ЗАХИСТ ОВТ ВІД ЗАСОБІВ ВИЯВЛЕННЯ ТА УРАЖЕННЯ

PROTECTION OF WEAPONS AND MILITARY EQUIPMENT FROM DETECTION MEANS AND ENGAGEMENT

UDC 624.9 DOI: https://doi.org/10.33577/2312-4458.33.2025.169-175

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ENGINEERING SOLUTIONS FOR PROTECTING STRUCTURES FROM AERIAL THREATS

The article discusses an innovative approach to protecting objects from unmanned aerial vehicles (UAVs) – the use of anti-drone nets with elastic fastening of the upper part to fixed supports. The physical and operational disadvantages of traditional rigidly fixed nets are described and the advantages of elastic fastening are justified. A mathematical model of the moment of collision of a drone with a horizontally placed spring-loaded strip has been constructed. A functional dependence has been established that allows determining the influence of the nonlinearity coefficient and spring stiffness on the maximum downward displacement of the central point of the spring-loaded strip, which makes it possible to optimise the fastening parameters to ensure a balance between strength and elasticity. The results obtained can be used in the design of new types of protective structures adapted to field conditions and modern threats.

Keywords: *protection against UAVs, protective structures, anti-drone nets, elastic fastening.*

The statement of the problem

The full-scale war on the territory of Ukraine has vividly demonstrated the unprecedented rise in the significance of aerial threats in modern warfare. Massive missile strikes, the deployment of unmanned aerial vehicles (UAVs), and the use of precision-guided weapons have introduced new challenges for defence systems, particularly in the engineering protection of military and civilian infrastructure.

During the russo-Ukrainian war, the Defense Forces demonstrated that UAVs have ceased to be merely auxiliary elements of the armed forces and have become a key component of modern military strategy. The main advantages of drones include high manoeuvrability, the ability to operate in hard-to-reach areas, and a significant reduction in risk to personnel. Modern UAVs are capable of striking not only military positions but also energy, industrial, logistical, and residential targets, necessitating the development of new approaches to engineering protection – such as lightweight modular shelters, anti-perforation meshes, camouflage systems, anti-drone domes, and rapidly deployable protective structures. Ukrainian experience demonstrates that the effective integration of active countermeasures (electronic warfare, firepower) with passive engineering methods (fortifications, shelters, dispersion, multi-level camouflage) significantly reduces the effectiveness of enemy UAV attacks. Today, the issue of countering drone assaults is particularly relevant, as their rapid development outpaces traditional defense systems.

Therefore, engineering solutions must be flexible, adaptive, and rapidly deployable. Their effectiveness is critical not only for preserving material assets but also for safeguarding the lives of military personnel and civilians. The evolving of airborne threats necessitates the developing of innovative, technically validated, and operationally proven engineering systems for infrastructure protection.

Article history: Income 23 October 2025; Revised 24 October 2025; Accepted 31 October 2025; Primt 05 December 2025

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ISSN (Online): 2708-5228 / ISSN (Print): 2312-4458

Analysis of basic research and publications

The ongoing efforts to combat UAV threats in Ukraine encompass several strategic directions, including electronic warfare (EW), whose principal objective is the neutralization of control links, navigational signals, and data exchange pathways. An example of electronic warfare (EW) application in the russo-Ukrainian war is the deployment of relatively new EW systems such as "Bukovel-AD" [2], "Nota" [3], and others [4]. EW represents an effective, rapid, and relatively low-cost method for neutralizing large numbers of inexpensive, remotely controlled UAVs, providing time to organize additional countermeasures. However, its effectiveness diminishes with the increasing sophistication and protection of drones. Moreover, the deployment of such measures entails potential harm to civilian infrastructure and is subject to logistical and regulatory limitations.

