Earth Covered Magazines Vertical Seismic Ground Motion Effects

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Abstract:

Earth covered magazines (ECMs) are designed to contain explosives and weapons. Standard ECM designs were developed to provide a high degree of safety for explosives and weapons storage. The lead agency responsible for the development of ECMs has been the Defense Department Explosive Safety Board (DDESB). The DDESB's focus has been mitigating sympathetic detonations and limiting damage caused by an accidental detonation of the contents of an ECM. The U.S. Army Engineering and Support Center – Huntsville Environmental and Munitions Center of Expertise (EM CX) serves to provide standard designs for ECMs that can be constructed with minimal field adaptation. The EM CX has also further developed the standard ECM design. Unified Facility Criteria (UFC) 3-301-01 provides criteria for seismically induced ground motions. UFC 3-301-01 refers to American Society of Civil Engineers (ASCE) 7 to provide more detailed requirements for the design of structures including ECMs. Typically, an ECM is designated as Risk Category (RC) III. ASCE 7-16 included vertical ground accelerations for consideration. Vertical ground accelerations produce a significant risk of failure in the event of an earthquake. This paper's goal is to define the risk to ECMs from earthquake ground motions.

Introduction:

Earth covered magazines (ECMs) are designed primarily to contain explosives and weapons. Standard ECM designs were developed to provide a high degree of safety for explosives and weapons storage caused by an accidental detonation of the contents. The lead agency responsible for the development of ECMs has been the Defense Department Explosive Safety Board (DDESB). The DDESB's focus has been mitigating sympathetic detonations and limiting damage caused by an accidental detonation of and ECM's contents.

The U.S. Army Engineering and Support Center – Huntsville Environmental and Munitions Center of Expertise (EM CX) serves to provide standard designs for ECMs that can be constructed with minimal field adaptation. The EM CX has also further developed the standard ECM design. Unified Facility Criteria (UFC) 3-301-01 provides criteria for seismically induced ground motions. UFC 3-301-01 refers to American Society of Civil Engineers (ASCE) 7 to provide more detailed requirements for the design of structures including ECMs. Typically, an ECM is designated as Risk Category (RC) III. ASCE 7-16 included vertical ground accelerations for consideration. Vertical ground accelerations produce a significant risk of failure in the event of an earthquake. This paper's goal is to define the risk to ECMs from earthquake ground motions.

For decades within some industries, vertical ground motions have warranted consideration, such as for the following:

- Liquid-containing vessels by the American Petroleum Institute
- Liquid-containing vessels by the American Water Works Association
- Nuclear power plants and other construction under the Department of Energy
- RC V facilities per UFC 3-310-04

ASCE 7 standards have historically ignored seismically induced vertical ground motions. But ASCE 7-16 introduced the concept to a wider engineering audience through Section 11.9, which was to address vertical seismic ground motions. Studies have indicated that structures with large dead loads and unusual structural configurations are especially sensitive to vertical ground motions.

Earth Covered Magazine Study

The DDESB was consulted regarding the concerns regarding seismic design for vertical ground motions. It indicated that its focus was on blast effects and that seismic considerations were under the purview of the EM CX. Discussions with the EM CX resulted in choosing a single ECM for the study. The ECM selected was the MSS Box-Type Std. 421-80-08 (500,000 pounds) (Figure 1). This type of ECM is constructed of precast concrete and currently appears to be the most commonly constructed ECM. The roof structures are a precast system using precast joists cast integrally with the roof slab. The precast roof structure bears directly on concrete walls (Figure 2).

