JOURNAL OF SCIENCE OF THE MILITARY ACADEMY OF LAND FORCES

Volume 47 Number 3 (177) 2015

DOI: 10.5604/17318157.1187460

DETERMINATION OF SAFETY LINES OF ARTILLERY FIRE

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Received on 15 August 2014; accepted in revised in April 2015

Abstract:

The article presents the issue of determining safety lines in terms of executing missions of fire support in the proximity of friendly forces by artillery units. The first part describes the existing rules on firing in the vicinity of own troops in combat operations. Further, there are defined simplifications used to determine safety lines and the capabilities of achieving greater accuracy of its calculation under conditions of contemporary warfare.

Keywords:

artillery, safety lines, safety of friendly forces, fire support

INTRODUCTION

Ensuring safety for forces fighting in direct contact with the enemy decisively affects the posibility of using artillery. In the history of wars there have been observed numerous cases of errors in result of which troops come under the friendly artillery fire. In addition to many victims and wounded, such firing has catastrophic psychological implications since it causes panic, intensifies fear, lowers morale and undermines the troops' confidence in their own artillery. Precise ammunition, which with 100% probability of point striking at a designated target, meets the requirements to ensure safety of units fighting in front of their own artillery troops, but its production costs are very high. Therefore, guaranteeing safety of troops without any significant cost increase is associated with the use of appropriate fire control systems and firing procedures, that enhace the effectiveness of unguided munitions.

The fundemental measure to reduce the risk of exposing own troops to an artillery attack is to set in the field safety lines of artillery fire, that is a line located at a minimum distance from the target under artillery fire where the troops can be positioned without the risk of being endangered by fragments or shock wave of falling missiles.

Despite the implementation of modern fire control systems leading to significant reduction of the time of open fire, it is not possible to eliminate errors in determining settings and precisely calculate the point of a shell impact. Undoubtedly, there is a close dependence of central errors in the direction and the range on methods of specifying the settings. The big problem is the dispersion effect, the value of which can be defined mathematically only within certain percentage classes. Thus, the phenomena accompanying shelling, such as the dispersion, errors in determining settings and the damage radius (shock wave) of fragments of shells constitute componentss the sum of which gives the value of own troops safe distance from the point of the impact of a shell.

The purpose of this article is to clarify methods of determining the position of safety lines during artillery firing in the vicinity of friendly forces, which must be considered in terms of firing conditions such as a tactical situation as well as ballistic and meteorological conditions.

1. REGULATORY ARRANGEMENTS FOR DETERMINING SAFETY LINES

Artillery fire brings the desired effect when its settings are determined by means allowing to surprise the enemy. Thus, the basic method to specify settings for shelling is to calculate them on the basis of complete information on firing conditions, which does not require prior ranging. Ranging fire which may signal the intention to use artillery is the method of secondary importance and it is implemented exclusively only when there is no comprehensive data on shelling conditions1. Regardless of the method of determining the settings, while performing fire tasks in the vicinity of friendly forces it is necessary to minimise the risk of artillery fire collateral damages.

In order to ensure safety of friendly forces around the area of targets the commander of an artillery unit is obliged to:

- appoint shells and loads that cause the least possible dispersion;
- conduct inspection for determining firing settings;
- avoid changing the number of a load during the implementation of a fire task as well as firing with different parts of loads;
- if settings for firing are defined as the range of fire – start the adjustment with such a calculation that allows obtaining the deviation of the first explosion from the target in the opposite direction from the position of own troops;

[1] *Instrukcja strzelania i kierowania ogniem pododdziałów artylerii naziemnej,* part I, the General Staff of the Polish Armed Forces, Warszawa 1993, point 11, p. 14.

- carry out continuous monitoring of explosions and activities of units of friendly forces;
- in defence – initiate and conduct fire from threaded high explosive fragmentation shells without ranging at targets located no closer than:
- 300 m (500 m with fire applied at the range of more than 10 kilometres) from own troops hidden in trenches, tanks or other armoured vehicles;
- 500 m (700 m with fire applied at the range of more than 10 kilometres) from own troops outside concealments or in unarmoured vehicles (Figure 1);
- in defence – initiate and maintain rocket artillery fire at the targets located no closer than 1000 m from own troops, regardless of the type of a shell and the range of firing[2].

