

MODULAR READY MAGAZINE DESIGN for REDUCED EXPLOSIVES SAFETY DISTANCES

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ABSTRACT

Explosives safety distances for storage of less than 45,000 lb. of high explosives in earth-covered magazines is controlled by the safe debris distance (1250 ft). The Marine Corps Base, Kaneohe, Hawaii requires storage of 2500 lb. of net explosive weight (NEW) at a site with less than 1250 ft of safe distance in all directions. Since the safe pressure distance for 2500 lb. is 475 ft. to the front and side (K35) and 340 ft to the rear (K25), the safe distance from the ready service magazine can be significantly reduced if the debris distance is controlled. The Naval Facilities Engineering Service Center (NFESC) was tasked to develop a ready magazine that would reduce the safe debris distance to less than 750 ft. to the side and rear.

Nonpropagation walls were designed, using High Performance Magazine methodology, to reduce the maximum credible event (MCE) to 500 lb. Analytical methods were then used to determine the safe distance for hazardous debris (1 critical fragment per 600 sq. ft.). The safe distance was determined to be less than the 750 ft required for safe siting.

This paper shows the modular earth-covered magazine concept and the basis for reducing the explosives safety distances.

1.0 INTRODUCTION

1.1 BACKGROUND

Activities at the Naval Air Station, Barbers Point, Hawaii are being transferred to the Marine Corps Base, Kaneohe, Hawaii (MCBH). Operational requirements can be best met at MCBH if 2500 lb. of ordnance can be stored near the Combat Aircraft Loading Area (CALA). Storage of 2500 lb. NEW normally requires a safe inhabited building distance (IBD) of 1250 ft. Since a safe inhabited building distance of 1250 ft is not available near the CALA, NFESC was tasked by the Pacific Division of the Naval Facilities Engineering Command to develop design criteria for a ready service magazine that could store 2500 lb. NEW within the available safe distance (approximately 1250 ft to the front and 700 ft. to the side and rear of the earth covered ready magazine). The desired explosives safety inhabited building distance (IBD) and public traffic route (PTR) distance for the ready magazine is shown in Figure 1.

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1.2 SCOPE

This paper summarizes the planning factors, explosives siting criteria, architectural & structural requirements, and conceptual design of a modular ready magazine with reduced explosives safety distance requirements for short term storage of 2500 lb. Net Explosive Weight of specific ordnance. The complete Basis of Design is contained in Naval Facilities Engineering Service Center Technical Report TR-2056-SHR "Basis of Design - Modular Ready Magazine, Marine Corps Base, Kaneohe, HI" by J. Tancreto, K. Hager, and P. Wager, Port Hueneme, CA, April 1996.

2.0 PLANNING FACTORS

2.1 FACILITY AND FUNCTION

The MCBH ready magazine is earth covered, as shown in Figures 2, 3 and 4, and designed to safely store the inventory of weapons described in section 2.3. In order to provide safety to inhabited buildings at site distances of less than the required 1250 ft. (ref. NAVSEA OP-5) from the ready magazine, the debris hazard must be mitigated and the safe debris distance must be reduced. The magazine design includes nonpropagation dividing walls to reduce the Maximum Credible Event (MCE). Four interior walls are used, as shown in Figures 2 and 3, to provide five storage cells. Because of the modular design, which may be modified to provide any number of cells each storing up to 500 lb. Net Explosive Weight (NEW), the magazine will be referred to as a Modular Ready Magazine (MRM).

The size and number of storage cells were chosen to meet the operational requirements of the users. Planning factors used in determining the magazine dimensions are provided in sections 2.2 and 2.3.

2.2 OPERATIONAL REQUIREMENTS

2.2.1 Storage Quantity Requirements. In order to satisfy the storage requirements for the type and quantity of weapons listed in paragraph 2.3, PACNAVFACENGCOM and NAS Barbers Point provided the following storage quantities:

- at least 500 lb. NEW per storage cell
- at least 5 storage cells (for storing at least 5 trailers of MK46 Torpedo's @ 400 lb. NEW per trailer)

2.2.2 Handling Equipment. The individual storage cells must be capable of storing a loaded AERO 51 trailer. The AERO 51 is a towed transport vehicle consisting of an automotive-type chassis and a flat deck body. The chassis has two axles and four single wheels with pneumatic tires. Critical trailer dimensions are given in Table 1. A loaded trailer, with less than 500 lb. HE of any of the weapons listed in 2.3.1, will have a height between the deck and the top of the weapon of less than 6.5 ft.