Another strategic direction entails the application of air defense assets, notably surface-to-air missile systems like "Avenger" [5], "Strela-10", Vampire, Mistral [6], Stinger, and "Igla", which are employed to intercept and destroy larger UAVs or coordinated drone formations. The main challenge of this approach lies in the use of expensive missiles against low-cost drones, which is not always economically justified.

Ukrainian Defense Forces deploy mobile firing groups for UAV mitigation, enabling rapid target acquisition, threat alerting, and destruction of airborne objects using infantry weapons and immediate protective means. These units are characterized by high speed and manoeuvrability: unlike stationary air defense systems, mobile groups can be rapidly redeployed to any terrain sector currently facing the greatest threat. Mobile fire teams accounted for the largest proportion of neutralized combat drones. By July 2025, their effectiveness rate had reached 40%. A key limitation in the use of mobile fire teams lies in the elevated threat level near the front line, where enemy drones increase their susceptibility to attack. Shahed strikes are often coordinated with incursions by FPV drones that infiltrate deep into Ukrainian-controlled areas. Consequently, these teams must reposition to more distant locations to reduce exposure to hostile engagements.

These countermeasures allow for the successful destruction of numerous UAVs, yet the escalation in simultaneous strikes leads to more drones breaching defenses and achieving their goals. The primary factors contributing to this issue include the mass scale of simultaneous raids, the high velocity of aerial platforms, and the frequent occurrence of attacks during nighttime hours. A potential solution lies in the deployment of interceptor drones, which gained widespread attention in spring 2024 following Brave1's announcement of a competition to develop systems capable of countering russian reconnaissance UAVs. By July 2024, a new FPV interceptor with an X-shaped wing was showcased, capable of destroying drones flying at 100–160 km/h. These interceptors have proven to be an affordable and effective alternative to missiles and heavy weaponry. Each unit costs far less than a Shahed drone and is vastly more accessible than a missile. Ukrainian versions are available for under $10,000, positioning them as a cost-efficient tool for neutralizing both strike and reconnaissance UAVs. Currently, multiple teams are engaged in the development of anti-aircraft drones. Their efforts have resulted in systems that have not only successfully passed field trials but are already being deployed in active combat scenarios. Since late 2024, Ukraine has been conducting successful tests of the Tytan Interceptor, a drone developed through German-Ukrainian collaboration. It reaches altitudes of up to 2,000 meters, has an operational range of 15–20 km, and achieves speeds of up to 300 km/h. The system is powered by artificial intelligence, enhancing target detection, tracking, and classification, with full AI-based navigation automation planned. Control is executed via a standard gamepad. With a cost below €20,000, the platform offers an affordable and effective solution for neutralizing enemy reconnaissance UAVs, including the Orlan-10 and Zala. The "General Chereshnya AIR" drone represents another noteworthy case of an affordable and effective interceptor. With a unit cost of 39,900 UAH, it operates at altitudes up to 6 km, achieves speeds of 160 km/h, and maintains flight endurance of up to 35 minutes. Having already eliminated more than 300 targets, the platform is being mass-produced in the thousands, with plans to expand output to tens of thousands monthly. Each unit is equipped with 1.5 kg of explosives. Development is in progress to deploy next-generation software for automatic target acquisition and monitoring [7].

Another direction in combating enemy drones is the deployment of integrated systems that combine radar, imaging, thermal, and acoustic components to detect and classify threats in real time. Octava Defence has presented SFERA [1], the first unified system for protecting critical infrastructure. It uniquely integrates radar, acoustic sensors, opto-thermal platforms, and software that transmits targeting data to strike units for active fire response. The system's uniqueness lies in its ability to rapidly detect hostile targets and ensure their prompt elimination. By integrating radar data, acoustic sensing, and intelligent video surveillance, it enables reliable target identification. The system tracks the object and predicts its trajectory, providing both current and projected coordinates for engagement. Unlike certain conventional air defense assets, the complex is particularly effective against low-altitude threats. The probability of target detection approaches 100%. All data – including coordinates and trajectory – is automatically transmitted to strike units. Mathematical models forecast target movement and maintain tracking until neutralization. Automation enables decision-making within minutes and minimizes human error. Thus, SFERA represents a cutting-edge technological solution for protecting the nation's critical infrastructure.

