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소부대 전투시설 방호두께 기준의 타당성 검토에 대한 기초 연구

A Feasibility Study Evaluating Standards for Covered-Positions Built with Concrete Materials

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Abstract

In terms of protective engineering, there are no noticeable researches regarding covered-positions for smaller units in South Korea. So, standards to maintain and build protective facilities for larger units have been applied in ones for smaller units without any adjustment. The previous study was to calculate penetration depth of the concrete walls because the experiment performed indoor. In this outdoor experiment, velocity of projectile impact as one of the other important factors was considered to prove the validity of 30cm concrete wall thickness as effective protective level of the covered-position. Random effects and extraneous variables which could be occurred in outdoors experiment were controlled with statistical techniques. As a result, velocity of projectile impact was significant variable and the given standard, 30cm thickness of concrete walls was as valid as ever.

Keywords : Covered-Position, Protective Facilities for Smaller Unit(PFSU), Protective Facilities for Larger Unit(PFLU), Piercing Depth of Concrete Wall(PDoCW), Strength of Concrete Wall(SoCW)

1. Introduction

If protection provided combatants and equipment inside Protective Facilities for Smaller Units(PFSU) - mainly a covered-position - is inadequate against threatened attacks using anticipated weapon systems, it is difficult to secure the individual activities of each combatant on the battlefield in terms of tactics. Under these conditions, it is also impossible to guarantee effective operational activities of large units[8].

In spite of this importance, PFSU(generally speaking

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units below the battalion level) have been regarded less importantly than Protective Facilities for Larger Units (PFLU). For this reason, there has been no significant research in South Korea regarding PFSU built with concrete materials. At present in South Korea, either (A) the unmodified standards for PFLU have been applied “as is” to build and maintain PFLU or (B) this extrapolation of PFLU standards to the PFSU application has been replaced with guidelines based on anecdotal results. These results are the consequence of field experience, net organized research[7,8].

In case (A), according to the suggested equation, almost 100cm thickness of concrete walls is required to protect combatants and equipment against damage from threatening projectiles[6]. This value is too unrealistic to apply in the PFSU considering economic constraints and rough condition of the surface on which the facilities are built. Although case (B) is based on anecdotal results, the suggested 30cm wall thickness has been accepted as more reasonable and its application more practical[8]. Actually, the Kim's study provided some evidence that this wall thickness could be appropriate under certain conditions for PFSU[1].

There are, however, several limitations in Kim's research. The first one is that just one factor, Strength of Concrete Wall(SoCW), was used as an independent variable. Velocity of Projectile Impact(VoPI) was not included as one of the main factors because it was impossible to precisely measure the difference of projectile speed under indoor experimental conditions with high enough accuracy.

Therefore, the research team wished to re-evaluate the feasibility of protective standards for PFSU through outdoor experimentation considering Piercing Depth of Concrete Walls(PDoCW) as a dependent variable and both SoCW and VoPI as independents variables.

2. Theory and Standards regarding PFSU

Equation 1 was suggested to assess PDoCW against impact of non-changeable projectiles by US Engineering Corps and has been used on South Korea as the engineering basis to calculate the required thickness of concrete walls for military facilities. In this equation X is Penetration Depth(cm), P is cross-sectional pressure of the projectile(kg/cm^2), D is diameter of the projectile (cm), V is velocity ratio of the projectile to the standard impact velocity(305m/s), and f_{ck} is Concrete Strength (kg/cm^2)[7].

$$X = \frac{1{,}740 \cdot \ P \cdot \ D^{0.215} \cdot \ V^{1.5}}{\sqrt{f_{ck}}} \tag{1}$$

However, it is difficult to apply this equation to the PFSU built with concrete materials because this was devised through experiments using larger caliber projectiles. The projectiles for the smaller units are anticipated to be of relatively smaller caliber. In case of the larger caliber projectile, both the probable smashing thickness to avoid cratering of the rear side of concrete walls and the probable penetration thickness to avoid complete perforation must be considered. For smaller projectiles, this tendency dose not need to be considered[7]. However, with this equation, we can determine which factors can be considered as variables to constitute the predicting equation of concrete penetration depth against to the small bullets.