Table 1. AERO 51 Physical Characteristics

Length (stored position with drawbar):	138 in.
Width:	84 in.
Height (bed to deck):	32 in.
Height (with drawbar in stored position)	94 in.
Track:	72 in.
Wheel base:	89 in.
Ground Clearance	8 in.
Weight (approx.):	2900 lb.
Capacity:	8500 lb.

2.3 WEAPON STORAGE

2.3.1 Weapon Type and Description. The following weapons will be stored in the MRM:

1.	MK50 Torpedo
2.	MK46 Torpedo (MK103 warhead)
3.	GM Tactical, Harpoon Missile
4.	GM Tactical, Maverick
5.	Bomb GP, MK82
6.	Bomb GP, MK83
7.	Bomb, Rockeye MK20
8.	GM Tactical, Penguin
9.	Sonobuoy HE, SSQ-110

These are the only weapons currently considered for storage in the MCBH Modular Ready Magazine. Most other weapons would qualify for safe storage in the MRM. However, each additional weapon must be reviewed for special donor and acceptor characteristics before being added.

2.3.2 Weapon Quantity and Location. The maximum NEW in any storage cell shall be 500 lb. The height of the weapons in storage must not exceed 6.5 ft. (deck to highest point of weapon). The 7 ft. nonpropagation wall will therefore prevent line of sight fragment paths between the weapons stored in adjacent cells. Storage of 500 lb. NEW of the weapons in 2.2.1, on an AERO 51 trailer (see 2.2.2), will meet this height requirement.

The calculation of donor loads from an accidental explosion of 500 lb. assumes a reasonable separation between the weapons and the wall (i.e. a center of gravity of the total NEW from all weapons in an individual cell of at least 3 ft. from the nonpropagation wall). This will easily be achieved by keeping a minimum 1.5' standoff between the wall and any weapon surface.

2.3.3 Storage Compatibility Groups. Since the nonpropagation walls provide physical separation and prevent sympathetic detonation between cells, they will provide adequate separation between the weapons listed in 2.3.1 that are in noncompatible storage groups. The weapons in 2.3.1 must comply with the hazard compatibility group requirements of NAVSEA OP-5 for storage in an individual cell. However, noncompatible weapons may be stored in adjacent cells. The Harpoon is the only weapon that may not be stored with other weapons in a single cell. It must be stored in a separate cell.

2.3.4 Special Considerations. All weapons are HERO safe. The bombs will be unfused in MRM storage. Mavericks and MK50 Torpedoes are directed energy weapons. They must therefore be stored so that the direction of the explosion effects is away from adjacent weapons storage bays (i.e. directed towards backwall or door). That is the natural direction of storage in the MRM (weapon axis of symmetry parallel to the magazine nonpropagation walls). It is normally recommended that directed energy weapons be faced toward an earth-bermed wall (e.g. the backwall of the MRM) to allow the reinforced concrete wall and earth berm to mitigate the directed energy effects. Since the front of the MRM faces the bay, it would be acceptable for the directed energy weapons to face either the door or backwall of the MRM.

The Rockeye bomblets are also directed energy explosives. However they are too small to breach the nonpropagation wall (and cause sympathetic detonation). The orientation of the Rockeye is therefore not critical.

3.0 SITING

3.1 SITE PLAN

The Modular Ready Magazine (MRM) will be located at the Marine Corps Base, Kaneohe, Hawaii (MCBH). The explosives safety siting plan is shown in Figure 1 for inhabited building distance (IBD) and public traffic route (PTR) distance. The final site plan must provide safe separation distances from the MRM to all existing facilities and public transport routes at MCBH, in accordance with safe distance criteria in NAVSEA OP-5 and this design criteria.

3.2 MAXIMUM CREDIBLE EVENT

3.2.1 Explosion Hazard. The quantity of Class 1, Division 1 explosive stored in each 10 ft x 15 ft. storage cell is limited to 500 lb. The total storage capacity of the MRM, with 5 cells, is 2500 lb. Since the nonpropagation wall will prevent sympathetic detonation between cells, the Maximum Credible Event (MCE) will be 500 lb.

3.2.2 Fire Hazard. A mishap could lead to a fire in a cell. Given the venting that would be provided by the door openings (which would fail from the pressure produced in a fire) and the separation provided by the nonpropagation walls, it is unlikely that the heat from the burning of 500 lb. of HE in a donor cell could cookoff the weapons in an adjacent cell. However, if enough

heating did occur to cause cookoff in the donor or an acceptor cell it is unlikely that the cookoff would occur simultaneously in more than one cell. The nonpropagation wall would prevent the resulting detonation in one cell from propagating to other cells. Weapons in adjacent cells would be dispersed, and the MCE would be the Class 1, Division 1 explosives storage capacity in one cell (500 lb.).