Engineering solutions represent another strategic avenue for countering UAV threats. These include:

- concealment and decentralization – relocating and hiding assets to lower vulnerability to coordinated attacks;

- protective structures – including mesh coverings, overhead shields, and domes that reduce detectability and blast damage, occasionally reinforced with Armor or anti-fragmentation layers;

- hardened facilities – such as reinforced shelters, subterranean bunkers, and steel or concrete hangars for safeguarding vehicles and infrastructure.

Evidently, such measures do not eliminate the source of the threat but serve to mitigate its consequences. They are preventive in nature, reducing the probability of impact and damage even before the threat is detected. Moreover, they are less susceptible to cyber or electronic warfare attacks: physical shelters remain functional even when the adversary disrupts the spectrum or communication channels. Engineering solutions are effective regardless of drone type and play a critical role in protecting civilian infrastructure. Their cost-effectiveness compared to other UAV countermeasures is also noteworthy.

Ukrainian troops have employed a practical engineering method to defend rear positions and supply routes in areas prone to fiber-linked drone ambushes: spreading barbed wire that slices through the UAV's optical cable and interrupts its connection to the operator. In contrast to standard FPV drones, fiber-linked UAVs route their optical cable along the ground rather than through the air. This characteristic makes low-level barriers near transport routes, storage facilities, bridges, or logistics hubs highly effective in intercepting and severing the tether. Undoubtedly, this engineering solution has certain limitations: such barriers require manual installation, power supply, and concealment, as well as the provision of access routes for friendly forces. However, in the long term, the system can be modularly scaled and deployed in the most vulnerable areas, supplemented with radar sensors, cameras, or infrared projectors to enable timely threat detection.

Another engineering method for countering UAV threats involves the use of anti-drone nets. These structures create a protective barrier that impedes or entirely blocks drone attacks, particularly those carried out by FPV systems and loitering munitions. The primary rationale for this defense lies in the limited visibility caused by degraded video transmission, which prevents the operator from recognizing the net, leading to the drone's propellers becoming ensnared. The use of anti-drone netting extends beyond logistical corridors to include coverage over trenches and access points to dugouts. These barriers protect troops from direct impacts and fragmentation, while also defending artillery emplacements – common targets for hostile FPV drones. In addition to physical protection, such measures enhance camouflage and reduce the likelihood of accurate enemy strikes.

Low-cost FPV drones have fundamentally transformed the nature of modern warfare in recent years. Their latest generation, equipped with fiber-optic control systems, has compelled military strategists to reassess conventional defense paradigms. The widespread deployment of such platforms in frontline areas has rendered the location of the next strike unpredictable – posing a threat not only to military targets but also to civilian vehicles on the road. Consequently, large protective nets have been installed along major transportation routes near the front line to shield vehicles from direct drone strikes. Figure 1 illustrates the appearance of these "anti-drone" barriers in the vicinity of Kostiantynivka and Kramatorsk.

Fig. 1. **Anti-Drone Netting Along Ukrainian Roadways**

Materials for anti-drone structures are selected based on the formula "availability + rapid deployment + effectiveness against FPV drones." Synthetic polymer meshes – such as nylon, polyester, and polypropylene – are widely used above trenches, dugouts, vehicles, and at the entrances to depots and field positions, serving both as camouflage and protective elements. These materials are favored for their light weight, flexibility, low cost, and immediate availability in field conditions, often being repurposed from construction or sports netting. These structures are easy to install and replace, do not obstruct visibility or airflow, produce minimal radar signature, and are effective against lightweight FPV drones – whose operators often fail to detect the barrier due to poor video feed quality. However, their use has certain drawbacks: deformation under wind, rain, or icing; melting or destruction upon strong impact; and the need for regular maintenance.

