Field Performance and Rapid Repair Method of an Airfield Pavement under the Blast Load of Cluster Bomb Unit

Injae Hwang¹ Sungkon Kim¹

¹ Seoul University of Science and Technology, 232 Gongneung-ro, Nowon-gu, 139-743, Seoul, Korea

skkim@seoultech.ac.kr

Abstract. This paper discusses a field test of airfield pavement under cluster bomb unit (CBU) blast load and a study of repair method upon the examination of the damage geometry. Cluster bomb unit blast load shows a similar level to that of a typically known air-to-ground munition, and the penetration depth was calculated using empirical formulae with terminal velocity during a free fall following an explosion and dispersion 20km above the ground. Based on the calculations, the field test was executed assuming a cluster bomb unit penetration depth of 33cm for concrete pavement surface. The concrete slab on the test site was casted in a circular shape at the field and then cured. This slab was an unreinforced concrete structure with a similar compressive strength and thickness as that of airfield pavement currently in use. The test reflected the cluster munition penetration depth of 33cm, and the concrete slab was drilled in the center and explosive with a weight resembling that of the cluster munition installed. As results of the blast test show a damage to the pavement expanded the crater to a depth of 78cm, down to the crushed stone layer and with a diameter of 30cm. The concrete fragmentation requiring removal was of about 156cm in radius on average. The 7 tensile cracks across the pavement were not so heavily damaged to require removal. Cutting and removing the crushed concrete slab with dimension of 1.8m × 1.8m, compacting the disturbed crushed stone layer and repairing the concrete slab section using ultra-rapid hardening concrete are reviewed the appropriate repair method based on the above results.

1. Introduction

Recent war history shows that air operations play a critical role in securing air superiority in the initial stages of modern warfare. Therefore, the impairment of enemy air operations is an essential element in achieving victory in war. To accomplish this objective, we must preemptively attack enemy airfields in order to prevent air operations. Recently, attacks on airfields have changed to involve creation of multiple small craters by dropping cluster bomb units with multiple small warheads in the forms of Theater Ballistic Missiles (TBM) or Air-to-ground Missiles. In addition, a recent study proposes a basic structure of a multi-layer pavement system and notes that asphalt concrete is used as a sacrificial layer to partially absorb kinetic energy. However, flexible pavement weak against heat is not appropriate for airfields operating fighter jets; therefore, most airfields use rigid concrete pavements. This paper assesses the protection capabilities of rigid concrete against such attacks to identify problems with current repair methods and to propose methods for rapid damage repair. The objective of the study is to calculate concrete penetration depth using empirical formulae based on submunition dispersion height and to confirm explosion scale and form based on a live site blast test using a...
concrete pavement similar to that of an airfield pavement. A major part of the research involves a disengagement of the TBM cluster bomb unit 20km above ground and a vertical free fall to the target. The warhead forms a crater after it explodes into the pavement following its free fall. TNT amounting to that of a similar cluster munition was installed into the pavement and its explosion was used to confirm the damage to the pavement. The field test assumed that a typical dispersion warhead free fell from 20km above the ground into the airfield pavement, penetrating 33cm into the pavement. The test confirmed that an explosion within the concrete pavement causes a disturbance due to the explosive pressure from the surface to the 78cm-deep crushed stone layer. Concrete slab was deformed (upheaval and fragmentation) up to 156cm, limiting the movement of aircraft and thus requiring removal. In areas with no deformations, tensile cracks were observed but no upheavals or foreign objects, and thus requiring no foreign object removal. Paving slab with damages such as upheaval and fragmentation require dry cutting removal. The field test proved that for the removed pavement sections, the appropriate repair method is to replace the disturbed crushed stone layer and repair them with ultra-rapid hardening concrete method for quick repair completion.

2. Concrete slab penetration depth by cluster munition

There are several empirical formulae for assessing the penetration depth for concrete structures. US Army recommends the assessment of concrete panels damage depth to use UFC 3-340-01[2], [3]. Empirical formulae for concrete penetration depth for design of protection structure against impact load can used Conwep, Army corps, Haldar, Ammann and Whitney, UKAEA, BRL, Modify petry and modified NDRC.[4] Therefore, this paper assesses penetration depth using some of the above empirical formulae and determined the penetration depth for the field test assuming no complete penetration of the pavement.

2.1. Cluster bomb unit Specifications

A variety of cluster bomb units based on different weapon forms exist. As a result, there are limitations to finding the most applicable warhead specifications. Therefore, we assumed weapon specifications for a typical similar weapon from the open source, as shown in Fig 1.

