Steel Box Earth-Covered Magazine

Tyler Ross, Ph.D., P.E.; A-P-T Research, Inc.; Huntsville, AL, USA

Patrick Medley; ARMAG Corporation; Bardstown, KY, USA

Joseph Haydon; ARMAG Corporation; Bardstown, KY, USA

Keywords: Earth-Covered Magazine, ECM, Steel, Prefab

Abstract

A new pre-fabricated steel box design is currently being reviewed by the Department of Defense Explosives Safety Board (DDESB) for use as an earth-covered magazine (ECM). The unique design of this magazine is presented. The design process for the steel headwall and vertical load transfer system is presented.

This magazine is 13.5' wide, 9' tall, and up to 40' long. The magazine is fabricated off-site, delivered for installation on a concrete pad, and then covered with soil. This new magazine type offers the Department of Defense (DoD) a faster, cost-effective method for sourcing new earth-covered magazines.

Introduction

The ARMAG Corporation, in conjunction with A-P-T Research, Inc., is currently seeking formal approval for the design of a steel-box earth-covered magazine (ECM) (see Figure 1). The design has been reviewed by the U.S. Army Technical Center for Explosives Safety (USATCES) and has been recommended for review by the Department of Defense Explosives Safety Board (DDESB) for inclusion in DDESB Technical Paper (TP) 15, "Approved Protective Construction" with a 3-bar headwall designation (Reference 1). Upon approval, the ARMAG ECM would be the first steel-box ECM approved for net explosive weight (NEW) quantities greater than 8,800 lb.

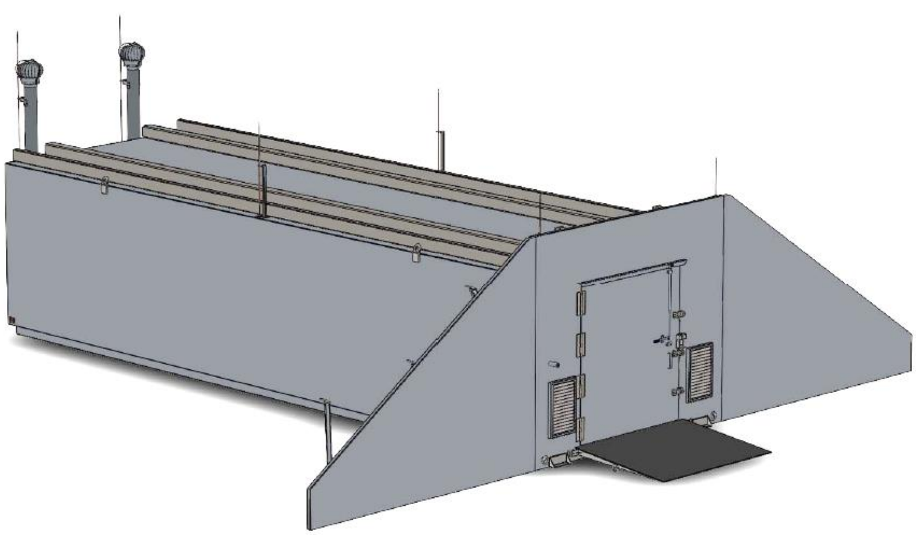

Figure 1. ARMAG ECM Conceptual Design

Purpose and Uses

The intent of the ARMAG ECM is to provide U.S. Department of Defense (DoD) and other entities with a cost-effective, expedited method of implementing practical explosives article storage options that can fully utilize the allowable reduced separation criteria for ECMs.

Currently, a variety of ECM designs are approved for new construction. However, in each case, extensive on-site construction is required. The ARMAG ECM is designed to be prefabricated and delivered to the site. An 8-inch concrete slab foundation is the only element required prior to delivery. Upon delivery, the soil cover can be placed the same day.

Existing design types for ECMs can cost near or in excess of $1M for arch magazines and $3-5M for large box-type magazines. The ARMAG ECM prefab design methodology and simplified foundation design greatly reduce these costs. The ARMAG ECM is expected to cost approximately $325,000 depending on location and locally available materials for the foundation and soil cover. This cost includes delivery, foundation, and earthwork.

Acquisition can also potentially be simplified in that the ARMAG ECM may be able to be purchased using equipment funds, if applicable acquisition procedures allow.

The ARMAG ECM provides an explosives storage option that can also alleviate limitations within existing storage facilities. In many locations, limited existing facilities are used to store Hazard Division (HD) 1.1 materials as well as less-restrictive HD 1.3 and 1.4 materials. The existing facilities can be prioritized to store the HD 1.1 materials if desired, whereas the ARMAG ECM is well suited to store material from any HD.

