

# **STORAGE OF LIMITED QUANTITIES OF EXPLOSIVES AT REDUCED Q-D**

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## **Abstract**

Department of Defense installations often desire storage locations for limited quantities of explosives which may exceed existing Q-D requirements. Department of Defense Explosive Safety Regulations (DOD 6055.9) and implementing Army regulations (AR 385-64) require safety zones based on a 670 foot arc for quantities of explosives up to 100 pounds and 1250 feet minimum for higher quantities. These default limits can impose a severe burden on installations. A limited explosive quantity storage magazine design has been completed in support of the Army's Safeload program which can be sited at reduced Q-D limits. The Mini Magazine has been designed to be consistent with approved DOD and Army design criteria. The Mini Magazine will be of great benefit to those requiring limited storage of explosives in congested areas.

## **BACKGROUND**

The Naval Civil Engineering Laboratory (NCEL) proposed, as a small quantity ammunition storage concept, a small earth covered concrete magazine. The design provided for reduced siting requirements based upon the mitigating effects of soil cover on secondary and primary fragment ranges. This proposal was in form of a rough outline and not suitable for construction purposes. It was also limited to 20 pounds of TNT.

The concept appeared promising and the explosive safety community expressed an interest in this type of reduced siting storage. The

Office of the Project Manager for Ammunition Logistics (PM-AMMOLOG), in support of the Safeload program, undertook the task of determining the need for this type of storage and what its requirements would be.

In 1992 a decision was made to develop a set of magazines for storage of limit quantities of explosives for use in congested areas and functions requiring close storage of explosives.

# Report Documentation Page

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## **REGULATIONS**

Dod 6055.9-STD "Ammunition and Explosive Safety Standards" (Reference 1) establishes uniform standards applicable to DoD ammunition and explosive facilities. The governing requirements for fragmentation and debris specify minimum Inhabited Building Distance (IBD) separations of 670 feet for Net Equivalent Weights (NEW) to 100 lbs and 1250 feet for higher quantities. These minimum default separation distances are intended to provide reasonable protection from exposure to hazardous fragments. A hazardous fragment is defined as one with kinetic energy greater than 58 ft-lbs. DoD 6055.9-STD allows a reduced separation distance for fragmentation if hazardous fragment density of not more than one per 600 square feet of impact area is proven by approved analysis. The only referenced analytical procedure for determining hazardous fragment density in DoD 6055.9-STD is described in Department of Defense Explosives Safety Board (DDESB) Technical Paper No. 13 (TP 13) (Reference 2).

## **DESCRIPTION**

**MAGAZINE REQUIREMENTS.** It was determined that a set of structures would be required. The following was decided based upon the Safeload (formerly Quickload) Questionnaire responses on a world-wide Army distribution.

Four magazine capacities , 400, 150, 75, and 30 pounds TNT, will be developed. Each magazine will be composed of a large main compartment with a minimum clear height of 7'-0", and two smaller separate secondary compartments. The explosive distributions will be as shown in

Table 1.

The magazine must have a capacity to store non-compatible munitions.

The magazines must be able to store hazard division (HD) 1.1, 1.2, 1.3, and 1.4 munitions.

**TABLE 1 - EXPLOSIVE DISTRIBUTIONS**

CHAMBER		
MAGAZINE	MAIN	SECONDARY
1	100 LBS	25 LBS
2	50 LBS	12.5 LBS
3	20 LBS	5 LBS
4	300 LBS	50 LBS

**TABLE 1 - EXPLOSIVE DISTRIBUTIONS**

Under agreement with PM-AMMOLOG, the U.S. Army Corps of Engineers Huntsville Division (HND) was tasked to provide complete design packages for each of the magazines.

MAGAZINE PROPERTIES. Although four separate design packages were requested, it was determined in the design process that two design packages would meet the requirements. The magazines had the properties noted in Table 2.

**TABLE 2 - MAGAZINE PROPERTIES**

DESCRIPTION	EXPLOSIVE LIMIT	MAIN CHAMBER			SECONDARY CHAMBER			
		LENGTH	WIDTH	HEIGHT	EXPLOSIVE LIMIT	LENGTH	WIDTH	HEIGHT
150 LB MIN MAGAZINE	100 LB TNT (H/D 1.1)	8'	7'	7'	25 LBS TNT (H/D 1.1)	4"	3'	4'
400 LB MINI MAGAZINE	300 LB TNT (H/D 1.1)	14'	14'	8'	50 LBS TNT (H/D 1.1)	4'	4'	6'

**TABLE 2 - MAGAZINE PROPERTIES**

The magazine chambers are covered with earth fill retained by the headwall at the front and retaining walls along the sides and back. A front fragment canopy and a front barricade are provided to intercept fragments. Figures 1 to 5 show the plan and sections of the 150 LB Mini Magazine and Figures 6 to 10 show the same for the 400 LB Mini Magazine.