Steel-based protective elements – including galvanized or stainless wire meshes, tensioned cables, and rebar frameworks – are widely utilized to safeguard armoured vehicles and to reinforce permanent defensive structures around vital installations, such as energy infrastructure, logistical depots, and administrative compounds. These materials are employed due to their ability to withstand impacts from FPV drones equipped with explosives or fragmentation payloads. Such meshes exhibit high mechanical strength, durability, reusability after minor damage, and proven effectiveness against heavier classes of unmanned aerial vehicles and loitering munitions. However, these systems also present certain limitations – namely, considerable weight requiring robust supports or frames, installation complexity (often involving machinery), and the risk of improper setup that may cause hazardous inward deflection of fragments. Such meshes are widely used to construct “anti-drone domes” over vehicles and to reinforce the protection of energy infrastructure facilities. Composite anti-drone nets, combining metallic and synthetic components, reinforced tapes, or plastic frames, are also employed by engineering units of the Armed Forces of Ukraine for rapid fortification of positions – primarily above dugouts, observation posts, and field shelters – as well as during the construction of quickly deployable protective structures in rear areas.

Aramid fibers (Kevlar, Twaron, Nomex) are used in the production of specialized industrial anti-drone nets designed to protect strategic assets such as power plants, ammunition depots, and government buildings. These materials are strong, heat-resistant, and cut-resistant. As a result, they can intercept fragments and partially absorb explosive energy, while being non-melting and electrically non-conductive. However, they are expensive, require professional installation, and demand regular inspection of fiber integrity. Due to their high cost, aramid fibers are used infrequently – primarily in state-funded protection systems for critical infrastructure.

Improvised materials – such as fishing nets, construction-grade reinforcement meshes, and football or volleyball netting – are widely used in frontline villages, by mobile units, and during the rapid setup of new shelters due to their high availability and low cost. These solutions can be installed within hours and often prove effective by disrupting the orientation of FPV drone operators. However, they are not always capable of withstanding direct munition impacts and require frequent replacement. Industrial fishing nets are considered among the most effective anti-drone solutions due to their high tensile strength, non-reflective surface under sunlight, and ability to withstand drone impacts. A Danish volunteer recently donated a batch of such nets to Ukraine. Demand for these protective materials is rapidly increasing along the entire front line, with Scandinavian countries – where the fishing industry is well developed – emerging as key suppliers [9]–[15].

Among the most pressing issues in anti-drone infrastructure is the challenge of securing netting systems. Effective mounting requires a balance between mechanical robustness, tactical mobility, and rapid deployment. Enhancing system efficiency calls for standardized fastening mechanisms, lightweight metallic or composite frames, and engineering solutions optimized for combat environments. This article is devoted to exploring and resolving this challenge.

Net tunnels are commonly installed using rigid fixation methods. However, such rigidly anchored anti-drone systems face notable mechanical and operational constraints that compromise their durability and reliability. During drone impact, the force is directly transmitted to the support structure, resulting in dynamic stress, deformation, and possible failure of attachment points. These systems also demonstrate limited adaptability to environmental fluctuations – including wind pressure, rainfall, and directional changes in UAV attacks – thereby diminishing their interception performance. Moreover, rigid mounting complicates installation and dismantling in field conditions, requires heavy-duty supports, and demands precise geometric alignment – making such systems poorly suited for rapid deployment at temporary positions.

This work proposes the use of elastic mounting. By incorporating flexible elements, such as springs, the system can partially absorb and dissipate the impact energy of a drone strike, thereby reducing peak loads on the supports and extending the overall service life of the structure. Such a mechanism minimizes the probability of net damage or collapse, thereby improving the chances of drone interception without compromising key structural elements. The use of elastic fixation further improves resilience to wind stress and climatic variability, enabling the system to accommodate air surges, thermal changes, and snow loads while maintaining structural tension. As a result, the net maintains structural integrity and operational functionality even during prolonged field use. Additionally, the system is lighter, easier to install, and does not require reinforced supports, which facilitates rapid deployment at temporary positions and makes it suitable for protecting various types of assets.