Otherwise, the thickness recommended in the Technical Manual of South versus North Korea suggests relatively thinner thickness of concrete wall as shown in Table 1[8].

Table 1. the Protective thickness for the covered-position(unit : cm)

Components	Slabs	Walls
South Korea	30	30
North Korea	50	50

The difference on recommended thickness between South and North Korea was due to the different assumptions used to determine required wall thickness. North Korea considered the effects of partial aerial bombing and artillery fire, so their values are more conservative.

For reference, South Korea Engineering Corps regards KM80 as the anticipated threatening weapon system to the covered-positions due to several reasons. For security concerns, the reasons cannot be discussed in this paper. The basis of this determination is that the aim of protective facilities for smaller units is not complete defense but a relatively more effective position than the enemy.

3. Overviews of the Experiment

3.1 Randomized Complete Block Design

Blocks in an experiment are designed so that an experiment can isolate variability due to extraneous causes. These extraneous causes, or nuisance factors, may be characteristics associated with the experimental units or with the experimental setting. Blocking is a statistical technique designed to identify and control variation among groups of experimental units. A blocking factor is often referred to as a nuisance factor because of it is a source of variability but usually not a research interest[3,4]. In this experiment, Randomize Complete Block(RCB) Design was used to isolate variability caused by extraneous variables such as outdoor weather conditions and lane conditions. The weather conditions of concern were : wind speed and its direction, humidity, visibility range, and atmospheric temperature at the time of the each shooting. Lane conditions of interest were : altitude(the lane surface of the gallery is not even), direction(for reference, all walls were place to the perpendicular direction of the each lanes), and angle between the wall and the land surface. These factors, which are different lane by lane, could affect the accuracy of the results, but the effect is so insignificant so that we regarded these factors as out of interest.

3.2 Defining Mixed Model

3.2.1 Variables

The results of previous studies suggest that SoCW and VoPI will probably be the most important factors. Besides these factors, there could be lots of factors which affect dependent variable, PDoCW. Among them, we tried to control the effects of outdoors experimental conditions with blocking. However, unlike indoors experiment in which shooting was performed with the precise shooting equipment, the outdoor shooting was done by randomly selected riflemen among 56～60 riflemen of the nearest infantry battalion. Thus, the variables in this experiment are as follows.

- Dependent variable : PDoCW(P)
- Independent variable
  - Fixed factors : SoCW(S), VoPI(V)
  - Random Factors : Lanes(Blocking, B), Riflemen(R)

For reference, due to the limitation of measuring the projectile velocity at the moment of impact, the range to the wall is used instead of VoPI in this experiment.

3.2.2 Mixed Model

Unlike a previous study using Regression Analysis, ANalysis Of VAriance(ANOVA) was used in this experiment because the independent variables, SoCW and VoPI, are categorical variable, and ANOVA could be much more useful and effective than Regression Analysis in the feasibility study under economic constraints of this experiment.

As mentioned earlier, both fixed and random effects were used as independent variables. Fixed effects are those factors whose levels are selected by nonrandom process or whose levels consist of the entire population of possible levels. In this experiment, we assumed that experimental levels of each SoCS and VoPI are enough to depict all possible levels within effective ranges of machineguns and concrete strength for the covered positions. Otherwise the factor, Riflemen, has a larger number of possible choices, and we could just select a subset of riflemen to be included in this study. Considering the inference from the data analysis is about the population of levels and not only the subset of levels included in this study, the factor, Riflemen has to be regarded as random effects. So, the mixed model was considered in this experiment to involve both fixed and random factors.

3.3 Manufacturing and Establishing Concrete Walls

Fig. 1 shows a concrete wall used in this experiment. The wall consists of 4 sections. The concrete strength of the first section(beginning from the far left side) is around 150kg/cm^2. The second section is about 200 kg/cm^2. The last section is the strongest and is approximately 250kg/cm^2. For reference, the third section was strengthened with an advanced composite and used for another experiment.