## **DESIGN BASIS**

The magazines were designed based upon the methodology described in TM 5-1300 (Reference 3) and the requirements in DoD 6055.9-STD. There were five major design concerns. They are as follows:

PRIMARY FRAGMENTATION

SECONDARY FRAGMENTATION

OVERPRESSURE

COMPATIBILITY AND STORAGE

SPECIAL HAZARD CLASSIFICATION 1.2 EXPLOSIVES  
REQUIREMENTS

### **Primary Fragmentation.**

Concrete walls, roofs, and barriers are used to contain all primary fragments. The Gurney and Mott equations were used to determine design fragments for a variety of munitions. The 8" artillery was used as a worst case for this storage quantity. The 8" artillery has a design values as follows for a confidence level of 95%:

FRAGMENT WEIGHT = 3.44 oz

FRAGMENT VELOCITY = 3780 fps

The penetration methodology for concrete in TM 5-1300 was used to determine the thickness of concrete required to contain the primary fragments. A thickness of 10" was determined. The roof and walls of the magazine chamber contain most of the primary fragments. A front barricade and canopy are provided to contain fragments that might escape out the door.

### **Secondary Fragmentation.**

Building debris makes up the greater part of the secondary fragmentation threat. Pallets and containers will be constrained by the building. The methodology described in the TP 13 was used to determine the hazardous building debris density. The secondary threat is from the roof surface only. The wall fragments are contained by the outer wall. The outer wall will

not fail for the design explosive weight and all scabbing from flexural response will be located low on the wall with low velocities and mass. The hazardous debris distance corresponding to one hazardous fragment with an impact energy of 58 foot-lbs per 600 square feet was determined for the roof surface. The earth cover thickness over the roof was varied to provide a hazardous debris distance less than the inhabited building distance for overpressure. The magazines were designed so that upon a detonation event equal to the chamber limit, the debris will be constrained to within the inhabited building distance required for overpressure. The hazardous debris distance for the magazines area as follows:

150 LB Magazine = 140 ft

400 LB Magazine = 200 ft

### **Overpressure.**

The inhabited building distance for overpressure was determined by procedure in DoD 6055.9-STD. The distance is equal to  $40W^{1/6}$  with W equal to the charge weight in pounds of TNT. The distances determined for the magazines are as follows:

150 LB Magazine = 186 ft

400 LB Magazine = 268 FT

This distance corresponds to an overpressure of 1.2 psi which is the limit for non-essential personnel.

### **Compatibility and Storage.**

One of the primary capabilities required was that there must be a capacity to store non-compatible munitions in the same location. In order to ensure this capacity two secondary chambers are provided in addition to the large main chamber. The secondary chambers are sufficiently protected from the main chamber to prevent a simultaneous detonation in the secondary chamber from a detonation in the primary chamber. The protection is a combination of the concrete walls of both chambers along with a minimum soil separation of 2 and 4 feet in the 150 lb and 400 lb magazines, respectively.

Sample storage combinations and limits for the 400 lb Mini Magazine are shown in Figures 11 and 12. The limits for HD 1.2 munitions are estimated with official limits to be shown in the final design package.

### **Hazard Classification 1.2 Explosives.**

Special design considerations were required for storage of hazard classification 1.2 (HD 1.2) munitions. The concern was that an explosion would collapse the roof. Since HD 1.2 munitions are resistant to mass detonation, unexploded munitions could remain in the

chamber. There is also a possibility that unexploded munitions may be kicked out of the structure. This would present a safety threat since any fragments from a subsequent detonation would have an unrestricted egress from the magazine.

In an effort to cover these concerns, the roof was designed to resist a explosive incident of two 105mm artillery shells simultaneous detonating. This was considered a conservative design value since it was considered by definition that HD 1.2 munitions would not detonate simultaneously.

The flexural response of the roof was limited to 4 degrees to ensure structural integrity. An earth-covered structure will withstand large deflections before failure so the structure will have an excess capacity after an explosion.

At the final submission in January 1993 for DDESB approval, recent testing resulted in a concern about possible partial mass detonation of confined hazard classification 1.2 munitions. DDESB was unwilling to approve the design for HD 1.2 munitions. The design has been tabled until this summer. Due to lack of funding no work to modify the package to cover DDESB concerns has been done.

## **HD 1.2 RESEARCH PROGRAM**

A research program to determine the effect of confinement on HD 1.2 munitions was begun in May 1994. Two 100 Lb Mini Magazines will be constructed for testing. The Naval Surface Weapons Laboratory will conduct the testing.