3.3 EXPLOSIVES SAFETY QUANTITY-DISTANCE REQUIREMENTS

The explosives safety distances that comply with USN explosives safety regulations for safe siting of the Modular Ready Magazine are covered in this section. Inhabited Building Distance (IBD), Public Traffic Route (PTR) distance and safe distances to airfield facilities are shown. The safe distances are based on the requirements of NAVSEA OP-5 and the calculations in NFESC TR-2056-SHR.

The default safe distance for storage of 2500 lb. in an earth-covered magazine is 1250 ft for IBD. PTR is 60% of IBD. IBD is chosen to limit the peak incident shock overpressure to 1.2 psi and the fragments (and debris) to 1 hazardous fragment per 600 sf. Calculations may be used to show that a specific Potential Explosive Site (PES), such as the MRM, provides this level of safety with the use of design features to mitigate blast effects. Sections 4.0 (Architectural) and 5.0 (Structural) of this design criteria detail the requirements for mitigating the safe debris distance (the critical hazard).

The following safe distances are based on a MCE of 500 lb., the calculations in NFESC TR-2056-SHR, and NAVSEA OP-5 requirements.

3.3.1 IBD and PTR. The safe Inhabited Building Distance is the greatest distance at which either (1) the peak side-on overpressure is 1.2 psi (about $40 W^{1/3} = 320$ ft, for $W = 500$ lb.) or (2) the hazardous debris density is 1 per 600 sf. For Net Explosives Weights (NEW's) less than 30,000 lb. inside a structure, the safe debris distance controls IBD. The safe debris distance default value for NEW's less than 30,000 lb. is 1250 ft.

By reducing the MCE to 500 lb., and with the design requirements in this criteria, the safe IBD for debris is shown to be less than 700 ft. to the side and rear of the MRM. Although the calculations shown in TR-2056-SHR justify a safe distance of 500 ft., **an IBD of 700 ft. is recommended to the side and rear of the MRM.** Because of the primary fragment and door debris hazard, the safe distance to the front of the magazine is the default value (in NAVSEA OP-5) of **1250 ft. within $\pm 60^\circ$ from the front direction.** PTR is 60% of the IBD values (420 ft. and 750 ft. respectively). Figure 1 shows the IBD and PTR for the Modular Ready Magazine. *The side and rear safe distances are very conservative and will allow some variation in design parameters if modifications are necessary.*

3.3.2 Safe Distances to Airfield Facilities. Safe distances between the MRM and combat Aircraft Parking or Helipads shall be based on $6W^{1/3}$. For $W = 500$ lb. (the applicable W from the MRM) the safe distance to Combat Aircraft Parking or Helipads is 48 ft. However, the weapons on the aircraft could control the safe distance. The maximum NEW must be determined for parked aircraft and used to establish safe distance requirements from the aircraft to the MRM. Lines shall be painted on the Aircraft Parking area or Helipad to show the allowable parking areas.

Runways and taxiways used only by the DOD do not have a safe distance requirement from the MRM. Safe distances to public recreational areas, in the open, must be at PTR distance. When structures, including bleachers, are a part of this area, IBD must be used. Also see NAVSEA OP-5 Table 7-29 for facilities not listed here. When using NAVSEA OP-5, the PTR and IBD shown in 3.2.1 and Figure 1, may be used rather than the default values in NAVSEA OP-5. If intermagazine distance or intraline distance is the basis for safe separation, use 500 lb. for W (the MCE in lb.).

4.0 ARCHITECTURAL

4.1 GENERAL

The Modular Ready Magazine (MRM) is an earth-covered reinforced concrete structure with nonpropagation walls (NPW's) dividing the floor area into separate cells (or modules). Each cell has a roll-up door to allow access for an ordnance trailer with weapons.

The MRM being designed for MCBH uses five cells, storing up to 500 lb. of Class 1, Division 1 explosive in each cell, for a Net Explosive Weight (NEW) of 2500 lb. Since the NPW's prevent sympathetic detonation, the Maximum Credible Event (MCE) is 500 lb. This magazine can be modified by adding any number of cells, in a single row, to increase (or decrease) the NEW while keeping the MCE at 500 lb. Architectural requirements in this section are needed to control design blast loads, prevent sympathetic detonation of the acceptors, and limit the explosives safety distances to those shown in Section 3.0.

