Safety Performance Enhancement Scheme for Munition Storages by applying the Concept of Shallow Underground Configurations

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Abstract. Practical demand for the expansion of military ammunition and explosives storage in both volume and number has been increased, but due to the regulations applying on safety distance that require those facilities to be isolated from a civilian presence there are constant complications that arise. Recent incidents include petitions to either alleviate said regulations or relocate several ammunition storage facilities neighboring civilian areas are further development. Two types of underground ammunition storage facilities will be considered in practice; the first is the tunnel-type which is applicable to areas that have sufficient depth of the cover and the latter is the sub-surface type that retains a sufficient depth of soil layer which can especially be utilized in areas that do not meet clearance requirements nor have geographical limitations. For the sub-surface type storage, there are two construction schemes for construction to meet safety-distance requirements. The existing popular ECMs (Earth Covered Magazines) have shallow soil cover for just plantation camouflage that is not affect the pressure suppression effect due to the internal explosion. Therefore, the scheme of the increasing soil cover depth to some amount, if applicable, pressure and fragment suppression can be achieved. The open-cut method for new construction is easily applied for this purpose in the field. This study addresses the safety distance reduction effect by increasing the soil cover depth on the ECM type storage facility by applying theoretical and numerical analysis.

1. Introduction
There is a growing demand for the expansion of military ammunition and explosives storage in both volume and number, but due to safety-distance regulations that require those facilities to be isolated from a civilian presence there are constant complications that arise. Recent incidents include petitions to either alleviate said regulations or relocate several ammunition storage facilities neighboring civilian areas are further development.

There are two classes of ammunition and explosives storage facility; above and underground types as shown in the Figure 1. One story house building type and ECM type belong to the aboveground class, whereas tunnel type and subsurface type belong to underground class. In the safety-distance point of view, above ground types are definitely required longer safety distance than the underground type.
Almost all of the newly constructed ammunition storage facilities, especially ECM (Earth Covered Magazines) types are above ground and thus requires a larger quantity-safety distance. The urgency to install underground options in order to decrease the safety distance, is rising and related investigations are being vigorously performed. Safety distance is basically considered by the quantity of the explosives and separation distance between the exposed sites. When a storage facility is exploded, blast pressure and fragments are propagated spherically toward nearby buildings, roadways, human, devices that are necessary to be protected.

Underground types are most suitable to secure the safety distance, whereas site conditions should be applicable and construction costs are inevitably obstacle to construct.

There are numerous research have been performed to reduce the safety-distance, such as applying suppressing barriers, NPW (Non propagation wall), supressing steel tunnels, However, study on increasing soil cover to reduce the safety distance for the ECM has begun in Korea in the research cited [1]. Based on the fundamental study [1], safety distance reduction effects by applying the soil-cover increasing scheme are analyzed by computational numerical methods and verified field blast experiments in this study.

2. Computational Numerical Analysis

2.1. FE Model
An existing RC ECM (63PY-Type) has soil cover with 60 Cm depth for only planting purpose as shown in the Figure 2. In order to have underground effect the soil cover depth can be increased some amount, then soil cover could suppress the blast pressure occurred by internal explosion.
All the structural components as shown in the Figure 2, a typical ECM has been modeled for finite element analysis.

- ECM Dimension (Standard drawings in DMFC)
  - RC Wall thickness: 26, and 21 Cm (Figure 3)
  - Compressive strength: 24 MPa
  - Rebar: D10 and D16 (Korean Standard)

- Loads
  - Soil cover: 2.0 tonf/m$^3$
  - RC: 2.3 tonf/m$^3$
  - Rebar: 7.85 tonf/m$^3$

- Elements (Table 1)
  - 8-nodes solid element (RC and Soil cover)
  - 2-nodes beam element (Rebar)

- Mesh Size
  - 25 ~ 30 Cm (RC and Rebar)
  - 50 ~ 100 Cm (Soil cover)

### Table 1. Material Properties

| Material | Properties |
|----------|------------|
| Concrete | Comp. str.: $f_{ck}=24$ MPa Model:*MAT_CSCM_CONCRETEin LS_DYNA |
| Rebar    | Yield. str.: $f_y=400$ MPa Model:*MAT_PIECEWISE_LINEAR_PLASTICITY in LS_DYNA |
| Soil     | $G_{mod}=32.5$ MPa, $\phi=0.628$ rad, $c=1.23$ kPa Model:*MAT_MOHR_COULOMBin LS_DYNA |

- Boundary Conditions
  - Fix vertically: lower soil cover boundary
  - Fixed in-plane strain

- Analysis Conditions
  - Explicit dynamic analysis
  - Gravitational acceleration for self-weight
2.2. FE Analysis
With the computational model described in the 2.1, the following items are verified by FE analysis.

