

Modeling Tunnel Magazine QD Arcs Using GIS

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Abstract

The Naval Facilities Command (NAVFAC) Engineering Service Center (ESC), located in Port Hueneme, CA, has developed tools to quickly provide map displays of the Quantity-Distance (QD) arcs for tunnel magazines using both DoD and NATO criteria. The development of the maps of possible NEW storage scenarios included a 3D analysis of the tunnels and the surrounding topography to assess available soil cover and the surface breach that could result if insufficient soil cover were available. The explosive hazard criteria intelligent tables linked with GIS map displays provided a means to rapidly model the QD arcs generated by alternative storage scenarios in underground explosive storage facilities. The 3D modeling and visualization of the expanding shock and pressure hazards for a range of NEW quantities compared to the soil surface allowed detailed examination of the potential surface breach crater characteristics.

Introduction

The Naval Facilities Command (NAVFAC) Engineering Service Center (ESC), located in Port Hueneme, CA, has developed tools to quickly provide map displays of the Quantity-Distance (QD) arcs for tunnel magazines using both DoD and NATO criteria.

ESC has integrated Geographic Information System (GIS) map display tools and intelligent tables containing QD arc calculations for tunnel magazines in order to rapidly examine alternative explosives storage scenarios. The tools were developed, tested, and used to delineate on planning maps the incremental increases in size of the QD arcs which would be derived from possible increases in Net Explosives Weight (NEW) of stored munitions. The goal of the effort was to quickly and inexpensively provide a series of planning QD arc maps to Asset Managers to permit better decision making on optimizing the balance between the need for increased NEW storage within operational constraints.

The development of the maps of possible NEW storage scenarios included a 3D analysis of the tunnels and the surrounding topography to assess available soil cover and the surface breach that could result if insufficient soil cover were available. The 3D analysis compared the tunnel geometry to a LIDAR model of the topography of the mountain in which the tunnels were constructed. Using the 3D analysis tools permitted a detailed examination of the interaction between the tunnel and the available soil cover.

Report Documentation Page

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14. ABSTRACT The Naval Facilities Command (NAVFAC) Engineering Service Center (ESC), located in Port Hueneme, CA, has developed tools to quickly provide map displays of the Quantity-Distance (QD) arcs for tunnel magazines using both DoD and NATO criteria. The development of the maps of possible NEW storage scenarios included a 3D analysis of the tunnels and the surrounding topography to assess available soil cover and the surface breach that could result if insufficient soil cover were available. The explosive hazard criteria intelligent tables linked with GIS map displays provided a means to rapidly model the QD arcs generated by alternative storage scenarios in underground explosive storage facilities. The 3D modeling and visualization of the expanding shock and pressure hazards for a range of NEW quantities compared to the soil surface allowed detailed examination of the potential surface breach crater characteristics.			
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The analysis tools were applied to the tunnel storage magazines at a US DoD installation. A sampling of the maps developed for that study is provided in this report. The maps and NEW storage amounts developed in that analysis do not represent the actual storage parameters of the magazines. The maps merely represent the QD arcs resulting from a range of possible storage amounts and are provided for example purposes only.

Tunnel Magazines

Tunnel magazines are a type of underground storage facility which can consist of a single explosives storage chamber or multiple connected chambers with protective features. According to DoD 6055.09-STD (Feb. 29, 2008, p50), “To qualify as an underground facility, the minimum distance from the perimeter of a storage area to an exterior surface shall be great than $0.25 W^{1/3}$ ($0.10 Q^{1/3}$)”. Normally the minimum distance requirement is met by the existing soil cover, which would be sufficient to contain most blast and fragment effects.

The calculated QD arc for a tunnel is dependent upon local geology and site-specific parameters such as the tunnel dimensions. Special protective features may be built for the structure to reduce the Inhabited Building Distance (IBD) for both the fragment debris and overpressure airblast (e.g. debris traps, expansion chambers, portal barricades, high pressure closures, and facility design/construction)

Overpressure and fragments are channeled out through openings such as doors and vents. The channeling of the airblast and debris fragments through openings, especially the front portal, can act like a shotgun. The QD criteria for overpressure and fragment hazards are therefore typically more severe than for standard earth covered magazines.

Tunnel Magazine QD Arc Criteria

The intelligent table tools developed by ESC determine the QD arcs for tunnel magazines using the DoD and NATO criteria for airblast overpressure, adit (portal) fragment debris, and surface breach debris. The two sets of criteria provide different QD arc patterns on the resultant maps. For the analysis, DoD and NATO criteria were examined for each tunnel magazine. The application of the different sets of criteria, either DoD or NATO, would have to be applied to all of the storage tunnels in the area.

The DoD explosive storage QD arc criteria are defined in DoD Standard 6055.09-STD. The NATO explosive QD arc criteria are defined in the NATO Allied Ammunition Storage and Transportation Publication 1 (AASTP-1). The DoD Standard and NATO Publication define underground storage facilities and describe the criteria for the QD safety arcs for tunnel magazines.

One of the main differences between the two sets of criteria is that the QD arc criteria for tunnel magazines defined in the DoD Standard 6055.09-STD have generally remained unchanged for 20 years. The NATO AASTP-1 criteria have progressed with continued development through the NATO working group.

The QD arc for adit debris using the DoD criteria requires an 1800 ft safety distance regardless of the HD 1.1 or 1.3 NEW quantities. The adit debris QD arc for NATO criteria is dependent upon the HD 1.1 and 1.3 quantities. The NATO criteria describe a minimum of approximately 750 ft safety arc, which progresses with increases in NEW. The safety distance surpasses DoD criteria above approximately 9,000 lbs NEW.

The overpressure QD arc defined by the DoD criteria describes an oval-shaped area. The overpressure DoD criteria for IB distance is 1.2 psi. The overpressure QD arc defined by NATO criteria describes a heart-shaped area with the point angled in the direction of the tunnel, i.e. in the direction of the “shotgun” blast. NATO criteria require the overpressure to be reduced to 0.725 psi to define IB distance. This is more conservative than the DoD criteria. The shape of the NATO arc provides a larger safety area along the forward centerline than the oval-shaped area defined by the DoD criteria. The back-side area provides a small safety arc than the DoD oval-shaped area.

The surface rupture debris QD arc described by the DoD criteria is a circular-shaped area centered on the probable rupture location at the point of least soil cover over the underground storage tunnel. The surface rupture debris QD arc described by the NATO criteria includes directional effects in the same way as the NATO adit debris arc, making it non-circular. The NATO surface rupture debris arc angle is determined by the slope azimuth at the probable rupture location at the point of least soil cover.

The different sizes and shapes of the QD arcs created to comply with the DoD and NATO criteria provided a wide variety of possible footprint areas depending on the specific NEW storage and the criteria which were used. The intelligent table and GIS tools created by ESC provide a means to rapidly develop maps for a range of NEW values and criteria to allow planners to compare and contrast the areas of impact versus the operational requirements in the area

Methods

Spreadsheets were used in Microsoft Office Excel to calculate coordinate points for the various arcs. Coordinates were calculated at 5 degree intervals to create a 360 degree arc of 72 points. Site-specific factors considered in the calculations include: magazine volume, loading density, hydraulic diameter, geology type, soil cover, and surface slope angle (for NATO criteria). The various arcs calculated include: overpressure, adit (portal) debris, surface breach (if applicable), ground shock, chamber separation, required soil cover, and PTRD (Public Transportation Route Distance) for various hazards. (See Figure 1)

Intelligent QD Hazard Arc Tables

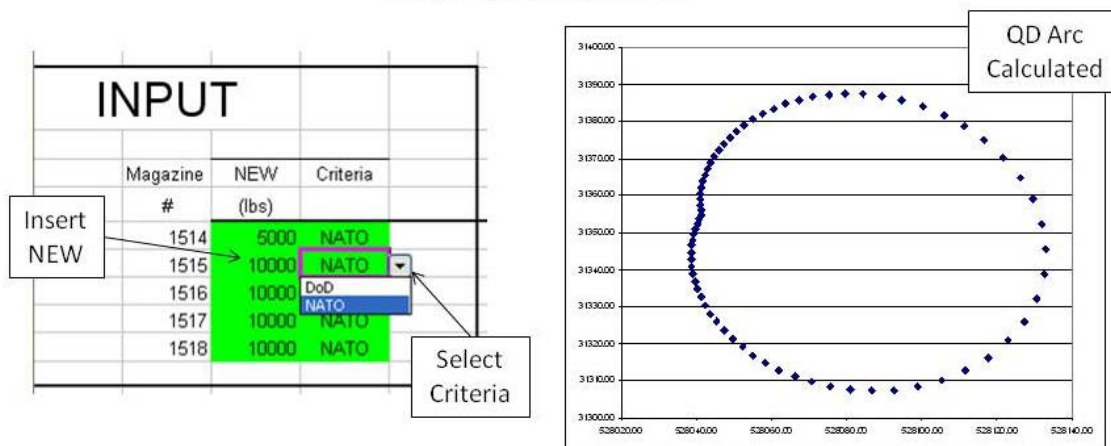


Figure 1

The hazard arcs for each magazine calculated by the intelligent tables were integrated into an ArcGIS Map Document for interactive display. It was essential to maintain an interactive connection between the intelligent tables and the GIS map display in order to rapidly develop a series of maps to evaluate a range of NEW storage scenarios. By maintaining the interactive connection between the intelligent tables and the GIS changes made to the NEW or changing from the DoD criteria to the NATO criteria could be immediately displayed when the map was refreshed.