One magazine will be tested to see the effects of sympathetic detonation. The magazine main chamber will be filled to capacity with HD 1.2 munitions and one munition will be set off to see the effects.

The other magazine will be tested for a fire in the main chamber. A bonfire test similar to the HD 1.2 classification test will be conducted in which a main chamber full of HD 1.2 munitions will subjected to an interior fire.

## **STATUS**

HND has been tasked to modify the 100 lb Mini Magazine design package for the research program. A value engineering analysis will be conducted to determine design modifications to reduce costs. Cost reduction modifications are expected to include replacing the concrete barricade with a geo-textile membrane soil barricade.

Although this change will not alter the performance of the magazine, it will not provide the longevity required for actual storage conditions.

In addition to changes for the research program, modifications will be done on the design packages in order to gain DDESB approval for field use. The magazine will have a severely limited HD 1.2 capacity until the research program is completed.

Expected limits on HD 1.2 are shown in Table 3.

**TABLE 3 - EXPECTED LIMITS ON HD 1.2 MUNITIONS**

DESCRIPTION	MAIN CHAMBER HD 1.2 LIMIT	SECONDARY CHAMBER HD 1.2 LIMIT
150 LB MINI MAGAZINE	30 lbs	25 lbs
400 LB MINI MAGAZINE	40 lbs	40 lbs

**TABLE 3 - EXPECTED LIMITS ON HD 1.2 MUNITIONS**

The modified design package will be completed by HND by 30 September 1994. Approval for use expected by December 1994.

The research package magazine design will be completed by HND by 30 September 1994. Research is expected to be conducted in fiscal 1995.

## **CONCLUSIONS**

The Mini Magazines will provide a significant benefit to signal battalions, transportation units, and others who have a need to store small quantities of munitions in congested areas. The approximate cost for construction of 400 lb and 150 lb Mini-Magazines is \$140K and \$90K, respectively. A 78% and 72% reduction in the inhabited building distance for fragmentation is provided by the 400 lb and 150 lb Mini Magazines, respectively, over conventional storage. The low separation distances allow for storage of small quantities of HD 1.1 munitions. While HD 1.2 limits are low at the present, the research program may produce results so that the limits can be greatly increased. The combination of main and secondary chambers provide a flexible storage arrangement for storage of explosives of all types. Mini Magazines will prove invaluable for storage of small quantities of explosives in congested areas.

## REFERENCES

1. Department of Defense Ammunition and Explosives Safety Standard, DoD 6055.9-STD, October 1992.
2. Technical Paper No. 13, Prediction of Building Debris for Quantity-Distance Siting, Department of Defense Explosive Safety Board, Alexandria, VA, April 1991.
3. Tri-Service Manual, Army TM5-1300/NAVFAC P-397/AFR 88-22, Structures to Resist the Effects of Accidental Explosions, Departments of the Army, Navy and Air Force, Washington, DC, November 1990.

**FIGURE 1. PLAN**

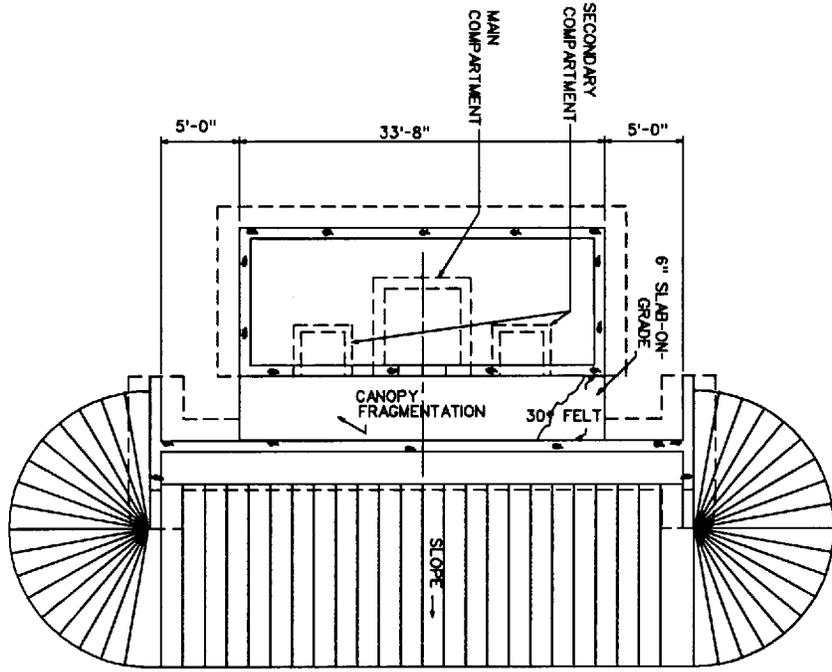
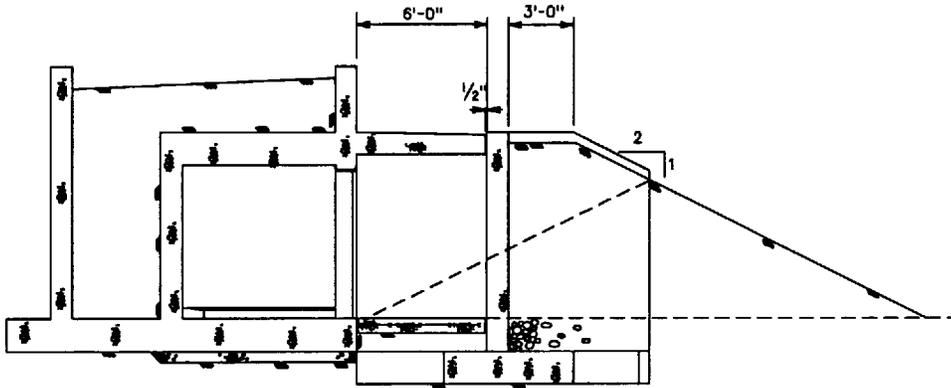