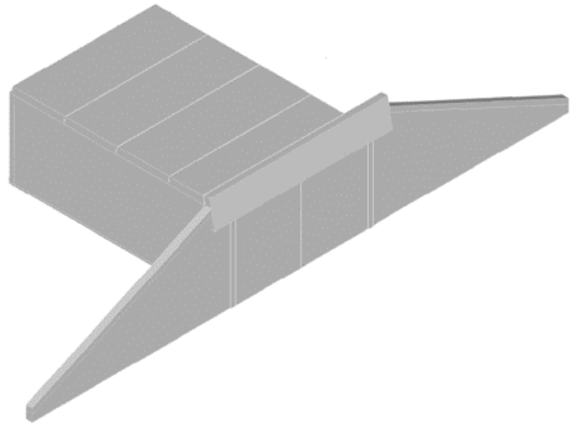

Figure 1 – Isometric View of MSS Box Type Std. 421-80-08

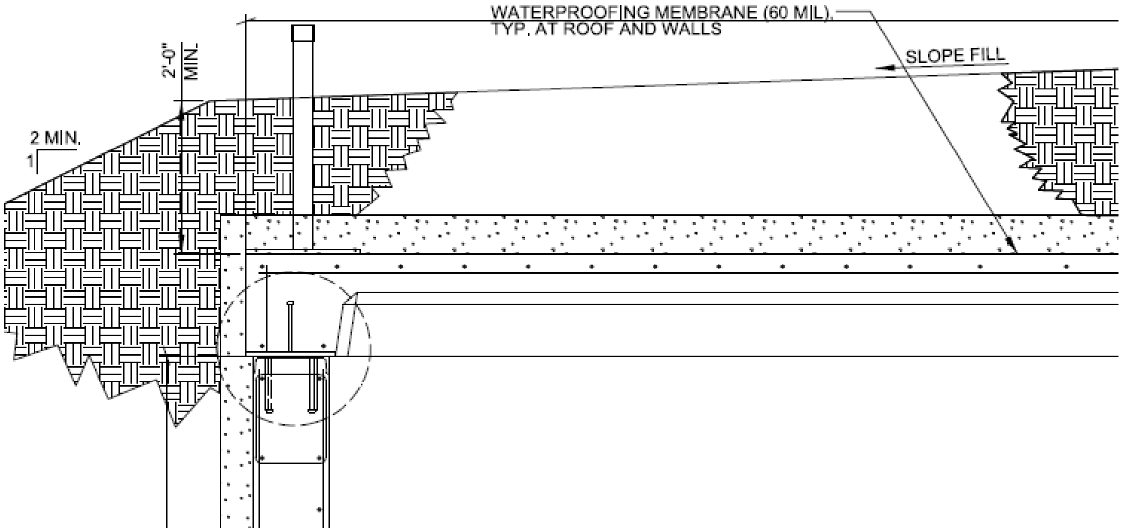

Figure 2 – Roof Wall Connection MSS Box Type Std. 421-80-08

The ground motions selected for the study were predicated on Guam. The ground motions in Guam (U.S. Geological Survey [USGS] 2015) are some of the highest for any U.S. Military installation (UFC 3-301-01). The values used in the study were from UFC 3-301-01 and are considered official for U.S. Military work. The seismic short-period earthquake for Guam has a maximum lateral acceleration, defined as the S_s, of 279% of gravity (UFC 3-301-01) (Figure 3).

UFC 3-301-01
1 June 2013
Change 3, 12 September 2016

Table E-3

	Seismic Data (Site Class B)								
Base / City	PGA (%g)	S_S (%g)	S_1 (%g)	$S_{S,5/50}$ (%g)	$S_{1,5/50}$ (%g)	$S_{S,10/50}$ (%g)	$S_{1,10/50}$ (%g)	$S_{S,20/50}$ (%g)	$S_{1,20/50}$ (%g)
Guam (b)	90	279	68	208	51	151	37	105	25

Figure 3 – Excerpt from UFC 3-301-01

The relationship between horizontal to vertical (V/H) seismic accelerations has historically been 2/3. This relationship holds relatively true unless the source fault is within 10 kilometers of the site in question. Noted exceptions to the 2/3 relationship have occurred. For example, the El Centro earthquake of 1979 had a vertical seismic ground motion of 3.77 g (Figure 4). Other exceptions include the Northridge earthquake and the recent earthquakes in New Zealand.