- Structural behavior due to the increased soil weight
- Protective performance against external explosion
- Blast pressure suppressing effect

2.3. Analysis Results
Structural behaviour due to the increased soil weight (Table 2 and 3)

- Maximum deflection at the crown should be in the 2% of the structure height. Therefore, in this case the limit deflection will be 106 mm. And also forming the plastic hinges is not allowed [3].
- All the cases of increased soil covers are satisfied for the deflection limits and plastic hinge limitation as follows.

| Soil cover depth | Maximum deflection (mm) | Limits (mm) | Remarks |
|------------------|--------------------------|-------------|---------|
| 6m               | 15.2                     | 106         | satisfied |
| 8m               | 14.6                     | 106         | satisfied |
| 10m              | 14.9                     | 106         | satisfied |
| 15m              | 14.3                     | 106         | satisfied |

Table 3. Plastic deformation limit state

| Soil cover depth | $T_f$  | $P_{pf}$ | $M_f$ | $M_{pf}$ | $\left(\frac{T_f}{P_{pf}}\right)^2 + \left|\frac{M_f}{M_{pf}}\right|$ | Remarks |
|------------------|--------|----------|-------|----------|-------------------------------------------------|---------|
| 6m               | 379.7  | 2516.3   | 30.9  | 112.3    | 0.29                                             | satisfied |
| 8m               | 401.1  | 2516.3   | 33.4  | 112.3    | 0.32                                             | satisfied |
| 10m              | 567.6  | 2516.3   | 45.4  | 112.3    | 0.46                                             | satisfied |
| 15m              | 526.9  | 2516.3   | 42.7  | 112.3    | 0.42                                             | satisfied |

- Protective performance against external explosion (Table 4 and 5)
  - Protective performance is evaluated applying the deformation flexibility. $\mu = X_m/X_e$ (DMFC)
  - $\mu < 1.75$ (no membrane action), $\mu < 6$ (membrane action)
  - All the cases of increased soil covers are satisfied for the protective performances as follows.
Table 4. Protective performance review (Upper explosion load)

| Soil cover depth | $X_m$ | $X_e$ | $\mu$ | $H_{allow}$ | Remarks      |
|------------------|-------|-------|-------|-------------|--------------|
| 6m               | 679   | 21    | 32.3  | 6           | dissatisfied |
| 8m               | 218   | 21    | 10.4  | 6           | dissatisfied |
| 10m              | 112   | 21    | 5.3   | 6           | satisfied    |
| 15m              | 45    | 21    | 2.1   | 6           | satisfied    |

Table 5. Protective performance review (Side explosion load)

| Soil cover depth | $\sigma_{max}$ | $\sigma_y$ | $\mu$ | $H_{allow}$ | Remarks  |
|------------------|-----------------|------------|-------|-------------|----------|
| 6m               | 157.1           | 269.5      | <1.0  | 1.75        | satisfied|
| 8m               | 218.4           | 269.5      | <1.0  | 1.75        | satisfied|
| 10m              | 234.7           | 269.5      | <1.0  | 1.75        | satisfied|
| 15m              | 234.0           | 269.5      | <1.0  | 1.75        | satisfied|

- Blast pressure suppressing effect (Figure 4, 5 and 6)
- Blast pressure leakage is considered due to the internal explosion (NEW: 50,000 lbs, 100,000 lbs, and 150,000 lbs).
- Blast pressure leakage is not occurred by the increased soil cover (10M) in the case of 50,000 and 100,000 lbs.
- In the case of the 150,000 lbs, soil cover is erupted and then blast pressure leakage is also happened.

Figure 4. Deformation shape due to internal explosion (TNT 50,000 pounds)
Figure 5. Deformation shape due to internal explosion (TNT 100,000 pounds)

Figure 6. Deformation shape due to internal explosion (TNT 150,000 pounds)

3. Blast Experiments

3.1. Test Scheme
Field explosive tests are performed with the test cases i) scale of 1/20, ii) scale of 1/16, iii) scale of 1/8 and iv) scale of 1/4 respectively as shown in Figure 7 and 8 [4].

Figure 7. Test Setups
3.2. Test Results
For the increased soil cover type ECM, suppressing effect of the blast pressure has been verified.

- The soil cover depth of the ECM is over 0.13W^{1/3}, then the safety-distance against the blast pressure due to the internal explosion with the net explosive weight (NEW, W) up 200,000lbs is decreased to 50% of the conventional ECM as depicted in the Figure 9 [4].
- The safety distance for fragments is still maintained in the case of net explosive weight is over 100,000 lbs because of the eruption.

![Figure 8. Explosion Test](image)

**Figure 8. Explosion Test**

![Figure 9. Explosion Test Results](image)

**Figure 9. Explosion Test Results**

4. Conclusions
A reduction effect of the safety-distance against the blast pressure due to the internal explosion from ammunition and explosive storage facilities. The increasing the depth of soil cover on the ECM is the most suitable scheme to suppress the blast pressure based on the construction easiness, field condition and construction cost evaluation. Both numerical and experimental analysis shows the identical result that the safety-distance can be reduced up to 50% of the conventional ECM which are described in the current DMFC. It is suggested, in this study, that the reduction of the safety-distance which is realistic upcoming problems and difficulties to be solved, can be achieved by applying the methods proposed in this paper.

**Acknowledgment**
This study has been performed by the support from Seoul National University of Science and Technology.

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