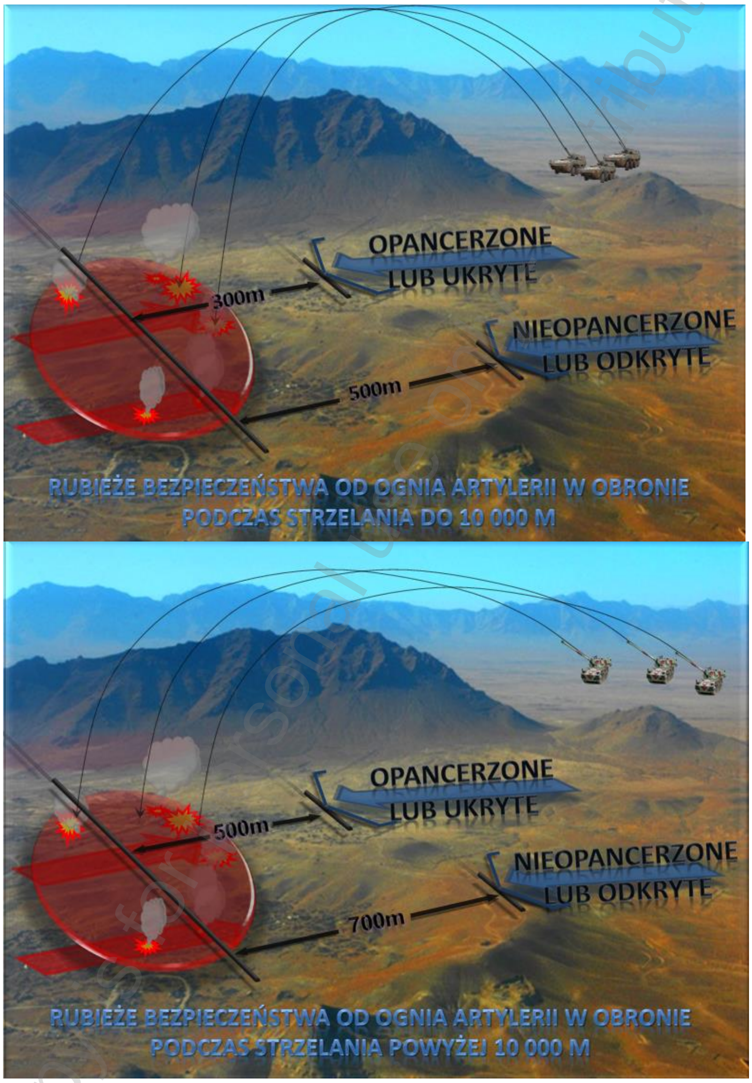

Fig.1. Safety lines from artillery fire in defence

Source: own study

[2] Ibidem, point 14, p. 15.

While conducting the close fire to support an attack, artillery units carry out tasks at targets being approached by friendly forces. The disabling artillery fire brings the expected effect provided that it is applied for a long time, that is until the point where own troops reach the safety lines. After the troops' approach, at the prearranged signal artillery interrupts shelling and moves it in the depth. The distance of safety lines from friendly forces during an attack is (Figure 2):

- 200 m – in the case of an assault of tanks;
- 300 m – in the case of an attack of infantry fighting vehicles and transporters;
- 400 m – during an attack of infantry.

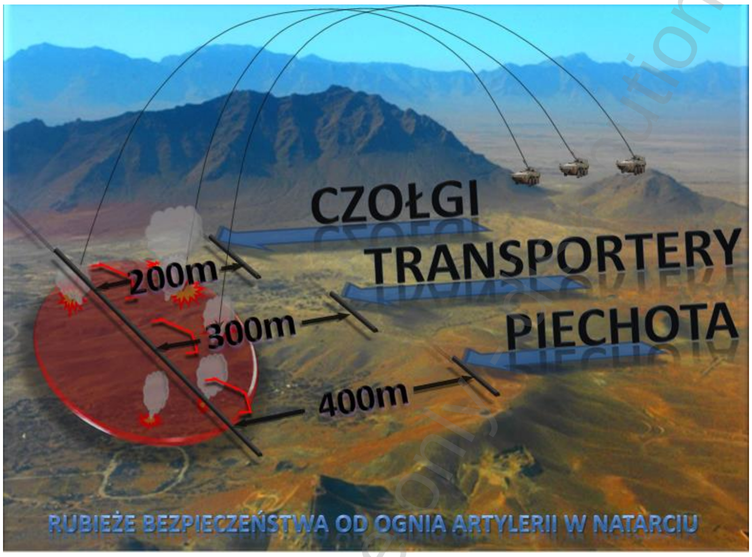

Fig.2. Safety lines from artillery fire during an attack

Source: own study

The aforementioned distances relate to essential combat operations (an attack, defence) and constitute certain simplifications in determining safety lines because they are defined as mean values while firing at 2/3 of the range. The determination of safety lines while applying effective fire without ranging at targets placed in the vicinity of own troops is made in accordance with the following formula[3]:

$$R_b = 4E_{Do} + 4Ug_o + r_{max} \quad (1)$$

where:

E_{Do} – calculation errors in determining settings in ranging;

Ug_o – calculation central tilts in the depth;

r_{max} –the maximum dispersion range of splinters.

[3] *Objaśnienia do instrukcji strzelania i kierowania ogniem artylerii naziemnej,* part. I, the Ministry of National Defence, Warszawa 1989, p.30.

The sum of errors determining settings of effective fire and the dispersion of explosions in the range (while a battery is shelling at the distance of up to 10 km) is $E_{Do} = 60$ m, $Ug_o = 30$ m, whilst at the range of more than 10 km, these figures are respectively 120 m and 60 m.