FIGURE 1 - PLAN

**FIGURE 2. CROSSECTION**



SECTION 

FIGURE 2 - CROSSECTION

**FIGURE 3. PLAN OF CHAMBERS**

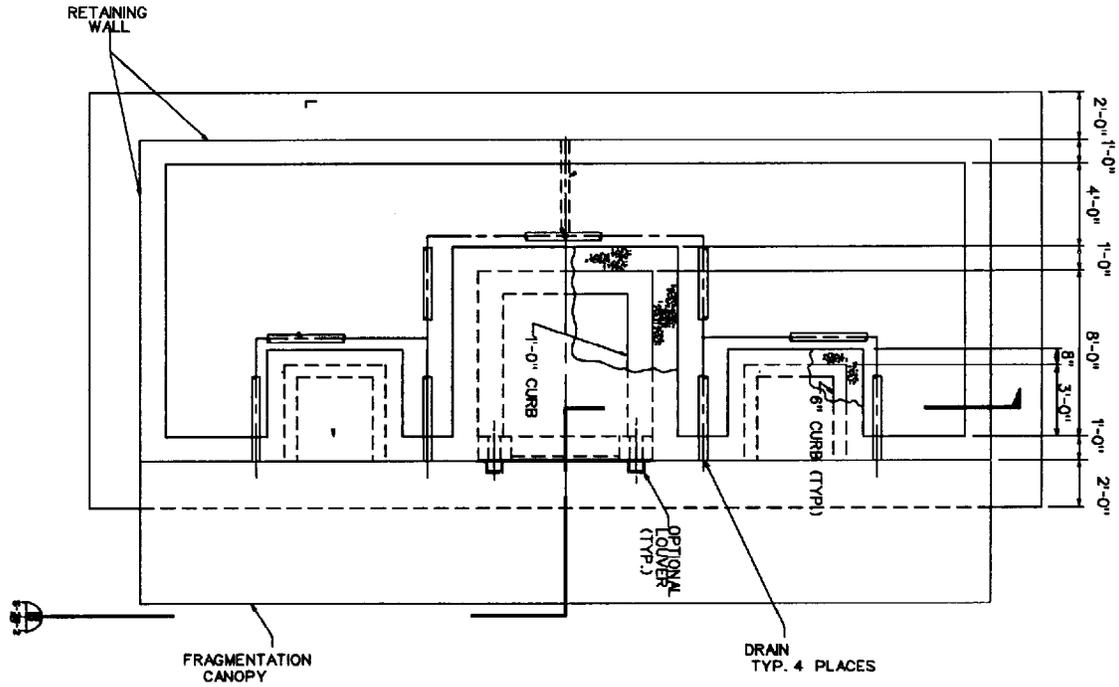


FIGURE 3- PLAN OF CHAMBERS

