall Component (m)			Blast Resistant Wall Dimension (m)	
	Concrete Donor Panel	Sand Fill	Concrete Acceptor Panel	Length	Height
1	0.575	1.4	0.575	5.2	2.5
2	0.575	1.15	0.575	5.45	2.5
3	0.575	1.15	0.575	5.2	2.5
4	0.575	0.4	0.575	2.78	2.5

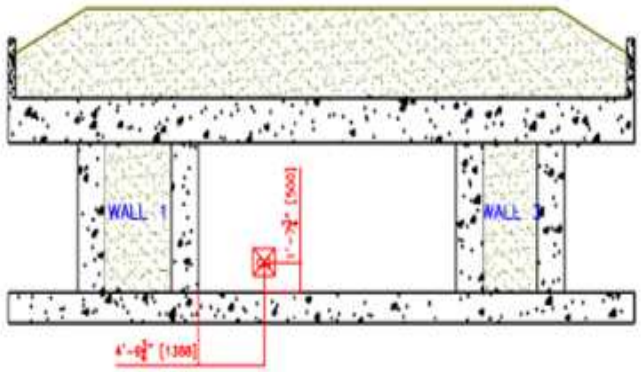
SCALED EXPLOSIVE VALIDATION TEST

Placement of Explosive Charges:

- 4 Numbers of C4 charges (with total NEQ 750kg) at 0.153 m/kg$^{1/3}$ from the nearest Wall 1
- Half-scale for 5 ton MCE with safety factor of 1.2