The maximum damage radius of fragments $(r_{\max})$ for uncovered or unarmoured troops is – 200 m and 100 m – for concealed or armoured ones.

The distance of safety lines calculated according to the formula (1) is somewhat overvalued (about 20–30%)[4]. This is due to the fact that during the wing fire of a battery the position of safety lines is laid down the same as in carrying out shelling at frontally placed targets, even though errors in determining settings in the direction are on average 1.5 times and the dispersion of shells is 5 – 8 times lower in relation to errors in determining settings and the dispersion in the range.

The exact distance of safety lines while conducting effective fire after ranging is calculated as the sum of the damage radius of fragments and the dispersion of shells. Errors in determining the setting are not included in the distance of safety lines because they are taken into account in the course of ranging. Therefore, the safe distance of own troops from a target of shelling after ranging is calculated as follows[5]:

$$R_b = 4Ug_o + r_{\max} \qquad \textbf{(2)}$$

If friendly forces are in lightly armoured vehicles, the damage radius of fragments does not exceed 50–60 m, but the rounded up value of $r_{\max} = 100$ m is taken to simplify calculations.

The interpretation of the method of determining safety lines when ranging presented in *"Notes to the instruction for shelling and artillery fire control Part I"* mainly deals with carrying out typical military operations where attacking friendly forces approach to the target which artillery is effectively firing at.

Due to the specificity of determining settings on the basis of ranging in which the position of explosions in the field must be observed, ensuring safety of own troops is not difficult. Simply the point of the settings determination needs to be moved to the direction opposite to the position of troops. The value of movement depends on the distance of friendly forces from the target, the location of own troops in relation to the direction of shelling, terrain conditions, the firing range, the level of the concealment (armouring) of own troops as well as the type of a projectile, a caliber and the flight trajectory of a shell.

[4] K. Krauze, Z. Olbrycht, R. Piotrowski, *Określanie nastaw do ognia skutecznego na podstawie strzelania,* WSO – JB Wewn 275/02, Toruń 2002, p. 52.

[5] *Objaśnienia do instrukcji strzelania i kierowania ogniem artylerii naziemnej,* part. I, the Ministry of National Defence, Warszawa 1989 p.31.

Shelling with fire adjustment prolongs the time of the artillery fire response that reduces its effectiveness and the probability of hitting a target. There is a need to open effective fire against the target without ranging, while guaranteeing safety of friendly froces at the same time. In this case, ensuring safety of own troops is much more difficult and the decision to open fire is burdened with a great responsibility that lies with the fire support coordinator. The positive decision on the execution of fire when own units are not far enough entails the consequences of attacking own troops (*friendly fire*)[6].

In the era of computerisation one should consider replacing simplifications applied in determining safety lines by precise calculations that allow to determine its optimal distance for various combat assets, taking into account the range of shelling and the respective positions of battle line elements.

The solution to this problem would be summary tables to determine safety lines or the development of a specific program which based on the parametres set would calculate its value in the given conditions of executing a fire mission.

2. THE INFLUENCE OF ERRORS IN DETERMINING SETTINGS ON MARKING OUT SAFETY LINES

The determination of settings of effective fire is burdened with central errors in the range and direction. For the analysis of the value of central errors in determining settings there are used two basic principles of the probability calculus: the assertion of the variance of the sum of independent random variables (random errors) and the assertion of the variance of the linear function of independent random variables[7]. Specifying settings based on full information about firing conditions (PDoWS) requires the following steps:

- defining coordinates and the height of a target;
- defining coordinates and the height of a fire post (SO) and targeting cannons in the main direction;
- defining meteorological and ballistic conditions of firing;
- preparation of cannons and ammunition for firing;
- determining settings for firing and introducing them into aiming devices of a cannon.

Errors in determining settings for firing in the range and direction are the sum of all errors made in carrying out the above mentioned activities. As sources of these errors are independent, thus the sum of occurring random variables is the value defined as the total value of central errors made. While analysing the individual steps one can extract those that during a fire mission occur once or repeatedly. When considering

6 *Eng. "friendly fire"* the term borrowed from the US Army nomenclature, is an accidental attack on friendly or alliance forces, caused by misidentifying own troops as hostile, or due to errors or inaccuracy (while attempting to attack the enemy the shells reached own troops positioned near the enemy forces).

7 K. Krauze, Z. Olbrycht, R. Piotrowski, S. Krzyżanowski, *Określanie nastaw do strzelania na podstawie pomiarów i obliczeń,* WSO – JB Toruń 2002, p. 154.

particular groups of errors it can be easily seen that errors in defining coordinates and the height of a target (except for a moving target) as well as determining settings for shelling and putting them on the sights during one fire mission are made once, so after corrections in the course of a task execution these errors no longer affect the accuracy of a mission. The same can be said about errors resulting from the determination of coordinates of a fire post, targeting cannons at the main direction as well as preparations of cannons and ammunition for shelling. The values of these errors, despite a variety of sources, substantially do not change in the course of performing a single task. The result of the occurrence of such errors is only the movement of the centre of a dispersion area in relation to the centre of a target. Once the appropriate corrections to the range and direction are introduced, these errors are not important any longer, as they do not change further during the task.