![Figure 1. Cluster bomb (BAP-100) geometry](image)

The test presumed that, among the TBMs and cruise missiles with available specifications, short range attack missile include 15 ~ 40 submunitions depending on the size of the warhead, and for mid-range missiles the warheads weigh between 500kg ~ 1,000kg.[5] The field test reflected the specifications for the runway-destroying BAP-100 cluster bomb with available information, given that the warhead weight and HE weight were similar to the figure derived from total warhead weight divided by the number of submunition. Therefore, the cluster bomb unit specifications for this test are as shown in Table 1.
Table 1. Cluster bomb characteristics and Configuration of explosive

| Munition Specification | Explosive        |
|------------------------|------------------|
| Length                 | 1.78m            |
| Total weight           | 32.5kg           |
| Length of warhead      | 675mm            |
| Warhead diameter       | 100mm            |
| Warhead weight         | 18kg             |
| Explosive weight       | 3.5kg            |
| Number of munitions    | 14~42

Explosive type: HE(PBXN-109)
Composition ratio: RDX 64%, AI 20%, HTPB 16%
Density: 1.68g/cm³
Explosion velocity: 7.45m/s
TNT Conversion factor: 1.17

2.2. CBU Concrete penetration depth Calculations

Assuming no air resistance, and dispersion and vertical fall 20km above the ground, the free fall speed can be calculated using the following formulae (1), (2):

\[ v = gt \quad (1) \]
\[ s = \frac{1}{2}gt^2 \quad (2) \]

Time to reach the ground from cluster bomb unit dispersion height of 20km is calculated as 63.9 seconds based formula (2), and the velocity is calculated to be \( v = 626\text{m/s} \) using formula (1). Taking air resistance into account, the final velocity of the falling object can be calculated using the following formula (3).

\[ v_f = \sqrt{\frac{2mg}{D\rho A}} \quad (3) \]

In the equation, \( m \): the mass of the falling object, \( g \): gravitational acceleration, \( D \): drag coefficient, \( \rho \): air density and \( A \): the effective surface area of the falling object. Table 2 shows the calculations for the final velocity.

Table 2. Cluster bomb and Concrete pavement coefficient

| Projectile weight (W) | 32kg | Velocity of projectile | 470m/s |
|------------------------|------|------------------------|--------|
| Projectile diameter(d) | 0.1m | Compressive strength of concrete (fc) | 41.7Mpa |
| Shape coefficient(D)   | 0.3  | Air density(ρ)         | 1.2kg/m³ |

Applying the numbers from the above table shows that the final velocity upon impact of the explosive onto the airfield pavement is 470m/s. Applying the result to the empirical formulae for penetration depth of 33 ~ 39cm, as shown in Table 3.
Table 3. Empirical formulae for evaluation of penetration depth [4]

| Proposed by          | Empirical formula (Imperial units)                                                                 | Penetration depth x(cm) |
|----------------------|---------------------------------------------------------------------------------------------------|-------------------------|
| Conventional Weapons (ConWep) | $x = \frac{222NW_{1.8}}{d^{1.8}f_{c}^{0.5}} + d$                                              | x = 39                  |
| Ammann Whiney        | $x = \frac{282NW_{1.8}}{d^{3}f_{c}^{0.5}} \left(\frac{v}{1000}\right)^{1.8}$                  | x = 37                  |
| Modified NDRC        | $G = \frac{180NW_{1.8}}{d\sqrt{f_{c}}} \left(\frac{v}{1000d}\right)^{1.8}$, $\frac{x}{d} = G + 0.9395$ for $G \geq 1.0605$ | x = 33                  |

Where, $x =$ Penetration depth, $N =$ Nose shape factor, $W =$ Projectile weight, $d =$ Projectile diameter, $f_{c} =$ Compressive strength of concrete, $v =$ Velocity of projectile

3. Field blast trial

3.1. Construction of simulated runway pavement

Depending on the use of different related formulae, the penetration depth calculations show different results; therefore, to conduct the test assuming no penetration of the pavement, a modified NDRC equation is used to apply a penetration depth of 33cm in the field blast test. For the field blast test, a concrete pavement similar to a real life runway pavement was constructed. As shown in Fig 2, the site runway pavement structure was built in the following order: 38cm unreinforced concrete slab on the top floor; 15cm cement stabilized base layer; and 30cm crushed stone layer(15cm drainage layer and 15cm separation layer).

![Figure 2. Pavement structure](image-url)
The simulated runway was a circle with a diameter of 11.5cm appropriate for the pressure dispersion form, given that the explosive pressure is dispersed in a spherical shape manner. The concrete slab was constructed on site. The completed site simulated runway was cured for 28 days and achieved pavement strength fit for explosive tests with a shear strength of 5.47Mpa and compressive strength of 41.7Mpa. As shown in Fig 3, the test perforated 42cm with a diameter of 10cm into concrete slab and installed 4kg of industrial explosive with similar explosive damage to that of a runway-destroying BAP-100 cluster bomb unit into the penetration depth of 33cm.

![Test concrete floor plan](image)

Figure 3. Field test pavement structure diagram

3.2. Field test results and discussion
When penetrated into the concrete, explosion results in an enormous amount of impact pressure, gas, and heat. The impact pressure and heat melt or destroy the concrete, and the transmission of shock waves by the blast pressure cracks the pavement. The results of the blast test show that as shown in Fig 4 a complete penetration of the concrete of the simulated runway due to the impact pressure and heat. The impact pressure also damaged the crushed stone layer, creating a small crater with a diameter of 30cm and a depth of 78cm.

