HRVATSKI CENTAR ZA RAZMINIRANJE

THEME: Worksite safety

Calculation of safety distance from the fragmentation impact during detonation of explosive ordinance

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INTRODUCTION

- **During the detonation, explosive ordinance with high blasting explosive in metal or plastic cartridge have a fragmentation effect on the target.**
- **Upon detonation of explosive, the body of a mine, projectile or bomb cracks and bursts into the environment.**
- **Fragments are the result of a detonation.**
- **They are of asymmetrical shape, of different volume, mass and speed.**
- **Density of a bundle of fragments is very important for the performance realization.**
- **Effects of a detonating wave and an impact wave result in an acceleration of fragments and, at specified distance, they reach their maximum speed.**
- **Transformation of energies of gaseous products of detonation into the kinetic energy of fragments of explosive ordnance body is evident.**
- **Correlation between factors that influence the fragmentation process (type of material, body shape, type of explosive charge...) of ERW body are mostly of empirical character.**

Different measurements, experiments and videotaping with an ultra- fast camera resulted in becoming aware of the pattern that governs the processes of fragmentation and distribution of pieces of shrapnel in space.

Since the mid-19th century until today, numerous scientists have been interested in this problematics such as Journée, Jousrow, Piobert, Morin, Poncelet, Newton, Harvey, Truet, Didion, Euler, Halie, Vallieur, Brezinski, Tasi, Adams and many others.

Efficacy of a fragmentation effect depends on two types of related factors:

a) ERW construction factor
b) ERW position factor

The following factors affect the ERW construction factor: shape, mass, configuration, type of material and thermal processing of a shell material.

ERW position factor is influenced by the detonation centre of a mine, bomb or projectile as well as the environment the detonation takes place.

Fragmentation effect of ERW upon detonation can be perceived from the aspect of theoretical calculations and results obtained by the experiment.

The findings refer to:

1. Number of ERW body fragments
2. Initial speed of ERW body fragment
3. Efficient reach of ERW body fragment
4. Density of lateral bundle of ERW body fragment
5. Testing of ERW fragmentation effect
6. Fragmentation of explosive ordinance in real conditions

1 Number of shell fragments

- According to **Justrow**'s formula, expected number of fragments upon detonation of ERW with metal body is as follows:

$$N_0 = k_p \left(\frac{m_e}{d} \right) \cdot \left(\frac{\sigma_m}{\varepsilon \cdot \sigma_d} \right) \cdot \left(\frac{K^2 + 0,5}{K^2 - 1} \right)$$

kp- coefficient of the type of explosives and charge density of explosive ordinance, e.g. TNT=46
me- mass (weight) of the explosive charge (kg)
d- outer diameter of a mine or other explosive ordinance (m)
бm- stress (tension) (MPa)
бd- ultimate stress (ultimate tension) (MPa)
ε – relative elongation of material in %
K= ds/du_ratio between the outer (ds) an inner (du) diameter of the body