To maintain the interactive connection between the intelligent tables and the ArcGIS map document required a three step process. First, the hazard arc distances were determined by the intelligence built into the tables based on the chosen NEW and the DoD or NATO criteria. The intelligent tables then used the QD arc distances to calculate the location of a series of points spread throughout the perimeter of the hazard area, with a point calculated every five degrees (5°) from the origin point of the hazard arc. The location of these five-degree arc points were brought into the ArcGIS map document as an Event Theme point dataset. In this way changes to the NEW or to the criteria, e.g. by switching from DoD to NATO criteria, would cause the intelligent tables to calculate new hazard arc distances that would feed into new recalculations of the five-degree point locations. The ArcGIS map display would have to be refreshed to prompt the Event Themes to reacquire the five-degree arc point locations. Once the map redrew it would show the new hazard arc as a series of points along the perimeter. (See Figure 2)

Intelligent QD Hazard Arc Tables Integrated with GIS Maps

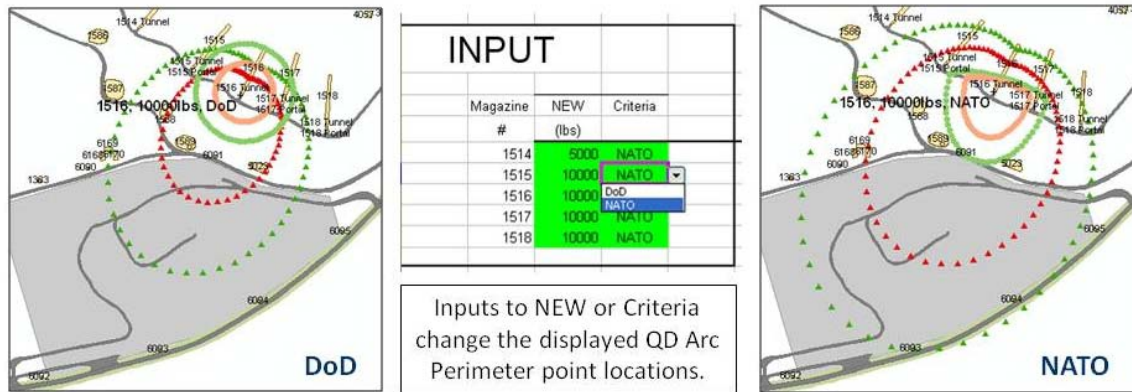


Figure 2

The hazard arc perimeter point locations are calculated based on the Quantity-Distances determined by the intelligent tables from the NEW and the chosen criteria, DoD or NATO. The distances are determined for each 5 degree arc from the given center point of the entry portal or of the surface breach location. The location of the origin point, and therefore also the derived five-degree arc points, were calculated using coordinates from projection NAD83 HARN State Plane Hawaii3 FIPS5103. This is the projection system used by the base. By calculating the positions using a known coordinate system, the ArcGIS event theme could readily display the calculated hazard arc points with other data such as buildings, roads, the base boundary, etc.

To adjust to an alternate tunnel location, or an alternate projection system, the origin point of the hazard arcs at the entry portal or the surface breach of the new X, Y coordinates need only be entered into the intelligent tables. The intelligent tables and integration with GIS were designed to facilitate adaptation of the process to other locations.

To determine the accurate location of the surface breach point, 3D analysis was performed with GIS comparing the soil cover available throughout the length of the storage chamber to the actual topographic landforms as determined by data available from a LIDAR survey of installation elevation. To perform the 3D analysis, contour line models were developed of the increasing shock and pressure hazard as the NEW quantities were increased. The contour line models were converted to 3D shapes that were then compared to 3D features derived from the existing elevation data. (See Figure 3)

Expanding 3D Surface for the Shock and Pressure Hazard for a Range of Soil Cover

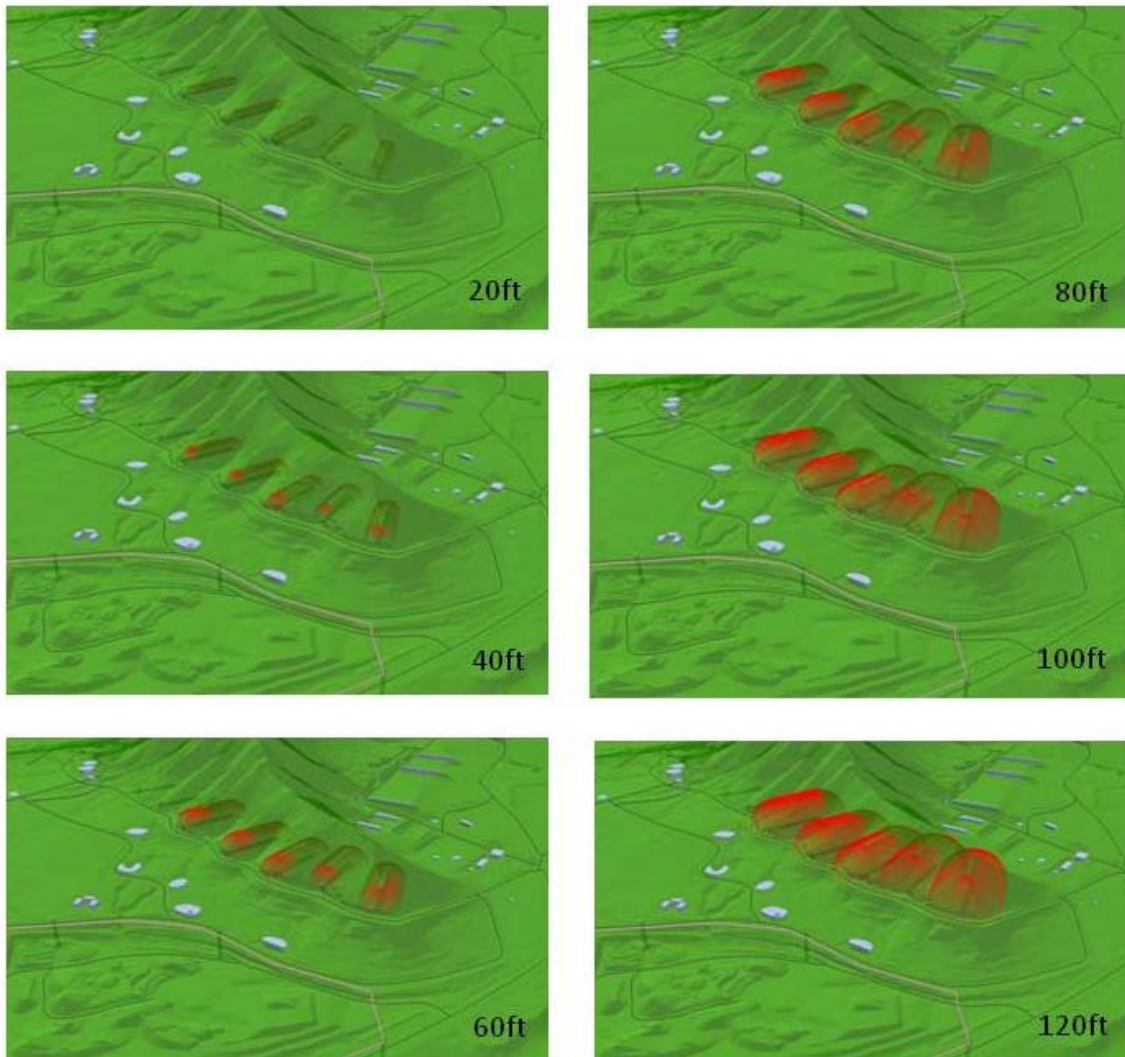


Figure 3

The comparison between the expanding surface for the shock and pressure hazard for a range of NEW quantities and the static elevation surface permitted the accurate determination of the location of least soil cover. The 3D model of the elevation surface was derived from one-foot contour line data. Therefore models were created of the expanding shock and pressure hazard surface at one-foot intervals. Comparison of the two models allowed the derivation of an estimate of soil cover accurate to within one foot of the actual distance to nearest surface breach. The calculated available soil cover permitted the reverse calculation of the NEW value that would not result in a surface breach for each underground storage facility. (See Figure 4)