Presentation of the main results

Consider the motion of a mechanical system consisting of a rigid body H modelling the fall of a UAV onto a spring-loaded strip AB. It is assumed that this strip is the upper part of an anti-drone tunnel (pic. 2). The rigid body H falls from a height h_1 onto a spring-loaded horizontally placed strip AB. It is attached to the hinged supports D and C by means of springs DA and BC. The aim of the work is to determine the maximum value h_2 to which the central point G of the strip will drop as a result of the contact of the body H with AB.

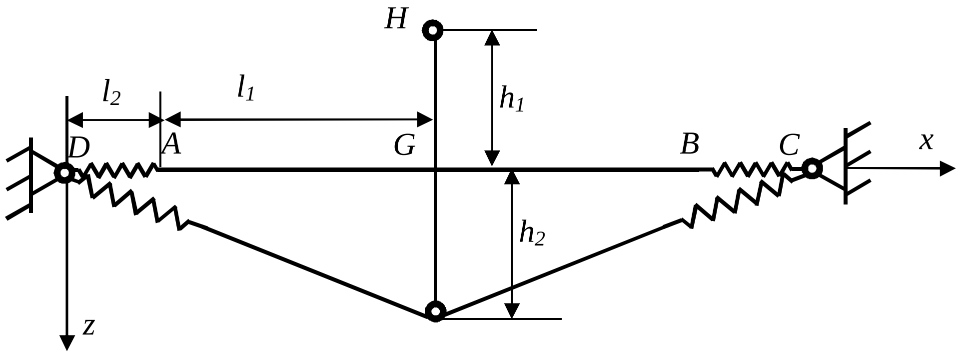

Fig. 2. **Schematic representation of the moment of collision between a body and a horizontally oriented elastic strip**

To determine the value h_2 we will use the theorem on the change in kinetic energy of a mechanical system

$$T_k - T_0 = \sum A_i^e + \sum A_i^i . \quad (1)$$

In formula (1) T_k denotes the kinetic energy of the mechanical system at the final moment of time, T_0 is the kinetic energy of the mechanical system at the initial moment of time, $\sum A_i^e$ is the sum of the work performed by the external forces of the mechanical system, $\sum A_i^i$ is the sum of the work performed by the internal forces of the mechanical system.

If air resistance is neglected, then the body H falling from a height h_1, at the moment of touching a horizontally placed strip AB, will have a speed,

$$V_{H_0} = \sqrt{2 \cdot g \cdot h_1}\,, \quad (2)$$

where $g = 9{,}8\ ms^{-2}$ is the acceleration of free fall of the body.

At the initial moment of time, the spring-loaded strip AB is stationary, so the initial kinetic energy of the mechanical system is equal to

$$T_0 = m_1 \cdot g \cdot h_1 , \quad (3)$$

where m_1 is the mass of the solid body H.

At the final moment of time, when the maximum downward displacement of point G is reached, the entire mechanical system will be at rest. Therefore, the kinetic energy of the mechanical system at the final moment of time is zero, i.e.

$$T_k = 0 . \quad (4)$$

The work is performed by the weight of the body H and the weight of the strip AB, therefore

$$\sum A_i^e = m_1 \cdot g \cdot h_2 + 0{,}5 m_2 \cdot g \cdot h_2 , \quad (5)$$

where m_2 is the mass of the strip AB, h_2 is the maximum downward displacement of point G.

Since the strip is spring-loaded, the springs DA and BC will stretch by an amount Δl during the downward movement of the strip and perform work. We assume that the elastic force of the springs is described by the relationship

$$F_{sp} = c \cdot \Delta l^{\nu} , \quad (6)$$

where c is the spring stiffness, ν is the nonlinearity coefficient.