Fig. 1. Concrete Walls

Concrete can be produced manually at 150kg/cm^2 on the average. Strength beyond 250kg/cm^2 cannot be made without the help of a manufacturing company. For this reason, three concrete strengths were used.

To ensure accurate concrete strength, all concrete pieces were made in Precast Concrete(PC) by a manufacturing company and then delivered to the gallery. For reference, PC was produced to satisfy the required strength within 99% confidential level and the strength of each piece in this experiment was checked using a Schmidt Hammer. The dimension of each concrete section is 150cm(width) × 130cm(Height) × 30 cm(thickness).

Fig. 2 depicts the scheme established for concrete walls in this experiment. Four lanes were used out of the 10 lanes in the gallery. Three ranges : 100, 200, 250m were tested. A concrete wall was placed at each range in each of the four lanes. Eight riflemen were randomly selected from among all possible riflemen in ○○○ infantry battalion.

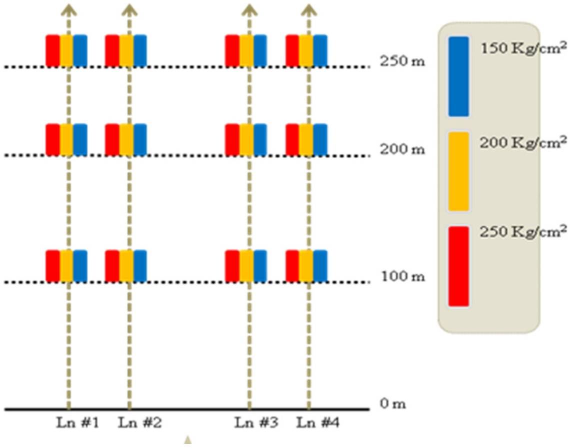

Fig. 2. Scheme for established concrete walls

4. Results

The 1st model for this experiment is as shown in Equation 2.

$$P_{ijkm} = C + S_i + V_j + SV_{ij} + R_k + L_m + SR_{ik} + SL_{im} + VR_{jk} + VL_{jm} + RL_{km} + E_{ijkm} \quad (2)$$

P_{ijkm} : The mth Observation(m=A, B, C, and D) for the ith SoCW(i=1 to 3), the jth VoPI(j=1 to 3), and the kth Riflemen(k=1 to 8)

C : Overall Mean, a Constant

S_i : Effect for the ith SoCW, a Fixed Factor

V_j : Effect for the jth VoPI, a Fixed Factor

SV_{ij} : Interaction between the ith SoCW and the jth VoPI, a Fixed effect

R_k : Effect of the kth Riflemen, a Random Effect

L_m : Effect of the mth Lane, a Random Effect

SR_{ik} : Interaction between the ith SoCW and the kth Riflemen, a Random Effect

SL_{im} : Interaction between the ith SoCW and the mth Lane, a Random Effect

VR_{jk} : Interaction between the kth VoPI and the kth Riflemen, a Random Effect

VL_{jm} : Interaction between the jth VoPI and the mth Lane, a Random Effect

RL_{km} : Interaction between the kth Riflemen and the mth Lane, a Random Effect
E_{ijkm} : Experimental Error

Covariance estimates for the random effects and the p-values for the fixed effects are shown in table 2 and 3. According to these tables, there is no significant variability contributed by the random effects : Riflemen, SoCW · Lanes, SoCW · Riflemen. In addition, the p-values of each level for these random effects are greater than significant value 0.05. This means that variability due to blocking is meaningless and any random effects need not be considered further. For reference, In the hypothesis testing of statistics, the p-value is the probability of occurring specific results at least as extreme as the one that was observed, when assuming the null hypothesis is not false. The fact that p-values are based on this assumption is critical to their correct interpretation. So, the p-values in Table 3 indicate the probability of specific occurrence can be in out of