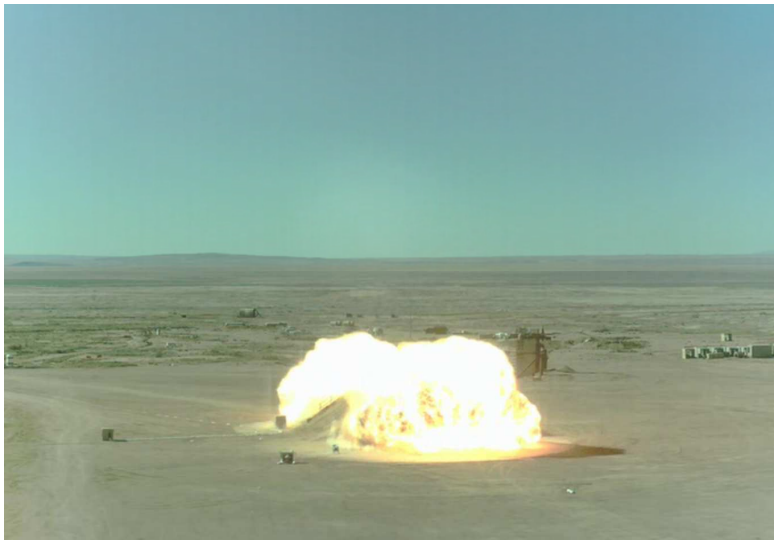


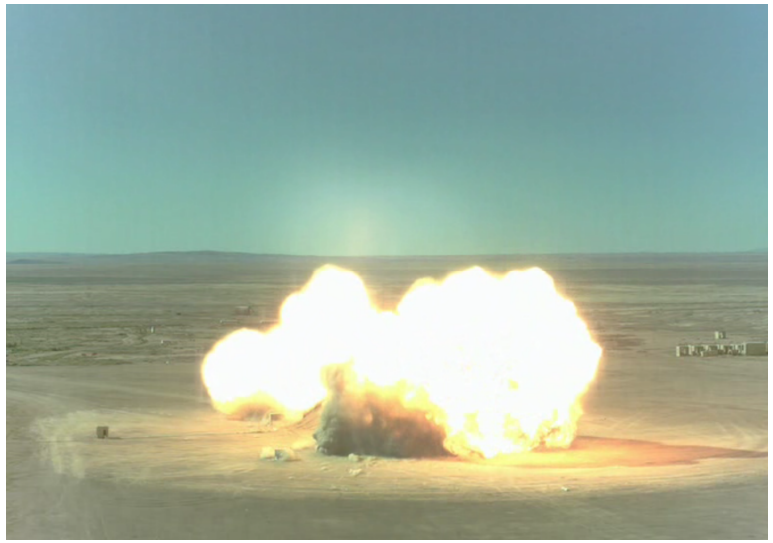
PLAN VIEW



SECTION VIEW

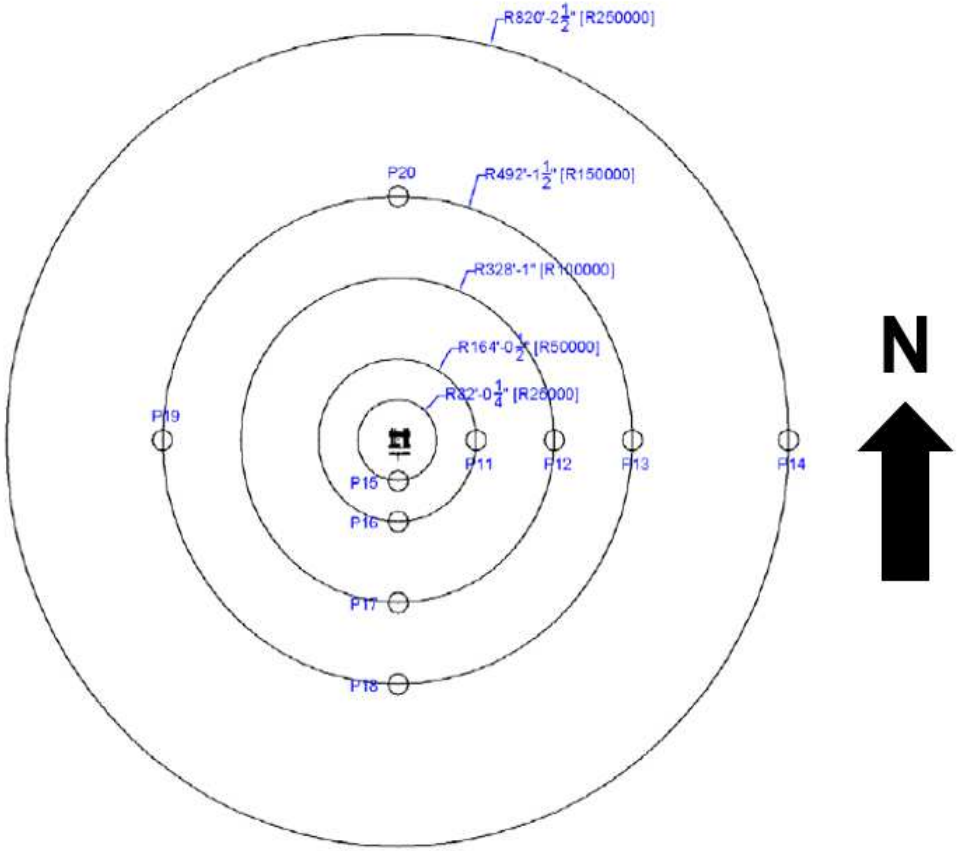
RESULTS AND POST TEST ANALYSIS





RESULTS AND POST TEST ANALYSIS

External Blast Pressure Measurements:

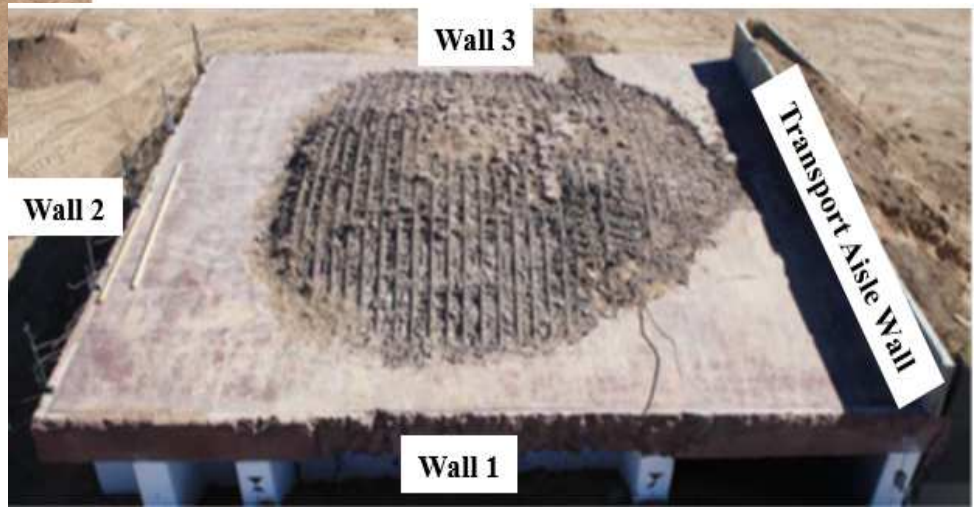


Gauge No.	Gauge Description	Peak Free-Field Pressure (kPa)
11	East, R = 50m	41.9
12	East, R = 100m	12.5
13	East, R = 150m	5.3
14	East, R = 250m	3.0
15	South, R = 25m	34.3
16	South, R = 50m	17.8
17	South, R = 100m	8.7
18	South, R = 150m	4.6
19	West, R= 150m	5.6
20	North, R = 150m	5.3

RESULTS AND POST TEST ANALYSIS

Post Test View of Test Structure

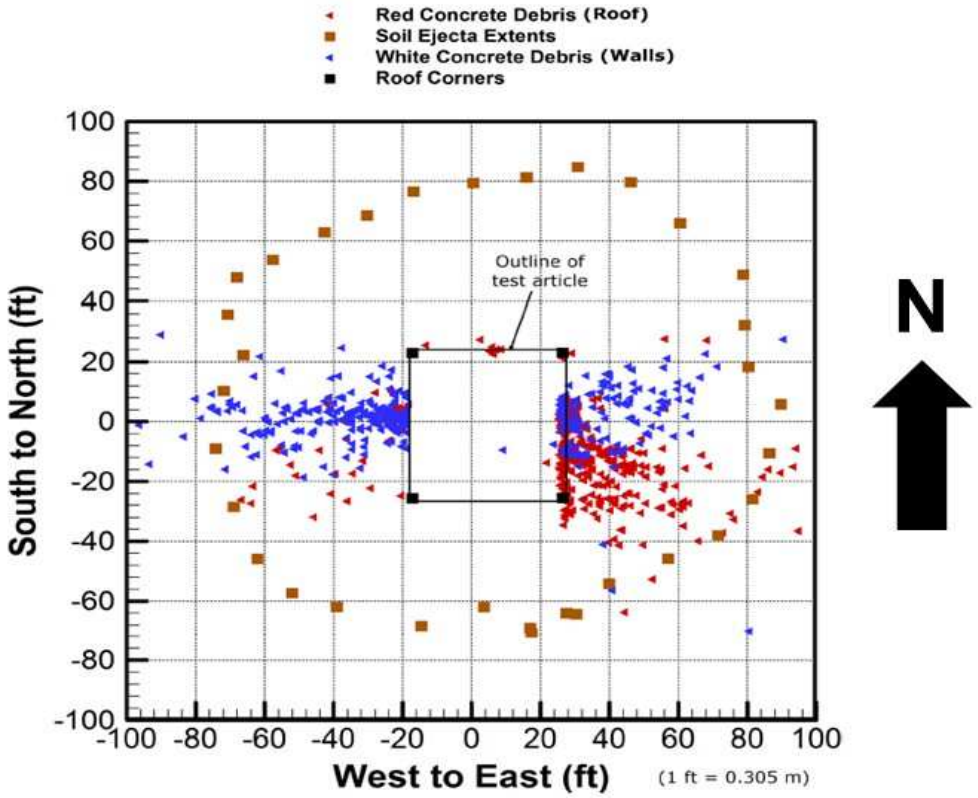
Post Test View of Test Structure with Soil Cover Removed