The exceptions are meteorological and ballistic conditions of firing, precisely the deviation of their actual values from conditions included in the calculation, because the parametres at each shot are not the same and taking instantaneous values into account in the process of determining settings is practically impossible. The values of elementary errors in meteorological and ballistic praparations are subject to constant changes, therefore in artillery practice when determining settings only their average values (median) are taken into consideration The typical example is measuring the wind speed and its direction while the atmosphere is being probed, which is marked as the median value for the individual altitudes. In fact, at any altitude the instantaneous values change causing some temporary deviations from the standard deviation being considered when determining settings. The important factor is also the time that elapsed from taking measurements for firing and the distance of a fire post (SO) from the place of probing the atmosphere.

As a result, central errors arising from defining the meteorological and ballistic firing conditions can be divided into two parts in terms of their impact on a flight trajectory of projectiles. The first part, which affects the moving of the dispersion area centre in relation to the target centre results from the difference between averaged values (standard deviations) of actual shelling conditions and values assumed for the purpose of identifying aggregated data. The second part is a derivation of instantaneous values occuring during each shot from the standard deviation of actual firing conditions, which is reflected in the size of the dispersion area.

Values of central errors in the range and direction for cannons and mortars when determining settings based on PDoWS are shown in Table 1, whereas during a fire maneouver – in Table 2.

If at the same time there are not more than two derogations from the conditions of a detailed preparation set out in section 110 of "Instruction for shelling", errors in the determination of settings in the range fall within the limits of 1.1–1.5%. In the case where ballistic and meteorological conditions of shelling are taken into account through an approximation, central errors in the cursory preparation increase to the value of 4% in the range and 0–10 thousand in the direction. In such situations, it is necessary to define settings for the effective fire on the basis of ranging. However, in a situation where it is not possible to take account of corrections to the deviation of actual shelling conditions from tabular ones, errors in determining settings increase rapidly and are within the limits of 8–10% in the range and 30–40 thousand in the direction. This type of determining settings commonly called "by sight" should be treated as a forced phenomenon, which in combat operations must be avoided and used only as a measure of last resort.[8]

Table 1. The accuracy of determining settings based on comprehensive data on the conditions of shelling

Types of artillery	Central errors	
	(E_D) in the range	(E_K) in the direction [in thousands]
Cannons	0,7 – 0,9 %D	3 – 5
Mortars	0,8 – 1,8%D	5 – 10

Source: "Notes to the instruction for shelling and artillery fire control", part I, the Ministry of National Defence, Warszawa 1989, p. 89.

Table 2. The accuracy of determining settings of effective shelling on the basis of a fire maneouver

Types of artillery	Central errors	
	(E_D) in the range	(E_K) in the direction [in thousands]
Cannons	0,5 – 0,7 %D	3 – 4
Mortars	0,7 – 1,6%D	5 – 10

Source: "Notes to the instruction for shelling and artillery fire control", part I, the Ministry of National Defence, Warszawa 1989, p. 190

The distance of safety lines which results from errors in determining settings in specific conditions of performing a fire mission, with the type of equipment and shelling range taken into account, can be calculated on the grounds of the data contained in Annex 2 to *"Notes to the instruction for shelling and artillery fire control Part II"* and the formula (3):

$$Rb_E = \sqrt{4E^2_{D_O} + 4E^2_{K_O}} \quad (3)$$

[8] *Objaśnienia do instrukcji strzelania i kierowania ogniem artylerii naziemnej,* part. I, the Ministry of National Defency, Warszawa 1989 p.107.

where:

E_{Do}, E_{Ko} – calculation values of central errors in determining settings in the range and the direction while advancing a target by a single squadron.

Maximum values of errors in determining settings in the range and the direction on the basis of full information regarding conditions of firing from cannons and mortars for high explosive fragmentation shells are shown in Table 3.

Table 3. Maximum values of errors in the range and the direction and the value of a circular error when determining settings on the basis of full information regarding conditions of firing for cannons and mortars

The type of equipment	Range	$4E_{Ko}$	$4E_{Do}$	$\sqrt{4E_{Ko}^2 + 4E_{Do}^2}$
Cannons	4000	84	144	167
	6000	126	216	250
	8000	168	288	333
	10000	210	360	417
	12000	252	432	500
	14000	294	504	583
	16000	336	576	667
	18000	378	648	750
Mortars	2000	84	144	167
	4000	168	288	333
	6000	252	432	500
	7200	302	518	600

Source: own study

Based on the data contained in Table 3 and the graphical interpretation shown in Figure 1 it is evident that the value of circular errors in determining settings is about 20% higher than the value of the central error in the range, which is the basis to determine safety lines in existing procedures. This means that the position of safety lines is not defined precisely in situations where safety of own troops is influenced by central errors simultaneously in the direction and the range.