Taking into account (6), we obtain

$$\sum A_i^i = -2 \cdot \frac{c \cdot \Delta l^{\nu+1}}{\nu+1} . \quad (7)$$

Substituting the determined dependencies into (1), we find

$$-m_1 \cdot g \cdot h_1 = m_1 \cdot g \cdot h_2 + 0{,}5 m_2 \cdot g \cdot h_2 - 2 \cdot \frac{c \cdot \Delta l^{\nu+1}}{\nu+1} . \quad (8)$$

Taking into account the geometry of the mechanical system, we obtain that

$$(l_1 + l_2)^2 + h_2^2 = (l_1 + l_2 + \Delta l)^2 . \quad (9)$$

From this equation, we will determine the amount of spring deformation

$$\Delta l = \sqrt{(l_1 + l_2)^2 + h_2^2} - l_1 - l_2 . \quad (10)$$

Substituting (10) into (8), we obtain a functional dependence that allows us to determine the influence of system parameters on the maximum downward displacement of the point G.

$$m_1 \cdot g \cdot (h_1 + h_2) + 0{,}5 m_2 \cdot g \cdot h_2 - \frac{2c}{\nu+1}\left(\sqrt{(l_1+l_2)^2 + h_2^2} - l_1 - l_2\right)^{\nu+1} = 0. \qquad (11)$$

We will use equation (11) to evaluate the relationship between spring stiffness and the coefficient of nonlinearity of elastic force. Suppose that in (11) $m_1 = 5kg$, $m_2 = 100kg$, $l_1 = 3m$, $l_2 = 0{,}5m$, $h_1 = 50\ m$. The spring stiffness values for different values of the nonlinearity coefficient and the deviation of the center point of the strip AB are given in Table 1.

Table 1

Dependence of spring stiffness on nonlinearity coefficient for different values of strip deformation AB

ν	0,6	0,7	0,8	0,9	1,0	1,1	1,2
c, Nm^{-1} at $h_2 = 0{,}5m$	453935	673376	995445	1467013	2155987	3160611	4622854
c, Nm^{-1} at $h_2 = 1{,}0\ m$	55588	71892	92656	119049	152563	194954	248602

Analysing the results presented in Table 1, we can conclude that:

- for a given displacement of point *G*, a smaller value of the nonlinearity coefficient corresponds to a smaller value of its stiffness;
- as the displacement of point *G* increases, the elasticity of the spring decreases significantly for the same values of the nonlinearity coefficient.

Let us investigate the effect of the strip mass on the spring stiffness. Assume that in (11) $m_1 = 5kg$, $l_1 = 3m$, $l_2 = 0{,}5m$, $h_1 = 50m$, $h_2 = 0{,}5m$. Let us evaluate the effect of the strip mass on the relationship between the nonlinearity coefficient and the spring stiffness.

Table 2

Dependence of spring stiffness on nonlinearity coefficient for different strip mass values

ν	0,6	0,7	0,8	0,9	1,0	1,1	1,2
$c,\ Nm^{-1}$ при $m_2 = 25kg$	423263	627878	928185	1367891	2010312	2947057	4310499
$c,\ Nm^{-1}$ при $m_2 = 50kg$	433487	643044	950605	1400931	2058870	3018242	4414617

Analysing the results presented in Table 2, it deduce that

- reducing the mass of the strip allows the spring stiffness to be reduced for the same values of the nonlinearity coefficient;
- as the nonlinearity coefficient increases, the spring stiffness increases for the same values of the strip mass.

Therefore, to reduce the maximum deformation of the strip onto which the body falls, it is necessary to use springs with a regressive dependence (ν less than one) of the elastic force and, accordingly, a lower value of its stiffness.