**FIGURE 4. SECTION THROUGH CHAMBERS**

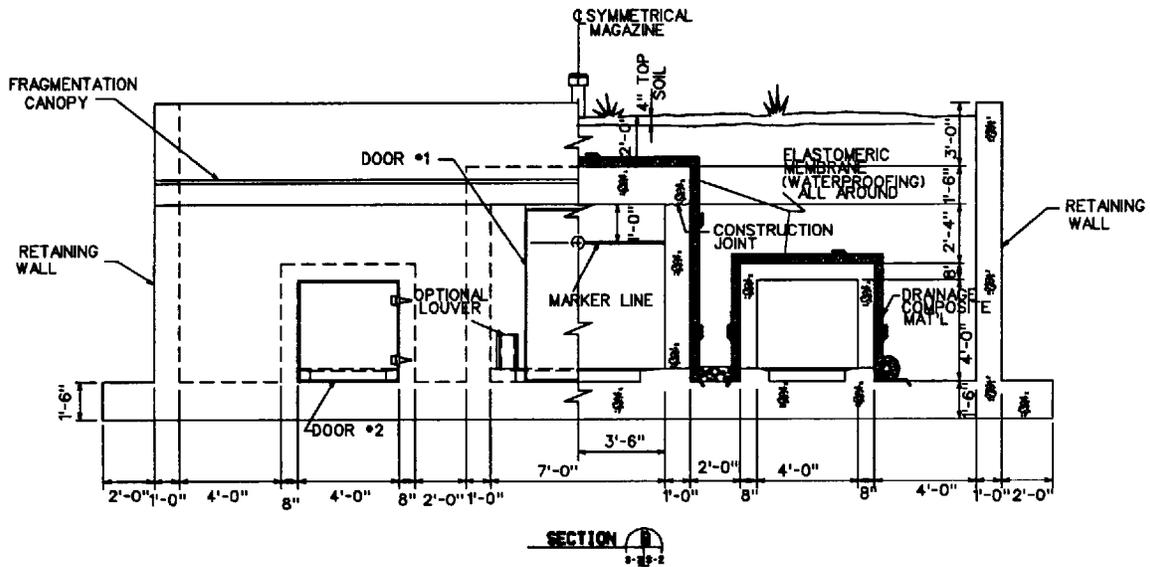


FIGURE 4 - SECTION THROUGH CHAMBERS

**FIGURE 5. SECTION THROUGH MAIN CHAMBER**

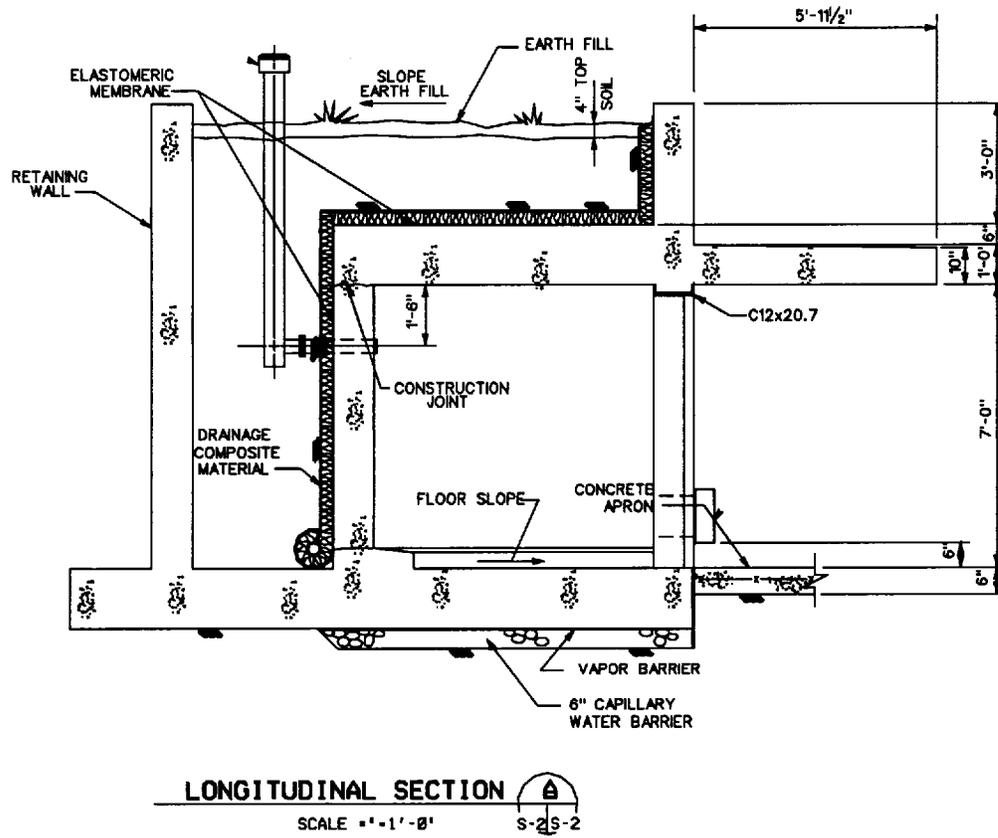


FIGURE 5 - SECTION THROUGH MAIN CHAMBER