Another equally important element in the safety lines determination is the fact that effective fire settings, excluding automated fire control systems, are basically established to the centre of a target, which hinders the determination of safety lines position in relation to the proximal parametre of a target. In the case of firing against group targets, the depth of which is 100 m or more, located in front of own troops and the firing plane, in calculations of the position of safety lines it would be more convenient to add ⅓ of the target depth (the value of the sight leap). However, in a situation in which the position of own troops in relation to the firing plane is perpendicular (wing), ½ of the target width should be taken into account, as the first (last) cannon (mortar) shoots respectively the right (left) boundary, including the value of the shaft in settings

In situations in which the position of own troops is diagonal towards the line of fire, the circular value of the two parametres should be similarly included in the calculations (⅓ of the depth and ½ of the width of a target). It follows that the value of safety lines is also dependent on the angle between the line of observation and the firing plane called the observation angle (*i*).

3. THE IMPACT OF THE DISPERSION ON DETERMINING SAFETY LINES

Despite the modernisation of unguided artillery ammunition, the dispersion effect which poses a serious threat to safety of units performing tasks around a target under fire cannot be eliminated.

The point at which an average flight trajectory of shells intersects the plane of the terrain is called the centre of the dispersion area. The parametres characterising the dispersion area size are the values of the deviation in the depth and width, which are compiled in artillery firing tables for each type of a load and range. So as to increase safety of own troops the parametre used in the formula (1) Ug_o should be replaced by the value of the deviation appropriate for actual conditions of the battle line, and the position of safety lines Rb_U caused by the dispersion of shells in the range and the direction should be calculated according to the following formula:

$$Rb_U = \sqrt{4Ug_o^2 + 4Us_o^2} \quad (4)$$

where:

Rb_U – the distance of safety lines from friendly forces determined by the dispersion of shells in the range and the direction;

Ug_o – the deviation in the depth;

Us_o – the deviation in the width.

Table 4 lists maximum values of the deviation in the depth and width appropriate for individual ranges for firing with the strongest load.

Table 4. Calculated values of the deviation in the depth and width and their circular values for selected artillery assets for the strongest load

The type of equipment	Range	$4Us_o$	$4Ug_o$	$\sqrt{4Us_o^2 + 4Ug_o^2}$
122 mm 2S1 Gvozdika	4000	8	52	53
	6000	14	64	65
	8000	23	80	83
	10000	25	92	95
	12000	29	112	116
	14000	38	132	137
152 mm self–propelled gun howitzer DANA	4000	5	76	76
	6000	7	68	69
	8000	10	72	73
	10000	13	96	97
	12000	17	124	125
	14000	23	144	146
	16000	30	168	171
	18000	48	212	217
120 mm M–120	2000	48	80	93
	4000	88	152	176
	5500	96	204	225
98 mm M–98	2000	32	80	86
	4000	68	160	174
	6000	100	240	260
	7200	120	288	312

Source: own study

The graphic interpretation of the impact of errors in determining settings, the dispersion of shells and the damage radius of fragments on the value of safety lines is shown in Figure 3

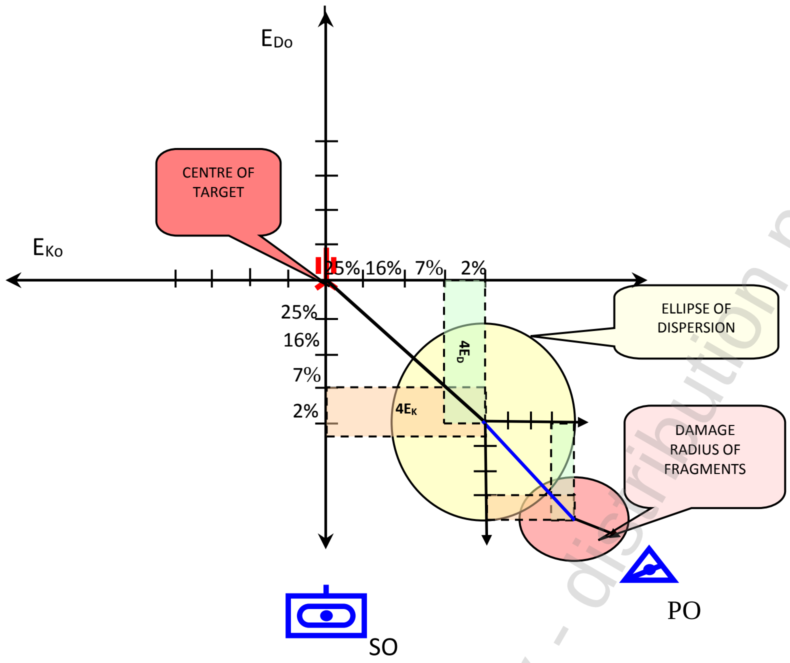

Fig.3. The impact of errors in determining settings in the range and the direction, the dispersion and the damage radius of fragments on defining safety lines