RESULTS AND POST TEST ANALYSIS

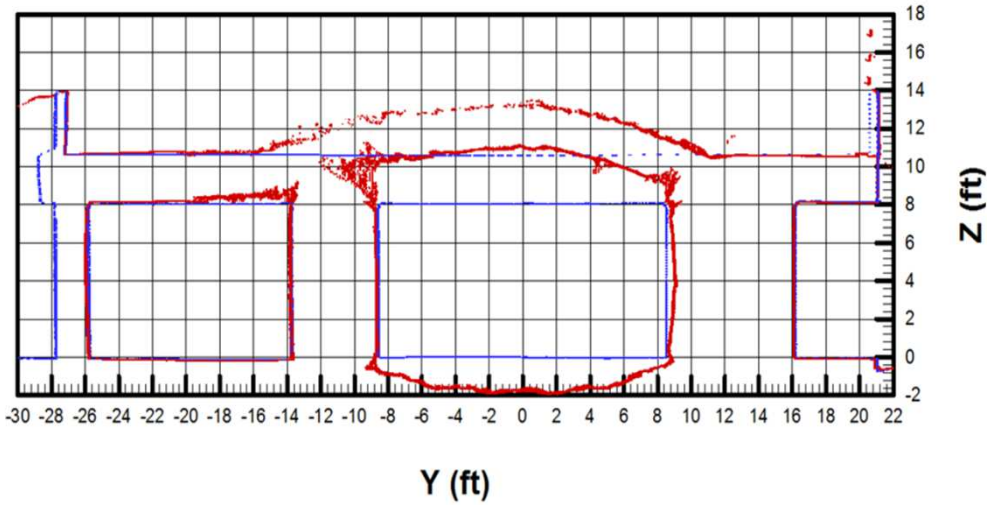
RESULTS AND POST TEST ANALYSIS

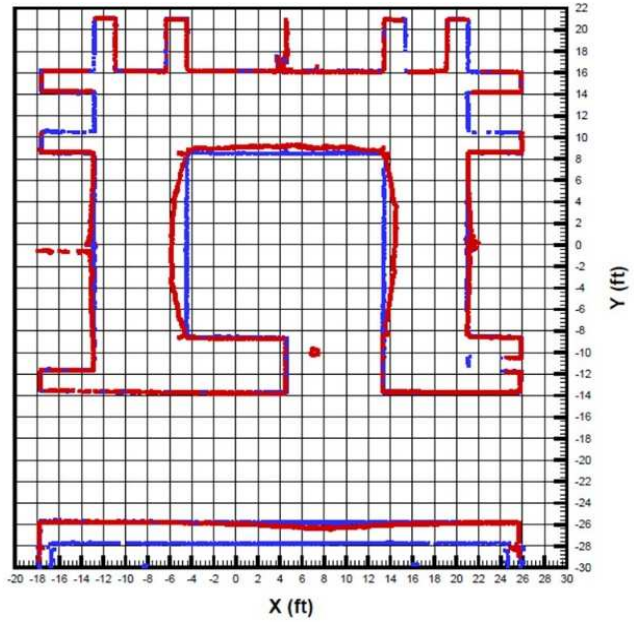
Debris Throw and Extent of Soil Ejecta Around Test Structure