Since the current magazine design is conservative for meeting the safe Inhabited Building Distance (IBD) of 700' to the rear and side of the magazine, some changes in the magazine dimensions are possible. However, all changes must be proposed and considered concurrently (by PACNAVFACENGCOM and NFESC) to properly evaluate the consequences.

4.2 PLAN AND ELEVATION

4.2.1 Floor Plan. The floor plan, chosen to satisfy the planning factors in Section 2.0, is shown in Figure 2. Minimum floor dimensions are shown. Dimensions and the floor area may be increased without affecting the explosives safety. The overall width of the magazine is also affected by the requirement for a 3 ft. minimum thickness nonpropagation wall.

4.2.2 Elevations. Sections through the magazine are shown in Figures 3 and 4. The 12 ft. minimum ceiling height helps mitigate internal design shock and gas pressure loads. The roof and floor shall be sloped for drainage.

4.3 REINFORCED CONCRETE STRUCTURAL ELEMENTS

The magazine floor, external walls, and roof shall be normal weight reinforced concrete ($f'_c \geq 3000$ psi). The magazine structure shall be designed for the loads specified in Section 6.0. The magazine roof must be at least 8" thick to satisfy the assumptions made in calculating safe debris throw distances (TR-2056-SHR). A thicker roof is acceptable, since a heavier roof would reduce the debris throw. NFESC must review and approve a roof design which uses less than 8" thickness of reinforced concrete.

4.4 NONPROPAGATION WALL

The nonpropagation wall, shown in Figures 2, 3 and 4, shall be 7 ft. high (from the deck) and 3 ft. thick. It shall be 15 ft. long (the distance between the front and rear walls of the magazine). The 5' space above the wall allows gas pressures to quickly disperse throughout the entire magazine. This reduces the internal loads which (1) create the debris hazard at IBD and (2) develop the impulse and momentum in the nonpropagation wall debris which impacts the acceptors.

4.5 COATINGS AND COVERINGS

4.5.1 Special Coatings. An explosion in the confined space of the magazine will produce hot gases that may cause ignition and rapid burning of coatings on interior surfaces of the structure. The long duration gas overpressures associated with rapid burning of coatings can increase the design gas pressure loads. Therefore, the interior surfaces of the magazine walls and ceiling shall not be coated.

4.5.2 Floors. The floors of the magazine shall be nonabsorbent and waterproof to prevent seepage of water or moisture from the underlying ground. Floors shall be sloped to provide adequate drainage and shall not have low spots that permit water accumulation. There is no requirement for conductive floors in the magazine.

4.5.3 Waterproofing. The magazine shall be waterproof. Waterproofing details shall be designed for a 50 yr. life. Interior joints may be sealed but the sealant shall be nonflammable when exposed to the hot gases from a fire or explosion.

4.6 DOORS

Double leaf steel doors shall be used at the entrance of each cell. The doors must provide a clear opening of at least 9 ft. in width and 10 ft. in height for access by the handling trailer. The maximum weight of the doors shall be 10 psf.. All metal doors shall be connected to the secondary grounding system.

4.7 EARTH BERM

The magazine has an earth cover, with a minimum thickness of 2 ft., and an earth berm behind the two sidewalls and the backwall. The earth berm reduces explosives safety distances and protects the contents from accidental explosions at other potential explosive sites. The earth berm must have a slope of not less than 3:2, as shown in Figures 3 and 4. The fill material must meet the requirements of NAVSEA OP-5, paragraph 8-2.5.5.

5.0 STRUCTURAL

5.1 GENERAL

The Modular Ready Magazine (MRM) shall be designed for normal building code loads (e.g. retaining wall loads from earth berm, seismic loads, earth cover dead load on roof, trailer loads on floor, etc.). There is no requirement for the A&E to design any part of the structure for blast loads. The structure (including the nonpropagation wall) will fail during a Maximum Credible Event. The dimension and material requirements in this design criteria (especially Sections 4.0 and 5.0) will prevent sympathetic detonation between storage cells, and control the explosion effects and safe distances.

Normal weight reinforced concrete with a 4000 psi minimum compressive strength shall be used for the exterior walls, roof, parapet, floor, foundation, and wingwalls of the MRM. The nonpropagation walls will use lightweight reinforced concrete (≤ 115 pcf dry density) with a maximum compressive strength of 3000 psi.

The design gas and shock loads used to calculate the explosive safety distances (for pressure and debris) in Section 3.0 and to design the nonpropagation wall are shown in NFESC TR-2056-SHR. Sections 4.0 and 5.0 provide the minimum requirements for the MRM design to satisfy the assumptions used in the calculations. If these minimum requirements are satisfied then the MRM will limit the MCE to 500 lb. and maintain the explosives safety distances shown in Section 3.0.