Similarly, storage space for large munitions (e.g., containerized missiles) is usually at a premium at storage locations. When smaller palletized material also requires storage, it often is required to utilize space within limited magazines. The ARMAG ECM is ideal for storing palletized materials, alleviating critical space within larger magazines for larger munitions.

Basis of Design

The ARMAG ECM is being designed as a mid-level storage capacity magazine with a 3-bar headwall designation. The 3-bar designation was selected in order to balance the competing demands of increased headwall strength and constructability of a steel headwall. Initial calculations performed for a 7-bar headwall design determined that extensive additional steel material would be required. Consultation with the U.S. Army Corps of Engineers (USACE) in Huntsville further influenced the design to be targeted to a 3-bar designation.

The design NEW is limited to 50,000 lb. HD 1.1. This NEW limitation is due to the reduced footprint of the magazine (13.5 ft x 40 ft). This limitation also applies to surrounding ECMs if sited at HD 1.1 Inter-Magazine Distance (IMD), which would generate the design loads.

The design loads for the magazine are obtained from DoD 6055.09-M (Reference 2) Section V2.E5.5.2. This criterion defines the load on the flat roof as 108.0 psi with a calculated impulse of 699.7 psi-ms and duration of 12.96 ms. The roof loading is independent of the headwall designation. Blast loads on the headwall (3-bar) are defined as 43.5 psi with a calculated impulse of 416.15 psi-ms and duration of 19.13 ms.

The headwall of the magazine consists of a 5/8th inch steel plate supported by various beam/column members. A steel headwall can be designed to perform well under blast loads and meet all criteria. The ductile nature of steel and the associated criteria allow the material to deform well and maintain significant load resistance. It is important to note that many of the currently approved 3-bar and 7-bar ECM facilities listed in TP-15 (Reference 1) have large steel doors that account for most of the headwall area. Several examples are presented in Table 1.

Table 1. Typical Currently Accepted ECM Types

Magazine	Headwall size	Door size	% Door (approximate)	Thickness of Steel
33-15-74	25 ft x 14 ft (arched)	10 ft x 10 ft	33%	5/8th inch
RC Box Type C	95 ft x 16 ft	(3) 26 ft x 12 ft	62%	13/16th inch
RC Box Type D	159 ft x 16 ft	(5) 25 ft x 11 ft	54%	13/16th inch
421-80-07 (MSM)	25 ft x 11 ft	24 ft x 10 ft	87%	3/8th inch

This table also presents the thickness of steel for each design, which can be compared to the proposed 5/8th inch headwall plate. This provides a relative comparison for potential shielding from external debris.

Magazine Design

The ARMAG ECM is box-shaped, 40 feet in length, 13.5 feet wide, and 9 feet tall, as shown in Figure 2. The headwall plate and wing-walls extend above the ECM roof and to the sides to support the soil backfill. The magazine door is a single-leaf design, 7 feet in width. A lightning protection system and ventilation stacks can also be seen in the figure. For additional views and sections of the magazine, please refer to the ARMAG ECM drawings (Reference 3).