Conclusions, practical recommendations and further generalization of results

A method of studying the dynamics of a spring-loaded strip under the influence of an action on it at the central point of an object with a given mass has been developed. The functional dependence between the maximum deflection and the values of the nonlinearity coefficient and spring stiffness for given values of the masses of the object and the strip was obtained.

It is established that:

- with a constant displacement of point G, lower values of the nonlinearity coefficient correspond to lower spring stiffness;
- with an increase in the displacement of point G, the spring stiffness decreases significantly at the same values of the nonlinearity coefficient;
- a decrease in the mass of the strip leads to a decrease in spring stiffness at the same values of the nonlinearity coefficient;
- with an increase in the nonlinearity coefficient, the spring stiffness increases at a constant strip mass.

The results of this work can be used in the creation of new protective structures and the modernisation of existing ones in order to reduce the dynamic load on their elements. It should be noted that elastic reinforcements can be used not only for horizontal but also for vertical parts of anti-drone tunnels.

In the case of an impact not in the central part of the strip, the amplitude of the deflection of the protective element will change and depend on the distance to the elastic fastening. Such tasks will be the subject of further research.

References

1. "Ukrayina zaprovadzhuye pershu yedynu systemu zakhystu ob'yektiv krytychnoyi infrastruktury" [Ukraine introduces its first unified system for protecting critical infrastructure facilities]. URL: https://octava.ua/v-ukrayini-

zyavylasya-persha-unifikovana-systema-zahystu-obyektiv-krytychnoyi-infrastruktury/ [in Ukrainian]

2. "Ukrayins′kyy kompleks radioelektronnoyi borot′by «Bukovel′-PD» zdiysnyv posadku rosiys′koho BPLA ZALA 421-16E2" [Ukrainian Bukovel-AD EW system landed Russian ZALA 421-16E2 UAV]. URL: https://militarnyi.com/en/ news/ ukrainian-bukovel-ad-ew-system-landed-russian-zala-421-16e2-uav/ [in Ukrainian]

3. Upgraded Nota complex by Tritel becomes an antidote to Russian EW systems. URL: https://defence-ua.com/ people_and_company/onovlenij_kompleks_nota_vid_kompaniji_ tritel_stav_antidotom_vid_rosijskih_sistem_reb-5736.html

4. Lavrenchenko M. V., Vakulenko I. V. and Mazur V. V. (2024), "Analiz vykorystannya peredovykh system radio-elektronnoyi borot′by pid chas rosiys′ko-ukrayins′koyi viyny" [Analysis of the use of advanced electronic warfare systems during the Russian-Ukrainian war]. *International Scientific and Practical Conference "Application of Information Technologies in the Training and Activity of Law Enforcement Forces": Collection of Abstracts (Kharkiv, March 14, 2024)).* Kharkiv, pp. 212–213. [in Ukrainian]

5. "Zbroyni syly Ukrayiny vykorystovuyut′ zastarili systemy proty bezpilotnykiv" [Ukrainian Armed Forces use legacy systems against UAVs]. URL: https://focus.ua/uk/ voennye-novosti/723096-zrk-avenger-zsu-vikoristovuye-stari-sistemi-proti-bpla-video / [in Ukrainian]

6. "Ukrayins′ki viys′ka demonstruyut′, yak frantsuz′kyy ZRK "Mistral′" zbyvaye rosiys′kykh shakhidiv" [Ukrainian forces demonstrate how French Mistral SAM shoots down Russian Shaheds]. URL: https://expres.online/podrobitsi/zsu-pokazali-yak-frantsuzkiy-zrk-mistral-zbivae-rosiyski-shakhedi-video / [in Ukrainian]

7. "Chy mozhut′ bezpilotnyky-perekhoplyuvachi zakhystyty nebo Ukrayiny?" [Can drone interceptors protect Ukraine's skies?]. URL: https://vgi.com.ua/chy-zmozhut-drony-perehoplyuvachi-zahystyty-nebo-ukrayiny / [in Ukrainian]