Event	Station(Mw)	Hor1(g)	Hor2(g)	Ver(g)	V/H
Gazli, Uzbeksitan 1976	Karakyr(6.8)	0.71	0.63	1.34	1.89
Imperial valley, USA 1979	El cenro array 6 (6.5)	0.41	0.44	1.66	3.77
Nahhani, Canada 1985	Site1(6.8)	0.98	1.10	2.09	1.90
Morgan hill, USA 1984	Gilroy array#7(6.2)	0.11	0.19	0.43	2.25
Loma-prieta, USA 1989	LGPC(6.9)	0.56	0.61	0.89	1.47
Northridge, USA 1994	Arleta fire station(6.7)	0.34	0.31	0.55	1.61
Kobe, Japan 1995	Port Island (6.9)	0.31	0.28	0.56	1.79
Chi Chi, Taiwan 1999	TCU 076 (6.3)	0.11	0.12	0.26	2.07

Figure 4 – V/H ratios From Several "Landmark Earthquakes" (Shrestha, 2009)

Determining vertical ground motions are required for RC V facilities, which are not in ASCE 7-10. The design provisions for RC V are solely contained in UFC 3-301-01 and UFC 3-310-04. Vertical ground motions are required for RC V. Vertical ground motions are technically not a requirement for RC III facilities. ASCE 7-16, Section 11.9, provided a method of determining pseudo static vertical ground motions predicated on horizontal ground motions. A general relationship of vertical to horizontal ground motions is illustrated in Figure 5.

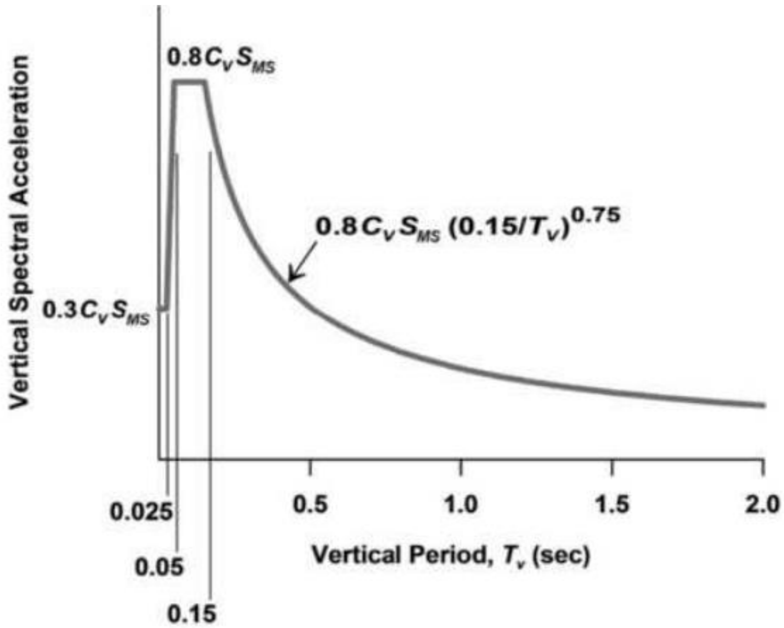

Figure 5 – ASCE 7-16 Figure C11.9-1

Risk Categories

The selection of a risk category has significant implications regarding performance. ECMs within a given facility are generally closely spaced (Figure 7). Because of this close construction to each other and because the ground will move uniformly over a large area, many ECMs within a given facility will have similar seismic performance. RCs were developed primarily for performance regarding lateral earth shaking as opposed to vertical seismic ground motions but can still be used as a measure of seismic performance relative to vertical seismic ground motions.

UFC 3-301-01
1 June 2013
Change 3, 12 September 2016

Risk Category	Nature of Occupancy	Seismic Factor I_E	Snow Factor I_S	Ice Factor I_i
III	• Buildings and other structures not included in Risk Categories IV *and V* containing sufficient quantities of toxic, flammable, or explosive materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with *NFPA 1: Fire Code*; and are sufficient to pose a threat to the public if released.[b] • *Facilities having high-value equipment, as designated by the AHJ*	1.25	1.10	1.25

Figure 6 – Excerpt From UFC 3-301-01

Figure 7 – ECMs (Globalsecurity.org)

The performance between an RC III and RC V facility is profound because of the consideration for vertical seismic ground motions. For many years, the tendency was to design an ECM for RC I or II because an ECM was not occupied on a regular basis. The RC II designation may have been adequate for easily replaceable small arms, mortar ordnance, and unguided aerially dropped ordnance like the Mk 82. As weapons and ordnance developed into smart-guided munitions, the tendency was to assign the ECMs as RC III due to their expense. A single Guided Bomb Unit 15 (GBU-15) infrared (IR)-guided bomb is about $300,000 (according to GlobalSecurity.org). If a standard ECM contains 20 similar weapons (which is a conservative lower bound), the dollar loss in the event of a failure would be more than $6 million for one ECM failure. If 20 ECMs are constructed identically, the cumulative dollar loss of the contents would be about $120 million. By comparison, the unit cost of a single GBU-15 IR bomb is $300,000, while the cost of one B61 nuclear weapon is estimated at $25 million (according to the Washington Post).