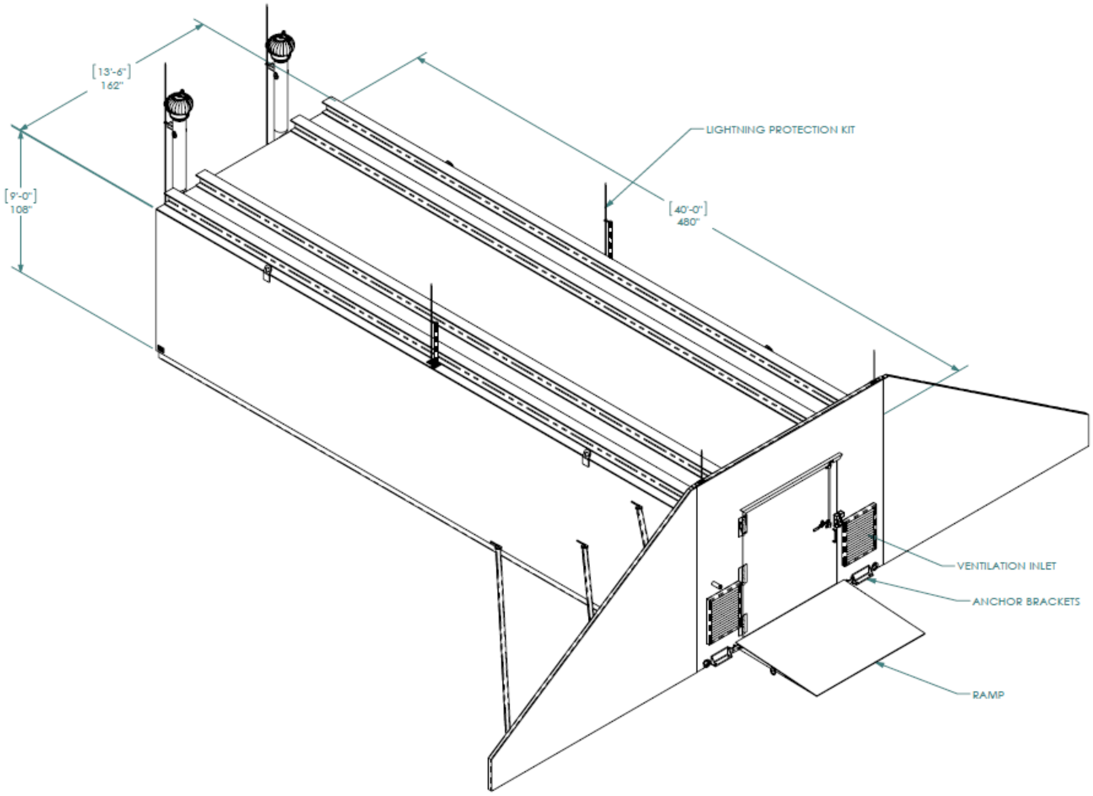

Figure 2. ARMAG ECM dimensions and components

The blast resistant structural system has two focus areas: (1) the vertical roof load, and (2) the horizontal headwall load. Each loading mechanism and corresponding structural resistance system will be described separately. The magazine is designed in accordance with United Facilities Criteria (UFC) 3-340-02, "Structures to Resist the Effects of Accidental Explosions" (Reference 4). The effects of rebound loading are also considered in the design. Mechanical properties of the sections are calculated, moment and shear capacities are calculated, and a resistance function is developed. SBEDS 5.1 (Reference 5) is used as a Single-Degree-of-Freedom (SDOF) analyzer to perform the dynamic analysis. The resultant maximum deflection is translated into a ductility value and support rotation value that are then compared to acceptability criteria.

All beams and columns are ASTM specifications A992 steel (50 ksi yield stress – treated as A588 for UFC increase factors). Longitudinal compression members (no moment loading) along the roof and floor are HSS tube members (A500 Grade B steel with 46 ksi yield stress, using a combination of A588 and A36 increase factors to match either yield stress or ultimate stress). All plates are A36 grade steel (36 ksi yield).

Each beam or column component of the ARMAG ECM is welded to an adjacent steel plate in 6-inch intervals (6 inches of weld then 6 inches without) along the length of the member. In reality, this would cause the plate to act as a built-up flange on one side of the beam or column and increase the flexural capacity of the members. This added flexural capacity is conservatively neglected in this analysis and the beams and columns are designed as stand-alone elements.

Vertical Loading

The load on the flat roof is 108.0 psi with a calculated impulse of 699.7 psi-ms and duration of 12.96 ms. The roof loading is independent of the headwall designation. Additional roof loads considered include dead load (wet soil), live load, and snow loads totaling 519.4 lb/ft^2. This value consists of 2.5 ft of wet soil (182.4 lb/ft^3) and 63.4 lb/ft^2 of combined live and snow load. Dead load is conservative in that it considers an extra 0.5 ft of wet soil (91.2 lb/ft^2). Live load assumes maintenance personnel and handheld equipment only. The slope of the earth cover prohibits access with other equipment. For magazines that do not exceed 2.0 ft of soil cover, the design vertical load accounts for an equivalent snow load of more than 100 lb/ft^2. A snow removal procedure shall be in place for locations having a ground snow load greater than 100 lb/ft^2 if the earth cover exceeds 2.0 ft.

The roof load is supported by a 3/8th inch steel plate and series of transverse W6x20 steel members spaced at 2 feet on center. The mass of the soil on top of the roof plays an important role in the dynamic response of the roof. To ensure proper performance of the roof members, two load combinations were considered. The first assumes the maximum dead load (519.4 lb/ft^2) to model the largest initial deflection of the member. The second load combination assumes only 2 feet of dry soil (120 lb/ft^3 totaling 240 lb/ft^2) to minimize the dynamic effect of the soil mass. Shear loads were also verified for both cases. The results of these two loading scenarios for both the roof plate span and the roof beams show that the highest ductility and support rotation values occur in the scenario with the minimum loading (lower dynamic mass).

The roof beams rest upon a series of 9-foot vertical W6x12 column sections, spaced at two-foot intervals and welded to a 3/8th inch continuous exterior side-wall plate. When loaded, the continuous side-wall plate braces the W-section columns providing continuous lateral support. The columns rest on the floor of the magazine that bears against an 8-inch concrete pad foundation.