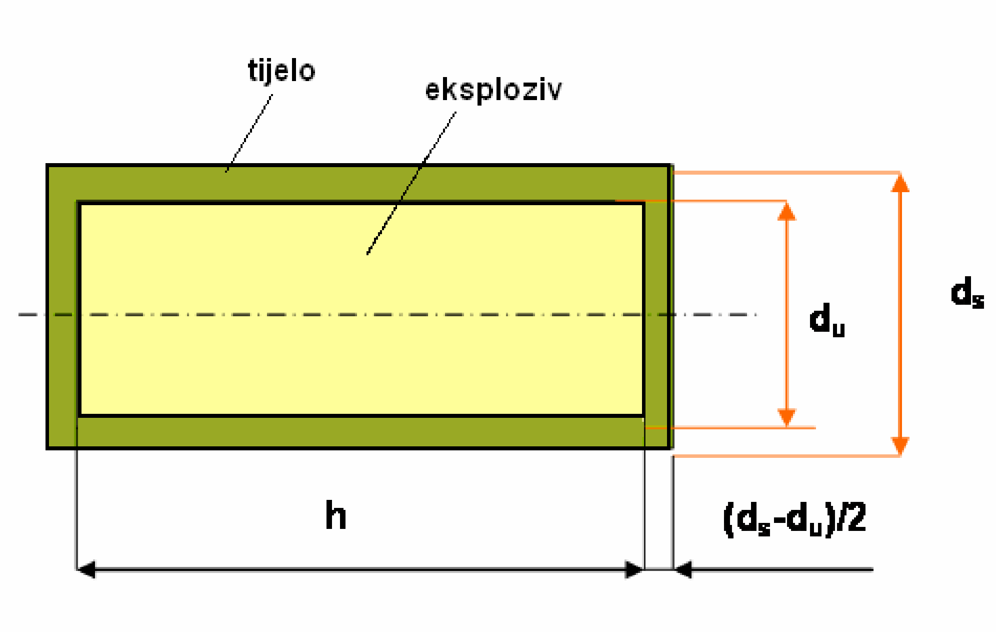


Figure 1 Cross-section of a mine with fragmentation effect on the target

Justrow's formula provides approximately accurate number of fragments during fragmentation of ERW body but does not provide data on the mass of each fragment (piece of shrapnel).

2 Initial fragment speed

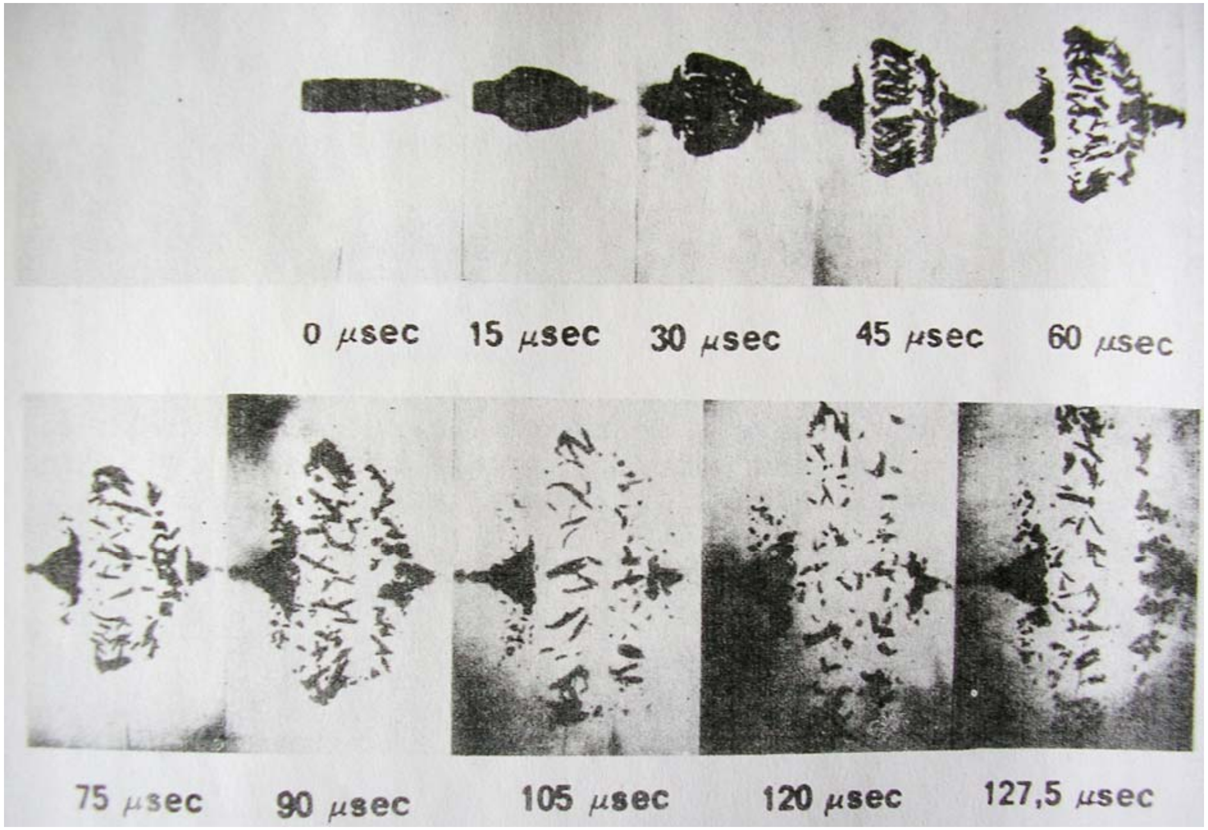


Figure 2 Fragmentation of a projectile shot by the ultra-fast camera

- There are several formulas for determination of initial speed of EO body fragment but most of them are in collision.
- Testing carried out in the French laboratory LRSL by using an ultra-fast camera has been taken in this case in order to be given full consideration.