Source: own study

4. THE IMPACT OF THE SIZE OF THE DAMAGE AREA OF A PROJECTILE ON DETERMINING SAFETY LINES

The impact of a high explosive fragmentation projectile consists of a shell fragmentation activity and demolition activity of a shockwave. When the two types of activities are combined in a single projectile, essential requirements for both types of projectiles are not possible to meet. High explosive fragmentation projectiles compared to similar masses of metal of a shell and an explosive must give way to fragmentation projectiles under frag actions and to high explosive projectiles under demolition actions. A frag action depends on the number and energy of projectile fragments obtained under the given conditions of firing. The ability to rupture a projectile into fragments, called the fragmentation, depends on[9]:

- a caliber and the weight of a projectile;
- the weight and the type of an explosive and the nature of detonation;
- mechanical properties of metal of the projectile shell;
- the structure of a projectile (the size and shape of the shell and the slit chamber on the body);
- firing conditions, i.e. from:

[9] *Amunicja wojsk lądowych, textbook, the Ministry of National Defence, Warszawa 1985, p. 35.*

- the type of firing (attack, ricochet, splash), and from the angle of the impact on an obstacle or the height of splash:
- the level of hardness of the ground in the place where a projectile falls ;
- the type of settings and properties of the fuse.

The fragmentation action of projectiles is defined by:

- the number of effective fragments;
- the location of fragments on the plane or within the space of an attack;
- the damage radius of fragments.

Knowledge of the degree of the projectile fragmentation allows the statement that for every 1 kg of the shell metal it is possible to obtain 50–55 fragments of the mass of 4–5 g and greater. In practice two types of fragmentation: random and forced are dealt with.

4.1. The damage area of a high explosive fragmentation projectile during direct firing

A steel projectile with random fragmentation during the explosion produces three shafts of fragments of: the warhead part (20%), walls of the shell (70%), and the bottom part (10%). The initial speed of fragments ranges from 500–1000 m/s and rapidly decreases due to their irregular shapes and in–flight instability, and consequently the effective damage area is small. The total area of effective striking is about 800 m^2, where the target is uncovered infantry and 300 m^2 when the infantry is hidden in the trenches[10]. In terms of the shape the area is similar to a rectangle the long side of which is perpendicular to the direction of firing. The area dimensions for 122 mm high explosive fragmentation projectiles are (40 x 8 m)[11], it follows that the maximum damage radius of fragmentation is about 36 m. The proportion ratio width / rectangle side length of the effective destruction area of fragments is 4:1, as shown in Figure 4.

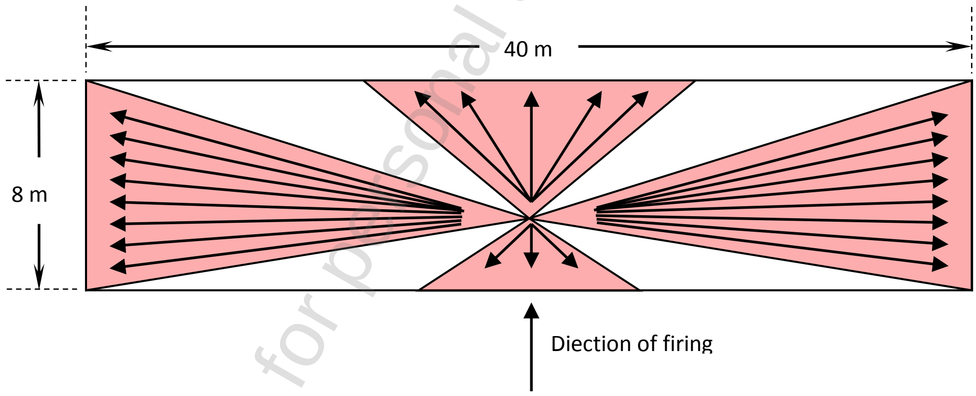

Fig. 4. The damage area of a projectile fragments at the angle of the impact up to 50° (plan view)

Source: Amunicja wojsk lądowych, textbook, the Ministry of National Defence, Warszawa 1985 p. 38

[10] *Artyleria i rakiety, textbook,* the Ministry of National Defence, Warszawa 1972, p. 243.

[11] *Amunicja wojsk lądowych, textbook,* the Ministry of National Defence, Warszawa 1985, p. 38.

The destruction area of fragments is approximately 950 m^2 for the 152 mm self–propelled gun howitzer DANA firing high explosive fragmentation projectiles[12]. The area dimensions for 152 mm high explosive fragmentation projectiles are about (64 x 15 m) and the maximum radius of fragmentation is approximately 36 m. When firing high explosive fragmentation projectiles the computing damage zone depends mainly on the angle of the fall. With the increase of the angle of the fall the computing destruction zone also increases, and particularly the growth occurs at the fall angle of (20 –30 °)[13].

At small angles of the fall, presented in Figure 5, a significant part of fragments go side-ways, some of them get stucked in the ground or fly up, and a small part of them, mainly from the head and bottom part of a projectile, falls apart forward and backward.