Modeling Surface Breach Crater at One-Foot Increments

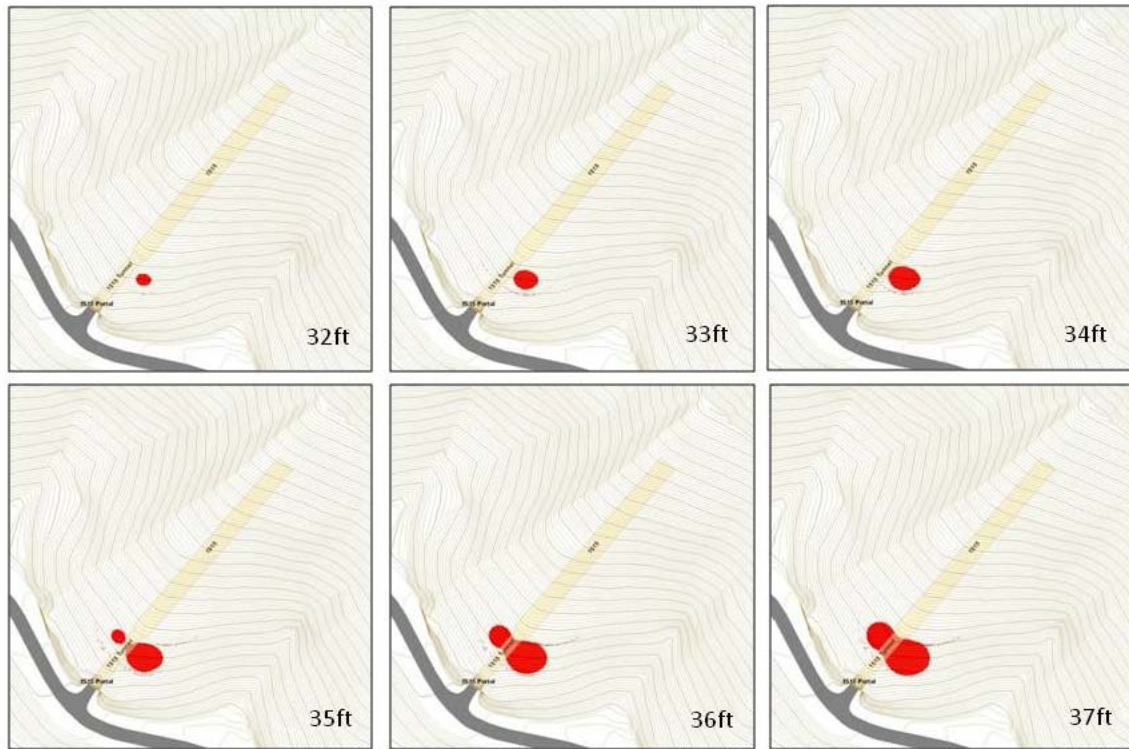


Figure 4

The models of the expanding shock and pressure hazards for a range of NEW quantities when compared to the soil surface allowed visualization of the size and shape of the surface breach. In the visualizations, the expanding area of potential surface breach could be observed wrapping around the mountain landforms. In some instances the expanding shock and pressure hazard would have a potential to cause two surface breaches, one on each side of the spur landform in which the underground storage facility was constructed. The models of the potential surface breach crater were used to derive the average centroid of the crater for each incremental increase in NEW so as to provide the best estimate of the origin point for the surface debris hazard arcs. (See Figure 5)

3D Modeling of Surface Breach Crater and Landform Surface

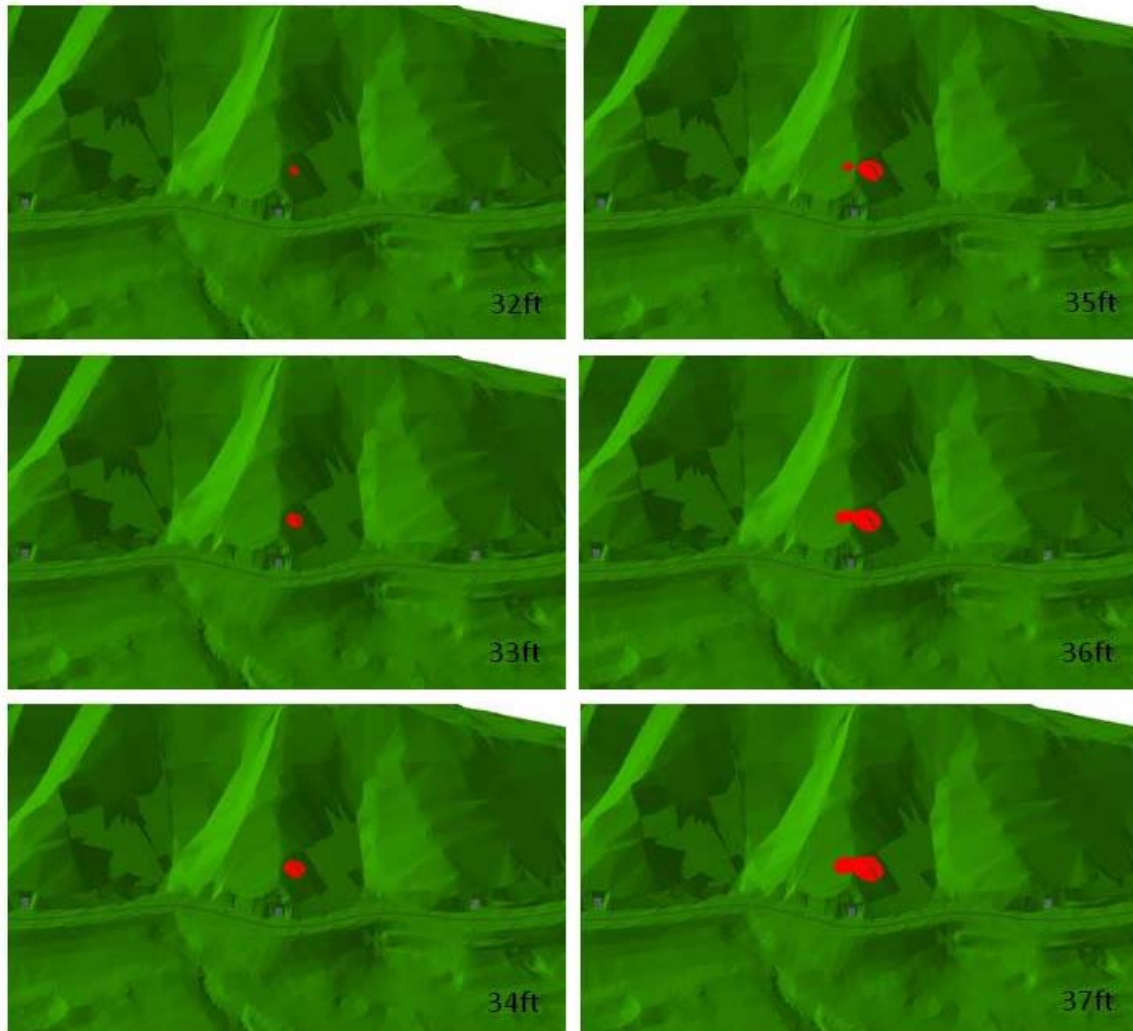


Figure 5

The accurate determination of the surface breach origin point permitted the identification of the topographic characteristics of slope and azimuth at the surface breach location. The NATO criteria have directional effects in their QD arcs for surface breach debris fragments. The direction is determined by the azimuth of the breach point. The 3D models thus provided a more accurate estimate of the surface breach point characteristics vital for development of the NATO QD arcs.