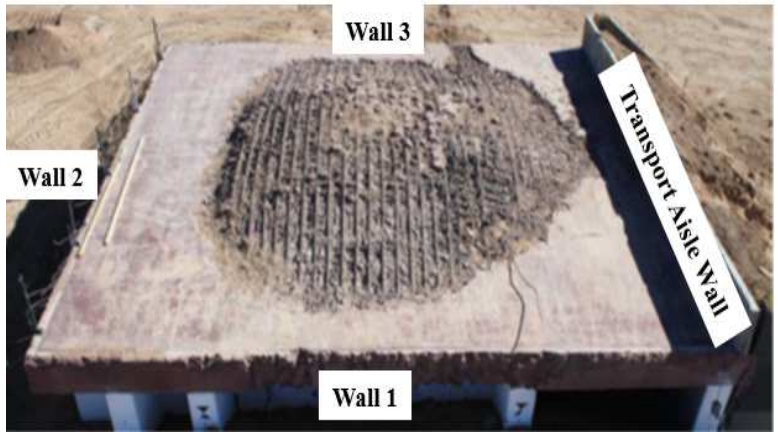


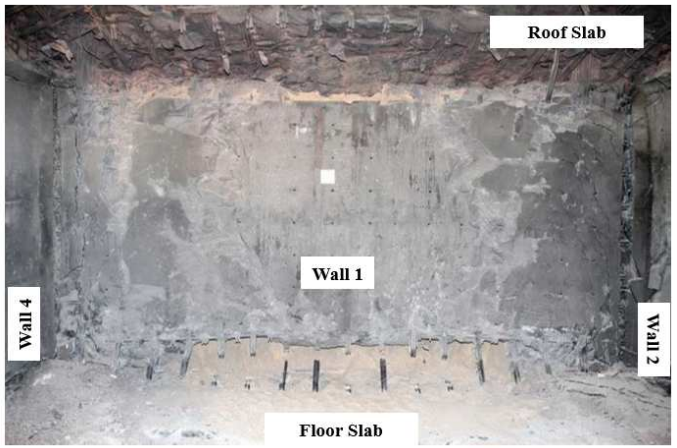
RESULTS AND POST TEST ANALYSIS

LIDAR Scan and Observations:









RESULTS AND POST TEST ANALYSIS

External Acceptor Panel Displacement Measurements and Observations:

Instrumentation	Wall 1		Wall 2		Wall 3	
	Displacement (mm)	Support Rotation (degrees)	Displacement (mm)	Support Rotation (degrees)	Displacement (mm)	Support Rotation (degrees)
LVDT	185	8.4	43	2.0	137	6.3
Accelerometer	181	8.2	34	1.6	Not installed	--

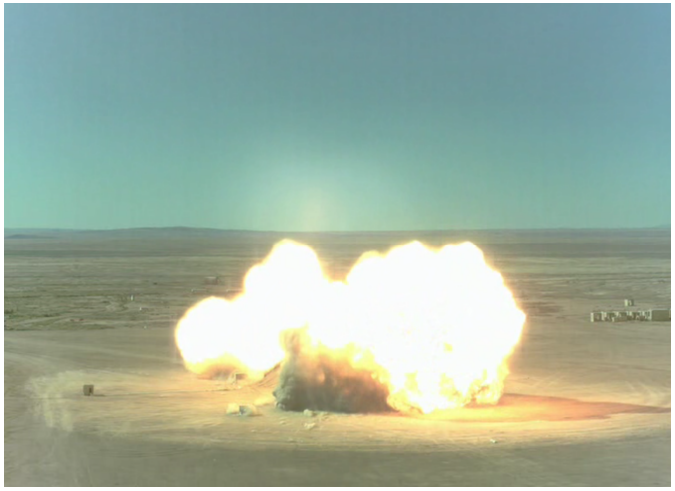
PROPOSED EXPLOSIVE SAFETY SITING

- Explosion Effects to be considered for IBD calculations:
  - Blast from openings of transport aisle
  - Debris from openings of transport aisle
  - Debris from the roof

- Valid for:
  - Maximum loading density of 9.23 kg/m^3
  - Maximum NEQ of 5,000kg
  - Transport aisle opening with scale vent area $(A/V_E^{2/3}) \leq 0.29$
  - Scaled cover $\geq 0.1Q^{1/3}$ (Q:NEQ in kg)
  - Presence of Effective Barricade