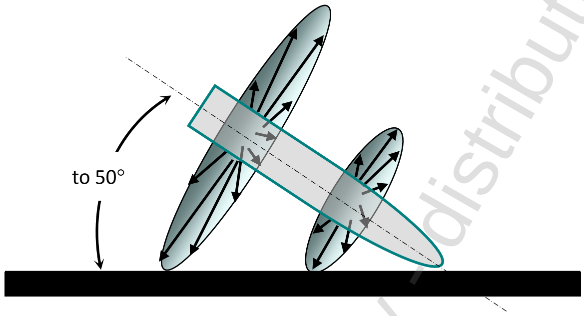

Fig. 5. The damage area of a projectile fragments at the angle of 50° fall (side view)

Source: own archive

Figure 6 shows the explosion of the 122 mm 462 OF projectile while firing the load No. 3 at the range of 5200 m with the fuse set on the action with a short delay release at the angle of about 25 ° fall. There are clear streaks of fragments flying upwards at the angle of about 70 °.

Fig. 6. The explosion of a projectile with the fuse set on the action with a short delay release

Source: own archive

[12] *Artyleria i rakiety, textbook,* the Ministry of National Defence, Warszawa 1972, p. 243.

[13] *Objaśnienia do instrukcji strzelania i kierowania ogniem artylerii naziemnej,* part I, the Ministry of National Defence, Warszawa 1989, p.17.

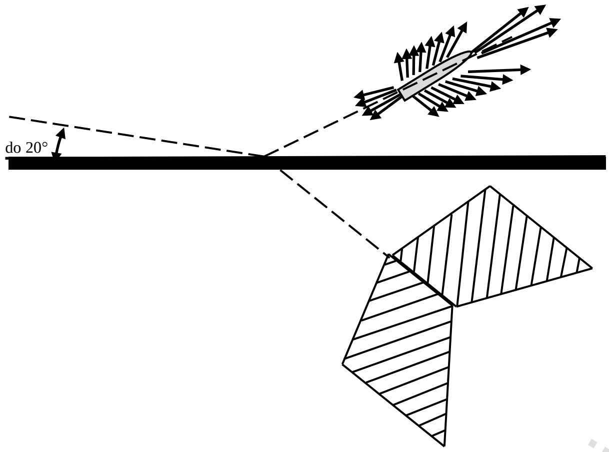

Fig. 7. The damage area during ricochet firing

Source: own study

The height of the detonation point of a projectile is not greater than 10 – 15 m, while its distance from the ricochet point caused by the long delay set on the fuse is between 3 to 5 m. Being low, the value of the shift of the detonation point can be skipped while calculating safety lines, and the shift is compensated by applying rounding of values of safety lines distances up to full tens of metres. A view of the air missile explosion during ricochet firing is shown in Figure 8.

Fig.8. The air missile explosion during ricochet firing

Source: own archive

Experiences of shelling at ground targets with high explosive fragmentation projectiles indicate that at the angle of up to 10° fall 100% of ricochets can be achieved, at the angle of 20 ° – about 75–80%, while at further increasing of the angle of the fall the number of ricochets quickly fall. On the other hand, with minimal fall angles (1° – 2°) the fuse does not work until the second or third ricochet, which is important for safety of own troops if an enemy is between friendly forces and a unit executing a fire task.

Splash firing is very effective, as the calculation surface of the damage area is nearly 2 times larger than the calculation area of a projectile detonating in the ground. Furthermore, due to the even dispersion of fragments and the minimised loss of energy of projectiles that is absorbed by the soil, the efficiency of targets destruction grows. Therefore, during firing at personnel with projectiles with a proximity fuse their consumption can be reduced by 1/3[14].

4.2. The damage area of a high explosive fragmentation projectile during high angle firing

At the angles of impact close to 90° the most of fragments of projectiles fall apart evenly in all directions, as shown in Figure 9, forming a circular surface of the effective destruction area. [15]

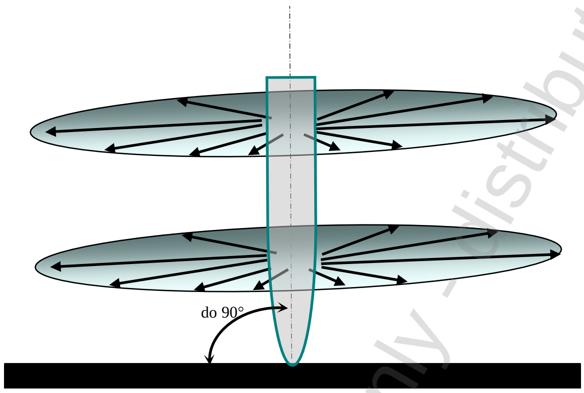

Fig 9. The damage area of projectile fragments at the angle of the impact within the limits of 50°–90° (side view)

Source: own study

During high angle firing the impact of fragments on uncovered targets spread on sandy ground or snow (to the depth of 20 – 40 cm) is about two times lower compared to targets situated on soild ground, and up to five times smaller with afloat targets. Depending on the ground type the destruction radius of fragments is from 40 to 75 m, but the effect of uniformity is provided by even firing in all directions. Assuming the twice maximum value of the impact of fragments we get the calculation value to determine safety lines of 150 m. 98 mm RAD–3 mortar grenades go off into around 4000 fragments weighing more than 1.7 grams, which strike targets within a radius of 75 metres. When firing at targets in open trenches it is recommended to use projectiles set at an immediate action. In this case, the targets are attacked not only by fragments but also a shock wave capable of destroying light fortifications. Based on the analysis of the destruction area of fragmentation shells the following conclusions can be drawn:

[14] K. Krauze, Z. Olbrycht, R. Piotrowski, *Określanie nastaw do ognia skutecznego na podstawie strzelania,* WSO – JB Wewn 275/02, Toruń 2002, p. 65.