![Formation of small crater](image)

Figure 4. Formation of small crater

As shown in Fig 5, due to the dispersion of the explosive pressure per the leveling results, there were pavement upheavals of 0 ~ 7mm and cracks, and formation of fracture zones of up to an average diameter 155.8cm on concrete slab. Pavement upheavals and fracture zones limit the movement of aircraft; therefore, prior to the pavement repair, they must be completely removed. Furthermore, the explosive pressure disturbed the crushed stone layer, requiring removal of the disturbed crushed...
stones, and repair and compaction. Such processes increase the required time of repair of the completely destroyed concrete pavements due to cluster munition.

![Figure 5. Formation of fracture zone](image)

When a warhead with an explosive weight over 23kg explodes, the thickness of the concrete pavement has little effect on the diameter of the crater. However, in the case of small weapons such as multiple warheads and rockets, the kinetic energy or explosive power is generally not sufficient to penetrate thick concrete, so the thickness of the runway pavement is very important to reduce damage.[6] Therefore, the concrete strength and thickness must be increased in order to prevent a complete destruction of the concrete pavement. Stress wave from the explosion caused tensile cracks on the concrete; however, tensile cracks formed after the fracture zone was not so severe (as upheavals and surface damage is) that they prevent movement of aircraft. Removal of pavement outside the fracture zone was not required.

4. Crater repair method

Airfield runway emergency repair includes surface spall repair method, crushed stone repair method, FOD cover (FFM or AM-2 MAT installation) method, concrete cover or ascon repair method, etc., and various methods can be applied depending on the damage situation. In general, damage caused by cluster munition generates a small crater, but the extent of the damage is not known exactly. However, through this field blast test, it was able to confirm the damage scale and to suggest an effective rapid repair method. In order to confirm the movement of the concrete paving slab, the test took leveling at 40 locations. The readings showed crater diameter of 300mm and fracture zone forming on average 155.8 cm from the center of crater, with upheavals of 0 ~ 7mm and cracks of 1 ~ 2mm. As shown in Fig 6, the leveling indicated that the largest deformations occurred in Section B with removal and repair section of 1.8m × 1.8m including the crater and fracture zone. Taking into account the required depth for clearing the bedding, the test derived at 84cm for repair. The repair method for surface layer damage has been established, but the repair method for this type of damage is not standardized. Therefore, it is necessary to propose an appropriate rapid damage repair method.
This crater is too small to apply the crater MAT installation method, the quickest and most convenient temporary repair method. A set of MAT has dimensions of 18.8m × 16.5m, fit for large craters. For repair of multiple craters due to cluster bomb units, large quantities of MAT are required and thus such method is not appropriate.[7]

**Table 4. Comparison of repair methods**

| Division       | Ultra-rapid hardening concrete | Ascon               | Epoxy resin cement                  |
|----------------|-------------------------------|---------------------|-------------------------------------|
| repair method  | Pour ultra-rapid hardening concrete after cutting and removing concrete | Pour and harden asphalt concrete after removing foreign objects | Pour epoxy resin cement after removing damaged parts |
| Storage period | 18 months                     | 6 months            | 12 months                           |
| Characteristics| - Early strength development  | - Good workability  | - Early strength development        |
|                | - Excellent durability        | - Weak against     | - Excellent durability              |
|                | - In field mixing and pouring| temperature changes| - Expensive material costs          |
|                |                               | - Poor storage      | - Weak against high temperatures    |

The rapid repair method must assume wartime scenarios and must implement methods fit for repair.
of small craters using materials with extended storage duration, fast hardening times, and resistance to heat from the jet engines. As shown in Table 4, the use of ultra-rapid hardening method is identified to be the most effective method among the three method.

5. Conclusions
The study confirmed through a field test the protection capabilities of the airfield pavement against cluster bomb unit attacks and proposed potential rapid repair method for resulting damages on the runway. Dispersion of the cluster munitions of a Theater Ballistic Missile (TBM) cluster bomb attack 20km above the ground, the free falling objects penetrated the concrete pavement with a final velocity of 470m/s, and the penetration depth of 33 ~ 39cm was calculated from the empirical formulae. Assuming no complete penetration of the pavement from the cluster bomb unit, the simulated runway constructed was drilled with explosives 33cm into the pavement. The resulting crater showed a diameter of 300mm, fracture zone occurring on average diameter of 155.8cm from the center of the crater and with upheavals of 0 ~ 7mm and cracks of 1 ~2mm. Therefore, the required repairs involved a repair surface of 1.8m × 1.8m with depth of 84cm, including some parts of the crushed stone layer. Damage in the crushed stone layer requires significant additional repair time; therefore, current construction standards should be revised to increase concrete strength or thickness requirements to prevent complete penetration damage on the pavement layer upon explosion. In addition, the study confirmed the appropriate rapid repair method to be the one using ultra-rapid hardening concrete with an early achievement of strength, an extended storage period and shortest repair time.

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