Results

The integration of intelligent QD hazard arc tables with GIS for display and analysis permitted rapid development of planning maps for a range of NEW quantities using both the DoD and NATO criteria. For the analysis of some of the underground storage facilities, the capabilities of the integrated tools were used to examine hundreds of

storage scenarios in order to visualize the effects of alternate storage scenarios and to develop an understanding of the area. For the final analysis, 77 planning maps and their concomitant GIS datasets were created for the base in order to provide them with the same type of understanding one could develop through using the tools interactively. (See Figure 6)

Rapidly Developed QD Arc Planning Maps

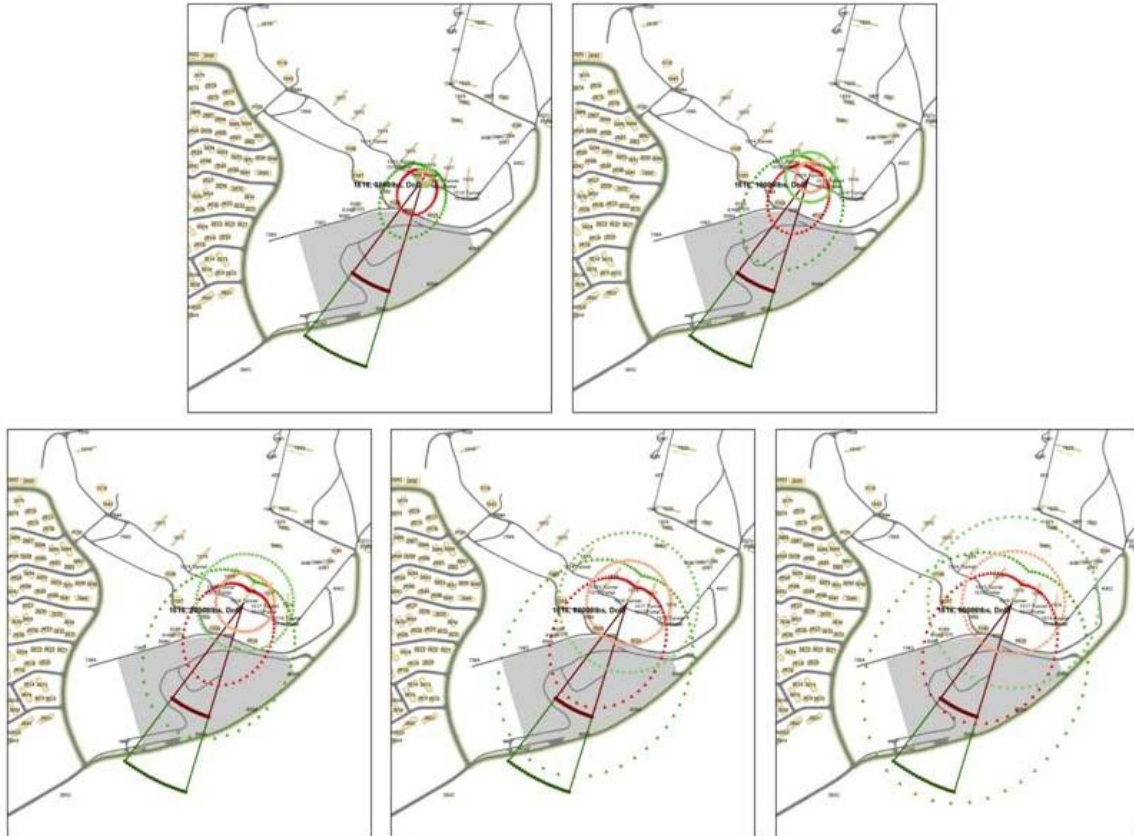


Figure 6

The analysis of the expanding shock and pressure hazards for a range of NEW quantities compared to the soil surface indicated that for some of the tunnels at high NEW quantities a second surface breach would be possible on the reverse side of the mountain ridge in which the tunnels were constructed. This result was unexpected and would probably not have been identified without the use of the GIS map visualization and modeling effort. The QD arcs for surface breach debris were extended from both the front and the back side of mountain when those high NEW values were considered. (See Figure 7)

3D Surface for the Shock and Pressure Hazard Reveals Potential
for Surface Breach on Reverse-Side of Mountain at High NEW

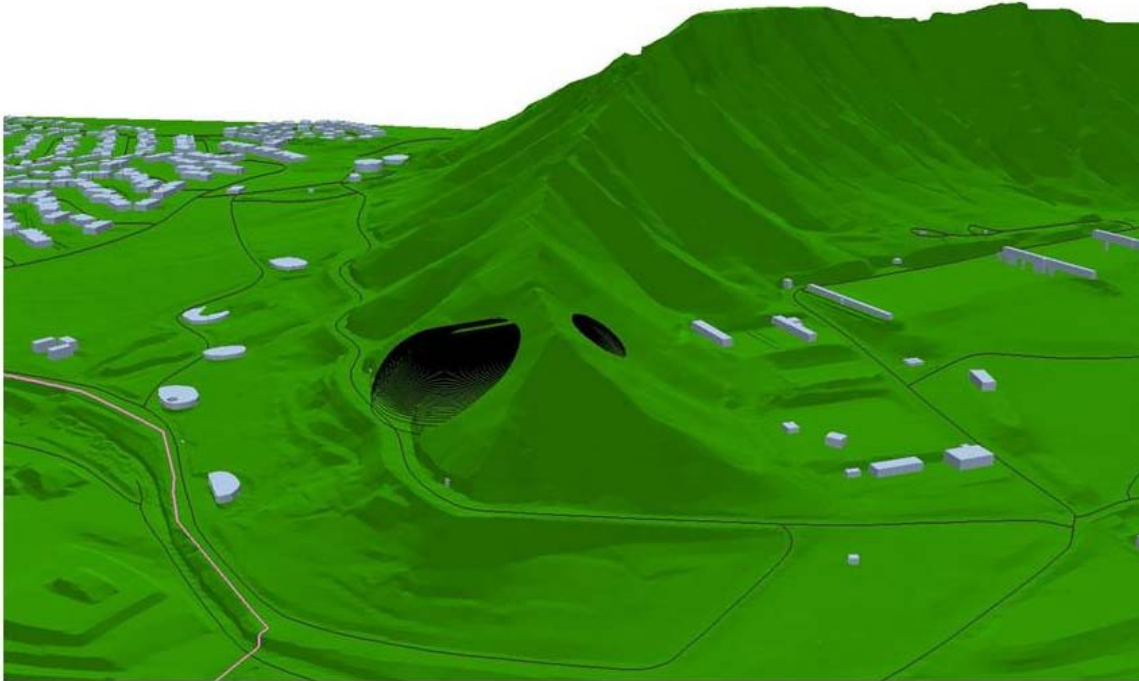


Figure 7

Conclusions

The explosive hazard criteria intelligent tables linked with GIS map displays provided a means to rapidly model the QD arcs generated by alternative storage scenarios in underground explosive storage facilities. The tools allowed the examination of a QD arcs for a range of NEW quantities and for switching between DoD and NATO criteria. The GIS map display allowed for immediate validation of the QD arcs compared to planning features such as buildings, roads, etc. The resultant QD planning maps acted as a decision support system for optimizing explosives storage within operational constraints of the site.

The 3D modeling and visualization of the expanding shock and pressure hazards for a range of NEW quantities compared to the soil surface allowed detailed examination of the potential surface breach crater characteristics. Accurate estimates of available soil cover were developed for the full extent of the underground explosives storage chamber. The size and shape of the potential surface breach was determined at a range of NEW quantities to examine the breach crater as it conformed to the landscape. The results of the analysis were used to determine the crater centroid for a range of NEW quantities. The revised centroid values were used to determine the slope and azimuth of the landscape at that centroid for inclusion in development of the QD arcs when using NATO criteria.

The intelligent tools integrated with GIS were developed so as to be readily transferable to other locations. In this way they can provide planners with a means to rapidly visualize the QD arcs resulting from a range of alternative storage scenarios in tunnel magazines.

Bibliography

DoD 6055.09-STD, "DoD Ammunition and Explosives Safety Standards," February 29, 2008, Incorporating Change 2, August 21, 2009

NATO AASTP-1 (ED 1), "Allied Ammunition Storage and Transportation Publication 1: Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives." May 2006



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13 July 2010**

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•Introduction

- Tunnel Magazines
- DoD and NATO QD Arc Criteria

•Methods

- QD Criteria Intelligent Tables Creation
- QD Hazard Tables Connected to GIS
- 3D Analysis of Required Soil Cover and Mountain Landform

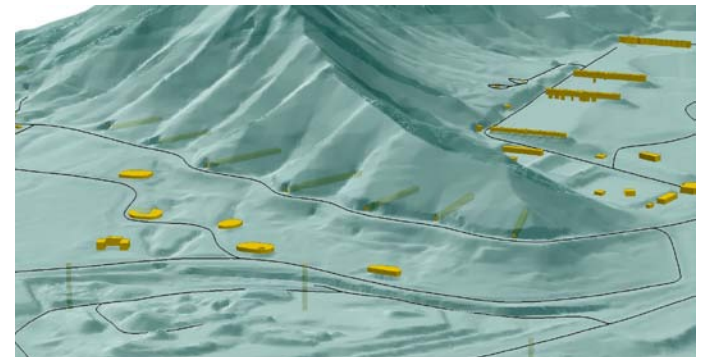
•Results

- Possible Surface Breach on Reverse Side of Mountain Ridge
- Rapid Development of Numerous Storage Scenarios

•Demonstration

•Summary

•Questions



Tunnel Magazines



- **Tunnel magazines have sufficient soil cover to contain most blast and fragment effects**
- **Overpressure and fragments are channeled out through openings such as doors and vents**
- **Quantity-Distance (QD) criteria for overpressure and fragment hazards differ from those of standard magazines and are typically more severe**
- **QD is dependant upon local geology and site-specific parameters such as tunnel dimensions**