5.2 NONPROPAGATION WALL

The nonpropagation wall (NPW) is shown in Figures 2, 3 and 4. Its cross-section is shown in Figure 5. It is a sand filled wall with lightweight reinforced concrete containment walls. The NPW reduces the blast effects on acceptor munitions to below threshold values for sympathetic detonation.

The mass of the NPW stops all primary fragments and reduces the kinetic energy loads on acceptors. The granular fill flows around the acceptors (reducing load coupling) rather than rigidly loading them with the entire wall momentum. The lightweight concrete exterior surface reduces initial peak impact loads on the acceptors to prevent shock to detonation transition (SDT). By reducing acceptor loads and structural damage, the criteria for preventing sympathetic detonation are satisfied.

The lightweight reinforced concrete surfaces must be designed to contain the sand fill. Internal ties may be used to support the exterior walls. No blast resistant design is required. See NFESC TR-2056-SHR for alternate design concepts which use materials other than lightweight reinforced concrete to contain the sand.

5.2.1 Lightweight Concrete. The lightweight concrete containment walls must not exceed 4 inches in thickness for dry densities between 100 and 115 pcf (see Section C-C, Figure 5). If the lightweight concrete dry density is less than or equal to 100 pcf, then the reinforced concrete wall thickness can be no greater than 6 inches. The lightweight concrete 28 day compressive strength shall be ≤ 3000 psi.

5.2.2 Steel Reinforcement. The steel reinforcement area should be kept to the minimum for meeting ACI building code requirements. The ties, between containment walls, should be protected against corrosion. The size of reinforcing steel should be kept $\leq 3/8$ in diameter. The ties should be steel or nonmetallic straps with little compressive load capacity.

5.2.3 Sand. The sand shall be placed without compaction. The nominal density shall be 100 pcf.

5.3 MAGAZINE FLOOR, FOUNDATION, ROOF & WALLS

The magazine floor, foundation, roof, and external walls shall be normal weight reinforced concrete. Design loads will include normal dead and live loads and will include the earth berm loads on the roof and walls and the trailer loads on the floor. No blast resistant design is required. The minimum thickness of the reinforced concrete roof shall be 8" (to obtain the minimum mass used in debris distance calculations).

5.4 MAGAZINE DOORS

The steel magazine doors shall have a weight of no greater than 10 psf to allow quick venting of internal gas pressures in the event of an accidental explosion. The purpose of the magazine door is to seal the magazine against the weather and to provide physical security. There are no blast design load requirements.