D- detonating speed of explosives (m/s)
V_0= initial separation speed of body fragments (m/s)
β – angle of separation of a fragment in relation to the axis of symmetry of the mine
Analysis of experimental results established that an angle β depends on ratio between the body mass (m_k) and mass of explosives (m_e)

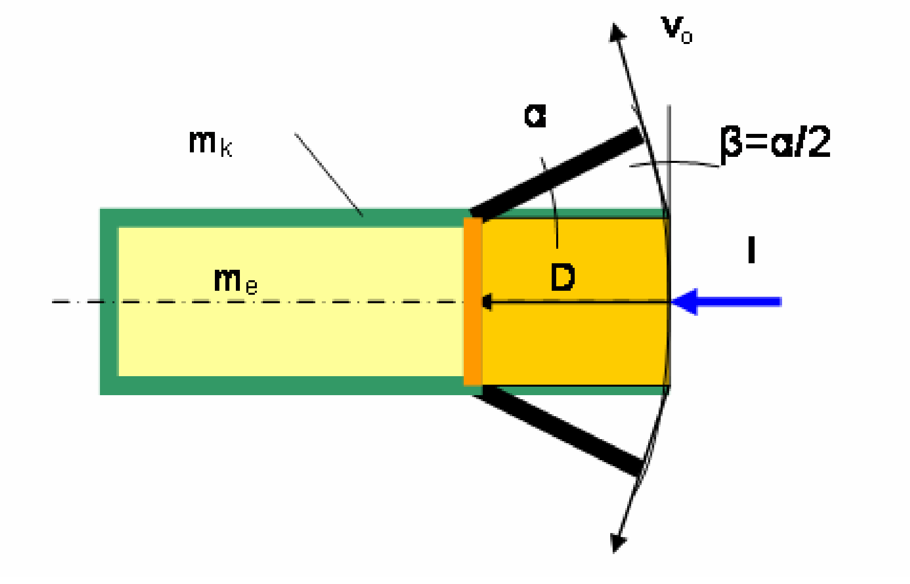


Figure 3 The scheme of separation of body fragments during detonation

Ratio mk/me > 0,5

$$\beta = \frac{\alpha}{2} = \frac{12^0 30'}{1 + \frac{0{,}5 m_k}{m_e}}$$

V_0= 2D sin β

Initial fragment speed during detonation is as follows:

$$V_0 = \frac{0{,}216 D}{1 + \frac{0{,}5 m_k}{m_e}}$$

1. Experiments (shooting with ultra-fast camera) proved that the fragmentation takes place gradually.
2. At first, gasses resulting from the detonation inflate the body and after that comes the fragmentation.
3. During the further movement of fragments, gasses still affect the fragments and they ''fly'' until the outer force does not change its course. At that moment, the fragments shall reach their maximum movement speed.
4. The fragments shall have the biggest initial speed V_0 at the distance of the size of several EO diameters.

e.g. The diameter is 60 mm. The biggest fragment speed is at the distance of 300 to 400 mm. (0,3 to 0,4 m).