DoD and NATO QD Arc Criteria



• DoD 6055.09-STD

- Generally remained unchanged for more than 20 years
- 1800 ft adit debris arc regardless of HD 1.1 or 1.3 quantity
- IBD overpressure criteria = 1.2 psi
 - Oval shape arc
- Surface rupture debris arc assumed to be circular

• NATO AASTP-1

- Continued development through NATO working group
- Adit debris arc dependent upon HD 1.1 or 1.3 quantity
 - Minimum of 750 ft and surpasses DoD criteria above 9,000 lbs NEW
- IBD overpressure criteria = 0.725 psi (more conservative)
 - “Heart” shaped arc
 - More conservative along the forward centerline
- Surface rupture debris arc includes directional effects

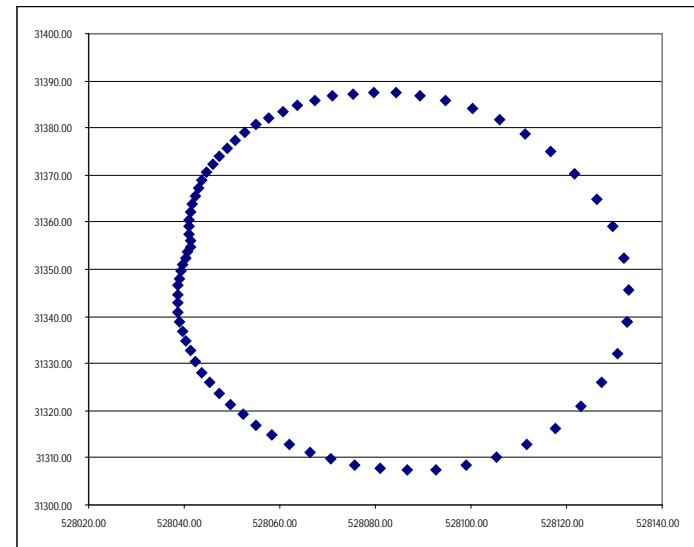
QD Criteria Intelligent Tables Creation



- Automated spreadsheet considers
 - Magazine volume
 - Loading density
 - Hydraulic diameter
 - Geology type
 - Soil cover
 - Surface slope angle (NATO)

INPUT		
Magazine #	NEW (lbs)	Criteria
1514	5000	NATO
1515	10000	NATO
1516	10000	DoD
1517	10000	NATO
1518	10000	NATO

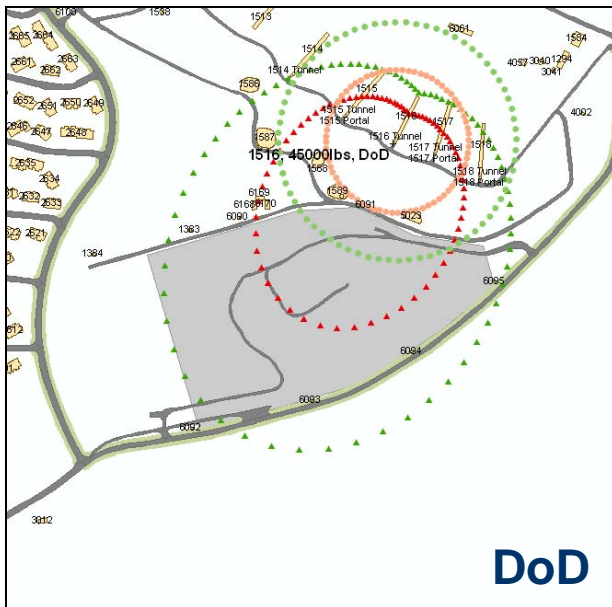
- Hazard Arcs calculated
 - Overpressure
 - Adit (Portal) debris
 - Surface breach (if applicable)
 - Ground shock
 - Chamber separation
 - Required soil cover
 - PTRD for various hazards



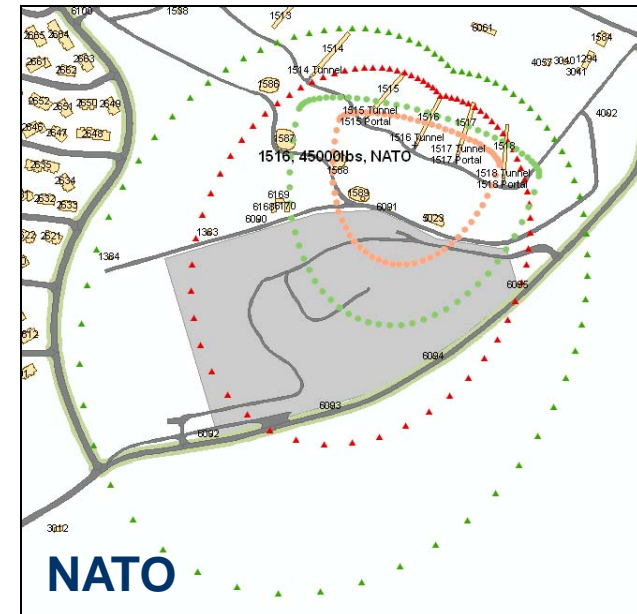
QD Hazard Tables Connected to GIS



- Calculated Hazard Arcs for each magazine integrated into ArcGIS Map Document for interactive display
 - Hazard Arc points calculated in Excel table using coordinates from projection NAD83 HARN State Plane Hawaii3 FIPS5103
 - Table of calculated hazard arc point values converted to ArcGIS Event Themes for map display with roads, buildings, etc.
- ArcGIS Event Theme maintains connection to source table
 - Changes in Hazard Arcs table immediately reflected on map



INPUT		
Magazine #	NEW (lbs)	Criteria
1514	5000	NATO
1515	10000	NATO
1516	10000	DoD
1517	10000	NATO
1518	10000	NATO



3D Analysis of Required Soil Cover and Mountain Landform



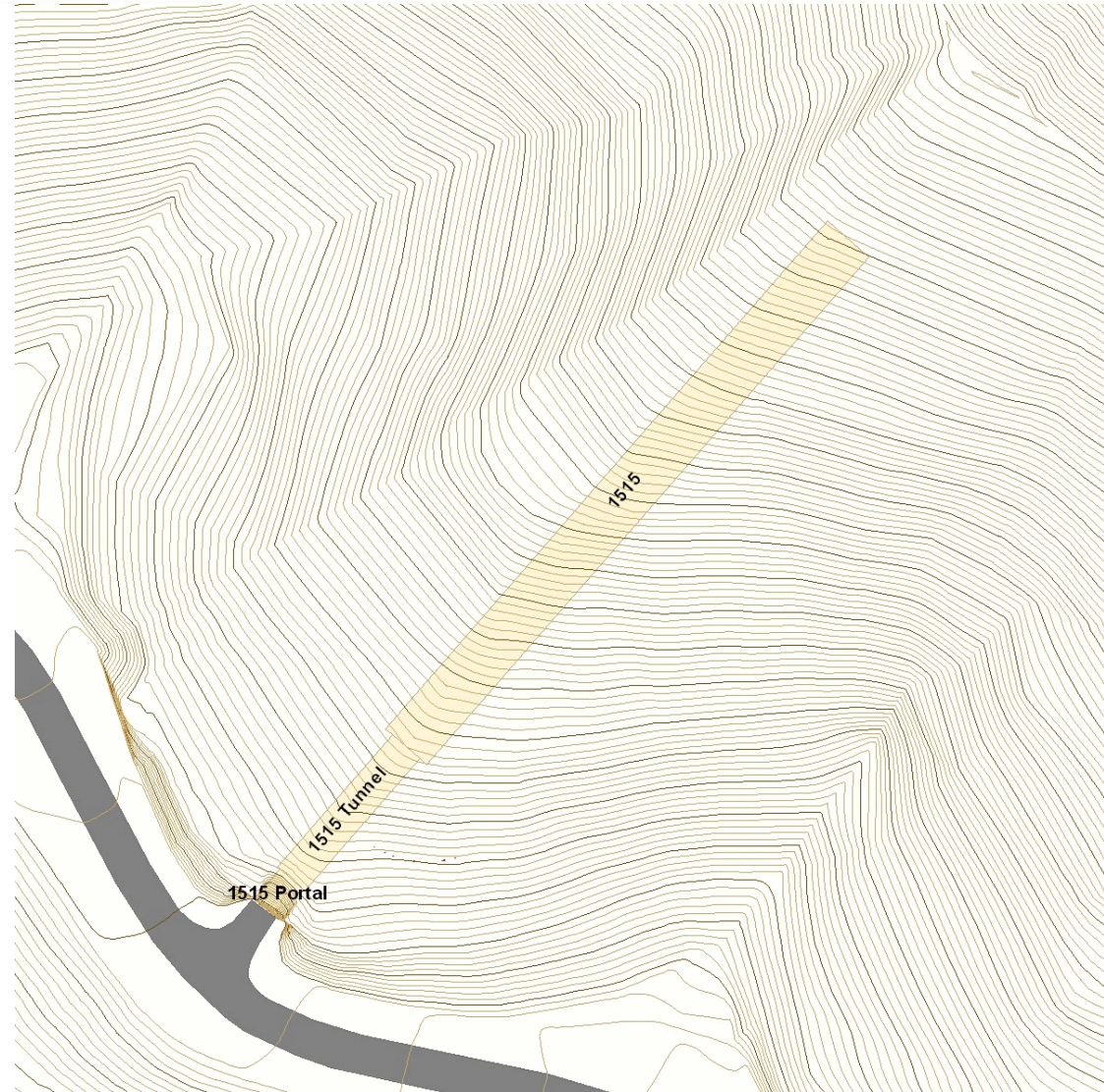
- Created models of the extent of the soil cover required to mitigate shock & pressure hazards for a given NEW
- Compared models against the detailed mountain landform