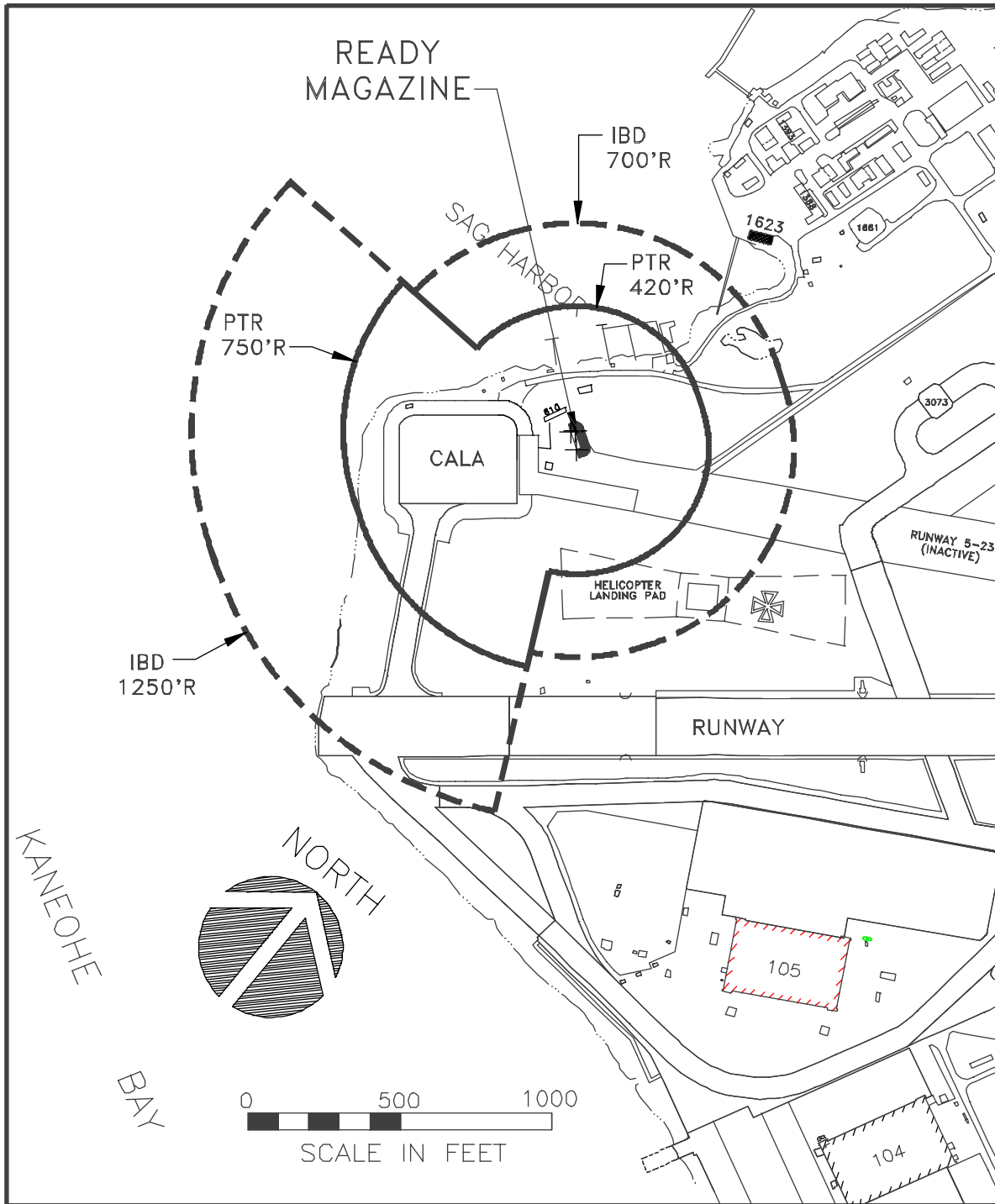


Figure 1. Modular Ready Magazine IBD and PTR Explosives Safety Distances

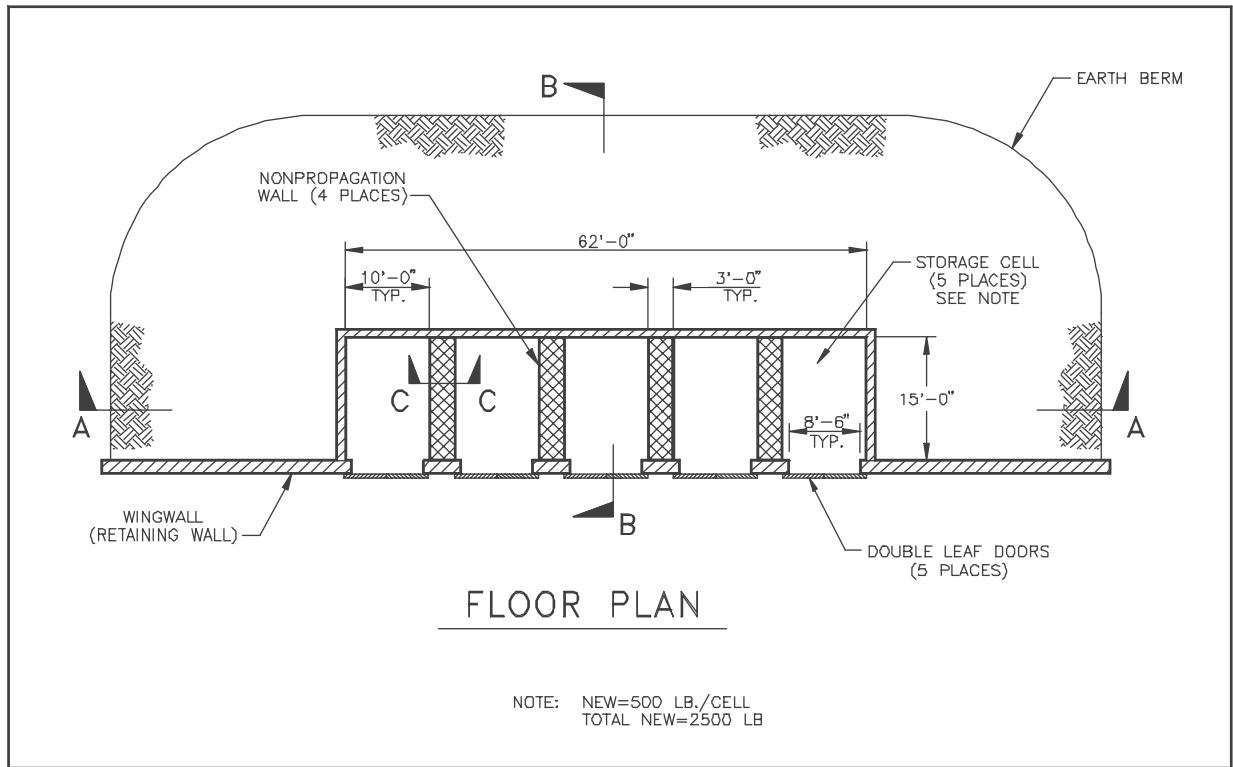