PROPOSED EXPLOSIVE SAFETY SITING

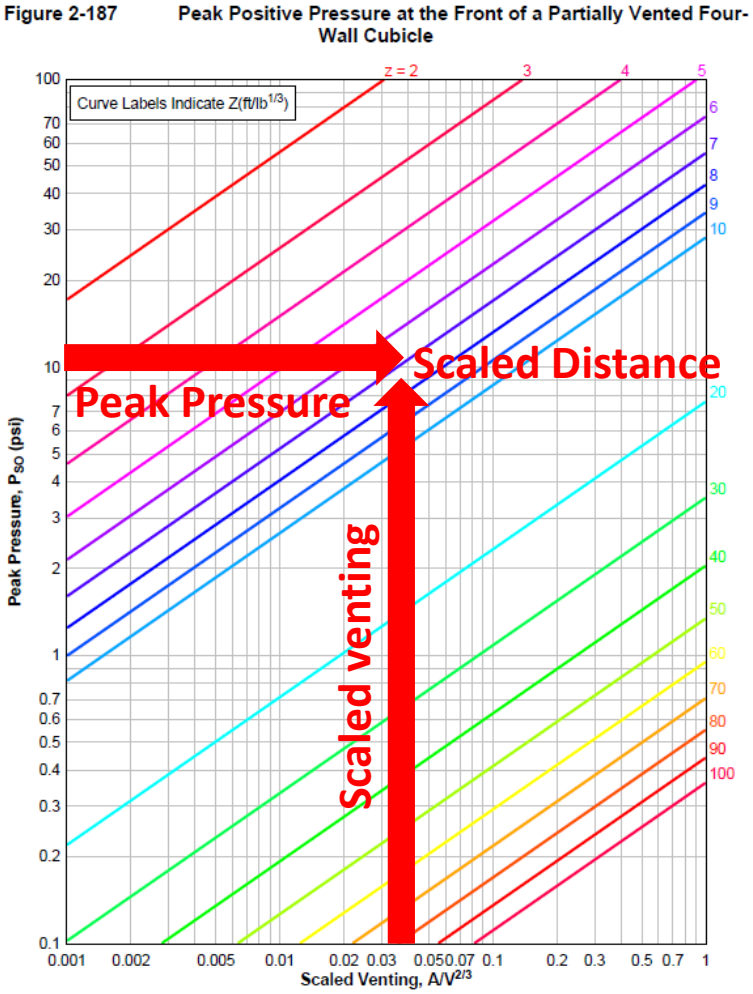
Blast from Openings of Transport Aisle



Based on test data and the descriptions from UFC 3-340-02, for transport aisle opening with scale vent area ($A/V_E^{2/3}$) ≤ 0.29, the proposed equation for calculating the 5kPa line is:

$$IBD\ (5kPa) = 16.5*Q^{1/3}$$

Where Q: Net Explosives Quantity (NEQ) in kg



[Source: UFC 3-340-02]

PROPOSED EXPLOSIVE SAFETY SITING

Debris from Openings of Transport Aisle

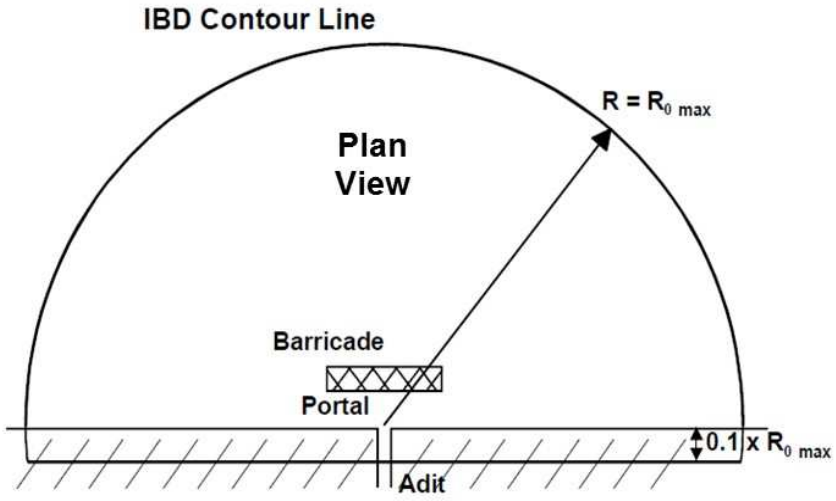
Based on Part III of AASTP-1 on Underground Explosives Storage, with an effective barricade, the maximum range $R_{0\ max}$ of the IBD contour line for debris throw from the openings of the transport aisle can be predicted by:

$$R_{o\ max} = 0.4*[(-4.025-A)/B]$$

Where $A = -5.25 + \ln(Q)$

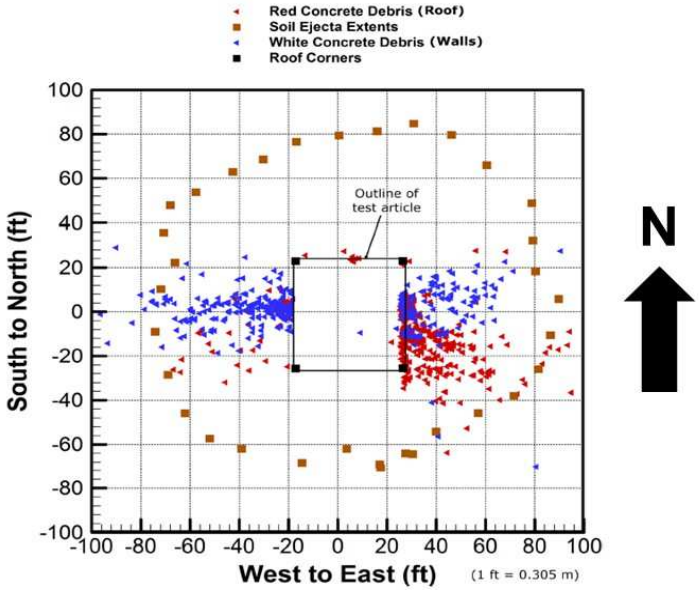
$B = -0.0085 - 0.25/(\sqrt{Q})$

Q: Net Explosives Quantity (NEQ) in kg



PROPOSED EXPLOSIVE SAFETY SITING

Debris from the Roof



Based on Part III of AASTP-1 on Underground Explosives Storage, the proposed IBD for debris throw from the roof of the PUGSS storage cell can be calculated by:

$$\text{IBD (Roof Debris)} = 38.7 * Q^{1/3} * f_v * f_c$$

Where $f_v = [(Q/V)/1600]^{0.35}$

$f_c = 0.45 + [2.5*(C/Q^{1/3})] - [2.11*(C/Q^{1/3})^2]$

Q: Net Explosives Quantity (NEQ) in kg

V: Chamber Volume in m^3

C: Overburden, Cover in m (assume $C/Q^{1/3} = 0.1$ m/$kg^{1/3}$ for conservativeness)

PROPOSED EXPLOSIVE SAFETY SITING

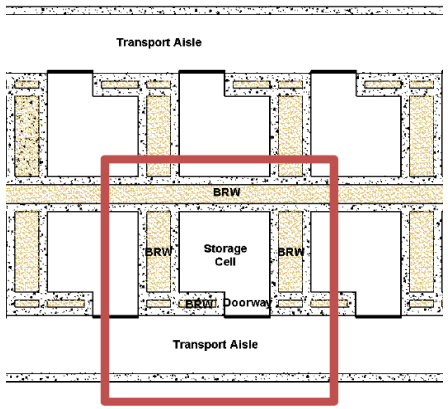
Explosion Effects	IBD for Conventional Aboveground Magazine (unbarricaded)	
	Q = 750kg	Q = 5,000kg
Air Blast	205m	380m
Debris Throw	400m	400m

Explosion Effects	IBD for PUGSS Storage Cell	
	Q = 750kg	Q = 5,000kg
Air Blast	150m	285m
Debris from Openings	125m	245m
Debris from Roof	40m	75m