[15] Ibidem, p. 17.

- During direct and indirect firing with 122 mm howitzer 2S–1 Gvozdika and 152 mm gun–howitzer DANA the radius of the effective striking distance of firing with high explosive fragmentation projectiles with the impact fuse does not exceed respectively 22 and 36 metres;
- The initial speed of fragments rapidly decreases due to their irregular shapes and in–flight instability, thus the effective destruction area is small. The maximum dispersion radius of fragments while firing with high explosive fragmentation projectiles with the impact fuse can be taken for the calculation as twice the maximum radius of the dispersion radius of fragments, which is 44 m – for 2S–1 Gvozdika, and 72 m – for 152 mm DANA. These values can be used regardless of the degree of concealment or armouring of friendly forces;
- High angle firing allows to achieve the effect of the even impact of fragments in all directions and the radius of destruction ranging from 40 to 75 m.

CONCLUSIONS

Contemporary armed conflicts are characterised by great dynamics of actions and extensive capabilities of conducting fire manoeuvres. The development of techniques of protecting equipment and soldiers from fire, wih the simultaneous increase of the accuracy of determining settings, allows the execution of fire support tasks in the very close proximity of friendly forces.

On the basis of the foregoing considerations the following **conclusions** can be drawn:

1. When the firing plane is parallel to the observation line (front fire) the formula for calculating the distance value of safety lines from friendly forces can be presented in the following form:

$$R_{B_c} = 4E_{D_O} + \frac{Gł_C}{3} + 4Ug_O + r_{\max} \quad \textbf{(5)}$$

where:

R_{B_c} – the size of front safety lines ;

E_{DO} – the calculation value of a central error in determining settings in the range;

$\frac{1}{3}Gł_c$ – the value of settings displacement towards closer (further) line of a group target fired at in an overlapped way or with graduation expressed in metres;[16]

Ug_o – the calculation value of the deviation in the depth;

$r_{\max}$ – the maximum damage radius of a projectile fragments.

[16] *In case of firing at a single target this value is zero, while firing at a target with two batteries without division into battery sections the value is* $\frac{1}{6}Gł_C$.

2. If the shelling plane is perpendicular to the observation line (wing fire) the value of safety lines can be expressed with the formula:

$$R_{B_S} = 4E_{K_O} + \frac{Sz_C}{2} + 4Us_O + r_{max} \quad (6)$$

where:

R_{B_S} – the wing safety line;

E_{K_O} – the calculation value of a central error in determining settings in the direction;

Us_O – the calculation value of the deviation in the width;

$\frac{1}{2}Sz_C$ – the value of settings displacement to the right (left) line of a group target, expressed in metres.

3. In the situation when the firing plane is located diagonally with respect to the observation line, the safety line can be calculated by the formula:

$$R_{B_U} = \sqrt{4E_{D_O}^2 + 4E_{K_O}^2} + \sqrt{4Ug_O^2 + 4Us_O^2} + \sqrt{\left(\frac{Sz_C}{2}\right)^2 + \left(\frac{Gł_C}{3}\right)^2} + r_{max} \quad (7)$$

where:

R_{B_U} – the diagonal safety line.

4. Taking twice the maximum value of the fragmentation action, the calculation value of the fragmentation radius of projectiles of 150 m can be set, while during ricochet firing – 200 m, regardless of the type of soil, a caliber, a fuse and a flight trajectory of a projectile.
5. With computerised fire control systems at disposal, formulas for the calculation of the distance from the position of safety lines from friendly forces in specific situations should be included in them. In this way it avoids simplifications used today and takes into account the real conditions of firing, such as a range, a caliber, a type and a trajectory of a projectile.

The above considerations clearly show that there is a need to increase the precision in determining the distance of safety lines from friendly forces. In contrast, the present solution is one of the possible proposals to eliminate simplifications in this regard. The presented issue needs further discussion and the end result may be an important factor in taking decision to open artillery fire.

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HOW TO CITE THIS PAPER

Świętochowski N., Piontek J., (2015). Determination of safety lines of artillery fire. *Zeszyty Naukowe Wyższa Szkoła Oficerska Wojsk Lądowych im. gen. Tadeusza Kościuszki*

Journal of Science of the gen. Tadeusz Kosciuszko Military Academy of Land Forces, 47 (3), pp. 118–137. http://dx.doi.org/10.5604/17318157.1187460