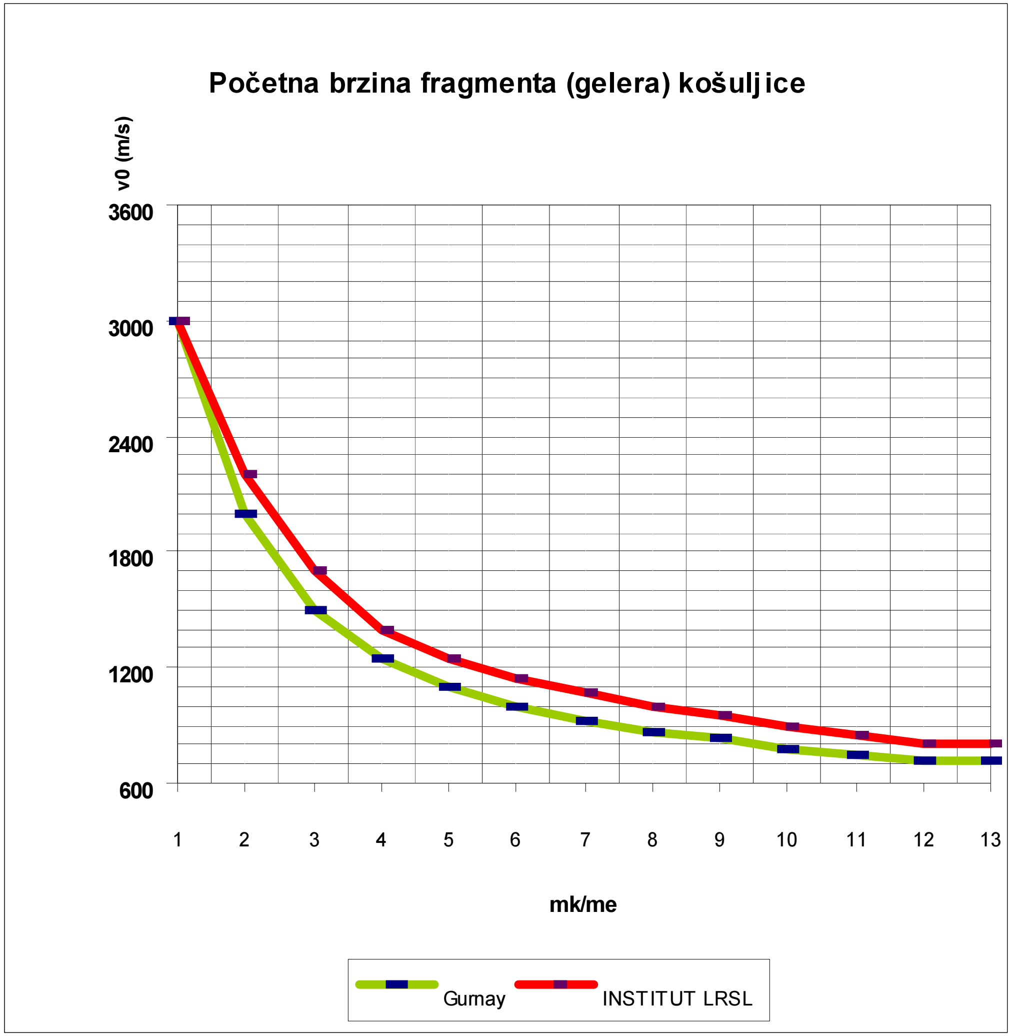
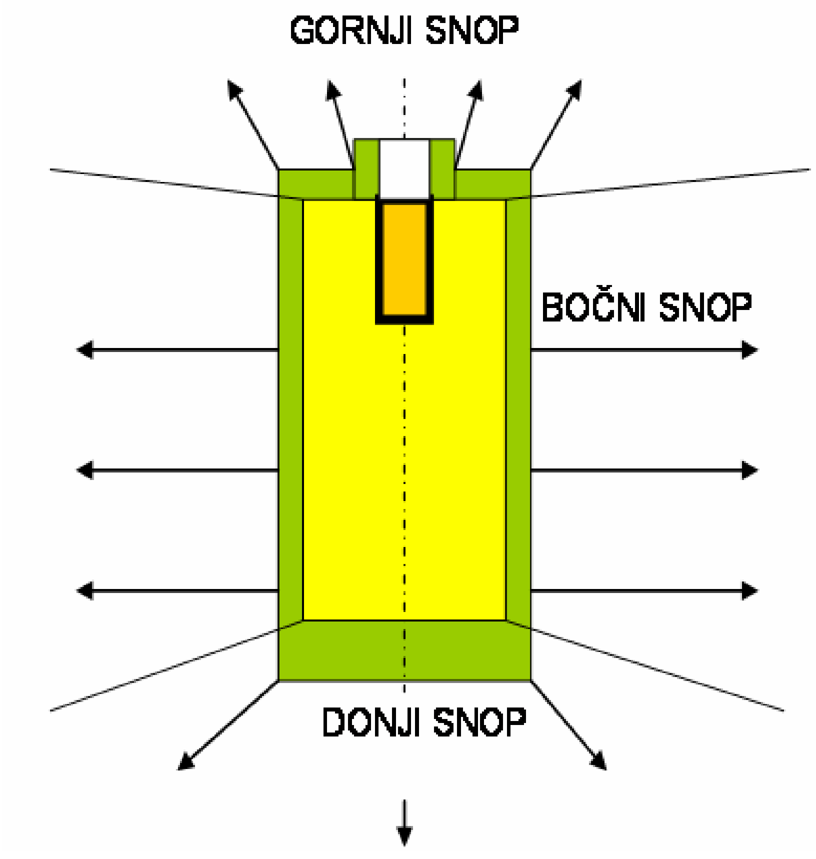


Diagram1 Initial fragment speed (m/s) is dependent of the ratio between the mass of the body and explosives.