Figure 2. Modular Ready Magazine: Floor Plan

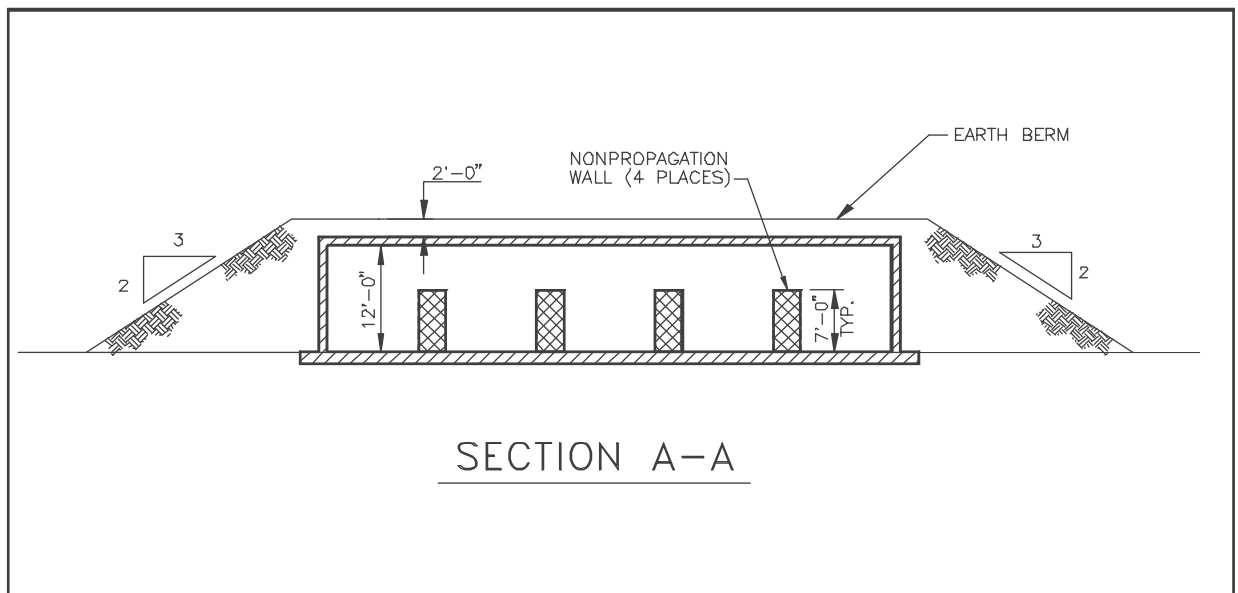


Figure 3. Modular Ready Magazine: Section A-A