Table 2. Covariance Estimates for the Random Effects

Covariance	Estimates
Lanes	1.9231
VoPI · Lanes	1.1265
VoPI · Riflemen	1.3602
Riflemen	0
SoCW · Lanes	0
SoCW · Riflemen	0
Residual	0.7274

Table 3. P-Vaules for the Fixed Effects

Effect	Degree of Freedom	F-value	p-value
VoPI	2	111.73	<0.0001
SoCW	2	120.72	<0.0001
VoPI · SoCW	4	5.33	0.0230

Table 4. The Estimates for the Fixed Factors

Effect	VoPI	SoCW	Estimate	Standard Error	Degree of Freedom	p-value
Intercept	·	·	43.25	0.9977	27	<0.0001
VoPI	100	·	10.5	1.4109	27	<0.0001
VoPI	200	·	1.75	1.4109	27	0.2255
VoPI	250	·	0	·	·	·
SoCW	·	150	5.5	1.4109	27	0.2255
SoCW	·	200	1.75	1.4109	·	·
SoCW	·	250	0	·	·	·
VoPI · SoCW	100	150	7	1.9954	27	0.0016
VoPI · SoCW	100	200	4.25	1.9954	27	0.0424
VoPI · SoCW	100	250	0	·	·	·
VoPI · SoCW	200	150	1	1.9954	27	0.6203
VoPI · SoCW	200	200	-2	1.9954	27	0.3251
VoPI · SoCW	200	250	0	·	·	·
VoPI · SoCW	250	150	0	·	·	·
VoPI · SoCW	250	200	0	·	·	·
VoPI · SoCW	250	250	0	·	·	·

both extreme points. In here, specific occurrences means that each fixed factors cannot be significant to form the predicting model. According to Table 3, All fixed effects do have meaningful p-values less than 0.05. So, fixed effects involved in this model have to be considered further. Thus, the modified 2nd model is as shown in Equation 3.

$$P_{ij} = C + S_i + V_j + SV_{ij} + E_{ij} \tag{3}$$

Table 2 and 3 show the estimates and p-values of each fixed effects.

According to these tables(4, 5), all fixed values are significant. The residual(E_{ij}) is 3.9815 and the adjusted R-square is 0.9110.

Table 5. Estimates for the Fixed Factors in the Modified Equation

Effect	Degree of Freedom	F-value	p-value
VoPI	2	111.73	<0.0001
SoCW	2	120.72	<0.0001
VoPI · SoCW	4	5.33	0.0230

Lastly, the p-value of the hypothesis as shown in Equation 4 for feasibility test of PFSU is 0.0211 which is less than significant value 0.05. This means that KM80 cannot penetrate 30cm of concrete wall when exposed to the anticipated threatening environment. Complete penetration means that projectile passes through half of the protective wall[7,8]. So the right hand value of the hypothesis equation is 15. For reference, the complete penetration considered the possibility of scab on the rear side of concrete wall. Although there were no scab phenomenons in this experiment, this tendency cannot be ignorable so that it has to be reflected to the total penetration depth of concrete wall.

$$Ho : PDoCW_{SoCW=150kg.cm^2,\ VoPI=100m} = 15 \tag{4}$$

5. Conclusion

The comprehensive aim of this research is to verify the feasibility of the protective standards for the PFSU (30cm). Prior to feasibility study, the first step is to identify the significant factors which affect the PDoCW. Among the possible fixed and random effects, two main factors : SoCW and VoPI and their interaction : SoCW · VoPI were significant. The random effects were proven insignificant at 0.05 and eliminated. Furthermore, blocking to control extraneous variation in the outdoors experiment could henceforth be ignored.

We obtained an ANOVA model with around with 0.9 adjusted R-square as shown in Equation 3. In addition, with a hypothesis test using this equation, we concluded that protective standards for the PFSU, 30cm wall thickness were valid.

However, although the 30cm wall thickness is reasonable in terms of protecting combatants and equipment in covered-positions, this thickness make the angle of fire narrow. So, to relieve this problem owing to heavy wall thickness, the alternative method is required.

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