In case of classical cylinder-shaped fragmentation mines, fragments fly in three zones:

1. **Upper bundle** of fragments emerges from the detonator and upper part of a mine. Those fragments are very small and in case of properly placed fragmentation mine (e.g. PROM 1 or PMR-2A), they have a very steep path what makes them inefficient.
2. **Lateral bundle** is vertical to the axis of symmetry of the fragmentation mine.
3. **Lower bundle** takes effect from the bottom of a mine towards its bearing.

Figure 4 The scheme of bundles during fragmentation of a cylinder-shaped explosive ordinance

3 Efficient fragment range (ballistic calculation of a fragment flight)

Air resistance that affects the fragment in the air is given as follows:

$$F_x = C_x \cdot S \cdot \rho \cdot \frac{v^2}{2}$$

Cx- coefficient of the aerodynamic air resistance
S- reference (turbulent or lamilar) surface area of the fragment's cross-section
ρ – specfic air density v- initial fragment speed

Differential equation of fragment movement is as follows:

$$m \cdot v \cdot dv = F_x \cdot dx$$

or

$$m \cdot \frac{d^2 \cdot x}{d \cdot t^2} = -C_x \cdot S \cdot \rho \cdot \frac{v^2}{2}$$

Integration of a differential equation results in the fragment speed:

$$v = v_0^{-\frac{C_x \cdot S \cdot \rho x}{2m}}$$

To conclude, the route that the fragment flies over during the specified moment is as given:

$$X = \left(\frac{2m}{C_x \cdot S \cdot \rho}\right) \ln \frac{V_0}{V}$$

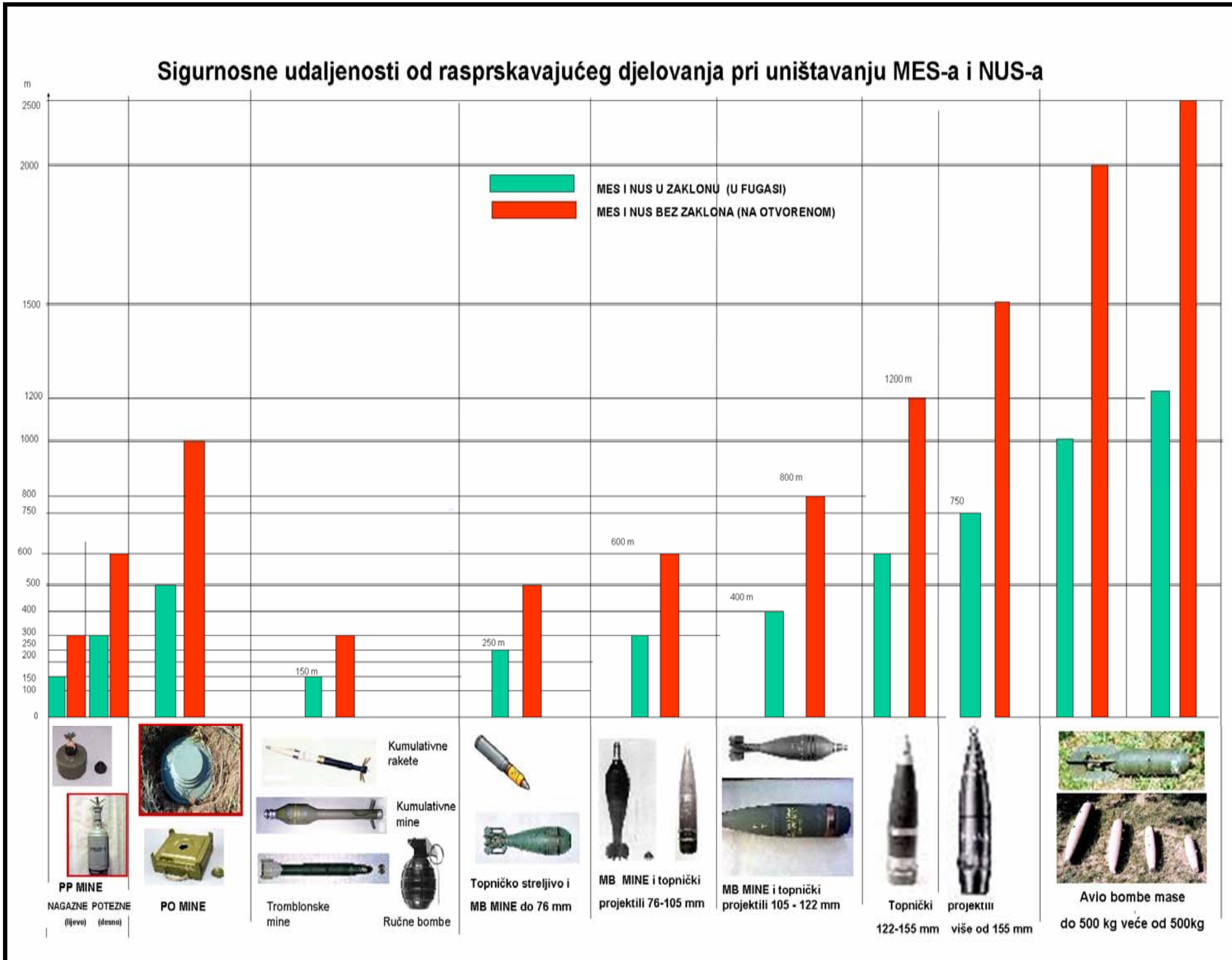


Diagram 2 Distances of dispersion of each EO fragments upon detonation on the surface and in the ground.

4 Density of lateral fragment bundle

The criterion for the efficient fragmentation effect is not only a specific kinetic energy of the fragments but also their **density γ (number of fragments per square meter) at a specified distance.**

After detonation of the explosive ordinance, fragment paths are becoming wider as they cross the distance. Therefore, their density as per area unit is reduced.

There is a number of information in the expert books for:

γ=1 fragment /m^2 or γ=0,1 fragment /m^2

For live targets: **γ=0,1 fragment /m^2**

According to that, **the probability of hitting the target is as follows: ph= 0,1**

For the surface area of the target

P=1 m^2 (section within the fence 2 m tall and 0,5 m wide), and continuous fragment bundle - probability of hitting the target ph= 0,1 shall happen within the bundle density:

γ=1 fragment / 10 m^2 or γ=0,1 fragment /m^2

What follows is: Re>R γmin

Re - efficient fragment range as per kinetic energy

R γmin - efficient fragment range as per density

50% fragments within the angle δ/4

82% fragments within the angle δ/2

96% fragments within the angle 3 δ/4

- 100% fragments until the angle δ

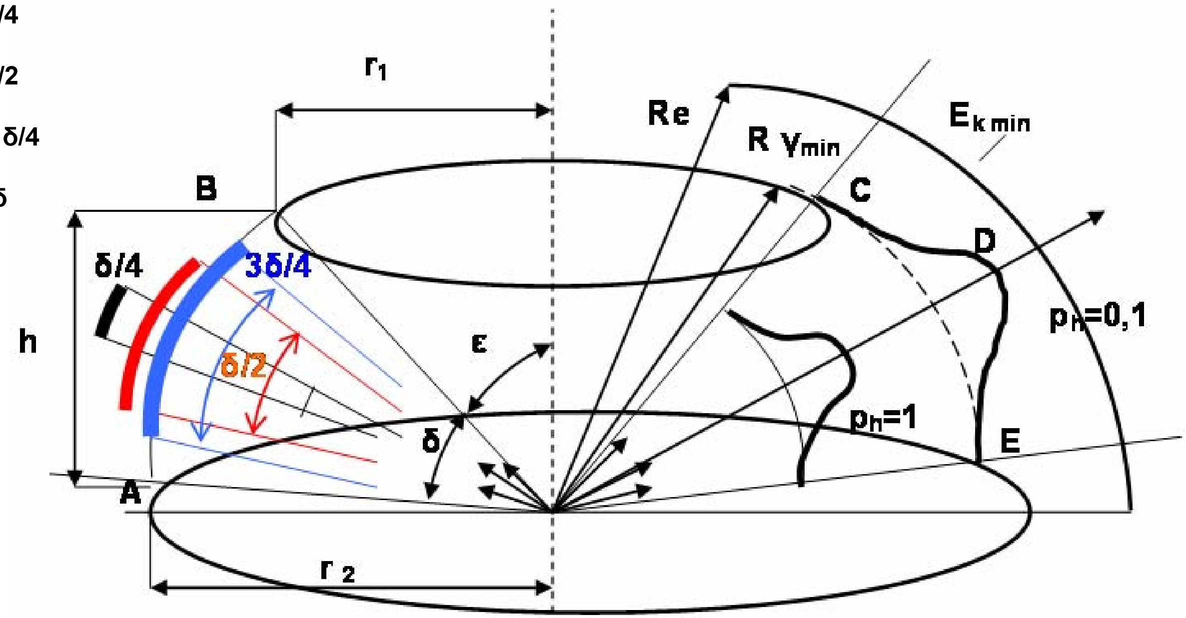


Figure 5 Dispersion and probability of hitting the lateral fragment bundle upon detonation