8. "Tylova oborona vid optovolokonnykh BPLA: ukrayins′ki viys′kovi rozrobyly prostyy, ale efektyvnyy metod" [Rear defense against fiber-optic UAVs: Ukrainian forces develop a simple but effective method]. URL: https://dev.ua/ news/zakhyst-tylu-vid-optovolokonnykh-bpla-zsu-rozrobyly-prostyi-ale-diievyi-sposib-1759233546 / [in Ukrainian]

9. "Zakhyst vid droniv: rybal′s′ki sitky z Daniyi dopomahayut′ ukrayins′kym soldatam vyzhyty (foto)" [Drone protection: fishing nets from Denmark help Ukrainian soldiers survive (photo)]. URL: https://focus.ua/uk/voennye-novosti/ 695983-zahist-vid-droniv-ribalski-sitki-z-daniji-dopomagayut-biycyam-zsu-vizhiti-detali-foto / [in Ukrainian]

10. "Shvetsiya postachaye na peredovu sitky dlya borot′by z droniv" [Sweden delivers anti-drone nets to the front line]. URL: https://www.radiosvoboda.org/a/shvetsiya-siti-drony-front/33552254.html / / [in Ukrainian]

11. Solomatin D., Sedliar A. and Pasichnyk V. (2024), Substantiation of technical characteristics for active protection systems of armored vehicles against FPV-drones and drones with "drops". *Military Science*, No. 2 (4), p. 9. DOI: 10.62524/ msj.2024.2.4.9 URL: https://themilitaryscience.com/ index.php/ journal/article/view/103

12.. Kovalchuk V.I. and Honcharenko O.M. Analysis of the effectiveness of countermeasures against unmanned aerial vehicles at the tactical level. *Collection of Scientific Works of KhNUPS*, 4(70), pp. 112–118. URL: https://www.hups.mil.gov.ua/ periodic-journals/

13. Melnyk, S.P. and Kravets, I.O. Technical aspects of using mesh barriers for protection against FPV-drones. *Bulletin of KhNUPS*, 2(68), pp. 89–94. URL: https://www.hups.mil.gov.ua/ periodic-journals/

14. Bondarenko, A.V. and Sydorenko, T.M. Study of mechanical properties of polymer materials for the manufacture of protective nets. *Scientific Bulletin of the NADPSU*, 3(101), pp. 56–62. Available at: https://academy.gov.ua/ naukovi-vidannya/

15. Grytsenko, Yu.M. and Lytvynenko, O.V. Prospects for the use of mesh structures in state border protection systems. *Collection of Scientific Works of NADPSU*, 2(98), pp. 73–78.

ІНЖЕНЕРНІ РІШЕННЯ УБЕЗПЕЧЕННЯ ОБ'ЄКТІВ ВІД ПОВІТРЯНИХ ЗАГРОЗ

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У статті розглядається інноваційний підхід до захисту об'єктів від безпілотних літальних апаратів (БпЛА) – застосування антидронових сіток із пружним кріпленням верхньої частини до нерухомих опор. Описано фізичні та експлуатаційні недоліки традиційних жорстко закріплених сіток та обґрунтовано переваги пружного кріплення. Побудовано математичну модель моменту зіткнення дрона з горизонтально розміщеною підпружиненою смугою. Встановлено функціональну залежність, яка дозволяє визначати вплив коефіцієнта нелінійності та жорсткості пружини на величину максимального переміщення вниз центральної точки підпружиненої смуги, що дає змогу оптимізувати параметри кріплення для забезпечення балансу між міцністю й еластичністю. Отримані результати можуть бути використані при проєктуванні нових типів захисних споруд, адаптованих до польових умов і сучасних загроз.

Ключові слова: *захист від БпЛА, захисні конструкції, антидронові сітки, пружне кріплення.*