3D Analysis of Soil Cover



- Modeled surface breach crater at 1 foot intervals of chamber to surface distance
- Derived accurate estimates of available soil cover at all points along full length of tunnels
- Allowed reverse calculation of allowable NEW to avoid surface breach



3D Analysis of Surface Breach Crater



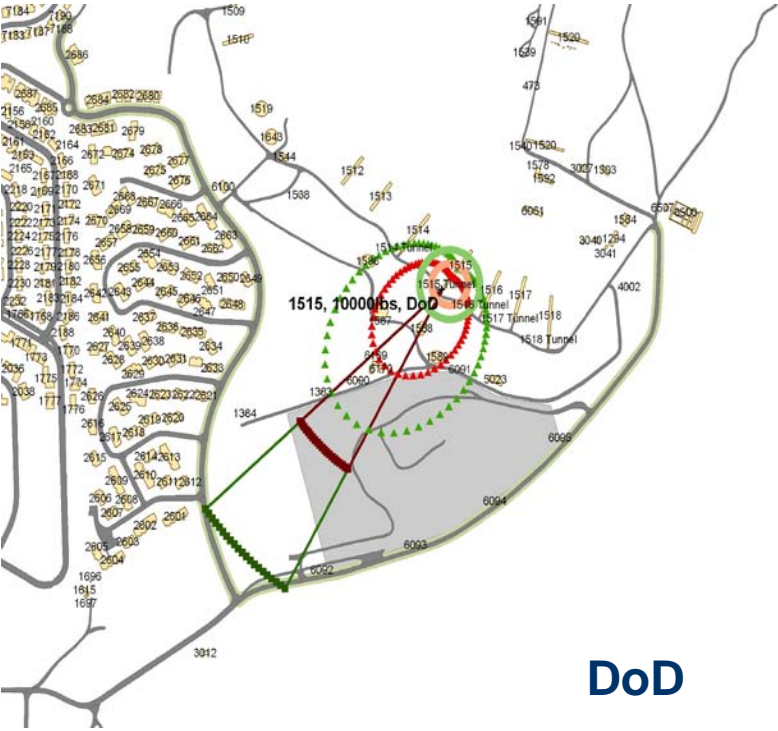
- **Modeled Surface Breach craters for range of NEW for each tunnel**
 - **Determined location, size, and shape of Surface Breach craters**
- **Changed Surface Breach Debris arcs to reflect breach crater center location (and azimuth of the hill slope for NATO criteria)**



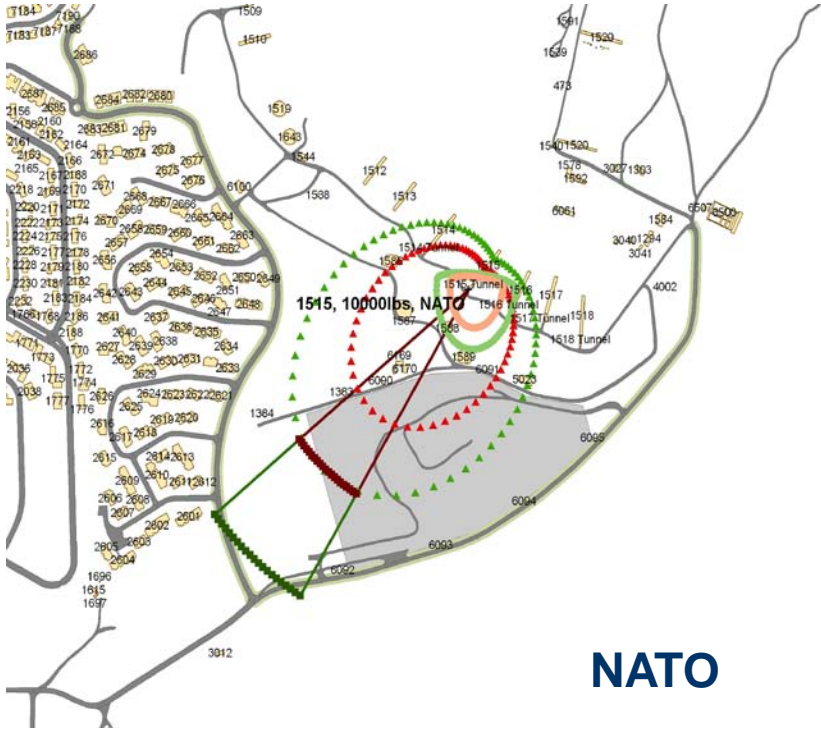
3D Analysis and QD Hazard Tables Linked to GIS



- 3D analysis results combined with maps linking QD hazard tables and GIS
- Provided rapid development of QD arc planning maps



DoD

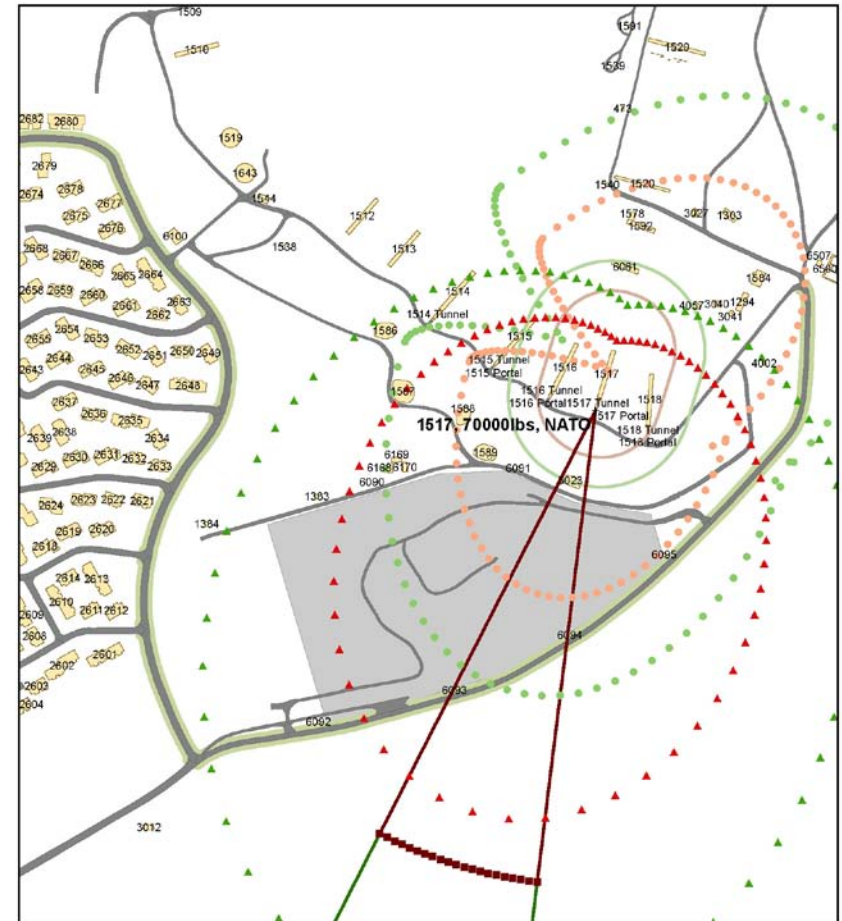
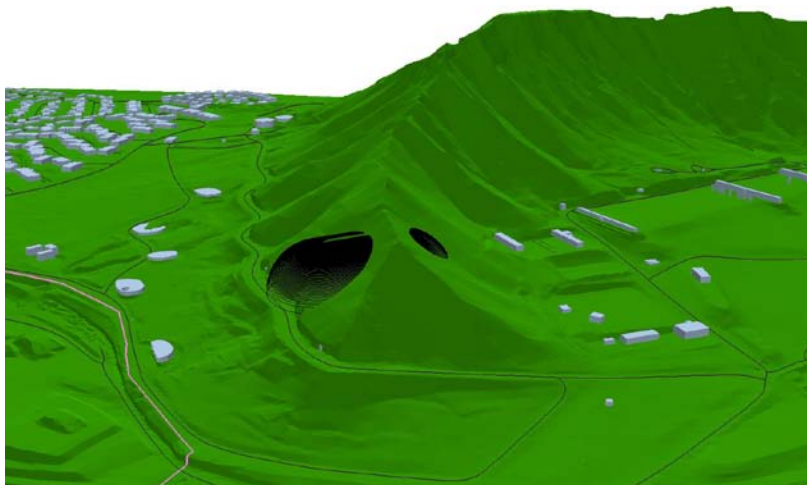