**FIGURE 6. PLAN**

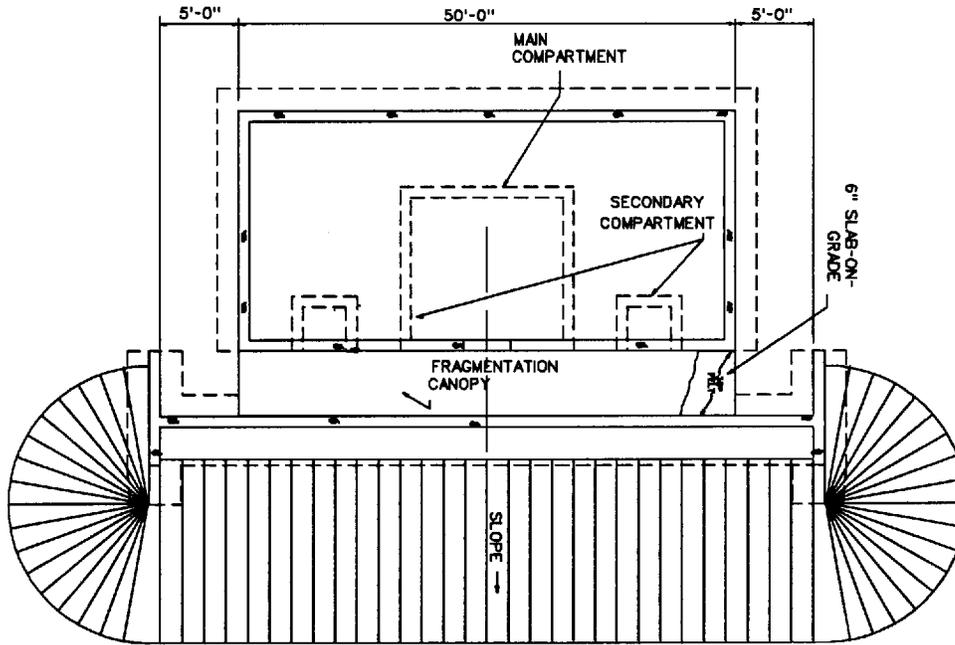


FIGURE 6 - PLAN

**FIGURE 7. CROSS-SECTION**

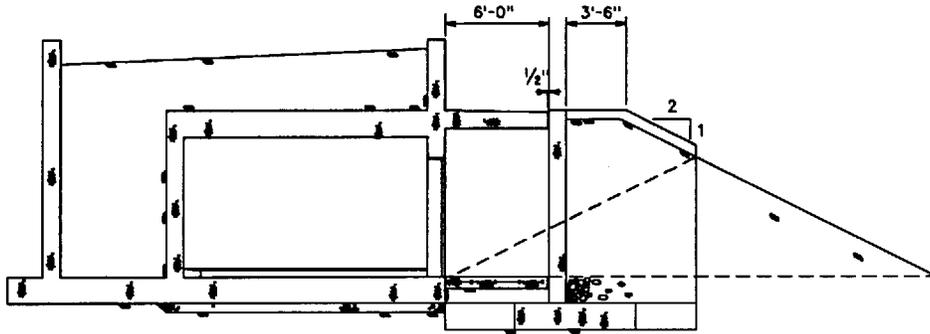
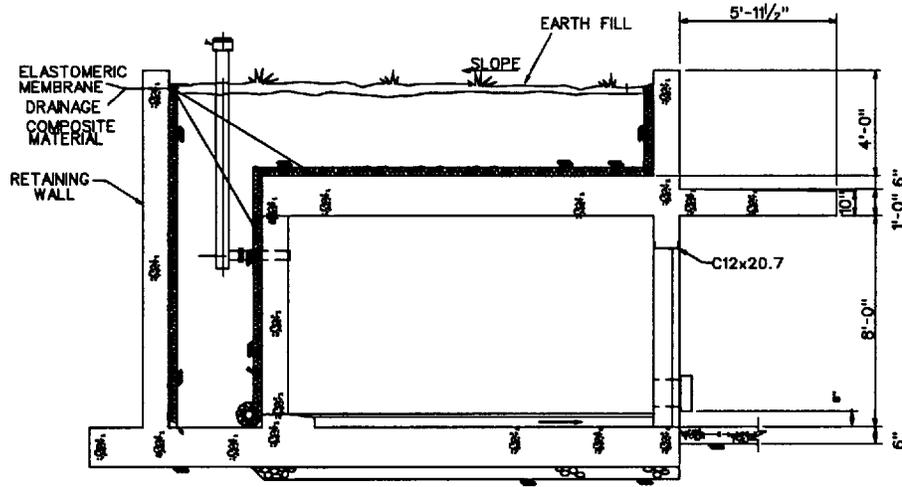