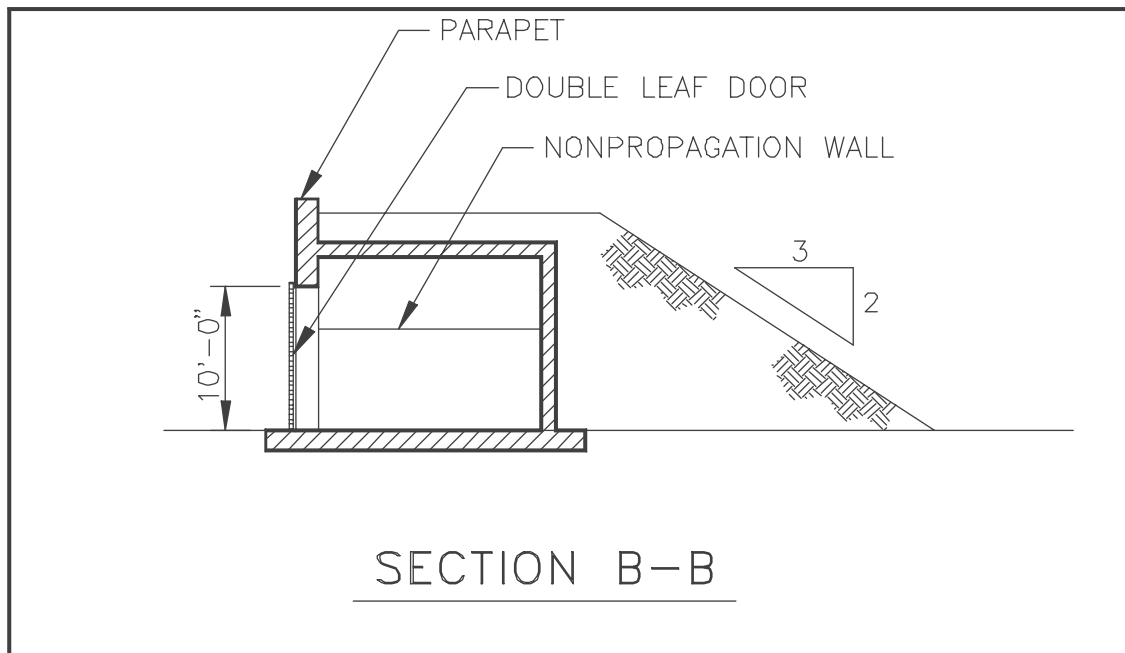


Figure 4. Modular Ready Magazine: Section B-B

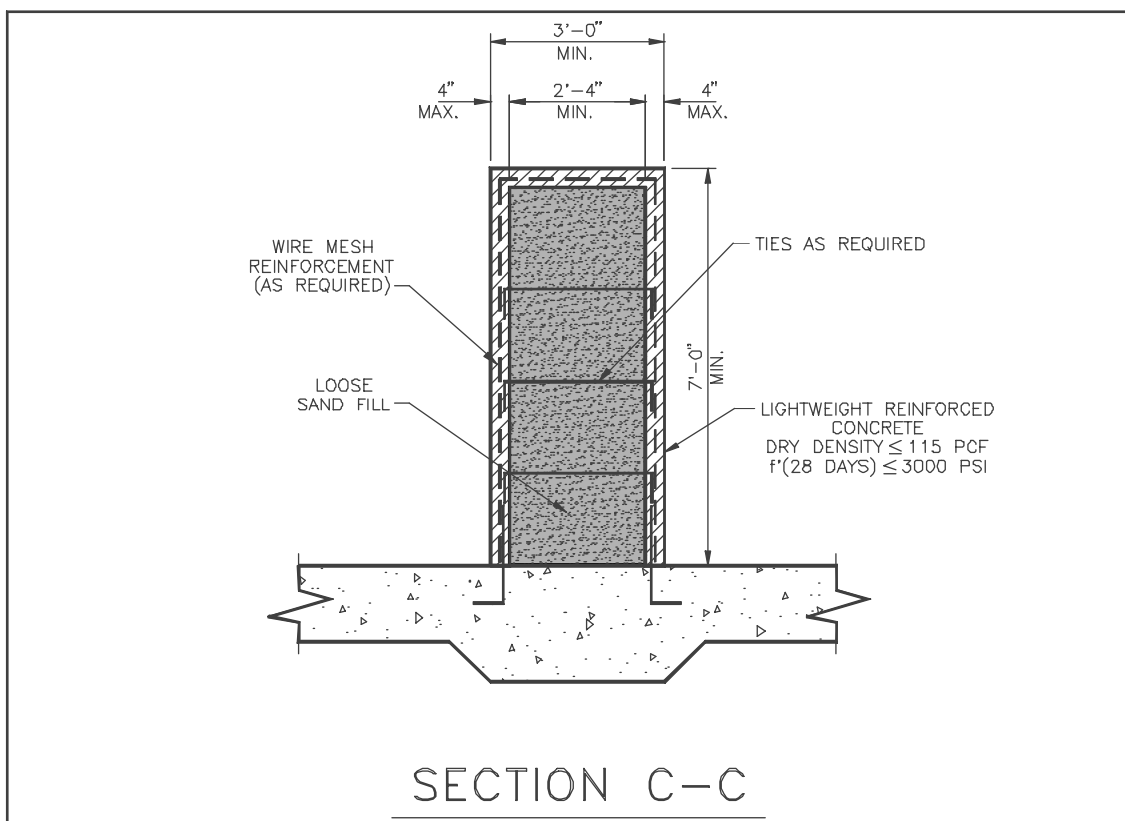


Figure 5. MRM Nonpropagation Wall Cross Section