NATO

Possible Surface Breach on Reverse Side of Mountain Ridge



- 3D analysis revealed that at high NEW shock & pressure hazards for some tunnels could extend from rear of magazine out to opposite side of mountain ridge in which they are located
- The QD Arcs for Surface Breach Debris were thus extended from both front and back side of mountain

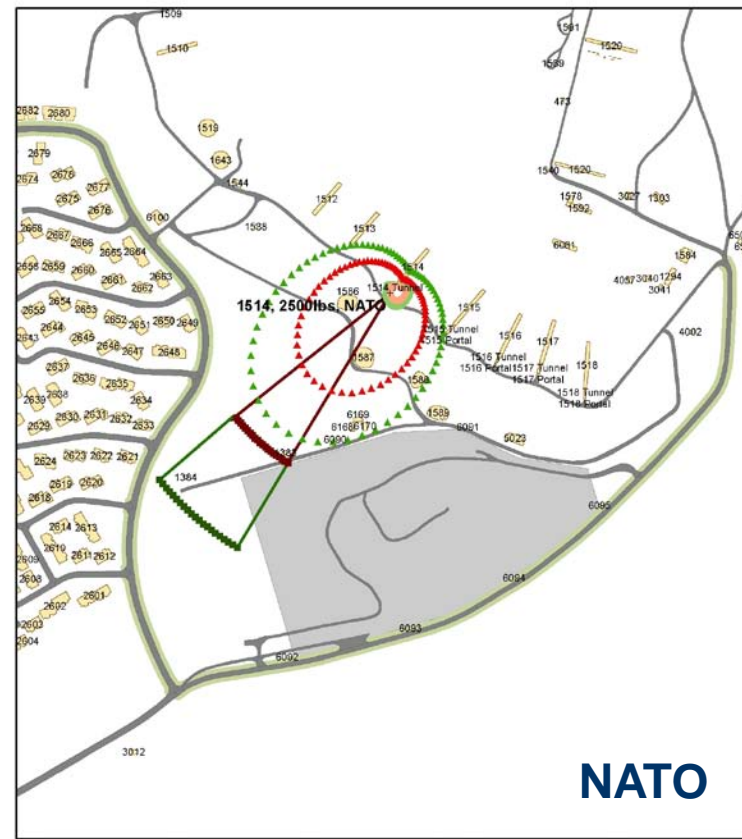
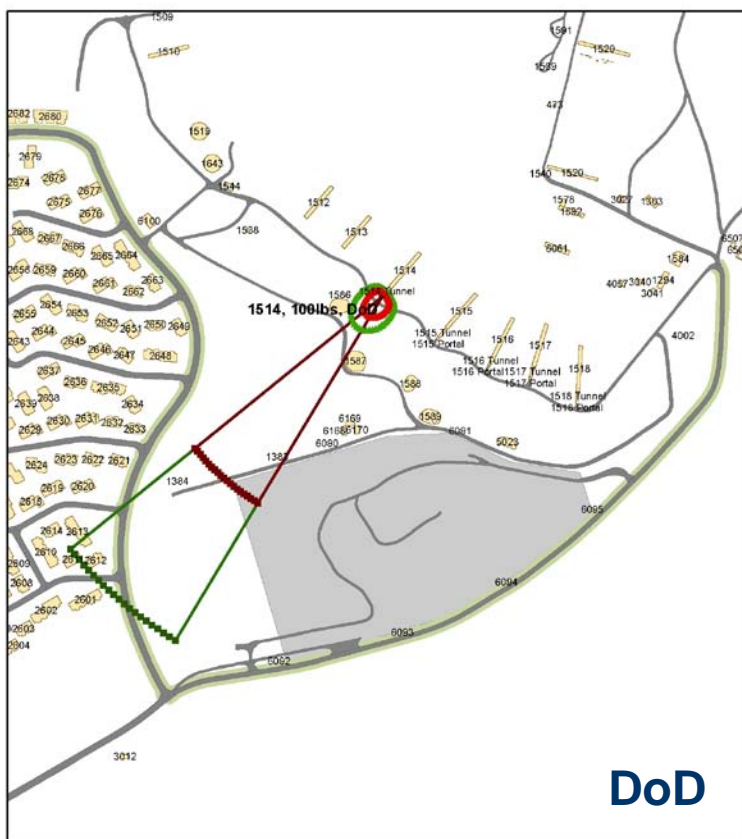


Rapid Development of Numerous Storage Scenarios



- ESC examined a wide range of NEW storage scenarios using both DoD and NATO criteria for tunnels

- Goal to achieve optimum balance of storage within operational constraints



Demonstration



Microsoft Excel - KaneoheArcCalculator_091029.xls

File Edit View Insert Format Tools Data Window Help Adobe PDF

Type a question for help

10 B U

100%

DoD

INPUT

Magazine #	NEW (lbs)	Criteria	Allowable Pso @ IBD psi (DoD)	Allowable Pso @ IBD psi (NATO)	Magazine Volume m ³	Magazine Volume m ³	W/V pcf	W/V kg/m ³	Hydr Dia, D ft	Hydr Dia, D m	DOD = IBD	NATO = IBD	Soil Cover ft	Scaled cover m/(kg ^{1/3})	Breach? yes/no	f, NATO f
1514	3500	DoD	1.20	0.725	54.609	1.548	0.09	1.03	12.45	3.78	6.12	880	32	0.835	YES	0.07631 0.7726
1515	2000	DoD	1.20	0.725	57.372	1.825	0.03	0.56	12.26	3.74	4.84	597	32	1.005	no	0.06158 0.47425
1516	2000	DoD	1.20	0.725	52.013	1.473	0.04	0.62	12.20	3.72	5.00	718	23	0.724	YES	0.06391 0.90043
1517	70000	DoD	1.20	0.725	55.474	1.571	1.20	20.2	12.50	3.81	1.780	2,560	36	0.347	YES	0.21653 0.94188
1518	60000	DoD	1.20	0.725	51.930	1.468	1.18	18.54	12.75	3.88	1.761	2,533	31	0.314	YES	0.2101 0.92717

16 User supplied info

17 Calculated data

18 DO NOT CHANGE

19 1514 DoD

20 1515 NATO

21 1516

22 1517

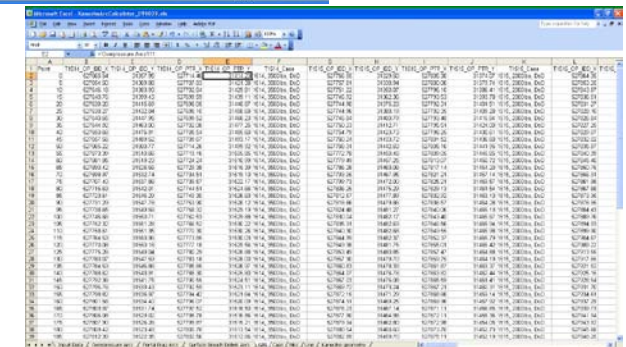
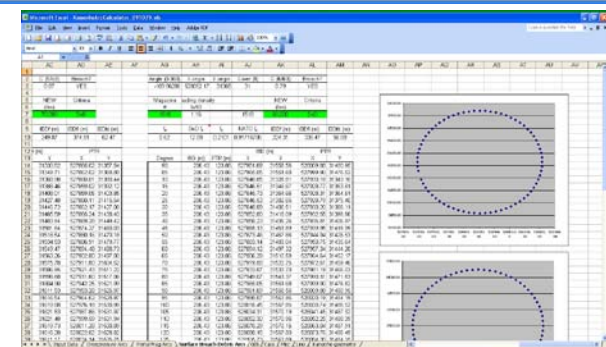
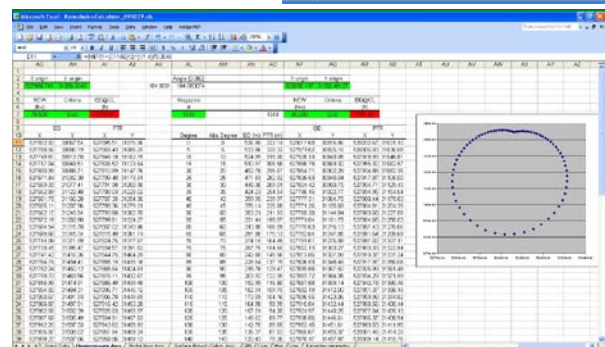
23 1518