As can be seen from the figure 5, during the explosion, the fragments are positioned along the ringlike surface. It is the part of a ball of R diameter and can be determined from the following formula:

Sb= 2π Rh

Fragment density is calculated as follows:

$$\gamma = \frac{N_0}{Sb}$$

No – total number of efficient fragments as per kinetic energy at the distance observed

From the geometrical display and previous formulas we can calculate the efficient fragment range per density:

$$R_\gamma = \left\{ \frac{N_0}{2\pi\gamma\left[\cos\varepsilon - \cos(\varepsilon + \delta)\right]} \right\}^{\frac{1}{2}}$$

5 Fragmentation effect testing

5.1 Testing of an explosion of a fragmentation mine in the pit

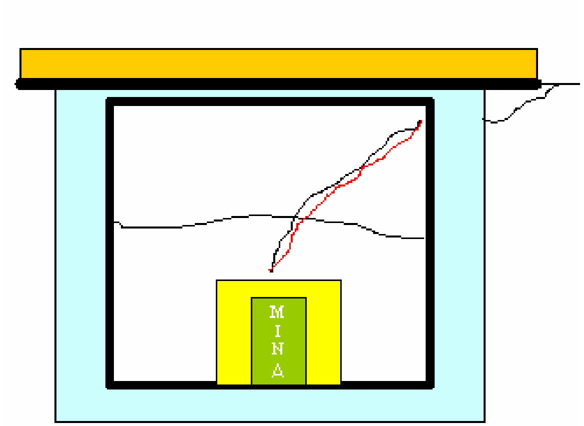


Figure 6 The scheme of fragmentation mine testing in the pit

Fragmentation mine is placed in the wooden crate in the pit covered with sand.

The crate width is equal to the length of several diameters of a mine, in order to ensure the initial fragment speed.

Upon the explosion of the mine, fragments are collected (shrapnel, fragments)
Losses of a metal part of the shell should not exceed 5 %.
The pieces collected (fragments) are collected according to the weight groups, e.g. of 1g. 1,5 g, 2 g 2,5 g etc.
Average fragment mass is calculated for each group.

$$m_s = \frac{m_g}{N_i}$$

mg– mass of fragments classified into one group
Ni – number of pieces in the group in question

5.2. Fragmentation testing within the fence

Fences within which testing is performed consist of four sections. They are placed at different distances from the centre of an explosion.
Wooden boards are 2 m tall, 0,5 m wide, 25 mm or 41 mm thick. There are 100 boards. The area covered by the fragmentation of a mine is 100 m².
Each board represents a live target – a man. The boards are made of:
a) Fir tree (25 mm thick), for checking the boundaries of serious injuries Eks = 80 J/ cm^2
b) Poplar tree (41 mm thick), for checking the boundaries of fatal injuries Eks = 150 J / cm^2

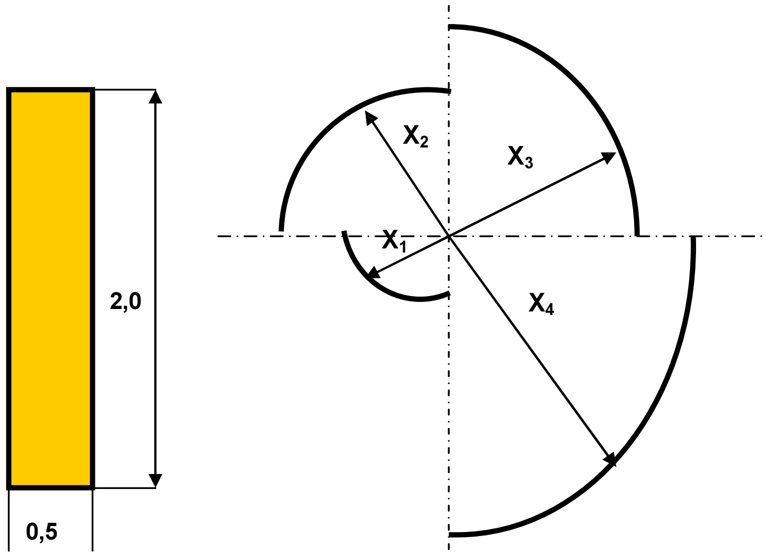


Figure 7 Testing of the fragmentation effect within the fence

The probability of a breakthrough of a section 0,5 x 2 m at the distance x is as follows:

$$p_x = \frac{f_x}{F_x}$$

fx- number of breakthroughs of sections at the distance x
Fx – number of sections 0,5 x 2 m at the sector, at the distance x

Density of a breakthrough (average no. of breakthroughs) per sections at the sector, at the distance x is a ratio between the total no. of breakthroughs and number of sections at the affected sector.

$$d_x = \frac{p_x}{f_x}$$

6 Explosion of explosive ordinances in real conditions

In 1880, French colonel **Journée** was the first to discover the intensity of the kinetic energy required for causing injuries and/or killing people and horses.

In case of humans, contusion and injuries happen during the crash of a shrapnel and a traget at specific kinetic energy of 20 J/cm2.

The border of the kinetic energy at which the bones are being injured comes to ca. 50 J. The bones are broken hen the intensity of the specific kinetic energy of a fragment exceeds 155 J/cm2.

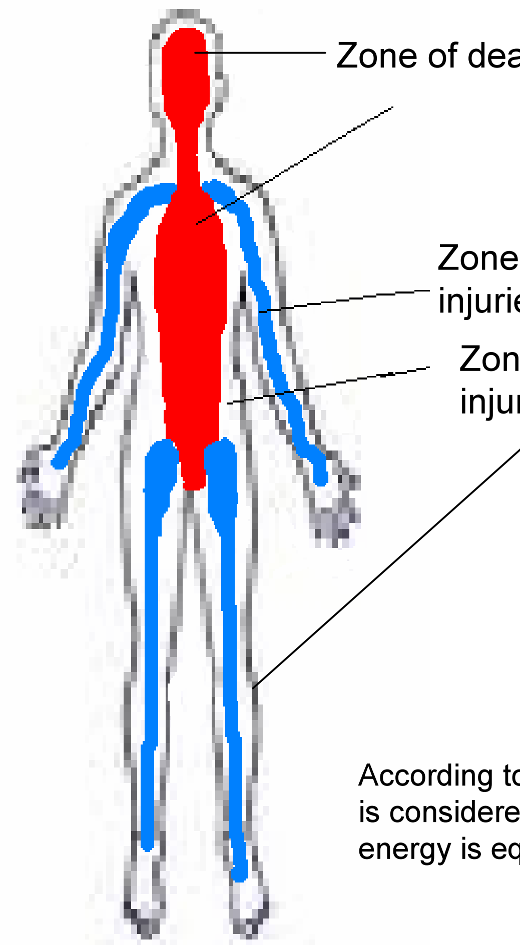
The value of the kinetic energy for injuries and breaking of horse’s bones is twice as bigger as the one for the humans.

<u>The analysis of other researches established that the boundary for serious injuries to occur is ca. 80 J and for fatal wounds is over 100 J.</u>

Example:

a) Shrapnel of 5 g, at speed of 200 m/s can kill a man under the condition that it hits a part of the body that is classified as deadly zone of injuries.

b) Shrapnel of 1 g, at speed of 500 m/s can kill a man under the condition that a man is hit in the deadly zone of injuries.



According to some authors, shrapnel is considered deadly if its kinetic energy is equal to 150 J /cm2

Figure 8 Zones and types of injuries at the human body

CONCLUSION

This paper provides an insight into the scientific approach to studying the effect of an explosion of explosive ordinance during detonation of explosives within the ordinance. After the scientific and theoretical analysis of the fragmentation effect during detonation of explosive ordinance supplemented with results from the practical experience, it can be concluded that most formulas and forms could be used for preliminary calculation of safety zones.

It is very important for the calculation of safety distances in space, during the work with mines and UXO in humanitarian demining operations in order to avoid unwanted consequences and increase the safety level to the highest level.

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   Topic: Effect of explosive ordinance to the target

   - Effect of an impact wave – Fragmentation effect – Cumulative effect – Penetration of projectile -Misnay – Sharidan's effect

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