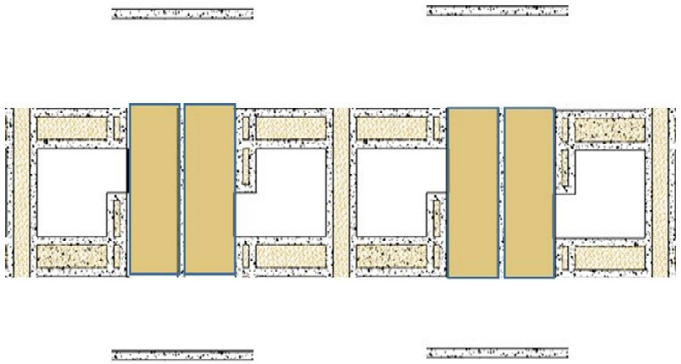
- For a NEQ of up to 5,000kg, the IBD of the conventional aboveground magazine is governed by the debris throw distance of 400m, whereas for the PUGSS storage cell, its IBD is governed by the 5kPa air blast distance of 285m.

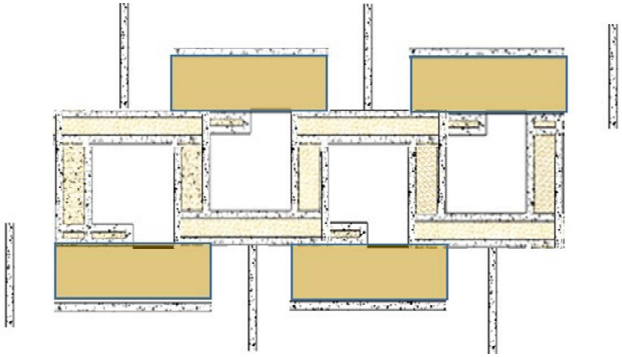
- In terms of sterilised land for explosive safety, the **savings in land area is approximately 50%** (502,655m^2 versus 255,176m^2).

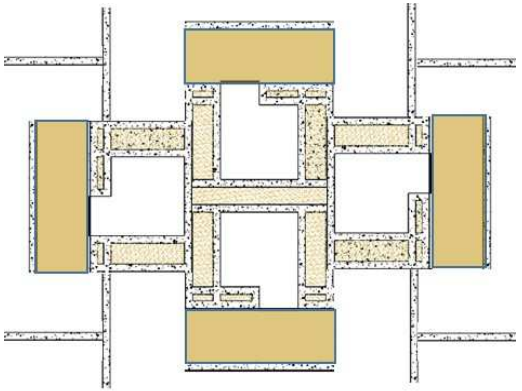
CONFIGURATIONS OF PUGSS



High Capacity Blast Door (4MPa) for large opening required







CONCLUSION

- DSTA had collaborated with NAVFAC EXWC to successfully design and develop the BRW technology and PUGSS.

- PUGSS is a specially engineered containment structure with BRWs and a hardened roof that are capable of withstanding the internal explosion effects of ammunitions stored within and limit the MCE of an accidental explosion to only one storage cell.

- PUGSS has raised the practical limit of the design loading density of an engineered RC containment structure from 2.4 kg/m^3 to 9.23 kg/m^3.

CONCLUSION

- The PUGSS storage cell design has been validated through an half-scale explosive test.

- IBD equations based on the descriptions of containment type structures in UFC 3-340-02 and Part III of AASTP-1 on Underground Explosives Storage were proposed for the explosive safety siting of the PUGSS storage cell.

- For the maximum storage of 5,000kg NEQ, a 50% saving in sterilised land can be achieved by the PUGSS storage cell when compared with a conventional aboveground magazine of the same NEQ.

ACKNOWLEDGEMENTS

DSTA and NAVFAC EXWC gratefully acknowledge the professional support provided by Defense Threat Reduction Agency (DTRA) and Applied Research Associates (ARA) in this research and development work.


THANK YOU FOR
YOUR ATTENTION!
QUESTIONS?