Assumptions
 Hard rock
 loading density < 3 lbs/ft³
 map output is in meters
 soil cover > 0.75m^{1/3}

Input Data / Overpressure Arcs / Portal Frag Arcs / Surface Breach Debris Arcs / GIS / Case / Misc / Line / Kaneohe geometry /

Read

NJM



Demonstration

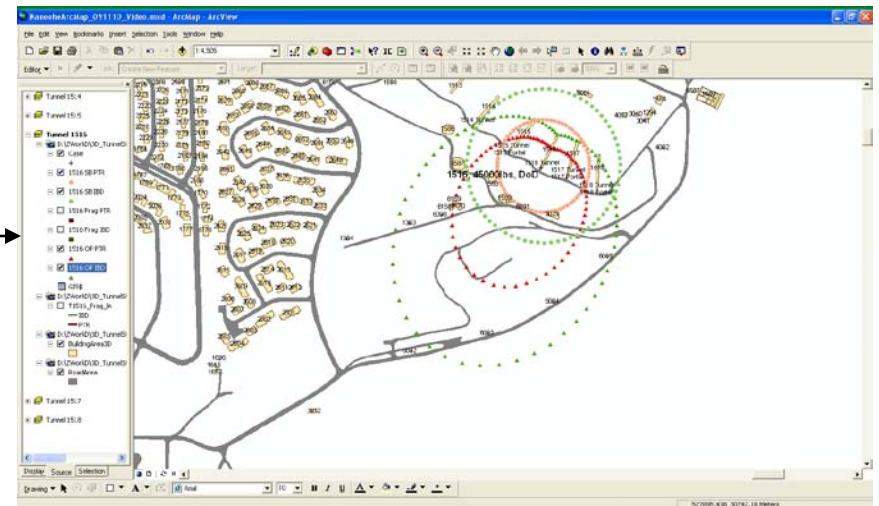


Microsoft Excel - KameshkiCalculator_011017.xls

INPUT			Allowable	Allowable	Magazine	Magazine	WV	WV	Hydr	Hydr	DOO	NATO	Soil	Scaled	Breach?		
Magazine	NEW	Criteria	Pco @ IBD	Pco @ IBO	Volume	Volume	pcf	kg/m ³	ft	m	D	D	m	m	ft	ft	NATO f.
#	(lbs)		psi (DoD)	psi (NATO)	m ³	m ³					= IBO/D	= IBO	ft	m/(kg*(10))	yes/no	f.	NATO f.
1514	3000	DoD	1.20	0.725	54,800	480	120	1241	12	3.6	1.20	1.20	1.20	0.008	no	10000	10000
1515	2200	DoD	1.20	0.725	39,200	360	120	1241	12	3.6	1.20	1.20	1.20	0.008	no	10000	10000
1516	4000	NATO	1.20	0.725	59,000	540	120	1241	12	3.6	1.20	1.20	1.20	0.008	no	10000	10000
1517	7000	NATO	1.20	0.725	104,474	960	120	1241	12	3.6	1.20	1.20	1.20	0.008	no	10000	10000
1518	3000	NATO	1.20	0.725	43,800	400	120	1241	12	3.6	1.20	1.20	1.20	0.008	no	10000	10000

■ User supplied info
■ Calculated data

Assumptions
 Hard rock
 loading density = 3 lbs/ft³
 map output is in meters
 soil cover > 0.75m(1/3)

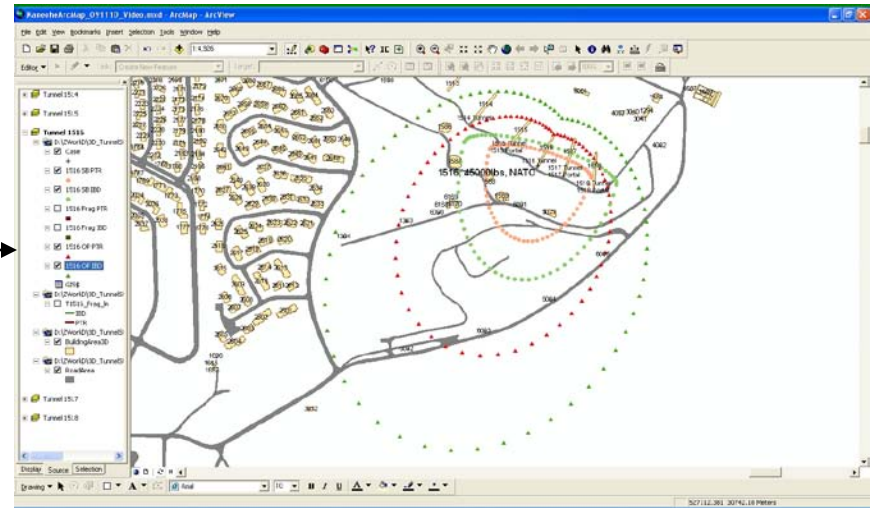


Microsoft Excel - KameshkiCalculator_011017.xls

INPUT			Allowable	Allowable	Magazine	Magazine	WV	WV	Hydr	Hydr	DOO	NATO	Soil	Scaled	Breach?		
Magazine	NEW	Criteria	Pco @ IBD	Pco @ IBO	Volume	Volume	pcf	kg/m ³	ft	m	D	D	m	m	ft	ft	NATO f.
#	(lbs)		psi (DoD)	psi (NATO)	m ³	m ³					= IBO/D	= IBO	ft	m/(kg*(10))	yes/no	f.	NATO f.
1514	3000	DoD	1.20	0.725	54,800	480	120	1241	12	3.6	1.20	1.20	1.20	0.008	no	10000	10000
1515	2200	DoD	1.20	0.725	39,200	360	120	1241	12	3.6	1.20	1.20	1.20	0.008	no	10000	10000
1516	4000	NATO	1.20	0.725	59,000	540	120	1241	12	3.6	1.20	1.20	1.20	0.008	no	10000	10000
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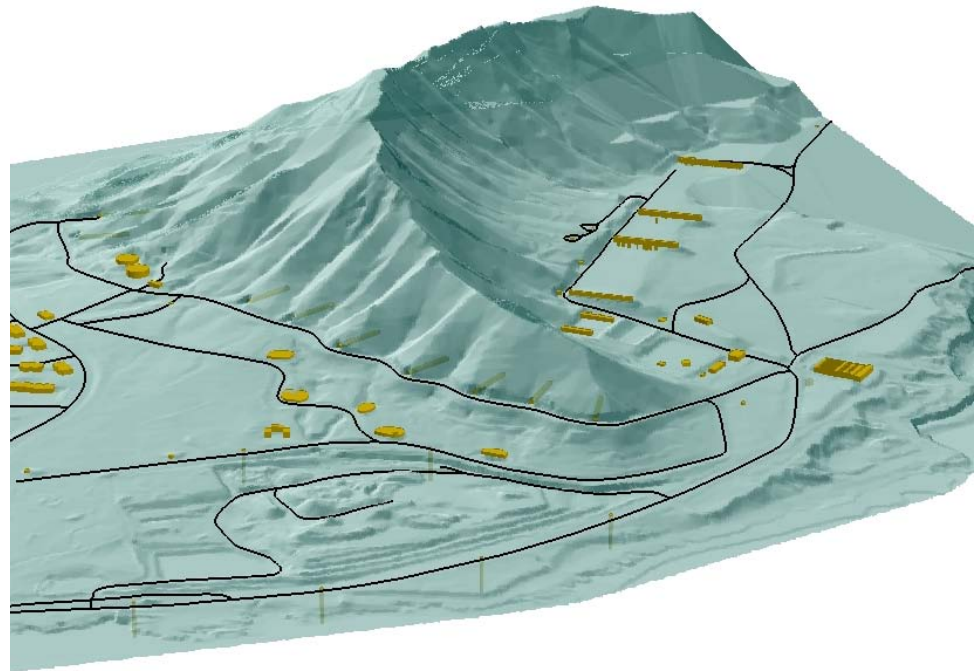


Summary



- **QD Criteria Intelligent Tables linked with GIS map displays**
 - Rapid development of alternative storage scenarios
 - Immediate validation of QD Safety Arcs compared to map features, e.g. roads, housing area, etc.

- **3D visualization of the ground shock**
 - Detailed examination of Surface Breach Crater creation
 - More accurate estimation of available ground cover



Questions?

Ed Falconer, GISP
Tyler Ross, PhD, PE
13 July 2010