The connections between the roof beams and columns are designed as simple bearing connections, as much as possible, to ensure no significant moment is transferred into the column.

The axial loading on the column comes from maximum shear load of the roof beams. To be conservative, it is also assumed that up to 50% of the maximum plastic moment from the roof beam is transferred into the column, even though the connection is designed as a simple pinned connection. Also, shear loads from the lateral earth pressure are considered.

The axial and bending moment loads are taken as greater of the results from the two scenarios considered for the roof beams.

Horizontal Loading

The horizontal loads are resisted by the headwall, which then transfers the loads throughout the structure into the surrounding soil and foundation. The door and door frame are described first, followed by the remaining portion of the headwall plate.

The magazine door is a single-leaf design consisting of a 5/8th inch front plate and horizontal steel W6x12 sections acting as stiffeners. The horizontal stiffeners bear against the door frame consisting of a W12x35 section on either side. These vertical door frame columns (W12x35) support the loads from half of the door (44 inches each) and 14 inches of the headwall plate on the opposite side. The remaining portions of the headwall (25 inches on either side) are supported by additional vertical beam-columns. These are W6x16 members. In summary, the door and headwall are supported by a total of four columns: (2) W12x35 sections and (2) W6x16 sections.

The door frame members support the load-bearing load of the magazine door. The frame is comprised of two vertical W12x35 sections (50 ksi yield) behind the 5/8th inch headwall plate on either side of the 7.27-foot door. The headwall plate is not in contact with the door frame column. A hollow structural steel (HSS) 6x2x1/4 door jamb member borders the door, sides, and top. This door jamb is analyzed for crushing loads, but has significant surplus capacity. The door frame beam columns support no axial load.

When loaded horizontally by the blast load, the door frame column is simply supported at the base and at the top of the column. The column extends above the 9-foot height of the magazine roof to bear against a specially designed longitudinal steel HSS compression members running the 40-foot length of the magazine roof and floor. The door frame columns (W12x35) bear against HSS8x8x3/8 members along the roof and floor. The outer headwall columns (W6x16) bear against HSS8x4x1/4 sections. These longitudinal roof and floor HSS sections are welded to the magazine roof providing a path for the headwall loads to transition into the structure over the entire length. The connection between these longitudinal roof and floor HSS sections and the vertical headwall columns is a simple bearing connection. This is a pinned connection to ensure that no moments are transferred between the roof and headwall during simultaneous loading. This also ensures that the roof acts as a one-way transverse element.

<u>Rebound Loading</u>

Rebound loading for connections has been considered in accordance with UFC 3-340-02 Chapter 5. Full (100%) rebound loads are considered for the following connections:

- Transverse roof beams (W6x20) connected to the sidewall columns (W6x12). Rebound loading for the roof beam is carried by a weld along the column web only. This weld is purposefully designed to not allow moment transfer through the flanges.
- Transverse door beams (W6x12) connected to the headwall door frame beams (W12x35). Rebound loading for the door beams is carried by a series of pins acting in shear.
- Headwall door frame beams (W12x35) connected to longitudinal roof beams (HSS8x8x3/8) through the roof and floor plates. Rebound loading for the headwall door frame beam is carried by a weld along the roof plate only. This weld is purposefully designed and located to not allow moment transfer to the longitudinal roof beam.
- Headwall beams (W6x16) connected to longitudinal roof beams (HSS8x4x1/4) through the roof and floor plates. Rebound loading for the headwall beam column is carried by a weld along the roof plate only. This weld is purposefully designed and located to not allow moment transfer to the longitudinal roof beam.

Conclusion

The ARMAG ECM provides a convenient, cost-effective option for storage of practical quantities of explosives articles utilizing reduced separation criteria for ECM structures. The design of the ARMAG ECM meets and exceeds UFC 3-340-02 requirements.

References

1. Department of Defense Explosives Safety Board, Technical Paper 15, Revision 3, "Approved Protective Construction," May 2010.
2. DoD Ammunition and Explosives Safety Standards, DoD 6055.09-M, 4 August 2010.
3. 40' X 13'-6" X 9' 3-Bar Earthen Covered Type 2 Magazine Fabrication Details, Drawing No. S1413, Armag Corporation, January 2018.
4. Unified Facilities Criteria 3-340-02, Change 2, "Design and Analysis of Hardened Structures to Conventional Weapons Effects", September 2014.
5. "Single-Degree-of-Freedom Blast Effects Design Spreadsheets (SBEDS)", Version 5.1 U.S. Army Corps of Engineers Protective Testing Center, December 2014.