FIGURE 7 - CROSS-SECTION

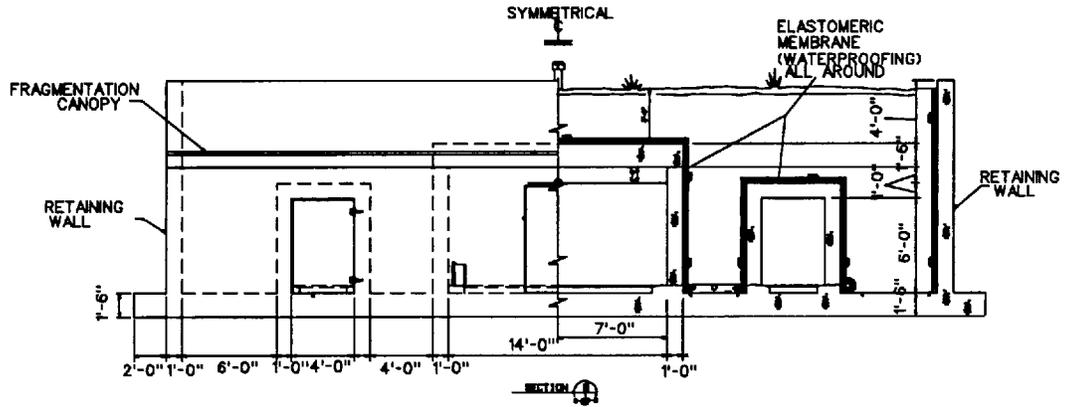
FIGURE 8. DETAILED CROSS-SECTION



LONGITUDINAL SECTION 

FIGURE 8 - DETAILED CROSS-SECTION

**FIGURE 9. FRONT ELEVATION/SECTION**



**FIGURE 9 - FRONT ELEVATION/SECTION**

FIGURE 10. PLAN SECTION

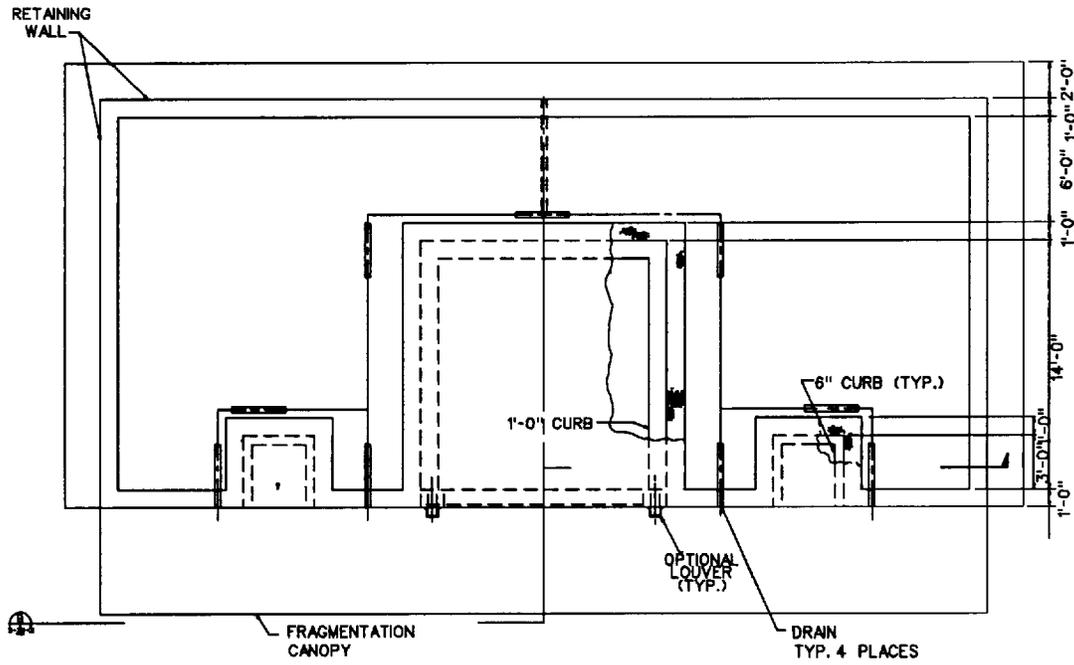


FIGURE 10 - PLAN SECTION

**FIGURE 11. SAMPLE STORAGE COMBINATIONS AND LIMITS 300  
LB MINI MAGAZINE**

TABLE 1 - MAXIMUM ALLOWABLE NET EXPLOSIVE WEIGHT LIMITS (SEE NOTE 2)		
HD	COMPARTMENTS	
	MAIN	SIDE
1.1	300	50 EACH
1.2	40	40 EACH
1.3	18,000	18,000
1.4	ALL COMPARTMENTS MAY BE LOADED TO PHYSICAL CAPACITY	