The design intent for seismic performance according to ASCE 7 is to be nonlinear to absorb energy from a seismic event within the framing structure. Properly designed buildings have had to be torn down because they were no longer functional following an earthquake.

The Missile Defense Agency (MDA) elected to use RC V for the design of its various structures about two decades ago. The MDA was the catalyst in the development of RC V and the previous designation of SUG IV. The development of RC V was intended for structures to be linearly elastic and operational for the maximum considered seismic event with a mean recurrence interval probability of about 2,500 years. An RC V structure was also to be designed to consider vertical seismic ground motions.

RC V structures require a seismic analysis for ground motions in all three orthogonal directions including seismically induced vertical ground motions. RC III currently does not require an analysis in the direction of vertical earthquake ground motions. UFC 3-301-01 and UFC 3-310-04 have no requirements for vertical seismic ground motions because they reference RC III per ASCE 7-10. When UFC 3-310-01 is updated, it will reference the 2018 International Building Code (IBC). The 2018 IBC references ASCE 7-16 and Section 11.9 of ASCE 7-16 requires the characterization of vertical ground motions.

Based on experience with many types of RC V structures for the MDA, the vertical seismic ground motions became the dominant structural demand for many structures analyzed dynamically and designed as part of the MDA projects in Europe and in Alaska. The MDA facilities were designed using a response history analysis in all three orthogonal directions. That same level of analytical rigor would be required to properly characterize the vertical seismic ground motions for ECMs categorized as RC III. How the design basis earthquake is characterized is a subject that must be properly vetted.

A pseudo static analysis was performed on a standard ECM (MSS Box Type Std. 421-80-08). The applied pseudo static forces were derived from ASCE 7-16, Section 11.9. The results indicated that an RC III ECM was about 87% stressed in bending and about 53% stressed in shear. An RC V ECM using a similar type of analysis was about 87% stressed in bending and about 53% stressed in shear. The pseudo static imposed forces are not able to characterize the soil and structure response as adequately as a dynamic response history analysis.

Summary

ECMs are unique structures in that they have a very substantial dead load that is required for fragmentation control and sympathetic detonation avoidance. Based on experience with various projects for the MDA, a response history analysis in all three orthogonal directions should be performed on current and select existing ECMs to determine a pattern of dynamic sensitivity and vulnerability to vertical seismic ground motions.

References:

ASCE 7-10; ASCE; ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures; 2010.

ASCE 7-16; ASCE; ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures; 2016.

UFC 3-301-01; 1 June 2013; Change 3, 12 September 2016; UFC; Structural Engineering.

UFC 3-310-04; 1 June 2013, Change 1, 20 June 2016; UFC; Seismic Design of Buildings.

USACE Huntsville Modular Storage Magazine, Box-Type Std. 421-80-08 With 14'-8" Door.

USGS 2015, Seismic Hazard Assessment for Guam and the Northern Mariana Islands; Mueller, Haller, Luco, Petersen, and Frankel; 2015.

Ghosh, 2016, "The Need for Explicit Consideration of Vertical Earthquake Ground Motion in the Design of Risk Category I-IV Structures," S. K. Ghosh Associates Inc., April 2016.

Sharma 2018, Sharma, Chen, Thiagarajan, and Sprague; *"Nonlinear Vertical-Horizontal Seismic Response of Earth Covered Magazines"*; Eleventh U.S. National Conference on Earthquake Engineering Integrating Science, Engineering & Policy; June 25–29, 2018; Los Angeles, California.

Shrestha, 2009, "Vertical ground motions and its effect on engineering structures: a state-of-the-art review," International Seminar on Hazard Management for Sustainable Development, Kathmandu, Nepal, November, pp. 29–30.