TABLE 3 - QUANTITY DISTANCE FOR STORAGE OF MIXED HAZARD DIVISIONS IN THE SAME COMPARTMENT - SEE NOTE 5
<p>WHEN HD 1.1 AND 1.2 ARE LOCATED IN THE SAME COMPARTMENT, THE DISTANCE SHOULD BE DETERMINED WITH THE TOTAL QUANTITY CONSIDERED 1.1.</p> <p>WHEN HD 1.1 AND 1.3 ARE LOCATED IN THE SAME COMPARTMENT, THE DISTANCE SHOULD BE DETERMINED WITH THE TOTAL QUANTITY CONSIDERED 1.1.</p> <p>WHEN HD 1.2 AND 1.3 ARE LOCATED IN THE SAME COMPARTMENT, THE DISTANCE SHOULD BE DETERMINED WITH THE TOTAL QUANTITY CONSIDERED 1.2.</p> <p>WHEN HD 1.1, 1.2 AND 1.3 ARE LOCATED IN THE SAME COMPARTMENT, THE DISTANCE SHOULD BE DETERMINED WITH THE TOTAL QUANTITY CONSIDERED 1.1.</p> <p>THE QUANTITY DISTANCE FOR HD 1.1, 1.2 OR 1.3, INDIVIDUALLY OR IN COMBINATION, ARE NOT AFFECTED BY THE PRESENCE OF HD 1.4.</p>

FIGURE 11 - SAMPLE STORAGE COMBINATIONS AND LIMITS  
300 LB MINIMAGAZINE

## FIGURE 12 - STANDARD NOTES

### NOTES:

1. THE MAGAZINE'S SIDE COMPARTMENTS PROVIDE SEPERATE AREAS FOR THE STORAGE OF INCOMPATIBLE MUNITIONS. SEE FIGURE 3-1 OF DOD 6055-9-STD, STORAGE COMPATIBILITY MIXING CHART.
2. FOR A GIVEN SITING, ACTUAL LIMITS MAY BE LESS THAN THESE DEPENDING ON AVAILABLE SEPERATION DISTANCES. SEE TABLES 2 AND 4.
3. THIS INCLUDES INHABITED BUILDING DISTANCE, PUBLIC TRAFFIC ROUTE, INTRALINE, AND INTERMAGAZINE.
4. THE MAGAZINE'S QUANTITY DISTANCE IS THE LARGEST OF THAT REQUIRED FOR EACH OF THE COMPARTMENTS CONSIDERED SEPARATELY.
5. IF MORE THAN ONE HAZARD DIVISION IS STORED IN THE SAME COMPARTMENT, THE MIXING RULES IN TABLE 3 APPLY. THESE MIXING RULES DIFFER SLIGHTLY FROM THOSE IN DOD 6055.9-STD DUE TO THE FRAGMENT SUPPRESSIVE FEATURES OF THE DESIGN.
6. TABLE 4 INHABITED BUILDING DISTANCE IS BASED ON THE FOLLOWING FORMULA:  
 $D=40W^{1/3}$  BASED ON THE COMPARTMENT WITH THE LARGEST NEW.
7. TABLE 4 PUBLIC TRAFFIC ROUTE DISTANCE IS BASED ON THE FOLLOWING FORMULA:  
 $D=24W^{1/3}$  BASED ON THE COMPARTMENT WITH THE LARGEST NEW.  
  
(IN THE FORMULAS, D=THE DISTANCE IN FEET AND  $W^{1/3}$  =THE CUBED ROOT OF THE NEW IN POUNDS)
8. TO DETERMINE THE TABLE 4 INTRALINE DISTANCE, TREAT THE MAGAZINE AS AN EARTH COVERED MAGAZINE, FRONT BARRICADED, AND USE APPLICABLE HD 1.1 INTRALINE TABLES IN EXPLOSIVE SAFETY REGULATIONS (DOD 6055.9-STD, DAR 85-64, AFR 127-100, NAVOP 5 VOL. 1) USING THE COMPARTMENT WITH THE LARGEST NEW.
9. TO DETERMINE THE TABLE 4 INTERMAGAZINE DISTANCE, TREAT THE MAGAZINE AS A NONSTANDARD EARTH COVERED MAGAZINE, FRONT BARRICADED AND USE APPLICABLE HD 1.1 INTERMAGAZINE DISTANCE TABLES IN EXPLOSIVES SAFETY REGULATIONS USING THE COMPARTMENT WITH THE LARGEST NEW.
10. THE REQUIRED SEPERATION DISTANCE FOR FRAGMENT PROTECTION HAS BEEN SHOWN BY ANALYSIS TO BE LESS THAN SPECIFIED BY TABLES 2 AND 4 AND THE ABOVE NOTES.